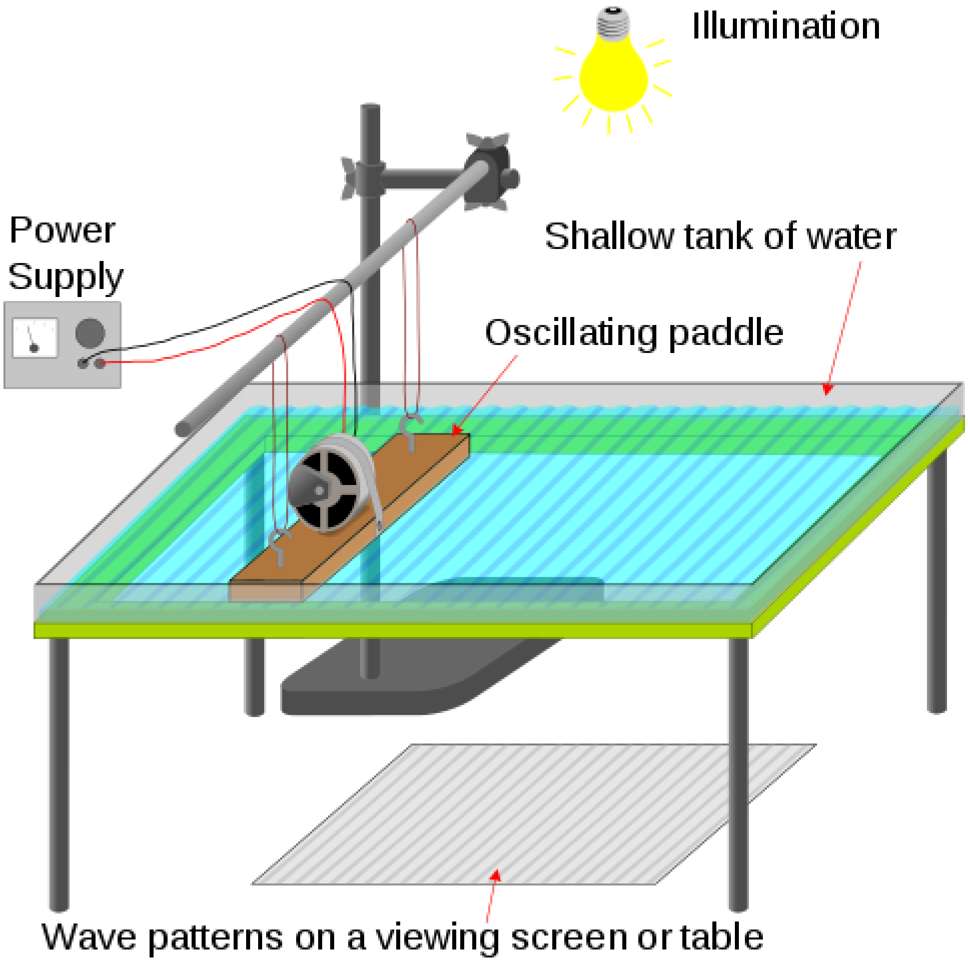
ELEMENTARY PHYSICS



BAGIRA DANIEL
BSC. EDUC. HONS. KYU.
+256 703300400 or +256 771900008

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INTRODUCTION TO PHYSICS

Physics is a branch of science that deals with the study of matter in relation to energy.

Branches of Physics

1. Mechanics and properties of matter: Forces, Motion, Molecular and Mechanical properties of matter.
2. Thermal properties of matter (or Heat): A form of energy that causes rise in temperature.
3. Optics: Light and waves.
4. Electrostatics and Electricity
5. Magnetism and Electromagnetism.
6. Modern Physics: Atomic and Nuclear Physics.

Relationship between Physics and other sciences like Chemistry, Biology, Geology and Astronomy.
Physics is the base of all natural sciences.

- Chemistry deals with the application of the laws and principles of Physics in explaining the formation of molecules and also the practical means of changing molecules from one form to another.
- Biology borrows from Physics and Chemistry in explaining the processes occurring in living organisms.

Besides providing the basic foundation on which all other sciences are built, Physics provides techniques which are applied in almost all areas of pure and applied research.
Thus, astronomers, geologists, meteorologists, oceanographers, medical laboratory technicians, Engineers, doctors, nurses, teachers, Computer technologists, e.t.c, depend on the techniques provided by Physics for their work.

Career Opportunities in Physics

Field of the career	Physics Work
Medicine	Use of X-ray, Ultra-sound scan machines, etc
Engineering • Civil • Mechanical • Electrical • Telecommunication • Chemical	Construction of structures from the simplest to the most complex.
Security	Nuclear and Atomic bombs
Education	Physics teachers and lecturers
Computer science, and Computer engineering	

A **hypothesis**: Is the possible tentative solution to a problem which gives direction and purpose for further investigations.

A **law** or **Principle**: Is a generally accepted scientific conclusion. *A Scientific Law or Principle is a generalised statement of observed facts.*
In Physics, laws are usually expressed in mathematical formulae.

A theory: A ScientificTheory is an idea put forward to explain the existence of a scientific law orprinciple.

Why we study Physics

- To help students develop an experimental attitude by performing experiments and acquire skills such as observation, measuring, drawing logical conclusions.
- To understand scientific theories, laws, principles and concepts.
- To prepare students for further studies in Physics.
- To understand the applicability of Physics in other disciplines like security, medicine, engineering, e.t.c and improve the world's technology.
- To understand and explain the principles of working of home appliances such as radios, Tvs, Microwaves, Computers, mobile phones, vehicles, e.t.c.

Appliance	Principle of physics
Computers	Electronics, Electricity & electromagnetism
Mobile phones	Electromagnetism and waves
Radios & T.Vs	Electronics, Electricity, waves electromagnetism
Cooker	Electricity and Heat
Camera	Optics(light) and Electronics
Fan	Electricity, electromagnetism & mechanics
Watch / clock	Electronics & mechanics
Vehicles, Aero planes	Heat & mechanics

The Problem-Solving Process

1. Identify the **quantities** in the problem, based on their names, **units** and any other information in the provided.

2. Assign the appropriate variables to those quantities.
3. Find an equation that relates all of the variables.

4. Substitute the values of the variables into the equation.
   (i) If you have only one variable left, it should be the one you are looking for.
   (ii) If you have more than one variable left, find another equation that uses one of the variables you have left, plus other quantities that you know.

5. Solve the equation(s), using basic algebra.

6. Apply the appropriate unit(s) to the result if any.

Common Symbols used in physics
Physics all over the world use a consistent set of symbols and abbreviations. You should be familiar with them. Most of the symbols used in physics are Roman and Greek letters. Some of which are:

α *- alpha,* β *- beta,* γ *- gamma,* λ *- lambda,*
μ *- mu,* θ *- theta,* η *- eta,* ϕ *- phi,*
ρ *- rho,* π *- pi.*

SCIENTIFIC NOTATION AND SIGNIFICANT FIGURES.

Scientific notation or Standard form

- A number is in scientific form, when it is written as a vnumber between 1 and 9 which is multiplied by a power of 10. i.e when it is written in the form $\mathbf{A \times 10^n}$. Where$1 \leq A < 10$; i.e A lies between 1 and 10 with 1 inclusive but 10 exclusive. **n** is an integer (….-2,-1,0,1,2…).
- Scientific notation is used for writing down very large and very small measurements.

Example:

(i) 598,000,000m = 5.98×10^8 m
(ii) 0.00000087m = 8.7×10^{-7} m
(iii) 60220m = 6.022×10^4 m

Questions:

Convert the following to scientific form.

(a) 0.048 = 4.8×10^{-2}
(b) $\frac{3}{4}$ = 0.75 = 7.5×10^{-1}
(c) 1000 = 1.0×10^3
(d) 8.72 = 8.72×10^0
(e) $\frac{1}{8}$ = 0.125 = 1.25×10^{-1}

Decimal places and Significant figures.

(a) Decimal Places

The number of decimal places (dp) is the number of digits to the right end of a decimal point. E.g. the number 3.6420 is given to 4dp.Thus 3.6420 ≈ 3.642(3dp), 3.6420 ≈ 3.64(2dp), 3.6420 ≈ 3.6(1dp), 3 .6420 ≈ 4 (0dp).

(b) Significant Figures

(i) None zero digits (1, 2, 3, 4, 5, 6, 7, 8 and 9) are significant figures.
(ii) Zeros

❖ Leading zeros (i.e. zeros at the left end of a number) i.e zeros before the first significant figure; are not significant figures e.g. 0.000456 (3s.f), 0.017 (2s.f).

❖ Tapped zeros; zeros between significant figures i.e. zeros between non zero digits are significant figures e.g. 6.0037 (5s.f), 0.0100034 (6 s.f).

❖ Trailing zeros(zeros at the right end of a number);

Trailing after a decimal point: These are significant figures. E.g 2.00 (3s.f), 0.0020 (2s.f), 0.0120700 (6s.f). Normally these values are obtained by using an instrument.

Trailing before a decimal point: These are NOT significant figures. E.g 20 (1s.f), 2400 (2s.f), 580100 (4s.f). Normally these values are obtained as a result of rounding off certain numbers to the nearest tens, fifties, hundreds, thousands, ten thousands e.t.c.

For example, if a number 348 is rounded off to 1 s.f, we get 300 and if it`s rounded off to 2 s.f we get 350. The trailing zeros in these approximations (i.e. 300 and 350) are due to rounding off and therefore are not significant.

Questions.

Write the following to the stated significant figures

a) 28.8 to 3 s.f b) $\frac{2}{7}$ to 2 s.f c) 4.027×10^{-2} to 3 s.f.

b)

Prefix and Surfix	Symbol	Exponent
Tera	T	10^{12}
Giga	G	10^9
Mega	M	10^6
Kilo	K	10^3
Hecto	H	10^2
Deca	D	10^1
Physical Quantity used		$\mathbf{10^0}$
Deci	d	10^{-1}
Centi	c	10^{-2}
Mili	M	10^{-3}
Micro	μ	10^{-6}
Nano	N	10^{-9}
Pico	P	10^{-12}
Fermto	F	10^{-15}
Atto	A	10^{-18}

Example:

Value	Scientific form	Prefix used
3000W	3×10^3W	3kW
4900 000J	4.9×10^6J	4.9MJ
0.00526m	5.26×10^{-3}m	5.26mm
0.00000125g	1.25×10^{-6}g	1.25μg

1. Write 0.000375 in scientific form:
A. 37.5×10^{-5} B. 3.75×10^4
C. 3.75×10^{-4} D. 37.5×10^5

2. Write the number 348.5 in ***Scientific form***.
A. 34.85×10^1 B. 3.485×10^2
C. 3.485×10^3 D. 3.485×10^{-2}.

3. Write the following in scientific notation.
i) 5.880 ii) 430000
iii) 60000 iv) 86000000
v) 5000000000000 vi) 0.00058
vii) 0.0000047

4. Write the following quantities from scientific notation to normal form
(i) The speed of light is 3.0×10^8 ms^{-1}
(ii) The mass of the earth is 6.0×10^{24} kg
(iii) The mass of the electron is 9.11×10^{-31}kg

5. Round off the number 49,128 to two significant figures.
A. 50,000 B. 49,100 C. 49,000 D. 50,100

6. A digital camera records each image as 8 megapixels, with each pixel transferring 14 bits of information. What is the minimum capacity for a memory card which could hold 120 images? **Ans C**

A	1.7 Mbyte
B	13 Mbyte
C	1.7 Gbyte
D	13 Gbyte

1. MECHANICS AND PROPERTIES OF MATTER

1:1. MEASUREMENTS:

Physics is concerned with measurement of physical quantities and classifying them into groups according to their nature.
To measure is to find the value of a physical quantity using a scientific instrument with a standard scale.

PHYSICAL QUANTITIES

A physical quantity is a physical property that can accurately be measured.
Non Physical quantities such as love, faith, e.t.c can not be accurately measured.

Types of Physical Quantities
There are two types of Physical Quantities namely;
(a) Fundamental Quantities or Basic Quantities
(b) Derived Quantities.

(a) FUNDAMENTAL OR BASIC QUANTITIES
These are quantities from which all other quantities are obtained. They are **eight** in total and these are:

Fundamental Quantities	S.I unit	Symbol
1. **Length**	**Metre**	**m**
2. **Mass**	**Kilogram**	**kg**
3. **Time**	**Second**	**S**
4. **Angle** (Plane & Solid)	**Degree**	**º**
5. Temperature	Kelvin	K
6. Electric current	Ampere	A
7. Amount of a substance	Mole	Mol.
8. Luminous Intensity	Candela	Cd

Note: *In mechanics, we use only four fundamental quantities; i.e.* ***Length, Mass, Time and Angle****.*

The **SI** (Système International d'Unités) system is a set of metric units now used in many countries. It is a decimal system in which units are divided or multiplied by 10 to give smaller or larger units.

(i)LENGTH:

Length is the distance between any two points.
It can also be defined as thedistance covered by matter. It is a measurement of the extent of something from end to end.
The S.I unit of length is **a metre (m).**
Other units of length include; Miles, kilometer, Hectometre, Decametre, Decimetre, Centimetre, etc.

CONVERSIONS OF LENGTHS
Example: 1
Convert the following as instructed:
(i) 16.4mm to metres (iii) 20m to centimetres
(ii) 0.092km to metres (iv) 250cm to metres
Solution
(i) 16.4mm to metres

Multiply →
← Divide

Km	Hm	Dm	M	Dm	Cm	Mm
			1	0	0	0

1m =	1000mm
x =	16.4mm

$$1000x = 16.4 \times 1m$$
$$1000x = 16.4$$
$$\frac{1000x}{1000} = \frac{16.4}{1000}$$
$$x = 0.0164m$$
Thus 16.4mm = 0.0164 m

(ii) 20m to centimetres
Solution
20m to centimetres

Km	Hm	Dm	M	Dm	Cm	Mm
			1	0	0	

1m =	100cm
20m =	X

$$1 \times x = 20 \times 100cm$$
$$x = 2000\ cm$$
Thus 20m = 2000 cm

(iii) 0.092km to metres
Solution
0.092km to metres

Km	Hm	Dm	M	Dm	Cm	Mm
1	0	0	0			

1km =	1000m
0.092km =	X

$$x = 0.092 \times 1000m$$
$$x = 92\ m$$
$$x = 92\ m$$
Thus 0.092km = 92 m

(iv) 250cm to metres
Solution
250cm to metres

Km	Hm	Dm	M	Dm	Cm	Mm
			1	0	0	

1m =	100cm
x =	250cm

$$100 \times x = 250 \times 1m$$
$$\frac{100x}{100} = \frac{250}{100}$$
$$x = 2.5cm$$
Thus 250cm = 2.5m

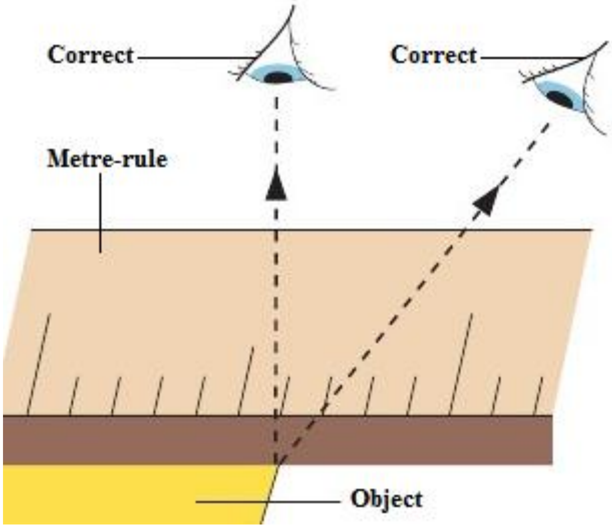
INSTRUMENTS USED IN MEASURING LENGTH

Instrument	Smallest measure ment	Accura ccy	Examples of length measured
Micrometer screw gauge	0.01 mm	2dp	-Diameter of a wire -Thickness of a card board
Vernier calliper	0.01 cm	2dp	-Diameter of a tennis ball -internal and external diameter of testtubes, beakers, etc
Metre-rule	0.1 cm	1dp	-Length of a book. -Length of a desk

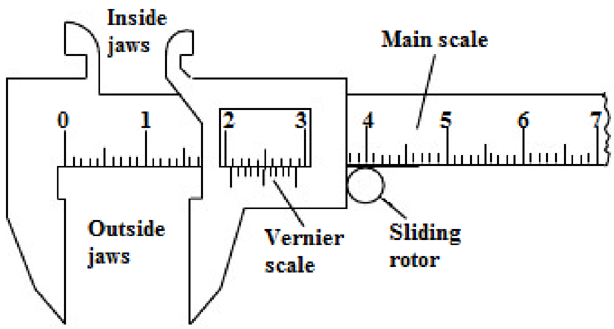
(i) **Tape-measure:** (Accurately measures length greater than 1metre

(ii) $:l > 1m$). E g length of a foot ball field, length of a plot of land etc.

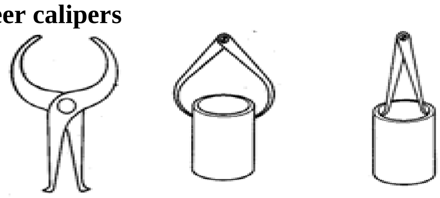
(iii) **Metre-rule** :(Accurately measures length greater than 12cm but less than 1metre:$12cm < l < 1m$). Eg length of a desk, breadth of a window, etc.
A metre rule gives readings in **cm** to **1dp**.



(iv) **Vernier calipers or Slide calipers :**
Accurately measures length greater than 1cm but less than 12 cm:2.5cm $< l <$ 12 cm. E.g Internal and External diameters of test tubes and beakers, breadth of a metre rule. etc.
A vernier caliper gives readings in **cm** to 2dp.



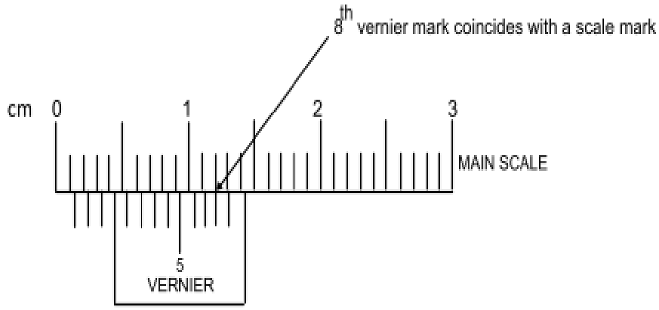
Engineer calipers



The distance between the jaws is after wards measured on an ordinary scale like a metre-rule.

Reading of vernier calipers,

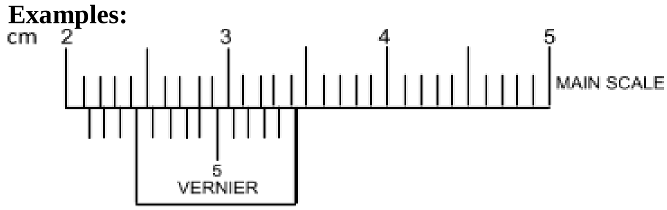
1. Insert the object between the jaws and use the roller to ensure that the object is gently gripped.
2. Record the reading on the main scale at the zero mark of the vernier scale to 1 dps in cm.
3. Look along the Vernier scale carefully until you see division on it which coincides with the main scale, this gives the second decimal place.



The main scale is in centimeters, 1cm has 10 divisions each division is $\frac{1}{10}$ cm = 0.1cm.

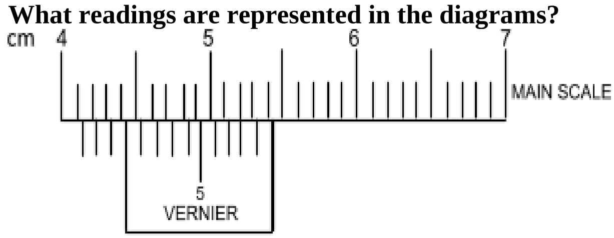
- Vernier scale, each division is $\frac{1}{100}$ cm = 0.01cm.

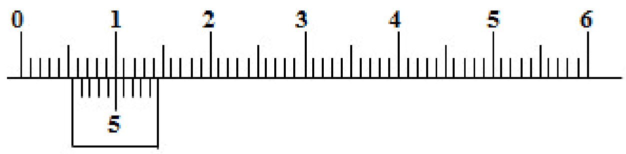
Examples:

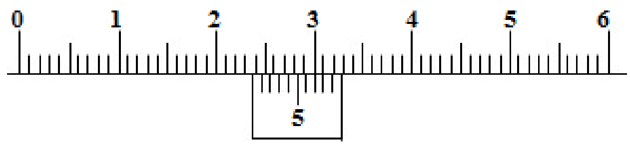


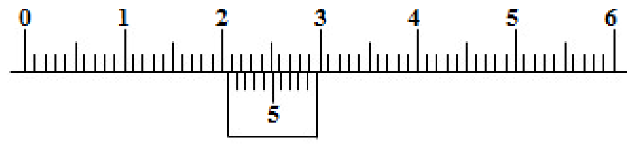
Main scale = 2.40cm
Vernier scale = 0.04cm
Final reading = 2.44cm

What readings are represented in the diagrams?

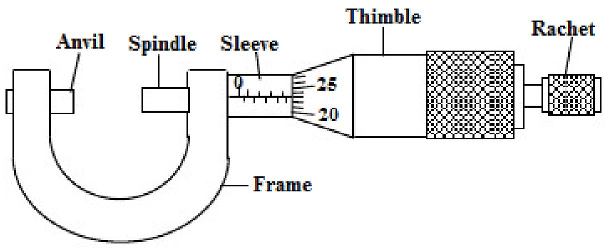








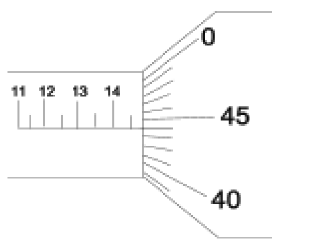
(v) **Micrometer screw gauge:** (Accurately measures length less than 1centimetre: 1mm < l < 25mm). Eg Diameter of wires, Diameter of ball beairings and pendulum bob, etc.
A micrometer screw gauge gives readings in millimeters (**mm**) to 2dp.



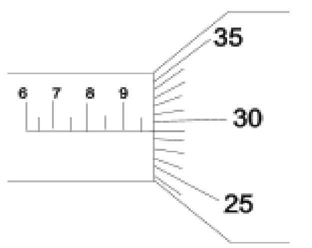
Turn the thimble using the Ratchet until the object is gently gripped between the anvil and the spindle. This is confirmed when the rachet produces a clicking sound.

For each turn the spindle moves through 0.5mm.The fraction of each turn is indicated on the thimble. This has a scale of 50 divisions on the thimble and represents $\frac{1}{50}$ of half a millimeter i.e. $\frac{1}{10} \times 0.5$ mm = 0.01mm.
The sleeve-reading gives units to the 1st two decimal places and the thimble gives 2nd decimal place.

Example I:

	Sleeve scale = 14.50mm Thimble scale = 0.44mm Final reading = 14.94mm

Example II:

	Sleeve scale = 9.50mm Thimble scale = 0.29mm Final reading = 9.79mm

Precautions taken when using a micrometer screw gauge

- The faces of the anvil and the spindle must be cleaned to remove dust so as to get accurate readings.
- The zero reading must be checked.

(ii) MASS:

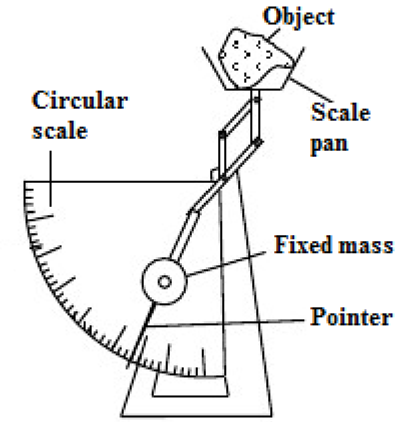
Mass is the quantity of matter in a substance.
Mass is better defined as the measure of a body's **inertia**.

The S.I unit of mass is **a kilogram (kg).**
Other units of mass include: Tonnes (1tonne = 1000kg), Hectogram (Hg), Decagram (Dg), Gram (g), Decigram (dg), Centigram (cg), Milligram (mg), etc.

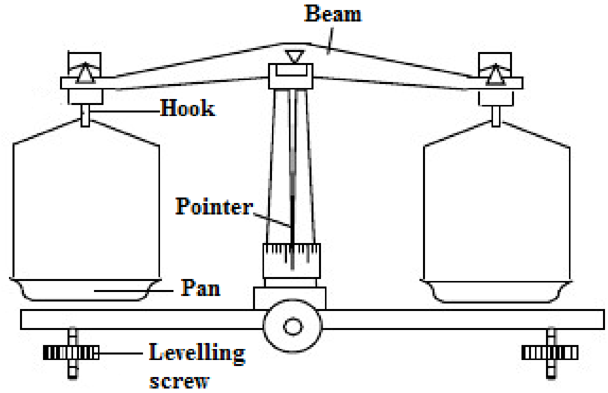
Instruments Used in measuring Mass

(i) weighing beam balance (ii) Digital beam balance (iii) Top arm beam balance	(iv) Lever arm beam balance (v) Tripple beam balance

(i) The Lever Balance
This balance has a scale pan, a pointer and a circular scale graduated in grams. It measures masses by raising a fixed mass. The distance the fixed mass is raised depends on the mass of the object placed on the scale pan (See the figure below)



(ii) Beam balance



The hooks which support the scale pans are hung at equidistant points from the pivot of the beam.
One or both of the levelling screws is/are adjusted until the pointer is at the central mark.
The object whose mass is to be determined is placed in the left-hand scale pan and standard masses are placed in the right-hand scale pan. When the two masses are equal, the pointer settles at the central mark.

Conversions
Example 1:
Convert the following as instructed:

(i) 100grams to kilograms
(ii) 40mg to kg
(iii) 2kg to dg
(iv) 20.55g to cg

Solution
(i) 100grams to kilograms

Kg	**Hg**	**Dg**	G	**Dg**	**Cg**	**Mg**
1	0	0	0			

1kg	=	1000g
x	=	100g

$1000 \times x = 100 \times 1kg$

$\frac{\cancel{1000}x}{\cancel{1000}} = \frac{100}{1000}$

$x = 0.1kg$

Thus 100grams = 0.1kg

Solution
(ii) 2kg to dg

Kg	**Hg**	**Dg**	**G**	Dg	**Cg**	**Mg**
1	0	0	0	0		

1kg	=	10,000dg
2kg	=	X

$1 \times x = 2 \times 10000\text{dg}$

$\underline{x = 20,000\text{dg}}$
Thus 2 kilograms = 20000dg

Solution
(iii) 40mg to kg

Kg	Hg	Dg	G	Dg	Cg	Mg
1	0	0	0	0	0	0

1kg	=	1000000mg
x	=	40mg

$$1000000 \times x = 40 \times 1kg$$
$$\frac{1000000x}{1000000} = \frac{40}{1000000}$$
$$x = 0.00004\text{kg}$$

Thus 40miligrams = 0.0000kg

Solution
(iv) 20.55g to cg

Kg	Hg	Dg	G	Dg	Cg	Mg
			1	0	0	

1g	=	100cg
20.55g	=	X

$$1 \times x = 20.55 \times 100cg$$
$$x = 2055cg$$

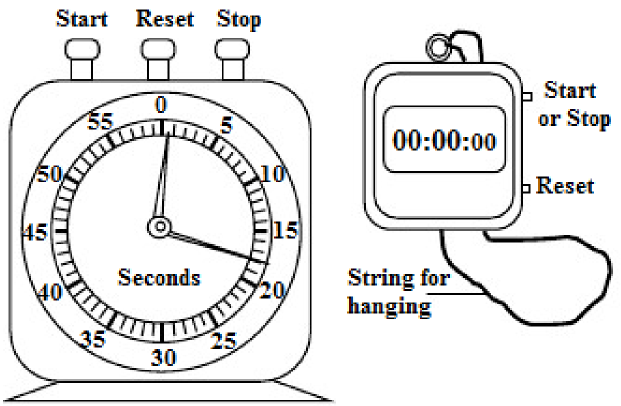
Thus 20.55grams = 2055cg

(iii) TIME:

Time is the interval between two events.
The S.I unit of time is **a second (s).**
Other units of time include Minute (1min = 60s), Hour (1hr=60min), Day (1day=24hrs), Week (7 days), fortnight (2weeks), Month (1month=30days), Year (1yr = 12months), decade, century, and a millennium.

Instruments Used in measuring Time

- Stop clock
- stop watch
- Half life of a radioactive substance eg Carbon – 14
- Shadows



(i) Stop Clock (ii) Stop watch

Time is measured using a stopwatch or stop clock . The stopwatch/stop clock must be reset to zero before using it to take any measurement, and this is done by depressing the knob provided for this purpose. A stop clock is reset when all the hands are in zero position while a stopwatch appears as the diagram above shows when reset.

On a stopwatch, a reading like **00:17 68** is recorded as **17.68 seconds.**
In order to get acquainted with the use of these instruments, it is advisable that the reader tries to time different events e.g. time to walk round the laboratory block, etc.

(b) DERIVED QUANTITIES
These are quantities which can be expressed in terms of the fundamental quantities. Besides the seven fundamental quantities, the rest of the Physical quantities' are derived quantities. Their S.I units are also called **Derived units**.

Examples of Derived Physical quantities include:

Derived Quantities	S.I unit	Symbol
1. **Area**	Squaremetre	m^2
2. **Volume**	Cubicmetres	m^3
3. **Density**	kilogram per cubicmetre	kgm^{-3}
4. **Speed and Velocity**	metres per second	ms^{-1}
5. **Pressure**	newton per square metre (or pascal)	Nm^{-2} (or Pa)
6. **Force and weight**	Newton	N
7. Momentum	kilogram metre per second	$kgms^{-1}$
8. Frequency	Hertz	Hz
E. t. c		

(i) AREA:

Area is a measure of the size of a surface of an object.

The S.I unit is a **square metre (m^2).**
Other units of area include: km^2, cm^2, mm^2, e. t. c

Example 1:
Convert the following as instructed
(i) 15 mm^2 to cm^2
(ii) 20 m^2 to mm^2
(iii) 16.4 mm^2 to m^2

Solution
(i) 15 mm^2 to cm^2

Km	Hm	Dm	M	Dm	Cm	Mm
					1	0

1cm	=	10mm
$(1cm)^2$	=	$(10mm)^2$
$1cm^2$	=	$100mm^2$
x	=	15 mm^2

$$100 \times x = 15 \times 1cm^2$$
$$x = 0.15cm^2$$

15 mm^2 = $0.15cm^2$

(ii) 20 m^2 to mm^2

Km	Hm	Dm	M	Dm	Cm	Mm
			1	0	0	0

1m	=	1000mm
$(1m)^2$	=	$(1000mm)^2$
$1m^2$	=	$1000000mm^2$
20 m^2	=	X

$$1 \times x = 20 \times 1000000mm^2$$

$x = 20,000,000mm^2$
Thus $20\ m^2 = 20,000,000mm^2$ or $2.0 \times 10^7 mm^2$

Solution

(iii) $16.4\ mm^2\ to\ m^2$

Km	Hm	Dm	M	dm	Cm	Mm
			1	0	0	0

1m	=	1000mm
$(1m)^2$	=	$(1000mm)^2$
$1m^2$	=	$1000000mm^2$
x	=	$16.4\ mm^2$

$1000000 \times x = 16.4 \times 1m^2$

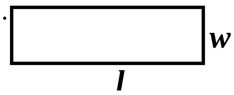
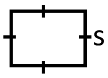
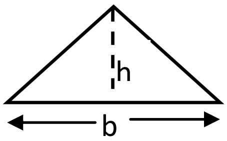
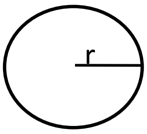
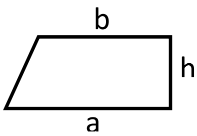
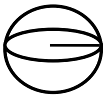
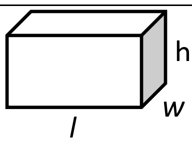
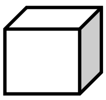
$\frac{1000000x}{1000000} = \frac{16.4}{1000000}$

$x = 0.0000164m^2$

Thus $20\ m^2 = 0.0000164m^2$ or $1.64 \times 10^{-5}m^2$

Types of areas

(i) Cross-sectional area (ii) Surface area

Figure	Name	Formula for Area
1. 	Rectangle	$A = lw$
2. 	Square (All sides are equal)	$A = S^2$
3. 	Triangle	$A = \frac{1}{2}bh$
4. 	Circle	$A = \pi r^2$
5. 	Trapezium (2 parallel un equal sides)	$A = \frac{1}{2}h(a+b)$
6. 	Sphere	$S.A = 4\pi r^2$
7. 	Cuboid	$S.A = 2(lw) + 2(wh) + 2(lh)$
8. 	Cube (All faces are equal)	$S.A = 6S^2$

(ii) VOLUME:

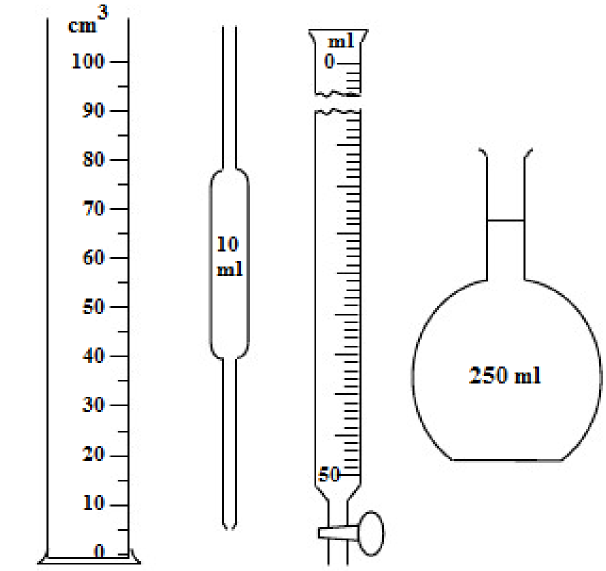
Volume is the amount of space occupied by matter.

The S.I unit of volume is cubic metre **(m^3).**

Other units of volume include: $cm^3, mm^3, km^3, millilitre(ml), litre(l). e.t.c$

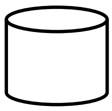
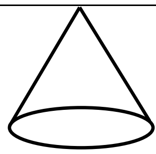
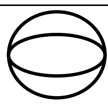
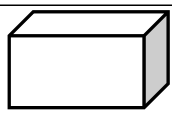
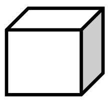
Instruments for measuring Volume include:

(i) Measuring cylinder (ii) Volumetric flask (fixed Vol.)
(iii) Burette (iv) Pipette (fixed Volume)

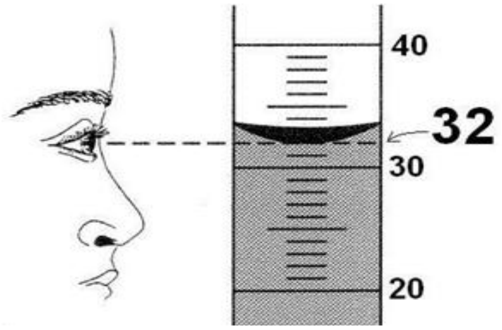


(a) Measuring cylinder (b) Pipette (c) Burette (d) Volumetric flask

Volume of regular objects

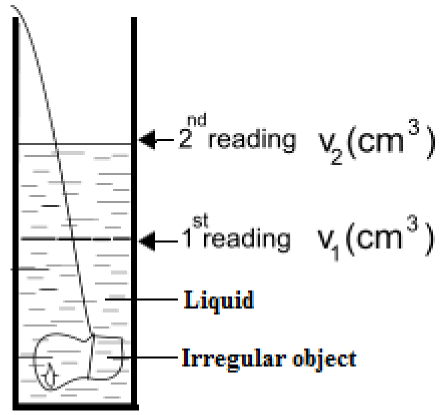
Figure	Name	Formula for Volume
1. 	Cylinder	$V = \pi r^2 h$
 2.	Circular cone	$V = \frac{1}{3}(\pi r^2)h$
3. 	Sphere	$V = \frac{4}{3}\pi r^3$
4. 	Cuboid	$V = lwh$
5. 	Cube (All faces are equal)	$V = S^3$

How to accurately read volume from a measuring cylinder.



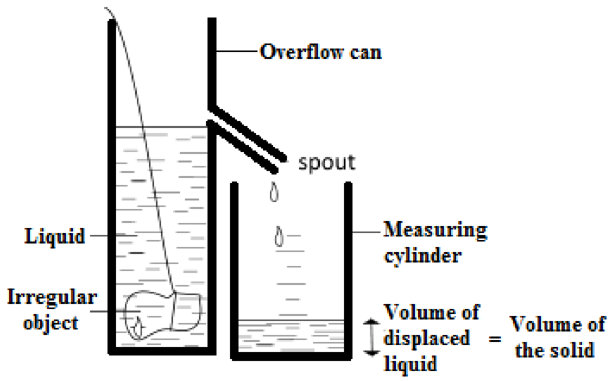
Experiment to determine the volume of an irregular object

The volume of an irregular object can be obtained by the**Displacement method.**



- Water is poured into a measuring cylinder up to a certain level. The volume of water (V_1) is recorded.
- A thread is tied on the irregular object and gently lower it into the water in the measuring cylinder. The new volume of water in the cylinder (V_2) is recorded.
- The Volume of the irregular object is then equal to the volume of displaced water; Thus **V = ($V_2 - V_1$).**

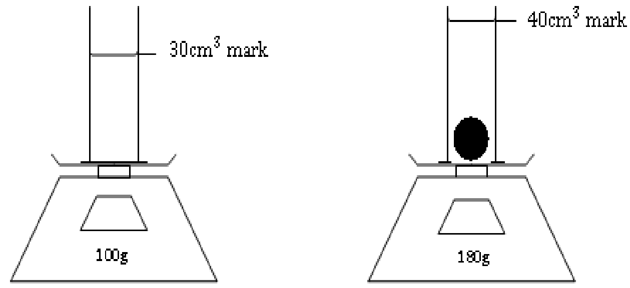
OR



- Water is poured in an over flow can up to the level of the spout. A measuring cylinder is placed just below the spout.
- A thread is tied around the irregular object and gently lowered into the overflow can.
- The volume of water, **V** that collects in the measuring cylinder is noted. It is equal to the volume of the irregular object.

Question:

A measuring cylinder containing some water stands on a scale pan. A solid ball is lowered into the water. The water level rises from the 30cm^3 mark to 40cm^3 mark. The scale reading increases from 100g to 180g.



What is the density of the material of the ball?

A. 2.0 gcm^{-3}. B. 4.5 gcm^{-3}.
B. 8.0 gcm^{-3}. D. 18 gcm^{-3}.

Example 1:

Convert the following as instructed

(i) 250 cm^3 to m^3 (iii) 0.032km^3 to m^3
(ii) 500ml to m^3 (iv) 10,000litres to m^3

Solution

(i) 250 cm^3 to m^3

Km	Hm	Dm	m	Dm	Cm	Mm
			1	0	0	

1m	=	100cm
(1m)^3	=	**(100cm)^3**
1m^3	=	1000000cm^3
x	=	250cm^3

$$\mathbf{1000000 \times x = 250 \times 1m^3}$$

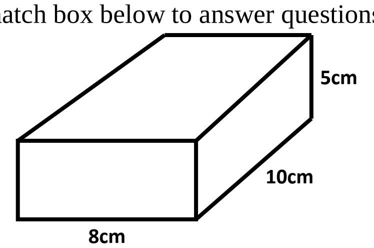
$$\frac{\cancel{1000000}x}{\cancel{1000000}} = \frac{250}{1000000}$$

$$x = 0.00025\ m^3$$

Thus $\mathbf{250\ cm^3 = 0.00025 m^3\ or\ 2.5 \times 10^{-4} m^3}$

Example 2:

Use the match box below to answer questions that follow.



Find the volume

(i) in cm^3 **[400cm^3]**(ii) in m^3 [**0.0004m^3]**

Exercise:

1. A cuboid has dimensions 2cm by 10cm. Find its width in metre if it occupies a volume of 80cm^3. [**0.04m]**

2. (a) Find the volume of water in a cylinder of water radius 7cm if its height is 10cm. [**1540cm^3]**

(b) The volume of the cylinder was 120m^3.When a stone was lowered in the cylinder filled with water the volume increased to 15cm^3. Find the height of the cylinder of radius 7cm. [**0.078 cm**]

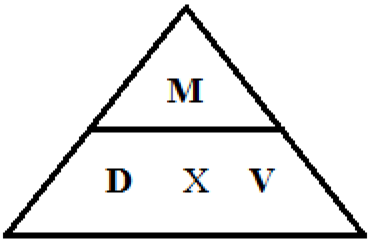
3. A Perspex box has 10cm square base and contains water to a height of 10cm. A piece of rock of mass 600g is lowered gently into the water and the level rises to 12cm. Find the;

(i) Volume of water displaced by the rock.
(ii) volume of the rock in cm^3 and m^3
(iii) density of the rock in gcm^{-3} and kgm^{-3}

(iii) DENSITY:

Density *is the mass per unit volume of a substance:*

$$\textbf{Density}, \boldsymbol{\rho} = \frac{\textbf{mass, M}}{\textbf{volume, V}}$$



The SI unit of density is a kilogram per cubic metres or kgm^{-3} other units are gl^{-1} or gcm^{-3}
Note: the density of pure water is $1000kgm^{-3}$ or $1gcm^{-3}$

Table showing the densities of common substances.

solids	Density (gcm^{-1})	Liquids	Density (gcm^{-1})
Aluminium	2.7	Paraffin	0.8
Copper	8.9	Petrol	0.8
Iron	7.9	Pure water	1.0
Gold	19.3	Mercury	13.6
Glass	2.5	**Gases**	
Wood	0.80	Air	1.3
Ice	0.92	Hydrogen	0.09
Polythene	0.90	Carbondioxide	2.0

Changing gcm^{-3} to kgm^{-3}
$1gcm^{-3} = 1000kgm^{-3}$
So when changing gcm^{-3} to kgm^{-3} simply multiply by 1000

Example:
Express 0.8 gcm^{-3} in kgm^{-3}

$1gcm^{-3}$=	**$1000kgm^{-3}$**
0.8 =	x

$x = 0.8 \times 1000kgm^{-3}$
$\underline{x = 800km^{-3}}$
$\underline{\text{Thus } 0.8gcm^{-3} = 800kgm^{-3}}$

<u>Simple density Measurements</u>
When the mass "M" and volume "V" of a substance are known; then the density is obtained from:

$$Density, \boldsymbol{\rho} = \frac{\boldsymbol{m}}{\boldsymbol{V}}$$

(a) *For a Regularly shaped solid*
- The mass of the solid is measured on a beam balance
- The volume of the solid is obtained by measuring the sides of the solid using a ruler, veneer calipers or micrometer screw gauge.
- The density is then got from the formula;

$$\text{Density of solid} = \frac{\text{mass of solid}}{\text{volume of solid}}$$

(b) *For an irregularly – shaped solid*
- The solid is weighed using a beam balance to obtain its mass.
- The volume of the solid is obtained by displacement methods; using a displacement can. The volume of displaced water is equal to the volume of the solid.
- The density is then got from the formula.

$$\text{Density of solid} = \frac{\text{mass of solid}}{\text{volume of solid}}$$

NOTE:

1. <u>For a floating object.</u> Tie a sinker on the floating object and gently dip it water. The volume of the water displaced, $\mathbf{V_1}$ is obtained.
The sinker alone is then dipped in the water and again the volume of water displaced, $\mathbf{V_2}$ is also obtained.
The volume of the floating object, V = $\mathbf{V_1 - V_2}$

2. <u>For a pin or a ball bearing.</u>
Tie a known number of pins together (eg 100 pins) and gently lowered them in an overflow can.
The volume of the water displaced by 100 pins, $\mathbf{V_1}$ is obtained. This is the volume of 100 identical pins.
The volume, V of a single pin is calculated from**:**

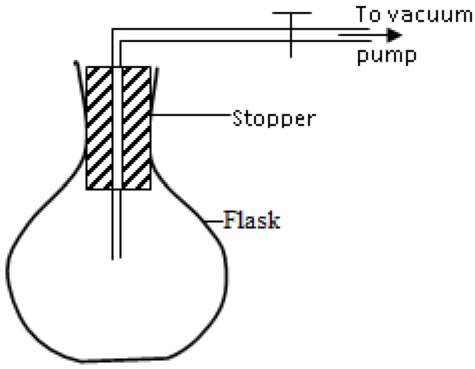
$$\mathbf{V} = \frac{\mathbf{V_1}}{\mathbf{100}}$$

(c) *For liquids*
- The volume of the liquid is measured using a measuring cylinder and the volume, V is noted.
- An empty measuring cylinder is weighed on a beam balance and its mass, M_o is noted.
- A liquid is added to it and it is weighed again using the beam balance;

$$\left(\begin{matrix} Mass \\ of\ liquid \end{matrix}\right) = \left(\begin{matrix} mass\ of \\ empty \\ cylinder \end{matrix}\right) - \left(\begin{matrix} mass\ of \\ cylinder \\ with\ liquid. \end{matrix}\right)$$

$$\text{Density of liquid} = \frac{\text{mass of liquid}}{\text{volume of liquid}}$$

(d) *Air*



(i) Measuring of mass
A round-bottomed flask is weighed using a beam balance when full of air and after removing the air using a vacuum pump. Then
(ii) Measuring of volume
The volume of air is found by filling the flask with water and pouring it into a measuring cylinder. Then volume of air = volume of water transferred into the measuring cylinder.

$$\text{Density of air} = \frac{\text{mass of air}}{\text{volume of air}}$$

Precautions taken

-The flask should be dried

-The atmospheric pressure and temperature should be noted.

-The air should be dry

Factors that affect Density

(i) **Temperature**

When the temperature of a substance is increased, it expands hence increasing its volume. The density then decreases.

When the temperature of a substance is reduced, it contracts hence reducing its volume. The density then increases.

(ii) **Pressure**

Pressure only affects the density of gases.

When the pressure of a given mass of a gas is increased, the gas molecules become squeezed and occupy a smaller volume. This increases the density of the gas.

When the pressure of a given mass of a gas is reduced, the gas molecules become occupy a larger volume. This decreases the density of the gas.

Uses of density

It is used to: -Identify materials for construction

-Test the purity of a substance

-Choose the light gases to fill balloons

Example 1:

A Perspex box has a10cm square base containing water to a height of10 cm. A piece of rock of mass 600g is lowered into the water and the level rises to 12 cm.

(a) What is the volume of water displaced by the rock?

V = L x w x h

= 10 x10 x (12-10)

= 200 cm^3

(b) What is the volume of the rock?

Volume of rock = volume of water displaced

= $200cm^3$

Alternatively,

Volume of water before adding the rock

V_1 = L x W x H

= (10cm x 10cm x 10cm)

= $1000cm^3$

Volume of water after adding the rock

V_2 = L x W x H

= (10 x 10 x 12) cm^3

= $1200cm^3$

Volume of water displaced

V= $V_2 - V_1$

= (1200 – 1000) cm^3

= $200cm^3$

(c) Calculate the density of the rock

$$\text{Density} = \frac{\text{mass}}{\text{volume}} = \frac{600\text{ g}}{200\text{ cm}^3} = 3\text{gcm}^{-3}$$

Example 2:

(a) The mass of $24.4cm^3$ of mercury is 332g. Find the density of mercury. **(=13.6 gcm^{-3})**

(b) An 800g solid measures 10cm by 5cm by 4cm. Determine its density. **(= 4 gcm^{-3})**

(c) A glass stopper of volume $16cm^3$ weighs 40g. Calculate its density in : (i) gcm^{-3}. **(=2.5 gcm^{-3})**

(ii) kgm^{-3}. **(=2500kgm^{-3})**

(d) The density of copper is $8.9gcm^{-3}$. What is the mass of $100cm^3$ of copper?. **(=890 g)**

(e) When a piece of irregular stone of mass200g is lowered in a measuring cylinder, the initial and final volumes were $500cm^3$ and $600cm^3$ respectively. Calculate the density of the stone. **(=2gcm^{-3})**

(f) An empty beaker weighs 120g in air and 180g when filled with 75cm3 of methylated spirit. Find the density of methylated spirit. **(=0.8gcm^{-3})**

(g) What is the mass of **1.5 litres** of water? **(= 1.5kg)**

2. The oil level in a burette is $25cm^3$. Fifty drops of oil fall from a burette. If the volume of one drop is $0.1cm^3$.What is the final oil level in the burette. [**$30cm^3$**]

3. A measuring cylinder has water level of 13cm.What will be the new water level if 1.6g of a metallic block of density $0.8g/cm^3$ is added.

4. A perspex box having 6cm square base contains water to a height of 10cm.

(a) Find the volume of water in the box. [$360cm^3$]

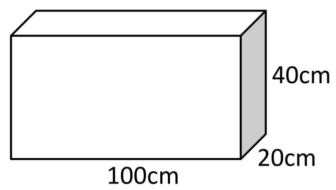
(b) A stone of mass 120g is lowered into the box and the level of water rises to 13cm.

(i) Find the new volume of water? [$468cm^3$]

(ii) Find the volume of the stone? [108 cm^3]

(iii) Find the density of the stone. [$\frac{2}{5}$ g/cm^3]

5. A steel C.P.U below, has a mass of 560g



Find its density (i) in g/cm^3 (ii) in kg/m^3

6. 200g of liquid Y of density $4gcm^{-3}$. Calculate the density of the mixture.

7. Liquids X and Yare mixed to form a solution. If the density of X is $0.8gcm^{-3}$ and volume is $100cm^3$, density of Y $1.5cm^{-3}$ and its volume is $300m^3$.Find the;

(i) mass of liquid X [80g]

(ii) mass of liquid Y [450g]

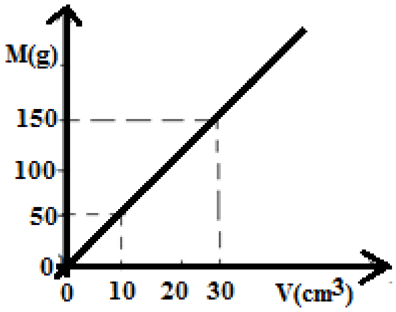
(iii) Density of a mixture [$1.325gcm^{-3}$]

8. In an experiment to determine the density of a pin, 100pins are gently lowered into a measuring cylinder containing $12cm^3$ of water. The water in the cylinder rose to $98cm^3$. Find the;

(i) volume of a pin. (ii) density of the pin in kgm^{-3}

9. A tin of volume 30 cm^3 has a mass of 94.8 g when full of sucrose and 62.8 g when half filled with the same solution. Find the density of sucrose .

10. The graph in the figure below shows how mass of sand varies with volume. Use it to find density of sand.



DENSITY OF MIXTURES

Suppose two substances are mixed as follows:

Substance	Mass	Volume	Density
X	M_X	V_X	$D_X = \frac{M_X}{V_X}$
Y	M_Y	V_Y	$D_Y = \frac{M_Y}{V_Y}$

$$\textbf{Density of mixture} = \frac{\textbf{mass of mixture}}{\textbf{Volume of mixture}}$$

$$\text{Density of mixture} = \frac{M_X + M_Y}{V_X + V_Y}$$

Example:1
100cm^3 of fresh water of mass100g is mixed with 100 cm^3 of sea water of mass103g. Calculate the density of the mixture.

<u>Solution</u>

$$\text{Density of mixture} = \frac{\text{mass of mixture}}{\text{Volume of mixture}}$$

$$= \frac{\text{mass of fresh water} + \text{mass of sea water}}{\text{Vol. of fresh water} + \text{Volume of sea water}}$$

$$\text{Density of mixture} = \frac{100 + 103}{100 + 100} = \frac{203}{200}$$

<u>Density of mixture = 1.015 gcm^{-3}</u>

Example 2:
Liquid Y of volume 0.40m^3 and density 900kgm^{-3} is mixed with liquid X of volume0.35m^3 and density 800kgm^{-3}. Calculate the density of the mixture.

<u>Solution</u>

$\text{mass of Y} = \text{Volume of Y} \times \text{Density of Y}$
$\text{mass of Y} = 0.40 \times 900 = 360\text{kg}$

$\text{mass of X} = \text{Volume of X} \times \text{Density of X}$
$\text{mass of X} = 0.35 \times 800 = 280\text{kg}$

Then:

$$\text{Density of mixture} = \frac{\text{mass of mixture}}{\text{Volume of mixture}}$$

Density of mixture

$$= \frac{\text{mass of liquid Y} + \text{mass of liquid X}}{\text{Volume ofliquid Y} + \text{Volume of liquid X}}$$

$$\text{Density of mixture} = \frac{360 + 280}{0.40 + 0.35} = \frac{640\text{ kg}}{0.75\text{ m}^3}$$

<u>Density of mixture = 853.33kgm^{-3}</u>

Exercise:

1. An alloy is formed by adding 500g of element P of density 5gcm^{-3} to 400cm^3 of element Q of density 4gcm^{-3}. Calculate the density of the alloy.[4.2gcm^{-3}].

2. 500cm^3 of liquid X of density 2gcm^{-3} is combined with 200 g of liquid Y of density 4gcm^{-3}. Calculate the density of the mixture.

3. Liquid M of density 0.5gcm^{-3} is mixed with liquid N in equal volumes. If the mixture has a density of 0.8gcm^{-3} , Find the density of liquid N.

4. 3cm^{-3}of water was mixed with 5cm^{-3} of milk of density 1500kgm^{-3}. Find the density of the mixture. [1312.5kgm^{-3}].

RELATIVE DENSITY (R.D)

Relative density is defined as the ratio of the density of a substance to the density of water.

$$\textbf{Relative Density} = \frac{\textbf{Density of substance}}{\textbf{Density of water}}$$

Note 1: Relative density has no units.
Note 2: Density of pure water = **1gcm^{-3} = 1000kgm^{-3}**

Since **Density** $= \frac{\textbf{Mass}}{\textbf{Volume}}$, then, keeping the volume constant, relative density can also be defined as follows:

(i) Relative density is defined as the ratio of the mass of a substance to the mass of **an equal volume** of water.

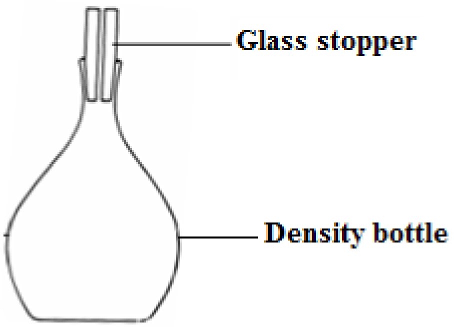
$$\text{Relative Density} = \frac{\text{mass of substance}}{\text{mass of equal volume of water}}$$

(ii) Relative density is defined as the ratio of the weight of a substance to the weight of **an equal volume** of water.

$$\text{Relative Density} = \frac{\text{weight of substance}}{\text{weight of equal volume of water}}$$

A densiy Bottle:
A density bottle contains exactly the same volume when the liquid level is at the hole. A **density bottle** and a **hydrometer** are the instruments used to measure the relative density of liquids.
Note: The advantage of using a density bottle in measuring the relative density of a liquid is that it is **accurate** compared to other methods.
A hydrometer however, is used to **directly measure** the relative density of a liquid.

Experiment: ***To determine the Relative density of a liquid using a density bottle.***



- mass of empty bottle M_0 : A dry density bottle with a stopper is weighed when empty using a balance.

- Mass of bottle filled with the liquid M_2: A dry density bottle with a stopper is weighed when filled with the liquid using a balance.
- Mass of bottle filled with water M_1 : After removing the liquid and rinsing out the density bottle with water, the density bottle is filled with water and weighed again.

- The measurements are recorded as below:

Mass of empty: $= m_0$
Mass of bottle full of water: $= m_1$
Mass of bottle full of liquid: $= m_2$
Mass of liquid: $= m_2 - m_0$
Mass of water: $= m_1 - m_0$

- Relative Density of a liquid $= \frac{\mathbf{m_2 - m_0}}{\mathbf{m_1 - m_0}}$

Measurement of relative density of a solid
- This can be found by weighing the solid in air and when fully immersed in water.
- The solid immersed in water displaces an amount of water equal to its volume. The relative density is then calculated using;
- Relative density $= \frac{\text{Weight in air}}{\text{Weight in water}} = \frac{W_a}{W_a - W_w}$

Example 1
A density bottle was used to measure the density of mercury. The following measurements were taken:
- Mass of empty bottle = 20g
- Mass of bottle full of mercury = 360g
- Mass of bottle full of water = 45g

Calculate the;
(i) Relative density of mercury
(ii) Density of mercury

Solution

(i)	(ii)
$R.D = \frac{m_2 - m_0}{m_1 - m_0}$ $R.D = \frac{360 - 20}{45 - 20}$ $R.D = \frac{340}{25} = 13.6$	$R.D = \frac{\text{Density mercury}}{\text{Density of water}}$ $13.6 = \frac{\rho}{1000}$ $\rho = 13.6 \times 1000$ $\underline{\rho = 13600kgm^{-3}}$

Example: 2
A density bottle has mass 75g when empty, 95g when full of water and 99g when full of a liquid. Calculate the:
(i) Relative density of the liquid.
(ii) density of the liquid

Solution

$m_E = 75g; m_L = 99g; m_W = 95g$	
(i)	(ii)
$R.D = \frac{m_L - m_E}{m_W - m_E}$ $R.D = \frac{99 - 75}{95 - 75}$ $R.D = \frac{24}{20}$ $\underline{R.D = 1.2}$	$R.D = \frac{\text{Density of liquid}}{\text{Density of water}}$ $1.2 = \frac{\rho}{1000}$ $\rho = 1.2 \times 1000$ $\underline{\rho = 1200kgm^{-3}}$

EXERCISE:

1. A bottle full of water has a mass of 45g, when full of ethanol, its massis36g. If the empty bottle weighs 20g, calculate the density of ethanol.

2. Density bottle has a mass of 70g when empty, 90g when full of water and 94g when full of liquid.
Find the relative density of the liquid and its density.

3. An empty 60-litre petrol tank weighs10kg. What will be its mass when full of petrol of relative density 0.72?

4. A density bottle was used to measure the relative density of a liquid and the following results were obtained.
Mass of empty bottle : = 30g
Mass of bottle full of water : = 130g
Mass of bottle full of liquid : = 110g
Calculate the density of the liquid. **(=0.8gcm^{-3})**

5. An empty density bottle is 46.00g. When fully filled with water, it weighs 96.00g. It weighs 86.00g when full of an unknown liquid. Find the density of the liquid. **(=0.8gcm^{-3})**

6. A piece of aluminum weighs 80N in air and 50.37N when completely immersed in water. Calculate the relative density of aluminum. **(=2.7)**

7. Two solid cubes have the same mass but their surface areas are in the ratio of 1 : 16. What is the ratio of their densities?
A. 1 : 2 B. 4 : 1
C. 64 : 1 D. 1 : 64

9. A metal cuboid of dimensions 3 cm by 2 cm by 1 cm and 8.9 g cm^{-3} is completely immersed in a liquid of density 0.8 g cm-3. The mass of the liquid displaced is.
A. 53.4 g. C. 29.1 g.
B. 7.5 g. D. 4.8 g.

10. 0.002m^3 of a liquid of density 800kgm^{-3} is mixed with 0.003m^3 of another liquid of density 1200kgm^{-3}. What is the density of the mixture?
A. 1,000 kgm^{-3} B. 4,000 kgm^{-3}
C. 2,500 kgm^{-3} D. 1,040 kgm^{-3}

11.A bottle weighs 160 g when empty, 760 g when filled with water, and 1 kg when filled with a certain liquid. Calculate the volume of the liquid in bottle.
A: 160 cm^3 B: 600 cm^3
C: 760 cm^3 D: 1000 cm^3

12. What mass of lead has the same volume as 1600 kg of petrol? {Density of lead = 11400 kg m^{-3}, Density of petrol = 800 kg m^{-3}}

A. 22 800 kg C. 1600 kg
B. C. 11400 kg D. 800 kg

13. A metal cuboid of dimensions 3 cm by 2 cm by 1 cm and 8.9 g cm-3 is completely immersed in a liquid of density 0.8 g cm-3. The mass of the liquid displaced is

A. 53.4 g. B. 29.1 g.
B. C. 7.5 g. D. 4.8 g.

14. A tank 2m tall and base area of 2.5m^2 is filled to the brim with a liquid, which weighs 40000N. Calculate the density of the liquid in kg/m^3.

A. $\frac{4000}{2\times2.5\times10}$ C. $\frac{4000}{2\times2.5\times10}$

B. $\frac{40000}{2\times2.5\times10}$ D. $\frac{40000}{2\times25}$

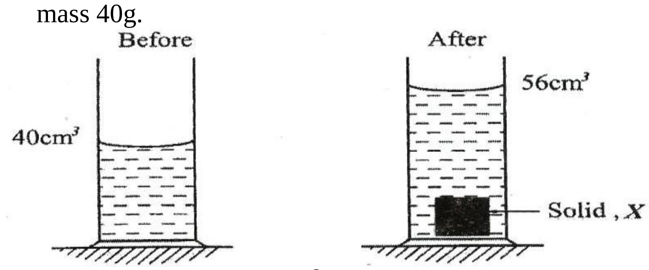
SECTION A

1. The abbreviation S.I units in Physics stands for;
A. Senior One units
B. Small International units.
C. Standard International units
D. Standard Improved units.

2. Which of the following instruments can be used to accurately measure the volume of a drop of water?
A. Beaker C. Pipette
B. Burette D. Dropper

3. The following reading were recorded when measuring the density of a stone; Mass of the stone = 25g, volume of water = 25 cm^3, volume of water and stone = 35cm^3. What is the density of the stone?
A. $\frac{25}{10}$ gcm^{-3} B. $\frac{35}{30}$ gcm^{-3}
C. 10 gcm^{-3} D. $\frac{25}{35}$ gcm^{-3}

4. The Figure shows levels of water in a measuring cylinder before and after immersing a solid **X** of mass 40g.

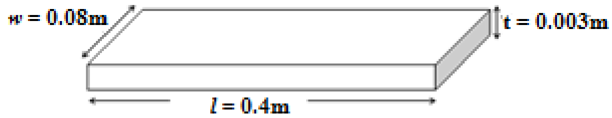


The density of solid X in gcm^{-3} is:
A. 1.0 B. 1.4 C.2.4 D. 2.5

5. Liquid Y of a volume 0.40m^3 and density 900 kgm^{-3} is mixed with liquid Z of volume 0.35 m^3 and density 800 kgm^{-3}. Calculate the density of the mixture.
A. 800 kgm^{-3} B. 840 kgm^{-3}
C. 850 kgm^{-3} D. 900 kgm^{-3}

6. The diameter of motor cycle spoke is measured accurately using.
A. metre rule B. vernier caliper
C. tape measure D. micrometer screw guage.

7. A manufacturer needs to measure accurately the dimensions of a wooden floor tile. The approximate dimensions of the tile are shown.



Which instruments measure each of these dimensions accurately?

	Length, *l*	Thickness, t	Width, w
A	Metre-rule	Micrometer	Vernier calipers
B	Metre-rule	Vernier calipers	Micrometer
C	Micrometer	Metre- rule	Vernier calipers
D	Vernier callipers	Micrometer	Metre-rule

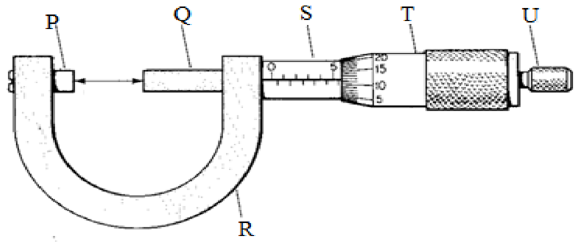
8. If a farmer measures the thickness of a pole to the nearest 0.1 mm which of the follow instruments can be used?
A. Screw gauge. B. metre rule
C. Vernier calliper D. Tape measure

9. Which of the following instruments is suitable for measuring the length of your desk?
A. Measuring cylinder B. Vernier caliper
C. Ruler D. Micrometer screw gauge

10. If a sphere has a diameter of 10cm. what is its volume;
A. 4190.5 cm^3 B. 523.8 cm^3
C. 1257.1 cm^3 D. 1571.4 cm^3

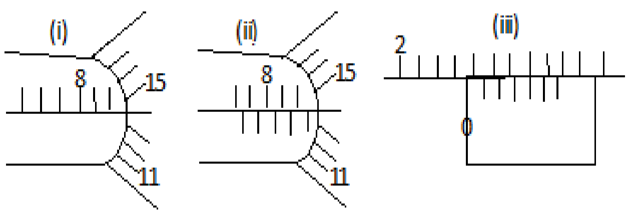
11. Which of the following is not a basic unit of measurement.
A. metre B. mole C. newton D. second.

12. The figure below shows an instrument used to measure length. What is the correct labeling of the parts?



	P	Q	R	S	T	U
A	Spindle	Anvil	Frame	Sleeve	Thimble	Ratchet
B	Anvil	Spindle	Frame	Sleeve	Thimble	Ratchet
C	Spindle	Anvil	Thimble	Main scale	Frame	Ratchet
D	Anvil	Spindle	Outer jaws	Main scale	Vernier scale	Ratchet

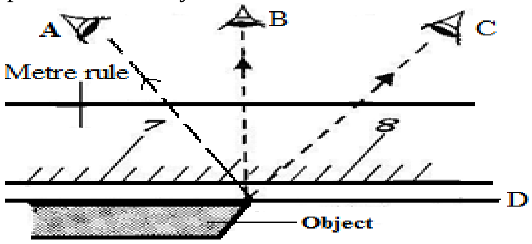
13. The figures below show some instruments for measuring length. State the reading on each instrument.



A. 10.15mm, 10.65mm and 2.34 mm
B. 10.15cm, 10.65cm and 2.34 cm
C. 10.15mm, 10.65mm and 2.34 cm
D. 10.15cm, 10.65cm and 2.34 mm

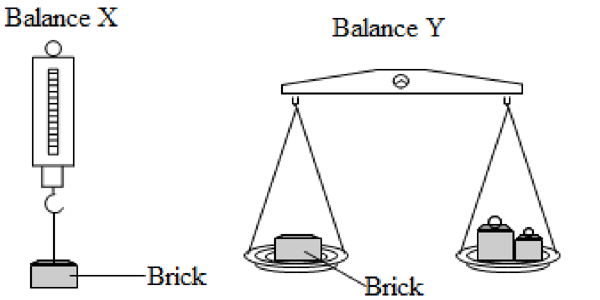
14. The quantity of matter in an object is referred to as;
A. volume B. mass C. density D. area

15. The figure below shows a metre rule being used to measure the length of an object. What is the correct position of the eye.



A. B. C. D.

16. A brick is placed on a newton balance X and then on a beam balance Y. What is measured by each balance?



	Balance X	Balance Y
A	Mass	Mass
B	Mass	Weight
C	Weight	Mass
D	Weight	Weight

17. Which of the following is a fundamental quantity?
A. Time B. Density C. Volume D. Area

18. What does a beam balance measure?
A. Area B. Mass C. Length D. Density

19. Which one of the following is not a method of science?
A. Measurement B. Observation
C. Experimentation D. Presentation

20. Which one of the following are not matter?
(i) Steam (ii) Pencil (iii) Light (iv) Space
A. (i) and (ii) B. (ii) and (iii)
C. (iii) and (iv) D. (i) and (iv).

21. How many cubic centimeters are there in a litre?
A. 500 B. 100 C. 2000 D. 1000

22. The sides of a black board are 2m and 5m, what is the surface area in m^2?
A. 0.1 B. 10 C. 1 D. 7

23. How many mm^2 are in 0.032 dm^2.
A. 3.2 B. 320 C. 32 D. 0.0032

24. Identify the correct statement.
A. Litre is a unit of length.
B. 1 dm is equal to 1 ten-thousandth of a metre.
C. A day is equal to one complete rotation of the earth.
D. A graduated cylinder is used to measure volume.

25. What is equivalent to 5 minutes?
A. 30s B. 60s C. 120s D. 300s

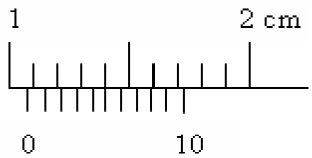
26. How many minutes are there between 05:30 and 21:15?
A. 715 B. 94 C. 1595 D. 900

27. The width of a meter rule is accurately measured by;
A. micrometer screw gauge B. vernier caliper
C. tape measure D. meter rule

28. A set of apparatus that is suitable for measurement of the volume of an irregular object includes;
A. Over flow can, measuring cylinder, irregular object and a string.
B. Measuring cylinder, irregular object, over flow cans, flask.
C. Overflow can, Irregular objects, string, retort sand and burette
D. Burette, overflows can, irregular object, a string, measuring cylinder, and retort stand.

29. Convert $25cm^3$ into m^3
A. 02.5×10^5 B. 2.5×10^2
C. 2.5×10^{-1} D. 2.5×10^{-5}

30. The figure shows vernier calipers. The diameter of the object is:



A. 1.05 cm B. 1.06 cm
C. 1.56 cm D. 1.60 cm

31. Three of the fundamental physical quantities are:
A. Density, mass and time
B. Length, time and mass
C. Length, time and weight
D. Volume, density and mass

32. An S.1 student made a record of 1.34cm in a lesson on measurements. If the value is correct, which instrument did the student use to make the measurement?
A: metre rule B: micrometer screw gauge
C: vernier calipers D: Tape measure

33. What would be the reading if a relatively second accurate instrument among the above instruments is used?
A. 1.34 mm B. 13.40 mm C. 0.04 ft D. 1.34 cm

34. (a) Copy the following table and complete the blank spaces.

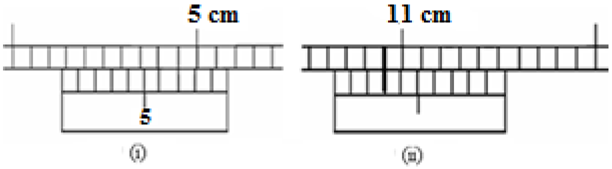
Material	Mass	Volume	Density
A	50g	$25cm^3$	
B		$100cm^3$	$8.6gcm^{-3}$
C	72g		$0.8gcm^{-3}$

(b) What volume of material **C** must be added to **10cm^3** of **A** to make a total mass of **65g**?

35. (a) Draw and label the diagram of the Vernier calipers.

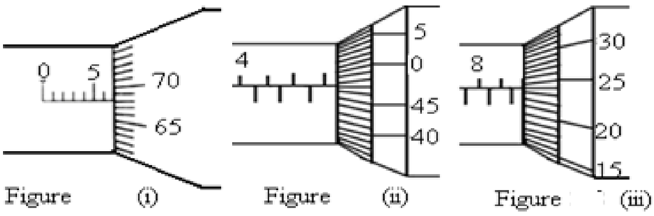
(b) Find the thickness of a text book measured using a vernier caliper if the main scale reading is **24 mm** and the **8th vernier mark** coincides with one of the marks on the main scale.

(c) Find the reading on the verniers shown in the diagrams below.



36. (a) Draw and label the diagram of the micrometer screw gauge.

(b) Find the reading on the micrometer screw gauge shown in the figures below.

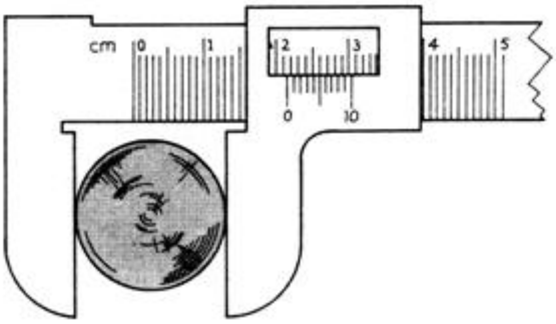


37. A seconds pendulum takes two seconds to complete one swing. On one occasion a seconds pendulum is kept in motion for two minutes. How many swings does the pendulum complete?

38. A physicist wants to measure the thickness of a piece of copper wire and a metal chip. She uses a micrometer to measure the thickness of the wire and a pair of vernier calipers to measure the thickness of the chip. Explain her choice of instrument.

39. The figure shows a vernier calipers being used to measure the diameter of a cylindrical rod.

(a) What is the reading shown by the instrument (2marks)

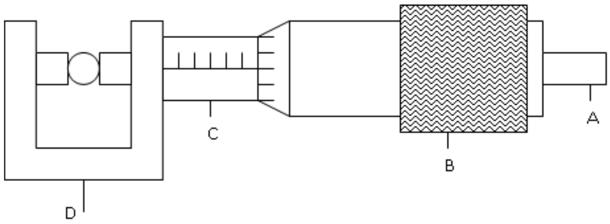


(b) .State two precautions to be taken when using a micrometer screw gauge. (2marks)

40. (a) What do you understand by the term least count in relation to a vernier calipers. (1mark)

(b) Some vernier calipers are said to have a zero error. What do you understand by the term zero error and how is it taken care of when taking a reading.(2mrks)

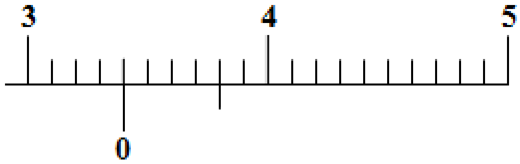
41. The figure shows a micrometer screw gauge with a thimble scale of 50 divisions. When the jaws are closed the metre reads 0.25mm



(i) Label the parts A, B, C and D. (4marks)

(ii) State the correct diameter of the ball. (2marks)

42. State the reading on the vernier caliper shown in the figure below. (2marks)



43. .You are provided with the following

- ✓ A large shallow tray
- ✓ Water
- ✓ Lycopodium powder
- ✓ Some olive oil
- ✓ Either apiece of thin wire with a kink and a millimeter scale or a burette

Describe an experiment to estimate the diameter of an oil molecule of the olive oil. (4marks)

44. The number of molecules in 18cm^3 of liquid is 6 x 10^{23}. Assuming that the diameter of the molecules is equivalent to the side of a cube having the same volume as the molecule. Determine the diameter of the molecule. (3marks)

45. In an experiment to estimate the thickness of an oil molecule an oil drop of diameter 0.05cm spreads over a circular patch whose diameter is 20cm.

(a) Determine

(i) the volume of the oil. (3marks)

(ii) the area of the patch covered by the oil. (2marks)

(iii) the diameter of the oil molecule. (2marks)

(b) State two possible sources of error in this experiment. (2marks)

46. (a) Write these fractions as powers of ten:

(i) 1/1000 (ii) 7/100 000

(iii) 1/10 000 000 (iv) 3/60 000

(b) Express the following decimals as powers of ten with one figure before the decimal point:

(i) 0.5 (ii) 0.084

(iii) 0.000 36 (iv) 0.001 04

47. The pages of a book are numbered 1 to 200 and each leaf is 0.10 mm thick. If each cover is 0.20 mm thick, what is the thickness of the book?

48. How many significant figures are there in a length measurement of:

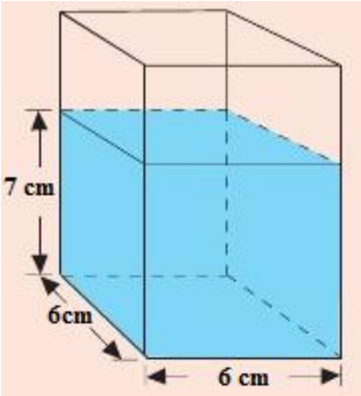
a 2.5 cm, b 5.32 cm, c 7.180 cm, d 0.042 cm?

49. A rectangular block measures 4.1 cm by 2.8 cm by 2.1 cm. Calculate its volume giving your answer to an appropriate number of significant figures.

50. A metal block measures 10 cm by2 cm by 2 cm. What is its volume? How many blocks each 2 cm by 2 cm by 2 cm have the same total volume?

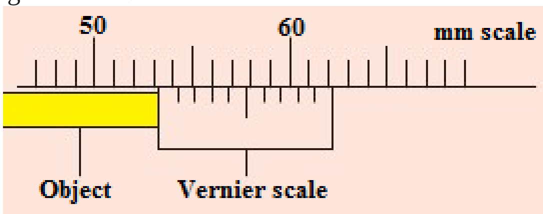
51. How many blocks of ice cream each 10 cm by 10 cm by 4 cm can be stored in the compartment of a freezer measuring 40 cm by 40 cm by 20 cm?

52. A Perspex container has a 6 cm square base and contains water to a height of 7 cm as shown in the figure below.

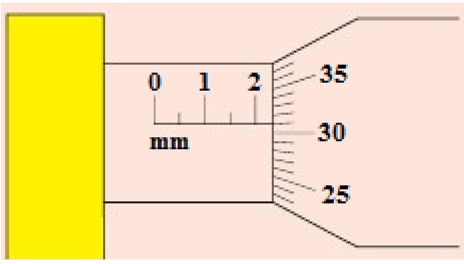


(a) What is the volume of the water?
(b) A stone is lowered into the water so as to be completely covered and the water rises to a height of 9 cm. What is the volume of the stone?

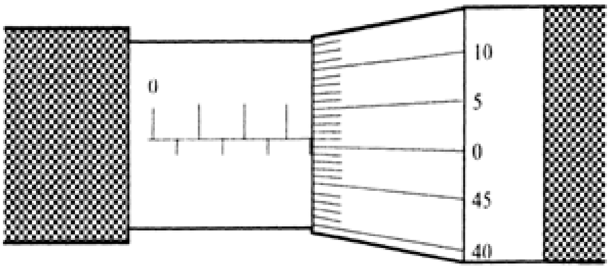
53. What are the readings on the vernier scale in Figure below?



53. What are the readings on the micrometer screw gauge in Figures below?



53. The figure shows a micrometer screw gauge being used to measure the diameter of a test tube. When the test tube is removed and the jaws of the micrometer screw gauge are closed, the reading is 0.13mm. Determine the diameter of the test tube (2marks)



54. A rocket has a mass of 500 kg.
(a) What is its weight on Earth where g = 10 N/kg?
(b) At lift-off the rocket engine exerts an upward force of 25 000 N.
   (i) What is the resultant force on the rocket?
   (ii) What is its initial acceleration?

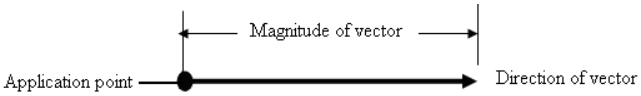
SCALAR AND VECTOR QUANITITIES

Physical quantities can be divided into two types namely:
i) Scalar quantity ii) Vector quantity

***A scalar quantity** is physical quantity which has magnitude only.*
<u>Examples:</u> Mass, volume, time, temperature distance, pressure etc.

***A vector quantity** is a physical quantity which has both magnitude and direction.*
<u>Examples:</u> displacement, Velocity, acceleration, force, momentum, Electric and magnetic field intensities.

Representation of vectors.
Vectors are represented by an arrow headed line drawn to scale is called a vector. A vector has the following properties:
- An application point (where it is applied).
- A magnitude (size i.e. how big or small it is).
- A direction.



Resultant Vector
***A resultant vector** is a single vector which produces the same effect on an object as two or more vectors acting on the same body.*

Moving from O to B along OB is the same as moving through OA followed by AB. This shows that a single vector OB produces the same effect as adding;
$\overrightarrow{OB} = \overrightarrow{OA} + \overrightarrow{AB}$

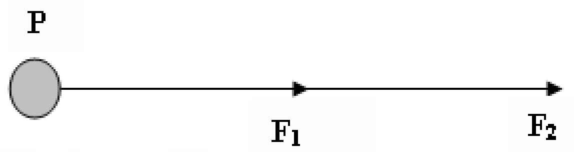
In general the resultant force is calculated by adding all the force. But when the forces are in opposite direction the resultant force is calculated by subtracting.

Addition and subtraction of vectors
The addition of vector takes place so long as the directions are the same though the magnitude may differ. The subtraction occurs when the directions are opposite.

Points to note: Since force is a vector, the direction is important. Therefore,
(i) If force(s) to the right are taken to be positive, then the one(s) to the left is/are negative. Likewise,
(ii) If force(s) acting to north or east is/are taken to be positive, then the one(s) acting to south and west respectively is/are taken to be negative.
(iii) The number of **F**s to the right of the above formula = to the number of forces acting on a body.

(a) Forces acting in a straight line.
The resultant force due to forces acting in a straight line is got by addition or subtraction of the forces depending on their directions.

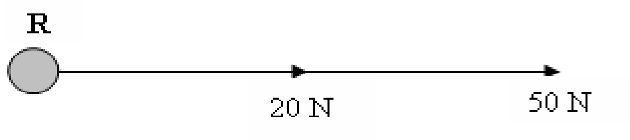
(i) Two forces acting on a straight in the same direction ($\theta = 0°$)
Consider two forces F_1 and F_2 acting on body P as shown in figure below.



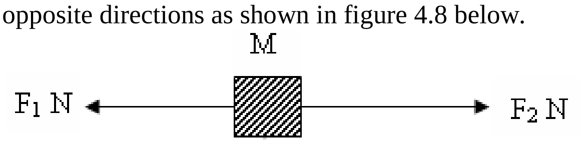
Since the forces are acting in the same direction, they are taken to be positive.
The resultant force, R, is got by addition of the forces. i.e

$$\overrightarrow{F_r} = \overrightarrow{F_1} + \overrightarrow{F_2}$$

Example 1
Two forces 20 N and 50 N act on body R in the same direction as shown in the diagram below. Find the resultant force.



(ii) Two forces acting on a straight in opposite directions (θ = 180°)
Consider two forces F_1 and F_2 acting on body M in opposite directions as shown in figure 4.8 below.



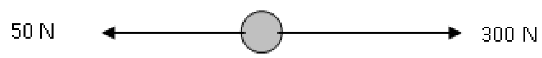
Since the forces are acting in opposite directions, one is taken to be positive and the other negative.Let F_1 be positive and F_2 be negative.

The resultant force, given by using the equation:

$$F_r = F_1 + F_2$$
$$= F_1 + {}^{-}F_2$$
$$\therefore F_r = F_1 - F_2$$

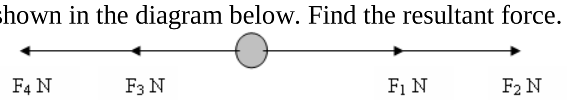
Therefore, the resultant force, F_r, $= (F_1 - F_2)$ in the direction of F_1.

Example 2
Two forces 300 N and 50 N are acting on a body Q as shown in figure 4.9 below. Find the resultant force.



NB: *Instead of taking one force to be positive and the other negative, you may simply subtract the smaller force (**Opposing force**) from the larger one (**Driving force**).*

(b) More than two forces acting on a straight in opposite directions (θ = 180°)
Consider four forces F_1, F_2, F_3 and F_4 acting on body S as shown in the diagram below. Find the resultant force.



Solution

For the case such as above where there are more than two forces acting on a body in opposite direction, follow the following steps.

Step I: Get the resultant forces in the directions shown in the diagram above.

Resultant force *towards right*, $R_r = (F_1 + F_2)$ N

Resultant force *towards left*, $R_l = (F_3 + F_4)$ N

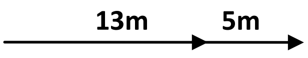
Step II: Get the final resultant force, R, of the two resultant forces above.

Resultant force, $R = R_r - R_l$

$= [(F_1 + F_2) - (F_3 + F_4)]$N

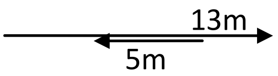
Example 1:

A goat moves 13m west and continue moving west ward 5m. Find the resultant displacement of the got .

	S_H =13+5 =18m in the western direction

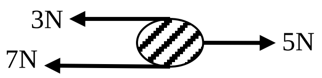
Example 2:

Move 13m west and the move 5m east.

	S_H =13-5 =8m in the western direction

Example 3:

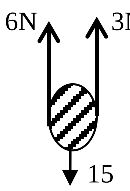
Three force of 3, 5N and 7N act on an object A as shown. Find single vector which can produce the same effect.

	F_H = (3+7) - 5 =5N towards the East

Example 4

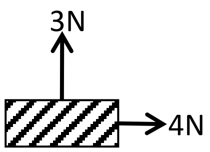
Three force of 3, 5N and 7N act on an object A as shown. Find single vector which can produce the same effect

.

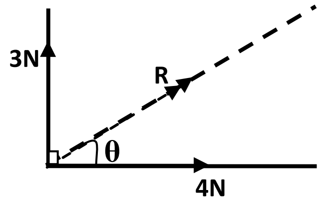
	F_V =15- (6+3) = 6N towards the South

Example 5

Two force of 3 and 4N act on an object as shown. Find single force which can produce the same effect as the two forces above.

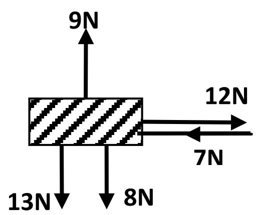


Solution:

F_H = 4N → F_V = 3N ↑ Resultant Vector diagram	Direction of the resultant force From the Vector diagram; $\tan\theta = \frac{\text{Opposite}}{\text{Adjascent}}$ $\tan\theta = \frac{3}{4}$
 Magnitude of the resultant force Using the Pythogras theorem; $(\textbf{Hypotenuse})^2 = (\textbf{Base})^2 + (\textbf{Height})^2$ $(R)^2 = (b)^2 + (h)^2$ $R^2 = 4^2 + 3^2$ $R^2 = 25$ $R = \pm\sqrt{25}$ $R = \pm 5N$ ∴The magnitude of the resultant force is 5N	$\theta = \tan^{-1}\left(\frac{3}{4}\right)$ $\theta = 36.9^0$ ∴The direction of the resultant force is 36.9^0above the horizontal (or above the 4N force)

Example 6

The figure below shows five forces acting on a 2.5kg mass.



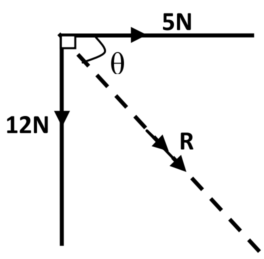
Calculate the;

(i) resultant force on the mass
(ii) direction of the resultant force
(iii) acceleration of the mass

Solution

(i) $F_H = (12 - 7)N = 5N \rightarrow$

$F_V = \{(13 + 8)N - 9N\} = 12N \downarrow$

Resultant Vector diagram 	The magnitude of the resultant force Using the Pythogras theorem; $(R)^2 = (b)^2 + (h)^2$ $R^2 = 5^2 + 12^2$ $R^2 = 169$ $R = \pm\sqrt{169}$ $R = \pm 13N$ ∴The magnitude of the resultant force is 13N

(ii)

- Direction of the resultant force

From the Vector diagram;

$\tan\theta = \frac{\text{Opposite}}{\text{Adjascent}} \Leftrightarrow \tan\theta = \frac{12}{5}$

$\theta = \tan^{-1}\left(\frac{12}{5}\right) = 67.4^0$

∴The direction of the resultant force is 67.4^0below the horizontal (or below the 4N force)

(iii)

- Acceleration of the mass

From $F = ma$

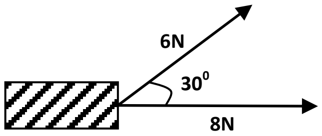
$13 = 2.5a$

$\frac{13}{2.5} = \frac{2.5}{2.5}a$

$\therefore \qquad a = 0.48 \quad ms^{-2}$

Example 7

Two forces 6N and 8N act on 2kg body as shown. Calculate (i) the resultant force (ii) the acceleration

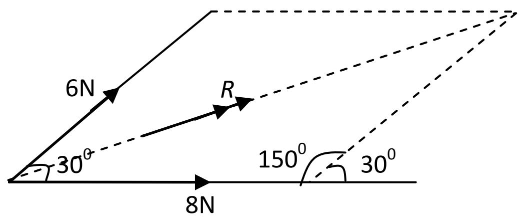


Methode I: Using Graphical Method.

Procdures

- Choose a scale for the axes
- Draw the vectors at the given angle
- Complete the Parallelogram of vectors.
- Measure the length R of the diagonal
- Multiply R by the scale to get the resultant Vector.

Method II: Using the Cosine Rule.



$a^2 = b^2 + c^2 - 2bc\cos\theta$

$R^2 = 8^2 + 6^2 - 2(8)(6)\cos 150$

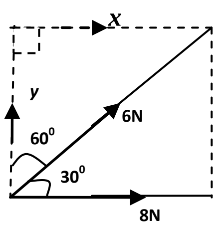
$R^2 = 64 + 36 - 104\cos 150$

$R^2 = 100 - 104\cos 150$

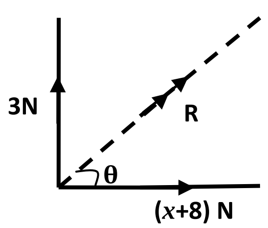
$R^2 = 190.07$

$R = \pm 13.8$ N

Method III: By Resolving the Forces Horizontally and Vertically.

	From the diagram; $\sin 60 = \frac{x}{6} \Leftrightarrow x = 6\sin 60$ $x = 6 \times 0.8666 = 5.2N$ $\cos 60 = \frac{x}{6} \Leftrightarrow x = 6\cos 60$ $x = 6 \times 0.5 = 3N$

Then; $F_V = y = 3N$, $F_H = x+8 = N$

	Using the Pythogras theorem; $(R)^2 = (b)^2 + (h)^2$ $R^2 = 5^2 + 3^2$ $R^2 = 169$ $R = \pm\sqrt{169}$ $R = \pm 13N$ $\therefore$<u>The magnitude of the resultant force is 13N</u>

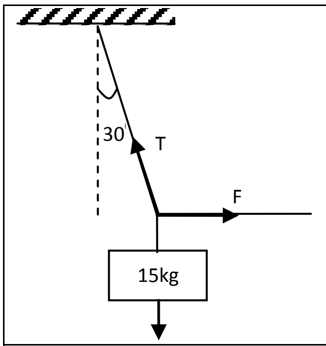
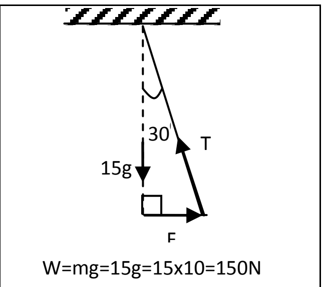
Example 8

A mass of 15kg is suspended using a string. The string is then pulled by a horizontal force F such that the string makes an angle of 30^0 with the down ward vertical. Calculate the;

(i) Tension in the string.

(ii) Horizontal force F.

Solution:

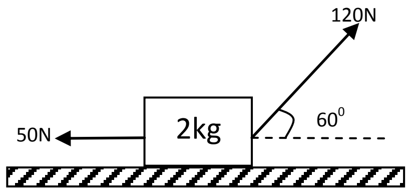
	
The three forces are in equilibrium Step 1: forming a closed triangle Step 2: resolving Vertically; $\text{Cos } 30 = \frac{150}{T} \Leftrightarrow T\cos 30 = 150$ $\Leftrightarrow T = \frac{150}{\cos 30} = 173.21N$	
Step 3: Resolving Horizontally $\text{Tan } 30 = \frac{F}{150} \Leftrightarrow 150\tan 30 = F \Leftrightarrow F = 86.6N$ OR $\sin 30 = \frac{F}{T} \Leftrightarrow T\sin 30 = F \Leftrightarrow F = 173\sin 30 = 86.6N$	

Example 9

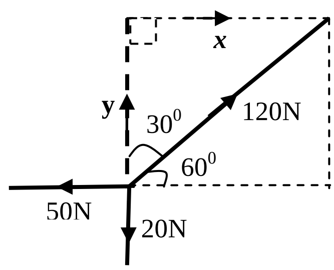
A block of mass 2kg is pulled along a rough horizontal ground by a force of 120N, with the help of a string, which makes an angle of 60^0 with the horizontal. If the friction between the block and the ground is 50N, calculate the;

(i) Resultant force on the block.

(ii) Acceleration of the block.



Solution



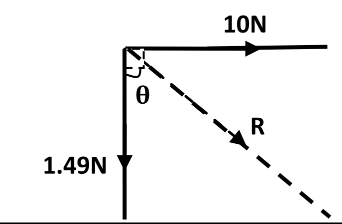
From the diagram;

$\sin 30 = \frac{x}{120} \Leftrightarrow x = 120\sin 30 = 120 \times 0.5 = 60N$

$\cos 30 = \frac{y}{120} \Leftrightarrow y = 120\cos 30 = 120 \times 0.866$
$= 18.51N$

Then;

$F_V = 18.51 + (-20) = -1.49$ N, $F_H = 60 + (-50) = 10$ N



Using the Pythogras theorem;

$(R)^2 = (b)^2 + (h)^2$

$R^2 = 10^2 + 1.49^2$

$R^2 = 102.2201$

$R = \pm\sqrt{102.2201}$

$R = 10.11N$

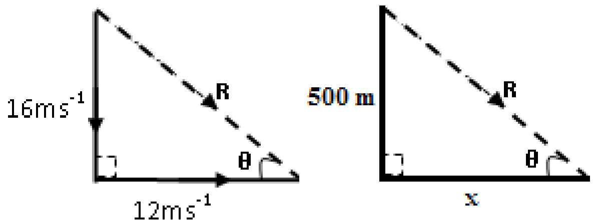
Exercise on Vectors and scalars

1. Two forces of 7N and 9N act perpendicularly on a body of mass 2kg. Find the acceleration of the body.

2. A man starts from point A and walks a distance of 20m due north and then 15m due east. Find his new position relative to A.

3. A parachutist falling with a constant velocity of 16 ms^{-1} is blown by wind horizontally at 12 ms^{-1}.
   (i) Find the resultant velocity of the parachutist.
   (Ans: 20 ms^{-1} at an angle of 53.1^0 to the horizontal)

   (ii) If the parachutist jumps from a height of 500m directly above a ground target, find the horizontal distance by which the parachutist will miss the target on landing. **(Ans: 375m)**



From the second diagram (displacement diagram),

$$\tan\theta = \frac{500}{x} \Rightarrow \frac{16}{12} = \frac{500}{x} \Rightarrow x = 375 \text{ m}$$

Alternatively:
Using similarity of figures, The velocity triangle is similar to the displacement triangle. Thus,

$$\frac{16}{12} = \frac{500}{x} \Rightarrow x = 375 \text{ m}$$

Alternatively:

$$y = u_y t$$
$$500 = 16t \Leftrightarrow t = 31.25\ s$$

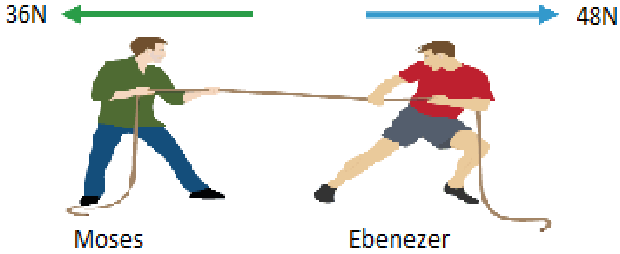
$$Then, x = u_x t$$
$$x = 12 \times 31.25 \Leftrightarrow x = 375 \text{ m}$$

4. A mass of 15kg is suspended using a string. The string is then pulled by a horizontal force F such that the string makes an angle of 30^0 with the down ward vertical. Calculate the;
   (i) Tension in the string. (ii) Horizontal force F.

5. A block of mass 2kg is pulled along a rough horizontal ground by a force of 120N, with the help of a string, which makes an angle of 60^0 with the horizontal. If the friction between the block and the ground is 50N, calculate the;
   (i) Resultant force on the block. <u>10.11N</u>
   (ii) Acceleration of the block.

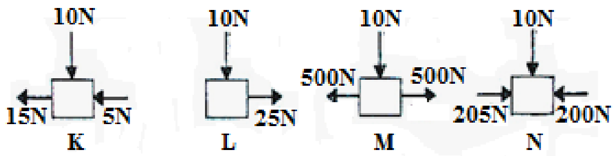
6. Which of the following is true for an object under shearing forces?
   A. the object does not change in shape.
   B. the layers of the object tend to slide on one another.
   C. the object gets twisted.
   D. the object tends to shorten

7. Two men Moses and Ebenezer apply forces of 36N and 48N respectively on a rope of mass 3kg as shown below.



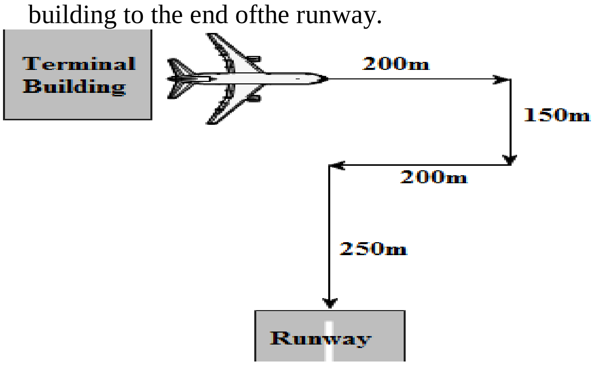
(i) Calculate the resultant force on the rope.
(ii) Find the acceleration of the rope.

1. (2004 PP1.A.Q:25)
8. The figure below shows forces applied on each of the identical blocks of the same mass.



The block which has the greatest net force is
A. K B.L C. M D. N

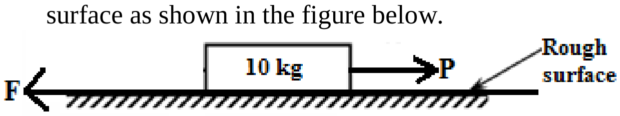
9. At an airport an aircraft moves from the terminal A a building to the end ofthe runway.



Which row shows the total distance travelled and the size of thedisplacement of the aircraft?

	Total distance Travelled (m)	Size of Displacement (m)
A	400	800
B	450	200
C	450	400
C	800	400
E	800	800

10. A 10kg block is pulled by a force, P along a rough surface as shown in the figure below.



If the coefficient of friction between the block and the surface is 0.25 and the acceleration of the block is $3ms^{-2}$, find the:
(i) Friction force, F on the block.
(ii) Pulling force, P.
(iii) New acceleration if P, is doubled. (07mrks)

FORCES

***A force** is a physical quantity which changes a body's state of rest or uniform motion in a straight line.*
- It is a physical quantity which makes a body to accelerate.
-It is a push or a pull on a bodywhich changes a body's state of rest or uniform motion in a straight line.

$$\mathbf{F = Ma}$$

Where**:** **F** = Force, **M** = Mass, **a** = Acceleration.

Force is a derrived vector quantity. The S.I unit is **a newton**, (**N)**.
Definition of a newton.
A newton is the force whic gives a mass of 1 kg an acceleration of 1 ms^{-2}.

Effects produced by a Force
A force acts in a particular direction and may have any of the following effects on an object.
It can:
- (i) Make a stationary object to move.
- (ii) Increase the speed of a moving object.
- (iii) Decrease or slow down the speed of a moving object or bring a moving object to a rest.
- (iv) Change the direction of a moving object.
- (v) Deform (change the shape of) an object.

Types of forces
There are various types of forces; some of the common ones include the following:
Gravitational force, weight, friction, upthrust force, electrostatic force, elasticforce, magnetic force, Centripetal force, centrifugal force, Tensional force, compression force, shear force etc.

Frictional force - *is the force, which opposes relative motion between two surfaces in contact.*

Centripetal force - *is a force which constrains a body to move in acircular path or orbit. Its direction is towards the centre of the circle.*

Magnetic force - *is a force in magnets that causes motion as a result of attraction or repulsion.*

Electrostatic force - *is a force that causes attraction or repulsion in an electric field due to static charges.*

Elastic force- *is a force in a stretched spring or rubber cord.*

Upthrust- *is an upward force that acts on a body immersed in a fluid (a liquid or a gas).*

Cohesive force - *is a force of attraction between molecules of the same kind. E.g force of attraction between water molecules.*

Adhesive force - *is a force of attraction between molecules of different kinds. E.g force of attraction between water molecules and glass molecules.*

Surface tension - *is the force on a liquid surface which makes the liquid surface to behave like a stretched elastic membrane or skin.*

Shear force: - *is a force which causes the layers of the body to slide over each other.*

Gravitational force - *is the force, which pulls a body towards the centre of the earth.*

(a) Gravitational force
The earth is surrounded by gravitational field which exerts a force on anybody in the field.

The strength of the gravitational field is the force acting on a unit mass in the earth's field. Experimental measurements show that on a unit mass on the earth's surface, a mass of 1kg experiences a force of 0.9 N i.e. its weight is 9.8N so the earth's field strength "g" =9.8N/kg or approximately, g =10N/kg

1kg = 10N
g = 10N/kg = $10ms^{-2}$

An object released from a height falls down to the ground. This indicates that there is a force acting on the object directed to the centre of the earth. This downward pull is called *gravitational force*.

It makes unsupported objects to fall until they reach the ground. The force of gravity pulls all objects at a particular place on the surface of the earth with the same acceleration of free fall called *acceleration due to gravity*.

(b)Acceleration due to gravity, g
Acceleration due to gravity, *g, is the acceleration with which the force of gravity pulls all objects on or near the surface of the earth towards its centre.*
The average value of $\boldsymbol{g}$on the surface of the earth is 9.8 ms^{-2}, but it varies slightly from place to place.

(c) The variation of Acceleration due to gravity, g
The acceleration due to gravity is not constant everywhere. It varies from place to place. For example g is 9.78 ms^{-2} at the equator, whereas at the poles it is 9.83 ms^{-2}. There are two main causes of this variation.

(i) Shape of the earth not a perfect sphere.
The earth is not a perfect sphere. It is oval in shape; It thins at the poles and bulges at the equator. Thus, the *equatorial radius*, $\boldsymbol{R_e}$of the earth is greater than the *polar radius*, $\boldsymbol{R_p}$. If M is the mass of the earth and G is the gravitational constant.
As $g = \frac{GM}{R^2} \Rightarrow \boldsymbol{g\ \alpha\ \frac{1}{R^2}}$. Thus,as,$\boldsymbol{R_e} > \boldsymbol{R_p} \Rightarrow \boldsymbol{g_e} < \boldsymbol{g_p}$

The value of the Acceleration due to gravity, *g*, depends on the distance from the centre of the earth to that place, R. The smaller the distance, the higher the value of *g*, and vice versa. Since the earth is not a perfect sphere, the distances from the centre of the earth to different points on the surface of the earth is different. Therefore the value of, g, varies from place to place. Thus, in places near to the centre of the earth like the north and south poles, the value of, g, is greater than at equator. It is also greater at sea level than at higher altitudes such as on top of mountains.

The acceleration due to gravity on the moon is about one-sixth of that of the earth. (i.e. $\frac{1}{6}$ x 9.8 = 1.6 ms^{-2}).

(ii) Rotation of the earth

Because the Earth rotates, its gravitational pull on the body at the equator provides the body with a centripetal acceleration. This effect does not apply at the pole.

The acceleration due to gravity due to earth's rotation is given by:

$$g^1 = g - Rw^2 \cos^2 \emptyset$$

Where, $\emptyset$ is the angle the weight of a body at the earth's surface makes with the earth's axis, R is the radius of the earth and w is the angular velocity.

Free fall is a vertical motion whose acceleration is due to gravity "g" = 10ms^{-2}. The gravitational force is towards the centre of the earth and its magnitude on the body of mass "m" is given by **mg**.

Planet or Moon	**Value of acceleration due to gravity, g in Nkg^{-1}**	**Mass ($\times 10^{24}$kg)**
Moon	1.6	0.073
Mars	3.7	0.642
Earth	9.8	5.970
Jupiter	23.1	1898.000

(a) WEIGHT

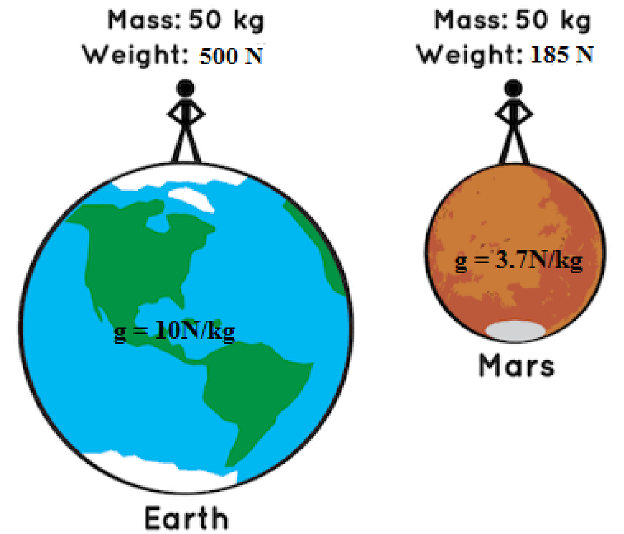
Weight of a body is the gravitational force with which a body is attracted by the earth towards its centre.

Is the force a body exerts on anything which freely supports it in the gravitational field.

$$\left(\textbf{Weight of body in N}\right) = \left(\textbf{mass of body "m" in kg}\right) \times \left(\textbf{acceleration due to gravity, g. in } \mathbf{Nkg^{-1}}\right)$$

$$\mathbf{W = mg}$$

The S.I unit of weight is a **newton "N"** Weight of a body varies from place to place or from planet to planet.



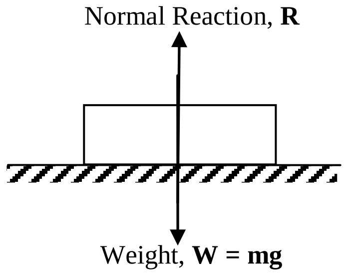
Why weight of a body varies

Weight of a body varies because of the following reasons:

i) <u>The shape of the earth is not a perfect sphere</u>. so at the equator the value of acceleration due to gravity is less than that at the pole. This makes the weight of the body to be less at the equator and greater at the poles.

ii) <u>Rotation of the earth.</u> This leads to a centrifugal force which slightly reduces the weight of the body.

ii) <u>Planets have different accelerations due to gravity</u>. A body resting on the surface experience a reaction force R from the surface which supports it.



Differences between Mass and weight

Mass	**Weight**
i) S.I unit is kg	SI unit is N
ii) Is a scalar quantity	Is a vector quantity
iii) Is constant at all places	Varies from place to place
iv) Is a measure of quantity of matter in a body	Is force of gravity acting on a body.
v) Is a funder mental quantity	Is a derived quantity
vi) Measured using a beam balance.	Measured using a spring balance.
vii) It cannot be zero	It is zero when g = 0

Example:

A body of mass 30 kg weighs 60N on planet X. What is the acceleration due to gravity on planet X.

Solution:

m = 30kg, W_X = 60 N

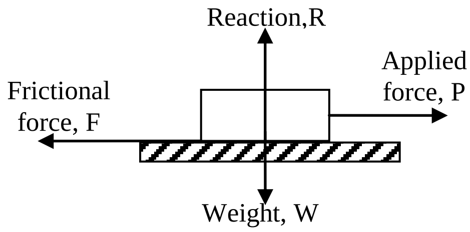
$\mathbf{W_X = mg_X}$

60 = 30 × g_X ⇒ $g_X = 2\ ms^{-2}$

(b) FRICTION

<u>Friction is the force which opposes one surface moving or trying to move over another.</u>

It acts in the opposite direction to that of the force causing motion.



$$R = W = mg \ldots\ldots\ldots\ldots\ldots\ldots\ldots .(i)$$
$$F = \mu R = \mu mg \ldots\ldots\ldots\ldots\ldots\ldots\ldots (ii)$$

Where, $\mu$is called the coefficient of friction**,** **R** is the normal reaction on the body of mass, **m**, w is the weight of the body.

As the applied force, P increases, the frictional force, F increases until it reaches a maximum value, $\mathbf{F}_{max}$beyond which friction cannot be increased.
This maximum value of frictional force, F_{max} is called **Limiting friction.**
`
When $\mathbf{P} = \mathbf{F}_{max}$**,** mass (body) is just about to move, i.e, it is at the point of moving. At this point, any extra slightest force applied to the mass in the direction of P will move the mass.
Therefore, it should clearly be noted that the mass will only move if the applied force, P is greater than the maximum frictional force, $\mathbf{F}_{max}$**.**

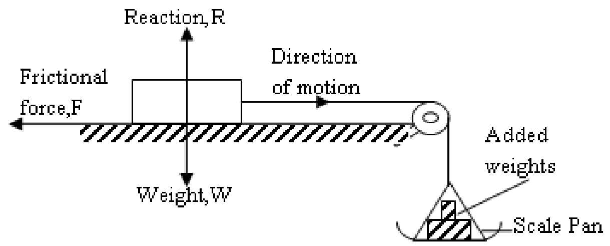
Note:
(i) **If**, $\mathbf{P} < F$, the mass does **not** move. It remains at rest.
(ii) **If**, $\mathbf{P} = \mathbf{F}_{max}$, the mass does **not** move. It is at the point of moving.
(iii) **If**, $\mathbf{P} > \mathbf{F}_{max}$, the mass moves. It can move with a constant speed or it can accelerate, in which case the acceleration is obtained from: $\mathbf{P} - \mathbf{F}_{max} = \mathbf{ma}$

Types of friction
These are:
a) Static friction b) Sliding or dynamic friction
c) Viscosity

a) **Static Friction**:
Static friction is the friction which opposes ***attempted motion*** *between two surfaces* ***at rest****.*

It is the friction which opposes motion between two surfaces in contact at rest.
❖ It prevents motion.

Experiment for measurement of static friction

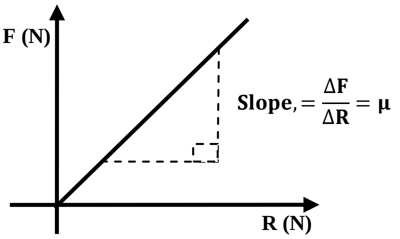


i) Adding weight on pan
Know weights are added to the scale pan until the block just starts to move.

ii) The above will occur when weight of scale pan + weights on the pan (loads) = maximum friction, F. This maximum friction is called limiting friction.

iii) Repeating
The procedure is repeated by increasing weight of the block "W" and obtaining the corresponding "F"

iv) Plotting a graph
A graph of F against W (= normal reaction "R") is plotted .and its slope = coefficient of static friction**μ.**



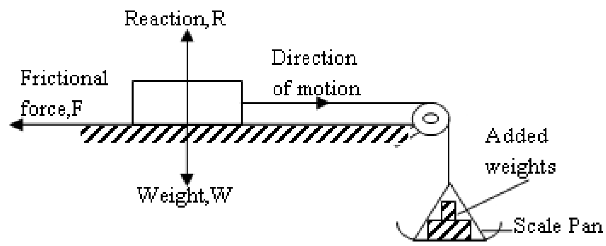
$$\begin{pmatrix}\text{Frictional}\\ \text{force, F}\end{pmatrix} = \begin{pmatrix}\text{coefficient}\\ \text{of friction, } \mu\end{pmatrix} \times \begin{pmatrix}\text{Normal}\\ \text{Reaction, R}\end{pmatrix}$$
$$\mathbf{F = \mu R}$$
Thus Coefficient of static friction **μ** is the ratio of limiting frictional force F to the normal reaction R. i.e $\mu = \frac{F}{R}$
Note: Coefficient of friction μ has no units.

Example
Calculate the static friction when a body of mass 6kg rests on a surface; given that coefficient of friction of surface is 0.5.
Given: m= 6kg; $\mu = 0.5$; g = 10ms^{-2}
From; Frictional force, $F = \mu R$

But $R = W = mg$ $= 6(10)$ $R = 60N$	Then From; $F = \mu R$ $F = 0.5(60)$ $F = 30N$

b) Sliding or kinetic or dynamic friction:
Is friction which opposes relative motion between two surfaces in contact and in motion.
It is the force which opposes the motion of one surface moving with uniform velocity over another surface.
❖ It slows down motion.

Experiment for measurement of kinetic friction.

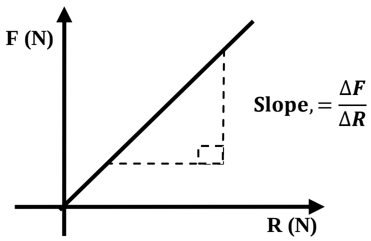


i) Adding weight on pan
Known weights are added to the scale pan and **a small push is given** each time until the block move with a uniform velocity.

ii) The above will occur when weight of scale pan + weights on the pan (loads) = maximum friction, F. This maximum friction is called limiting friction.

iii) Repeating
The procedure is repeated by increasing weight of the block "W" and obtaining the corresponding frictional force F'.

iv) Plotting a graph
A graph of "F" against R is plotted and its slope = coefficient of sliding friction **μ.**.



c) Viscosity:
Is the opposition to the relative motion between layers of a fluid.

Advantages of friction
(i) It enables bodies to come to rest
(ii) It enables bodies to move without sliding
(iii) It helps in writing
(iv) It helps in making fire

Disadvantages of friction
(i) causes unnecessary heat
(ii) reduces the efficiency of machines
(iii) Causes things like tyres, soles of shoes to wear out.
(iv) Causes parts of machines to break.
(v) Causes un necessary noise

Reduction of friction
(i) Lubrication using oil or grease
(ii) Using ball bearings
(iii) Using rollers.

***Limiting friction** is the maximum friction between any two surfaces in contact.*

Laws of friction
- The limiting does not depend on the surface area in contact but depends on the nature of the face contact.
- Frictional force is not affected by velocity with which a body moves for sliding friction.
- Friction always opposes motion.
- Limiting friction is proportional to normal reaction which is equal and opposite to the weight of the body.
- Friction always increases from zero to maximum value called limiting friction.

EXERCISE

1. Two forces of 7N and 9N act perpendicularly on a body of mass 2kg. Find the acceleration of the body.

2. A man starts from point A and walks a distance of 20m due north and then 15m due east. Find his new position relative to A.

3. A parachutist falling with a constant velocity of 16 ms^{-1} is blown by wind horizontally at 12 ms^{-1}.
(i) Find the resultant velocity of the parachutist.
(ii) If the parachutist jumps from a height of 500m directly above a ground target, find the horizontal distance by which the parachutist will miss the target on landing.

4. What is the mass of a man on the earth if his mass on the moon 60kg.
A. 6kg B. 10kg C. 60kg D. 360kg

5. Assume that you are taking measurements with a spring balance (dynamometer), where can you get the greatest reading for the same object?
A. At the centre of the earth B. On the moon
C. At the equator D. At the poles.

6. What is the name of any push or pull exerted?
A. Mass B. Force
C. Friction D. Tension

7. What do we call the pull of gravity on an object?
A. Mass B. Weight
C. Moment D. Tension

8. Which one of the following is **not** a measuring tool?
A. Equal-arm balance B. Dynamometer
C. Lever D. Ruler

9. Which one of the following is the unit of weight?
A. Newton B. Kilogram
C. Meter D. Tonne

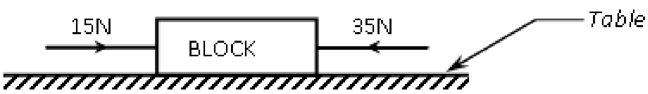
10. A mass of 60kg weighs 600N on the earth and 100N on the moon. What is the mass and weight of an object on the earth if it weighs 50N on the moon?
A. 60kg mass, 600N weight
B. 10kg mass, 60N weight
C. 30kg mass, 300N weight
D. 5 kg, mass, 100N weight

11. Which one of the following is a force?
A. Energy B. Mass C. Weight D. Speed

12. Which one of the following statements is **not** correct?
A. Force can change the speed of an object.
B. Force can change the shape of an object.
C. Force can change the direction of motion.
D. Force can change the mass of an object.

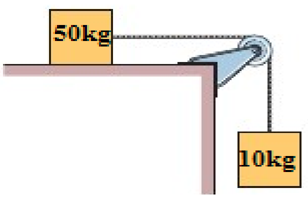
13. Which one of the following are SI units of mass and weight?
A. g and n respectively B. N and kg respectively
C. kg and g respectively D. kg and N respectively

14. Two forces of 15 N and 35 N act on a block placed on a smooth table as shown in the figure below. Find the resultant force on the block.



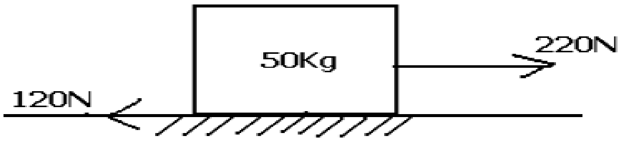
A. 20N. B.50N. C.525 N. D.1000 N.

15. The diagram above shows a trolley of mass 50kg connected to a mass of 10kg by a light string which passes over a smooth pulley. The trolley moves over a smooth horizontal surface



(a) What is the horizontal force acting on the trolley?
(b) What is the total mass in motion?
(c) Find the acceleration of the trolley.

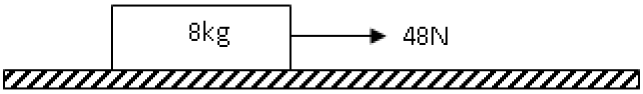
16. A block of mass 50kg is pulled from rest along a horizontal surface by a rope tied to one of the block as shown below.



The tension in the rope is 220N. the frictional force between the block and the horizontal surface is 120N.

(i) Find the acceleration of the block.
(ii) Calculate the distance moved by the block in 4.0s.
(iii) What is the reaction of the surface on the block.
(iv) Compare the work done by the tension in the rope during the 4.0s interval with kinetic energy gained.

17. A block of mass 8kg slides on a rough horizontal surface under the action of a force of 48N as shown below.



If the block moves with an acceleration of $5ms^{-2}$, calculate the frictional force between the mass and the surface.

18. The mass of a rock on the Earth is 2.0 kg. What is the mass of the rock on the Moon?
A. 1.7 kg B. 2.0 kg C. 3.4 kg D. 20 kg

19. The weight of a rock on the Earth is 20 N. What is the weight of the rock on the Moon?
A. 2.0 N. B. 3.4 N. C. 12 N. D. 20 N

20. The weight of a rock on the Moon is 200 N. What is the mass of the rock on the Earth?
A. 20 kg B. 118 kg. C. 200 kg D. 1180 kg

21. The weights of three objects measured on three celestial bodies are listed below. The weight of object A on the Moon is 200 N. The weight of object B on the Jupiter is 6000 N. The weight of object C on the Mercury is 400 N. Which of the following sequence shows the mass of the three objects in ascending order? (The acceleration due to gravity of the Moon, Jupiter and Mercury are 1.7 m s^{-2}, 25.4 m s^{-2} and 3.8 m s^{-2} respectively.)
A. object A, object B, object C.
B. object C, object A, object B
C. object A, object C, object B
D. object B, object C, object A

22. An astronaut of mass 80 kg jumped out of the rocket after it had landed on Jupiter. The astronaut took 0.40 s to drop for 2.0 m. What was the weight of the astronaut on Jupiter?
A. 800 N. B. 1000 N.
C. 1800 N. D. 2000 N

23. The following experiment was set up. Which of the following substances has the lowest density?
A. Air B. Oil. C. Water. D. Mercury

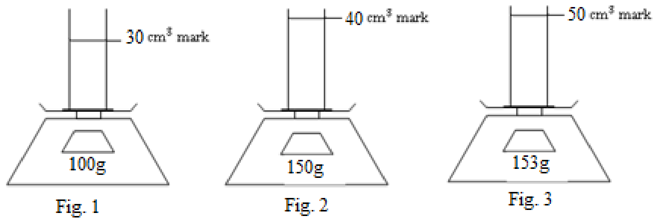
24. The following experiment was set up. Which of the following is in ascending order of density?
A. water, mercury, oil B. mercury, water, oil.
C. oil, water, mercury oil. D. Oil, mercury, water.

25. The following experiment was set up. Which of the following is a possible density for iron in kg m^{-3}?
A. 600. B. 1000. C. 8000. D. 14000

26. When solid A of mass 2 g is immersed in a measuring cylinder filled with water, it displaces a volume of 4 cm^3. What is the density of solid A?
A. 0.5 g per cm cubed. B. 2 g per cm cubed.
C. 5 N per cm cubed. D. 20 N per cm cubed

27. The figures below show the difference in water level before and after solid A is submerged in measuring cylinder. Given that solid A is 20 g, what is the density of solid A?
A. 0.3 g per cm cubed B. 0.5 g per cm cubed.
C. 2 g per cm cubed. D. 4 g per cm cubed.

28. In an attempt to find the density of a piece of floating object, the following measurements were carried out. Figure 1: Measuring cylinder with water. Figure 2: Measuring cylinder with water and a piece of stone submerged within. Figure 3: Measuring cylinder with water and a piece of stone tied to the floating object such that the floating object is also submerged under water. What is its density?



A. 0.23 g per cm cubed. B. 2.65 g per cm cubed.
C. 0.30 g per cm cubed. D. 3.06 g per cm cubed

29. What is the mass of a man on the earth if his mass on the moon 60kg.
A. 6kg B. 10kg C. 60kg D. 360kg

30. When solid A of mass 12 g is immersed in a measuring cylinder filled with water, it displaces the same volume of water as solid B of mass 8 g. What can be deduced about the densities of solids A and B?.
A. Both A and B have the same density.
B. Density of A is 4 times density of B.
C. Density of A is 2/3 times density of B.
D. Density of A is 3/2 times density of B.

31. In an attempt to find the average mass of an iron ball, the following measurements were carried out. Figure 1: Measuring cylinder with water. Figure 2: Measuring cylinder with water and 20 iron balls submerged within. Given that iron has a density of 7.5 g cm-3, what is the mass of one iron ball?
A. 1.87 g. B. 5.25 g C. 16.9 g. D. 105 g

32. A bottle full of water has a mass of 200 g. When the same bottle is filled with liquid X, the mass becomes 180 g. If the mass of the empty bottle is 100 g, what is the density of liquid X in g cm^{-3}?

(Take the density of water to be 1.0 g cm^{-3}).
A. 0.2 B. 0.8 C. 0.9 D. 1.2

33. A wooden block of dimension $1m \times 1m \times 1m$ has a mass of 800 kg. If Ashwin sawed half of the block away, what is the density of the remaining wooden block in kg m^{-3}?
A. 200. B. 400. C. 800. D. 1000

34. A wooden block of dimension 1 m X 1 m X 1 m has a mass of 800 kg. Ajay attached a steel plate of dimension 1 m X 1 m X 0.02 m to the block. Given that the steel plate has a mass of 140 kg, what is the density of the combination in kg m-3?
A. 800. B. 922. C. 3900. D. 7000

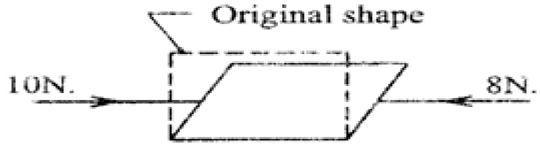
35. 5000 kg of iron is melted and mixed with 2.0 m^3 of molten copper. If the density of molten iron and molten copper are 7.5 g cm^{-3} and 9.0 g cm^{-3} respectively, what is the approximate density of the mixture?
A. 7.5 g per cm cubed. B. 8.3 kg per m cubed
C. 8300 kg per m cubed D. 8600 kg per m cubed

36. A 100 kg rock is being hung freely on the Moon. When an astronaut pushes the rock upwards, he will feel that the rock;
A. is easier to be pushed than on Earth.
B. is more difficult to be pushed as it is on Earth.
C. requires as much effort to be pushed as on Earth.
D. requires no effort to be pushed.

37. When an astronaut jumps on the Moon (given that the acceleration due to gravity of the Earth and the Moon is 10 m s^{-2} and 1.7 m s-2 respectively).
A. He will take a longer time to reach the top and a longer time to come down as compared to jumping on the Earth.
B. He will take a longer time to reach the top and a shorter time to come down as compared to jumping on the Earth.
C. He will take a shorter time to reach the top and a longer time to come down as compared to jumping on the Earth.
D. He will take a shorter time to reach the top and a shorter time to come down as compared to jumping on the Earth.

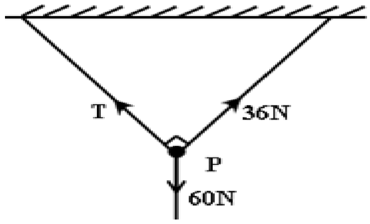
38. An astronaut in space wants to compare the mass of two balls. He holds the two balls in each of his hands and moves both hands up and down slightly for a few times. What is the reason for doing so?
A. He is trying to compare the inertia of the two balls. The one with a higher mass tends to be more difficult to be moved and to be stopped.
B. He is trying to compare the inertia of the two balls. The one with a higher mass tends to be easier to be moved and to be stopped.
C. He is trying to compare the weight of the two balls. The one with a higher weight tends to be more difficult to be moved and to be stopped.
D. He is trying to compare the weight of the two balls. The one with a higher weight tends to be easier to be moved and to be stopped.

39. The Figure shows two forces of 10 N and 8 N acting on a body. What is the value and direction of the force needed to resolve its original shape?



A. 2 N to the left. B.18 N to the left.
C. 2 N to the right. D. 18 N to the right.

40. The figure **below** shows two forces of **T** and 36 N acting on a body **P** of weight 60 N. Find the size of the force **T**.



A. 96.0 N
B. 70.0 N
C. 48.0 N
D. 24.0 N

41. Assume that you are taking measurements with a spring balance (dynamometer), where can you get the greatest reading for the same object?
A. At the centre of the earth B. On the moon
C. At the equator D. At the poles.

42. What is the name of any push or pull exerted?
A. Mass B. Force C. Friction D. Tension

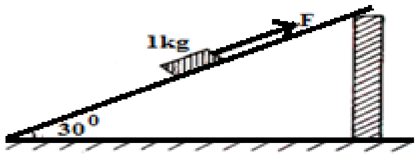
43. What do we call the pull of gravity on an object?
A. Mass B. Weight
C. Moment D. Tension

44. Which one of the following is **not** a measuring tool?
A. Equal-arm balance B. Dynamometer
C. Lever D. Ruler

45. Which one of the following is the unit of weight?
A. newton B. kilogram C. meter D. tonne.

46. A mass of 60kg weighs 600N on the earth and 100N on the moon. What is the mass and weight of an object on the earth if it weighs 50N on the moon?
A. 60kg, 600N B. 10kg, 60N
C. 30kg, 300N D. 5kg, 100N

47. A block of mass 1kg is supported by a force *F* on a rough plane inclined to the horizontal at 30^0. If the static frictional force is 5N.



Find the value of F.
A. 25N B. 8. C. 5.0N D. 0.0N

48. Which one of the following is a force?
A. Energy B. Mass C. Weight D. Speed

49. Which one of the following statements is **not** correct?
A. Force can change the speed of an object.
B. Force can change the shape of an object.
C. Force can change the direction of motion.

D. Force can change the mass of an object.

50. Which one of the following are SI units of mass and weight?
A. g and N respectively B. N and kg respectively
C. kg and g respectively D. kg and N respectively

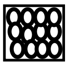
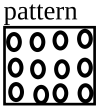
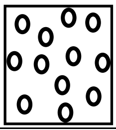
51. The acceleration due to gravity on the earth is $10ms^{-2}$ and on the mars it is $4ms^{-2}$. A space probe has a mass of 100kg on earth. On mars, its mass will:
A: and weight will decrease
B: be smaller but the weight will be the same
C: be smaller but the weight will have increased
D: be the same but its weight will have decreased.

PARTICULATE NATURE OF MATTER

(a) MATTER:

Matter is anything that occupies space and has weight.

States of matter:
There are three states of matter namely:
- Solids → e.g stone, ice, e.t.c
- Liquids → e.g water, paraffin, e.t.c
- Gases → e.g oxygen, nitrogen, e.t.c

Property	Solids	Liquids	Gases
1. **Arrangement of molecules.**	Closely packed in regular pattern called lattice 	Fairly closely packed in regular pattern 	Far apart from each other. 
2.**Intermolecular forces.**	Strong	Weak	Very weak
3. **Motion of the molecules.**	Vibrate within fixed position	Vibrate with greater amplitude	Move randomly throughout the container, at greater speed
4.**Shape**	Have definite shape	No definite shape. Take shape of container	No definite shape.
5.**Rate of diffusion**	Very low in some solids	Low	High
6.**Compressibility**	Incompressible	Incompressible	Compressible

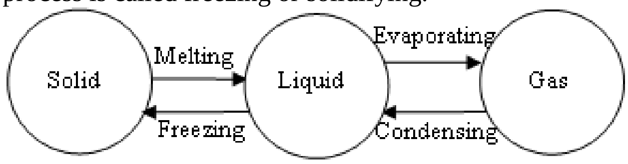
Note:
- Solids and liquids are incompressible, meaning that their volumes cannot be reduced by squeezing them.
- Gases are compressible at high speeds because of the large spaces between their molecules at room temperatures and standard pressure (1atm).

Change of state
- Heating of matter

When a solid is heated, it changes to a liquid at constant temperature called melting point. The process is called melting or fusion.
When the liquid formed is heated further, the liquid changes to vapour at constant temperature called boiling point.The process is called boiling or evaporation.

- Cooling of matter

When a gas or vapour is cooled, it condenses to a liquid at constant temperature called freezing point. The process is called condensation or liquefying.
When the liquid formed is cooled further, it changes to a solid at constant temperature called freezing point. The process is called freezing or solidifying.



(b) KINETIC THEORY OF MATTER

The kinetic theory of matter states that:
- *Matter is made up of small particles called molecules or atoms that are in a state of constant random motion.*
- *The speed of motion of the particles is directly proportional to the temperature.*

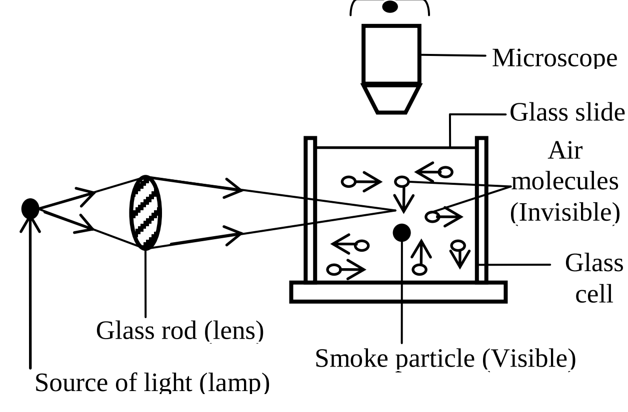
The kinetic theory of matter can be proved by using:
(i) Brownian motion (ii) Diffusion

(i) BROWNIAN MOTION

***Brownian motion** is the constant random (or haphazard) movement of tiny particles in fluids.*

Experiment to demonstrate Brownian motion
Experiment 1: Using Pollen grains.
- When pollen grains molecules are dropped in water or suspended in water and observed through a microscope, the molecules will be seen making irregular movements in random directions.
- This shows that particles of matter are ever in a state of constant random motion.

Experiment 2: Using Smoke particles in air.



- Smoke is placed in a glass cell and the glass cell illuminated with light from one side.

- The smoke particles are then observed from above using a microscope.

Observation:

- White specks or Bright points(smoke particles) will be seen moving in a constant random motion.
- This shows that particles of matter are ever in a state of constant random motion.

Explanation:

The bright points are smoke particles. The constant random motion is due to un even collision (or bombardment) of the invisible air molecules with the visible smoke particles.

Factors that affect Brownian motion

(i) Temperature

- When the temperature of the smoke cell is increased, smoke particles are seen moving faster and when it is reduced, they are seen moving slowly.
- Increase in temperature (eg by heating the glass cell), increases the kinetic energy of the molecules, hence they move faster than before.
- Decrease in temperature (e.g by placing the glass cell on top of an ics block), decreases the kinetic energy of the molecules, hence they move slowly.

(ii) Size and density of the particles

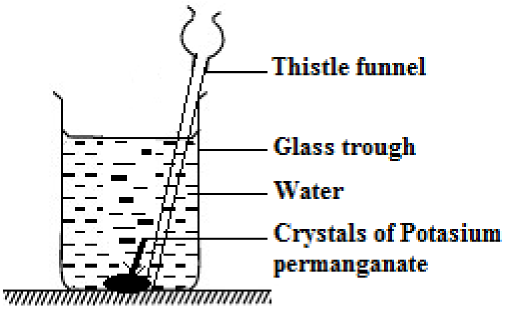
- When the size of the particles is increased, Brownian motion is reduced and when the size of particles is reduced, Brownian motion increases.

(ii) DIFFUSION

***Diffusion** is the spreading (or flow) of molecules a substance from a region of high concentration to a region of low concentration.*

Diffusion in liquids:

Experiment to show diffusion in liquids



Procedures:

- Water is placed in a clean glass trough
- A crystal of potassium permanganate is then introduced at the bottom using a drinking straw.

Observation:

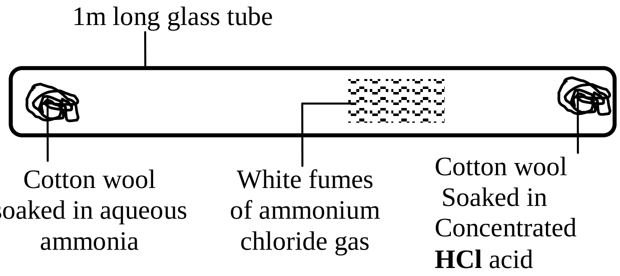
- The purple crystal of potassium permanganate dissolves and spreads throughout the water forming a purple solution.

Conclusion:

- This means that potassium permanganate has diffused through the water in the glass trough.

Diffusion in gasses:

(i) Experiment to show diffusion in gases



Procedures:

- Cotton wool soaked in aqueous ammonia is placed at one end and another cotton wool soaked in concentrated hydrochloric acid is placed at the other end of a glass tube of about 1m long.

Observation:

- White fumes of ammonium chloride forms inside the tube near the end with cotton wool soaked in **HCl** acid.

Conclusion:

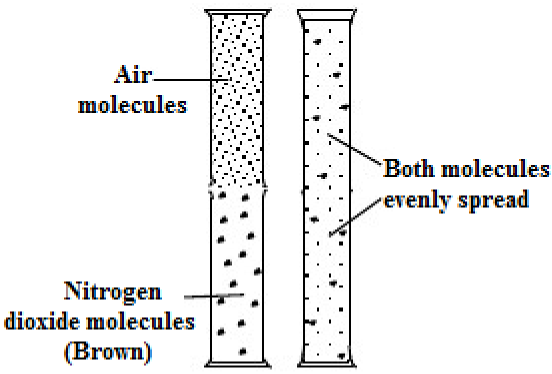
- This means that:

(i) The gases have diffused through the air in the tube.

(ii) Ammonia diffuses faster thanHydrogen chloride.

Alternatively

The speeds of random motion of the molecules of gas at the same temperature depend on the masses of the molecules. The heavier the molecules, the lower their speed. So a denser gas will be slower in diffusion than a less dense one. i.e. gases diffuse at rates that are inversely proportional to their densities.

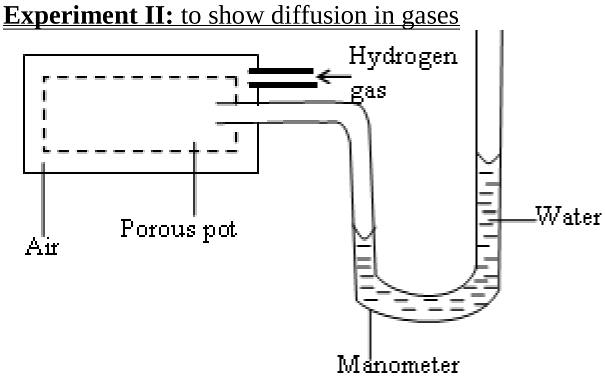


Note: Alternatively;

An air molecule tube is inverted over brown nitrogen dioxide molecules tube.

Observation: the brown colour spreads into the upper tube at the same time the air molecules spread into the lower tube.

Experiment II: to show diffusion in gases



- Connect a water manometer to a porous pot containing air.
- Pass hydrogen into the air enclosed in the porous material as shown in the diagram above.
- The water level in the left arm of the manometer falls while that in the right arm rises.
- The hydrogen molecules diffuse through the porous material into the air. This increases the pressure in the porous pot, which then acts on the water surface in the left arm of the manometer, thus pushing the water level down wards.

Factors that determine the rate of diffusion

(i) Size of diffusing particles: Smaller molecules diffuse faster than larger molecules. This is because more smaller moleculespass through the porous partition than larger molecules.

(ii) Size of the pores of the diffusing medium. The larger the pores, the greater the number of particles that pass through it per unit time and hence the greater the rate of diffusion.

(iii) Temperature: The rate of diffusion is directly proportional to temperature. This is because increase in temperature of the particles increases the speed at which particles move.

(iv) Pressure: The rate of diffusion is directly proportional to pressure. This is because at a higher pressure, gas molecules are squeezed, move faster and collide frequently than at low pressure.

(v) Concentration gradient.

(vi) Distance across which particles have to diffuse.

(vii) Molecular weight: Lighter molecules diffuse faster than massive molecules. Eg. hydrogen diffuses faster than carbon dioxide.

PROPERTIES OF MATTER

(a) MOLECULAR PROPERTIES OF MATTER

The properties of matter are many, however, in physics we shall focus on the following properties:

(a) Molecular properties of matter
(b) Mechanical properties of matter
(c) Thermal properties (Heat)

Molecular properties of matter are based on the behavior of the molecules. These are observed in the following;

(i) Diffusion
(ii) Capillarity
(iii) Elasticity
(iv) Molecular forces
(v) Surface tension

(i) MOLECULAR FORCES:

Intermolecular forces are forces of attraction or repulsion between molecules of matter. The molecules may be of the same substance or of different substance.

Types of molecular forces

- Cohesion (or Cohesive) force

Cohesion is the force of attraction between molecules of the same kind or same substance.
E.g Forces between water molecules themselves, forces between mercury molecules themselves e.t.c.

- Adhesion (or Adhesive) force

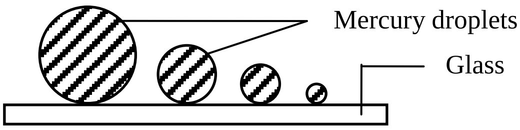
Adhesion is the force of attraction between molecules of different kinds or different substances.
E.g Forces between water molecules and glass molecules, forces between mercury molecules and glass molecules, forces between water molecules and mercury molecules, e.t.c.

NOTE: The magnitude of the cohesion and adhesion forces determines the:

- Shape of liquid meniscus in contact with a solid
- Ability of the liquid to wet asubstance
- Rise or fall in a capillary tube.

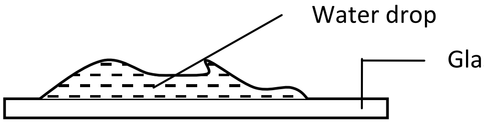
When cohesion is greater than adhesion forces, e.g mercury and glass, then the liquid;

(i) Does not wet glass
(ii) Forms spherical balls when spilled on a glass surface
(iii) Depresses in a capillary tube
(iv) Meniscus curves downwards.



When adhesion is greater than cohesion forces, e.g water and glass, then the liquid;

(i) Wets glass
(ii) Spreads when spilled on a glass surface
(iii) Rises in a capillary tube
(iv) Meniscus curves upwards



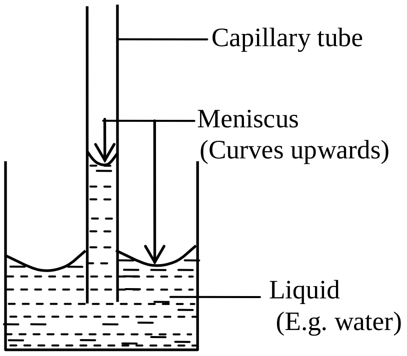
Water spreads on the glass surface due to greater adhesion forces between glass and water molecules than the cohesion forces between water molecules themselves hence wetting the glass.

(ii) CAPILLARITY:

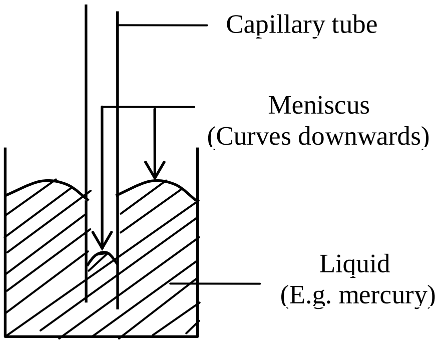
***Capillarity** is the elevation (or rise) or depression (or fall) of a liquid a narrow porous medium e.g tube.*

Capillary action depends on cohesion and adhesion forces.

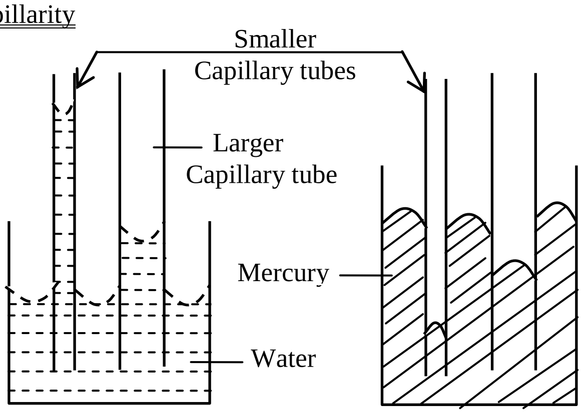
(i) When adhesion is greater than cohesion forces, e.g water and glass, then :
   - the liquid rises in the capillary tube
   - the meniscus curves upwards (concave);
   - The liquid wets glass



(ii) When cohesion is greater than adhesion forces, e.g mercury and glass, then the :
- liquid falls (or depresses) in the capillary tube
- the meniscus curves downwards (convex);
- the liquid forms spherical balls when spilled on a surface.
- does not wet glass



<u>Effect of size or diameter of the capillary tube on capillarity</u>



- Water rises higher in a capillary tube of smaller diameter than the one of a larger diameter.
- Mercury depresses deeper in a capillary tube of smaller diameter than the one of a larger diameter.

Uses of capillarity
- It helps paraffin (fuel) to rise up in wicks of stoves and lamps.
- It helps water to move up tree-trunks to the leaves
- It helps blotting papers to absorb liquids

NOTE: *All the above uses are possible because of <u>greater adhesion forces than cohesion forces</u> between molecules of the two substances. (i.e Fuel and wick, water and tree-trunk, liquid and blotting paper respectively). Thus, the wet part of the solid goes on increasing upwards.*

Damp proof material e.g polythene is put in the foundation course of abuilding to stop capillary action. This is because bricks, plaster and mortar are porous, so water can rise up through the narrow pores and weaken the wall.

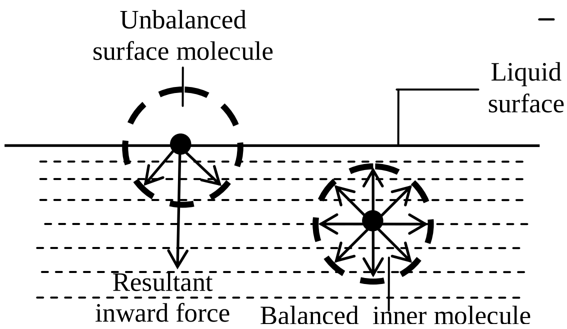
(iii) SURFACE TENSION:

Surface tension is the force acting normally on a one-metre length of a line drawn on the surface of aliquid. Its S.I unit is $\mathbf{Nm^{-1}}$.

*Surface tension is a propertyof liquids by which surface molecules of a liquid hold the liquid together by acquiring the **minimum surface area** and acting like a **stretched membrane***. It is due to cohesion forces between the liquid molecules.

***Surface tension** is the force on the liquid surface that causes it to behave as if it is covered with a thin elastic membrane.*

Molecular explanation of surface tension:

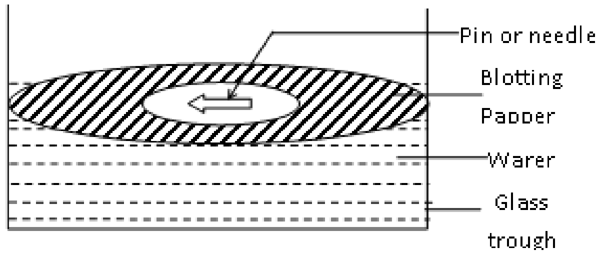


❖ According to Kinetic theory surface tension is explained as follow:-
❖ *Molecules on the surface experience a net down word force on them and surface of the liquid, thus tends to contract and acquire a state of tension.*

❖ A molecule inside the surface of the liquid is surrounded by equal number of molecules on all sides. The intermolecular forces between it and the surrounding molecules is zero.
❖ A molecule on the surface has very few molecules on the upper side compared to those bellow the liquid surface.
❖ Thus if this molecule is displaced upwards, a resultant attractive force due to the large number of molecules bellow the liquid surface has to be overcome.
❖ This force is trying to pull the molecule out of the surface into the bulk. It is trying to make the surface smaller, hence surface tension.

*This also explains why **liquid drops are spherical**. Surface molecules are not attacted outwards.They are only attracted inwards and side ways. However, side ways forces can neutralize leaving only the <u>inward forces which cause each surface molecule to contract</u> to form the **minimum possible surface area** which is a **sphere**.*

Experiment to demonstrate existence of Surface tension using a needle and a blotting paper.



Procedures:

- ❖ A clean beaker is filled with water.
- ❖ Ablotting paper is placed on the surface of the water.
- ❖ Apin or needle is gently placed on the blotting papper and observed.

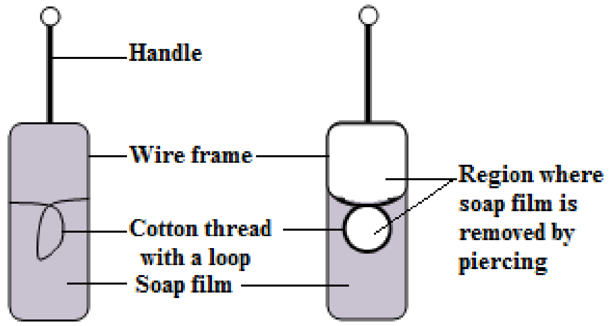
Observation:

- ❖ After some few minutes, the blotting paper absorbs water and sinks to the bottom.
- ❖ The needle remains floating on the water surface.

Conclusion:

- ❖ The needle is held by surface tension.

Experiment to demonstrate existence of Surface tension using a soap film.



A wire frame with a piece of cotton thread with a loop tied across it is dipped in a soap or any other detergent solution so that a film is formed on the wire frame.
When the film on one side of the cotton thread is removed by piercing it, the tension on the opposite side pulls the thread into an arc of a circle.
When the film in the loop of the cotton thread is removed by piercing it, surface tension of the film pulls the loop into a circle.

Effects of surface tension

(i) A needle (pin) floats on water surface.
(ii) Tents keep water, umbrellas and raincoats keep water off due to surface tension.
(iii) Insects e.g pond skater can walk across a water surface.
(iv) Water drops from a tap form spherical shapes. This is because; a free falling drop will take the shape that has the least (minimum) area.

Factors affecting surface tension

(i) Temperature: Increase in temperature (or heating a liquid) weakens or reduces surface tension.

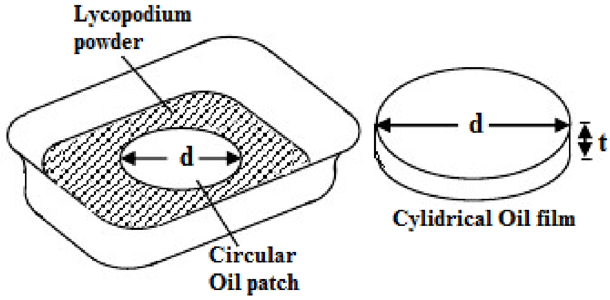
(ii) Impurities: Impurities such as detergents, soap solution, alcohol e.t.c reduce surface tension.

(iv) THE THICKNESS (OR SIZE) OF AN OIL MOLECULE:

A drop of oil is able to spread into a thin film of a large area when placed on a clean water surface.
This is because the end of the oil molecule has greater adhesion forces than cohesion forces for neighboring molecules.

The size of an oil molecule is too small to be accurately measured. Its approximate size can only be estimated using an experiment.

Experiment to estimate the size of an oil molecule

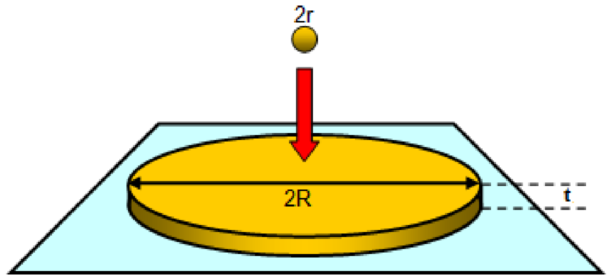


- ❖ A clean trough is filled with clean water and lycopodium powder sprinkled on the surface of the water.
- ❖ A **known volume**, V_o of the oil is droped onto the water surface covered with lycopodium powder.
- ❖ The oil spreads forming a cylindrical oil film with a circular patch, whose **diameter** ''**d**'' is measured.
- ❖ The thickness or size of the oil film is estimated from:

$$\textbf{Thickness of oil drop; } t = \frac{\textbf{Volume of oil drop}}{\textbf{Area of oil patch}}$$

$$t = \frac{V_{oil\ drop}}{A_{patch}}$$

NOTE:



It is a common procedure to;

- ✓ Dissolve a known volume of a solute (e.g cooking oil or oleic acid) V_1 in a known volume of a solvent (e.g Petroleum, alcohol or ether) V_2 to form a solute-solvent solution.
- ✓ Then a known volume, V_3ofthe solute-solvent solution is dropped onto the water surface covered with lycopodium powder.
- ✓ The solvent in the drop either dissolves in water or evaporates and the solute (oil) spreads forming a cylindrical oil film with a circular patch, whose diameter ''**d**'' is measured.
- ✓ The thickness or size of the oil film is estimated from:

$$\textbf{Volume of cylindrical film} = \left(\textbf{Volume of oil in the spherical drop}\right)$$

Area of Patch×Thickness(t) = Volume of oil

Thickness of oil drop; $t = \dfrac{\textbf{Volume of oil drop}}{\textbf{Area of oil patch}}$

However, the volume of the oil in the solution which forms the oil film is calculated as follows:

(V_1+V_2) of solution =(contains)	**(V_1)** of solute or oil
(V_3) of solution dropped=(contains)	**V** (volume of oil in drop)

$$(V_1 + V_2) \times V = V_3 \times V_1$$

$$V = \frac{V_1 V_3}{(V_1 + V_2)}$$

Volume of oil in drop, $\mathbf{V = \frac{V_1V_3}{(V_1+V_2)}}$

Assumption made in the above experiment.

(i) All the solvent has evaporated or dissolved in water.
(ii) The oil patch is circular.
(iii) The oil film or molecule formed is cylindrical.
(iv) The oil film formed is one molecule thick. (i.e the spaces between the molecules in the oil film are assumed to be negligible).
(v) The oil drop is spherical.
(vi) The molecules are standing perpendicularly on the water surface.
(vii) Volume of cylindrical film=Volume of oil in spherical drop

NOTE: The water surface should be sprinkled with **lycopodium powder** so that:

(i) The film becomes stationary.
(ii) A clear circular patch for measuring diameter is formed.

Example 1:

A solution is made by dissolving 1cm^3 of cooking oil in 1999cm^3 of methanol. When 0.004 cm^3 of the solution is dropped on the surface of water, an oil film of diameter 12cm is obtained.

(i) Calculate the volume of cooking oil in the film.
(ii) Estimate the thickness of a molecule of cooking oil.
(iii) State any two assumptions made in (i) above.

Solution:

Volume of solute or oil, **(V_1)** = 1cm^3
Volume of solvent (methanol), **(V_2)** = 1999cm^3
Volume of solution dropped, **(V_3)** = 0.004cm^3
Volume of solute or oil, in **V_3** = **V**

Volume of oil in drop , $V = \frac{V_1V_3}{(V_1+V_2)} = \frac{1\times(0.004)}{(1+1999)}$

$$V = \frac{0.004}{(2000)}$$

Volume of oil in drop , $V = 0.000002$ cm^3

Alternatively:

Volumes	
Volume of Solution	**Volume of Oil**
2000cm^3	1 cm^3
0.004 cm^3	V

$$2000V = 1 \times 0.004$$
$$V = 0.000002 \text{ cm}^3$$

Area of oil patch, $= \pi R^2$
$= \pi(\frac{12}{2})^2$
$= 3.14 \times 36$

Area of oil patch, $A = 113.097$cm^2

Thickness of oil drop; $t = \dfrac{\text{Volume of oil drop}}{\text{Area of oil patch}}$

$t = \dfrac{0.000002}{113.097} \Leftrightarrow t = 1.76 \times 10^{-8}$ cm

Thickness of oil drop; $t = 1.76 \times 10^{-8}$ cm

Example 2:

In an oil film, experiment to estimate the size of a molecule 0.005cm^3 of oleic acid was dropped on lycopodium powder on a water surface. The mean diameter of the acid was 5cm. Calculate the thickness of a molecule of oleic acid.

Solution:

Volume of solute or oleic acid, **(V_1)** = 0.005cm^3
Volume of oil in drop , $V = 0.005$ cm^3

Area of oil patch, $= \pi R^2 \quad = \pi(\frac{5}{2})^2$
$= 3.14 \times 6.25$

Area of oil patch, A $= 19.63$cm^2

Then, from: $A \times t = V$

Thickness of oil drop; $t = \dfrac{\text{Volume of oil drop(V)}}{\text{Area of oil patch(A)}}$

$$t = \frac{0.005}{19.63}$$

Thickness of oil drop; $t = 2.55 \times 10^{-4}$ cm

Example 3:

An oil drop of volume 1x10^{-9} m^3 spreads on a water surface to form a patch of area 5x10^{-2} m^2. If the patch is one molecule thick, find the approximate number of molecules in the drop.

Solution:

Volume of oil in drop , $V = 1\text{x}10^{-9}\text{m}^3$

Area of oil patch, $A = \pi R^2$
$A = 5 \times 10^{-2}\text{m}^2$

Then, from $A \times t = V$
$(5 \times 10^{-2}\text{m}^2) \times t = 1 \text{ x } 10^{-9}\text{m}^3$

$$t = \frac{1\text{x}10^{-9}\text{m}^3}{5 \times 10^{-2}\text{m}^2}$$

$t = 2 \times 10^{-8}$ m

NOTE: Remember the oil drop is spherical thus its diameter is equal to its thickness, t. Therefore its radius, r is equal to half the thickness, $\frac{t}{2}$ of the oil film.

Thus the radius of the spherical oil drop, r is given by;,

$$r = \frac{t}{2} = \frac{2\times10^{-8}}{2} = 1\times10^{-8}\ \text{m}$$

If n is the number of molecules in the oil drop, then

$$n\left(\text{volume of sphere of radius}, \frac{t}{2}\right) = (\text{volume of oil drop})$$

$$n\left(\frac{4}{3}\pi r^3\right) = 1\text{x}10^{-9}$$

$$n\left\{\frac{4}{3} \times 3.14 \times (1 \times 10^{-8})^3\right\} = 1\text{x}10^{-9}$$

$$n(4.189 \times 10^{-24}) = 1\text{x}10^{-9}$$

$$n = \frac{1\text{ x }10^{-9}}{4.189 \times 10^{-24}}$$

n =2.39 x 10^{14} molecules .

EXERCISE

1. In an experiment to estimate the size of an oil molecule, a volume of 0.12cm^3 was placed on a clean surface and spread into a patch of area 0.0006cm^2. Calculate the size of the oil molecule. (Ans: t =200 cm).

2. When 0.002 cm^3 of oil was dropped on the surface of water, an oil film of diameter 6.0cm was formed. Calculate the thickness of the film.
(Ans:t =7.08×10^{-5} cm).

3. The volume of 100 drops of certain oil is 1.0cm^3. One such drop was placed on a water surface and it spread into a circular patch of average diameter 50cm. What is the size of the oil molecule?
(Ans:t =5.09×10^{-6} cm).

4. If 1.8 x 10^{-4} cm^3 oil spreads to form a patch of area 150 cm^2. Determine the thickness of the patch.
(Ans: t =1.2×10^{-6} cm).

5. A drop of oil of diameter 0.5mm becomes a circular film of oil of diameter 30cm.
(i) Find the thickness of the oil film.
(Ans:t =9.2×10^{-10} m).

(ii) Calculate the number of molecules in the oil drop. (Ans:n =1.6×10^{17} molecules).

6. 1cm^3 of oleic acid was dissolved in 99 cm^3 of alcohol to form 100 cm^3 of solution. A 1-cm^3 drop of the solution was put on a water surface sprinkled with lycopodium powder. The alcohol dissolved in water leaving the acid which spread to form a patch of diameter 14 cm^3.
(i) Explain why lycopodium powder was used
(ii) Calculate the volume of the acid in the 1-cm^3 drop of the solution.
(iii) Estimate the size of oleic acid molecule.

7. In an experiment to determine the thickness of an oil molecules the following were done;
- 1cm^3 of oil was dissolved in 99cm^3 of ether and 1cm^3 of the solution was diluted to 200cm^3
- 0.4 cm^3 of the dilute solution was dropped onto the surface of water.
- The diameter of film formed was found to be 7cm. from the above. Calculate the thickness of the oil molecules. (Ans:t =5.19×10^{-7} cm).

8. A solution was made by dissolving 1cm^3 of cooking oil in 199cm^3 of methanol. When 0.004cm^3 of the solution was dropped onto the water surface, an oil film of diameter 12cm was obtained. Find the thickness of the oil molecule.

SECTION A

1. When a crystal of potassium permanganate is carefully placed at the bottom of a beaker containing water, it spreads uniformly in the water after some days. This is due to:
A. diffusion B. capillarity
C. surface tension D. Brownian motion

2. Soap is used to wash clothes because it.
A. increases capillarity in the clothes
B. reduces capillarity in the clothes
C. increases surface tension allowing water to penetrate the dirt easily.
D. reduces surface tension allowing water to penetrate the dirt easily.

3. Brownian motion experiment shows that molecules of gasses are
A. Stationary
B. in motion in one direction only
C. In constant random motion
D. More closely packed than molecules in liquid.

4. When mercury is spilt on glass it forms small spherical droplets because its.
A. Density is high.
B. Surface tension makes its surface elastic.
C. Molecules are small
D. Cohesive force is greater than adhesive force with the glass.

5. The rate of diffusion of a gas depends on the,
i. Speed of the gas molecules
ii. Mass of the gas molecules
iii. Temperature of the surroundings
A. (i) and (ii) only B. (i) and (iii) only
C. (ii) and (iii) only D. (i), (ii) and (iii)

6. A needle may float on a clean water but sinks when some detergent is added to water because the detergent
A. reduces the density of water.
B. increases adhesive force between the needle and water molecules.
C. lowers the surface tension of water.
D. makes water surface slippery.

7. The particles in a solid at room temperature are
A. Close together and vibrating.
B. Close together and stationary.
C. Far apart and moving at random.
D. Close together and moving at random.

8. Mercury forms spherical drops when spilt on a wooden bench because it
A. is very viscous
B. has a high density .

C. has a high cohesive force
D. has a low surface tension.

9. Water wets glass because.
   A. adhesive forces between water and glass molecules are greater than cohesive forces.
   B. adhesive forces between water and glass molecules are more than cohesive forces.
   C. surface tension forces between water and glass molecules are more than adhesive forces.
   D. Surface tension forces are less than cohesive forces.

10. The forces which hold the molecules in water drop together are called…
    A. A. Surface tension C. Adhesive
    B. Cohesive D. Electrostatic forces

11. When water spreads on a glass plate, the forces between it's molecules and glass molecules are due to
    A. Surface tension C. Adhesion
    B. Cohesion D. Viscosity.

12. In a Brownian motion experiment, the
    A. smoke particles are seen moving about with uniform velocity.
    B. motion observed is caused by the air molecules colliding with the smoke particles.
    C. Size of particles are found to increase the motion.
    D. smoke cell has a vacuum within it.

13. When smoke is introduced in a smoke cell and observed under a microscope, it is observed as particles moving at random. This is mainly because the particles:
    A. are hot
    B. collide with one another
    C. collide with air molecules
    D. collide with the walls of the smoke cell

14. Which of the following statements is incorrect when a tin containing air tightly sealed is heated?
    A. the average speed of molecules increases
    B. the molecules of air hit the walls of the tin harder
    C. The molecules of the air strike the walls of the tin less often.
    D. The pressure inside the tin increases.

15. When a room is filled with smoke, the smoke tends to concentrate
    A. around the walls
    B. close to the walls
    C. close to the roof
    D. midway between the roof and the floor

16. Capillary rise in a tube dipped in water is due to
    A. Surface tension
    B. adhesive force being greater than cohesive force
    C. high vapour pressure
    D. Atmospheric pressure acting on the surface of the water.

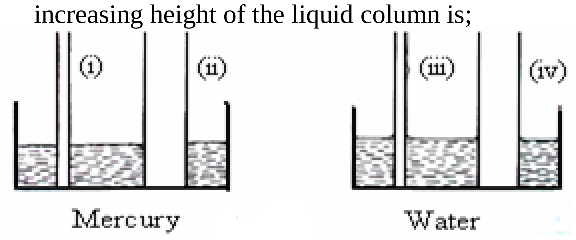
17. Which of the following statements about states of matter is/are true?
(i) a liquid has a definite volume but no a definite shape.
(ii) a vapour has no definite volume and no definite shape.
(iii) a solid has a definite volume and shape.
(iv) a gas has a definite volume and shape.
    A. (i) and (iii) only C. (i) only
    B. (i), (ii) and (iii) only D. (iii) only

18. When viewing Brownian motion in a smoke cell the observer sees:
    A. Air molecules moving in a random motion
    B. air molecules vibrating regularly
    C. air molecules colliding with each other
    D. Smoke particles in a random motion.

19. Which of the following is matter?
    A. Heat B. Sound
    C. Air D. Light

20. Which of the following statements below is *wrong*?
A. Matter is made up of atoms.
B. Solid, liquid and gas are states of matter.
C. Solids and liquids have definite shape and volume.
D. Gas molecules move freely.

21. The diagrams in figure show two capillary tubes standing in a trough of mercury and two capillary tubes standing in a trough of water. The correct order of arrangement of the tubes in order of increasing height of the liquid column is;

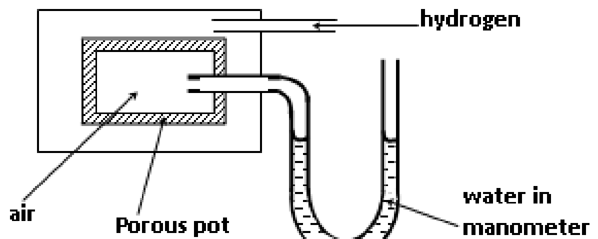


A. (i), (ii), (iv),(iii) B. (ii), (i), (iv), (iii)
C. (ii), (iv), (i), (iii) D. (iii), (iv), (i), (ii)

SECTION B

22. Describe the relationship between molecules of liquids, gases and solids in terms of:
(a) the arrangement of the molecules throughout the bulk of the material,
(b) the separation of the molecules,
(c) the motion of the molecules and
(d)The forces of attraction between the molecules.

23. (a) (i) What is meant by the term ***diffusion***?
(ii) State factors on which diffusion depends.
(b) Describe an experiment to show diffusion in liquids.
(c) A porous pot containing air is connected to a water manometer.

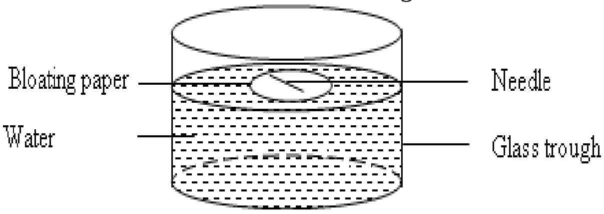


Explain what happens if hydrogen is let in the space surrounding the as shown in the figure.

(d) (i) Describe a simple experiment to show surface tension in water.

(ii) State two factors, which affect surface tension.

24. A pin is placed on a bloating paper, which is on the surface of water as shown in the figure below



(a) Explain what happens after some time.

(b) Explain what happens when some soap solution is carefully added to the water.

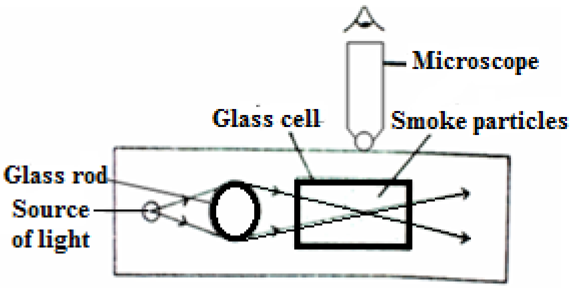
25. (a) Draw a well labelled diagram you would use to describe Brownian motion.

(i) How is the motion of the smoke particles best described?

(ii) What accounts for the motion of the smoke particles?

(iii) The motion is viewed using bigger smoke particles. What difference in the motion would this lead to. Give reason for the difference.

26. The diagram in figure below shows an arrangement for observing Brownian motion.



(a) Explain the:

(i) observation made.

(ii) observation when the glass cell is heated.

(b) State one factor which determines the rate of diffusion of a gas.

27. (a) Distinguish between cohesion and adhesion.

(b) Sketch diagrams to show the level of liquid in a capillary tube that is immersed in a liquid which has greater; (i) Cohesion than adhesion

(ii) Adhesion than cohesion

28. (a) Define **surface tension**.

(b) Describe a simple experiment to show the existence of surface tension in water.

(c) Explain the following observations as fully as you can.

(i) A small needle can be floated on the surface of water, but if a drop of detergent is added to the water the needle sinks.

(ii) Damp proof courses are used in modern houses.

(iii) Gases can easily be compressed but liquids cannot.

(iv) Diffusion occurs more easily in a gas than in a liquid.

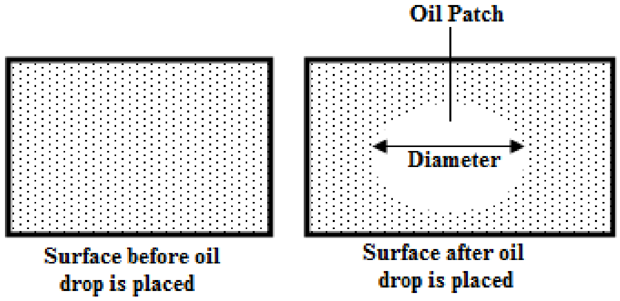
29. (a) State the **kinetic theory of matter**.

(b) Describe experiments, in each case, to show:

(i) Diffusion in liquids (ii) Diffusion in gases.

(c) Use kinetic theory to explain the result of your experiment demonstrating the diffusion in gases

29. In an experiment to determine the size of molecules of olive oil, small drop of oil ,of measured volume was placed on a water surface which had previously been cleaned and dusted lightly with fine powder. The observations are as shown in the diagram below.



(i) Explain why the patch appeared. (2marks)

(ii) The approximate diameter of the patch was measured and found to be 20cm, assuming the patch is circular, estimate its area. (2marks)

(iii) Describe how the volume of the drop of oil could be measured. (2marks)

(iv) Given that the volume of the drop was $1.7 \times 10^{-10} m^3$, calculate a value for the size of a molecule of olive oil. (3marks)

30. In an oil drop experiment the following results were obtained.

Volume of 10 drops of oil $= 3 \times 10^{-8} mm^3$

Diameter of the oil patch = 0.2mm

(i) Estimate the size of an oil molecule. (3marks)

(ii) State two assumptions made when estimating the size of the molecule. (2marks)

31. An oil drop of volume $0.15mm^3$ forms a film of an approximate radius of 14cm when dropped on the surface of water. Calculate the thickness of the oil film. (3marks)

(b) MECHANICAL PROPERTIES OF MATTER

Mechanical properties of matter are the behavior of matter under action of an external force.

Materials are things used in the construction of structures like buildings bridges, dams, etc. Before a material is put to use the following mechanical properties should be considered; strength, stiffness, ductility, brittleness and elasticity.

(i) **Strength:** It is the ability of a material to resist forces that want to deform it.
Is the ability of a material to resist breaking when stretched, compressed or sheared.

$$\text{Braking stress} = \frac{\text{Force}}{\text{Cross} - \text{sectional area}}$$

The strength depends on;
- Dimensions of the material, in that a large force is applied in order to bend a material of large diameter.
- Nature of the substance. Materials of same size but of different substance require different force to be broken. E.g. a large force is applied to a steel rod compared to a piece of wood of the same size.
- Magnitude of force applied

(ii) **Stiffness (toughness):** Is the ability of a material to resist bending or to resist forces, which try to change its shape or size so that it is not flexible. A material which is more stiff always needs a large force in order to bend e.g. wood is more stiff than rubber.
Stiffness is the measure of the rigidity of a material. Eg, glass, steel, wood, etc.

(iii) **Hardness:**Is the ability of a material to resist cracking or scratching on the surface.
E.g, diamond, Glass, steel, finger and toe nails. Etc.

(iv) **Ductility:** Is the ability of a material to deform when a force is applied.
Is the ability of a material to be changed/rolled/hammered/pressed/bent or stretched into other shapes without breaking.
Ductile materials can be hammered, bent or drawn into various shapes without breaking.
A Ductile material is one, which stretches elastically then plastically before it breaks when tensile force acts on it.
Examples;
- Wet clay, plasticine, Metals, steel, e.t.c.

Properties of ductile material.
i) can be molded into any shape.
ii) can be bent without breaking. Because of the above properties of ductile materials, they can be rolled into sheets drawn into wires or worked into other useful shapes without breaking.

(v) **Brittleness:** Is the ability of a material to break suddenly without bending when a force is applied on them..
A brittle material is one, which bends very little, then suddenly cracks without undergoing plastic deformation.
When a brittle material breaks, its pieces fit together almost exactly and can be glued back.

Properties of brittle material
i) Can bend very little and suddenly break without undergoing plastic deformation.
ii) Cannot easily be molded into any shape.

Examples;
- Glass, Rubber, chalk, stones, concrete, cast iron bricks, alloys like brass, and bronze.

(vi) **Elasticity:** Is the ability of a material to recover its original shape and size after a deformation force has been removed.
The material stretches due to the particle being pulled further apart from one another.
A material, which does not recover its original shape and size but is deformed permanently, is plastic.
Examples;
- steel, e.t.c.

The table below classifies some materials according to some mechanical properties.

Material	Strong	Stifff	Ductile	Tough
Steel	✓	✓	✓	✓
Glass	✓	✓	×	×
Rubber	✓	×	×	✓
Plasticine	×	×	×	×

HOOKE'S LAW:

Hooke's law states that the extension of a material is directly proportional to the applied force provided the elastic limit is not exceeded.
i.e. the material returns to its original length when the stretching force is removed, provide the elastic limit is not exceed

In short: **Force ∝ extension**

$$\mathbf{Force = k(extension)}$$
$$\mathbf{F = ke}$$

Where k is the proportionality constant or material constant in **Nm^{-1}**, Where, F is the stretching force in newtons and e is the extension in metres.
Extension, e = New length − Original length
$e = l_n - l_o$.

It is also important to note that;

$$\frac{F_1}{e_1} = \frac{F_2}{e_2} \quad \textbf{Or} \quad \frac{F_1}{F_2} = \frac{e_1}{e_2}$$

Where F_1 is stretching force producing extension $e_1$and F_2 is stretching force producing extension e_2 on the same material.

Example1:
A spring is stretched by 0.05m by a weight of 5N hung from one end.
(i) What weight will stretch it by 0.03m?
(ii) Determine the spring constant.

Solution:

Given;e_1=0.05m,e_2=0.03m, k=?, F_1=5N, F_2=?.	
Then from; $\frac{F_1}{e_1} = \frac{F_2}{e_2}$ $\frac{5}{0.05} = \frac{F_2}{0.03}$	$F_2 = \frac{5}{0.05} \times 0.03$ $\underline{F_2 = 3N}$

Example 2:
A spring increases its length from 20 cm to 25cm when a force is applied. If the spring is constant is 100N/m. Calculate the force.

Solution:

Given;l_o=20cm,l_n=25cm, k=100Nm^{-1}.	
$e = l_n - l_o$. e = 25 − 20 e = 5cm $e = \frac{5}{100} = \underline{0.05m}$	From Hooke's law; F = ke F = 100(0.05) $\underline{F = 5N}$

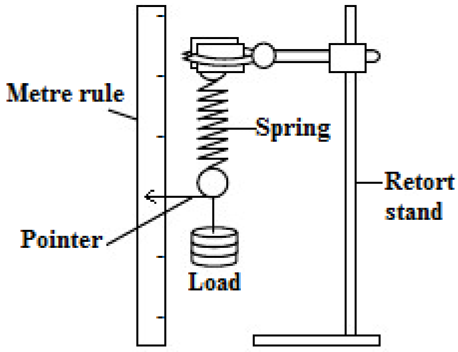
Exercise:

1. A vertical spring of length 30 cm is stretched to 36 cm when an object of mass 100g is place in the pan attached to it. The spring is stretched to 40 cm when a mass of 200g is placed in the pan. Find the mass of the pan.

2. A force of 500N extends a wire by 2mm. If the force is reduced by a half, what will be the new length of the wire, if the original length is 10cm.

3. A spring constant of natural length 8.0×10^{-2}m extends by 2.5×10^{-2}mmwhen a weight of 10N is suspended on it.
   (i) Find the spring constant.
   (ii) Determine the extension when a weight of 15N is suspended on the spring

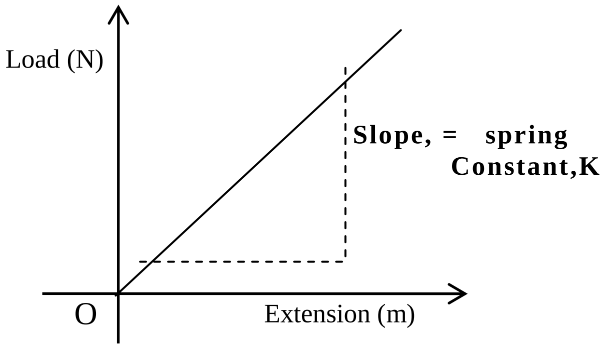
Experiment to verify Hook's law.



- Original length of the spring l_o is noted.
- Then various loads are suspended on the spring and the corresponding new length, l_n of spring for each is noted.
- The extension, **e** produced is calculated from; Extension, $e = l_n - l_o$
- The readings are noted in a table below.

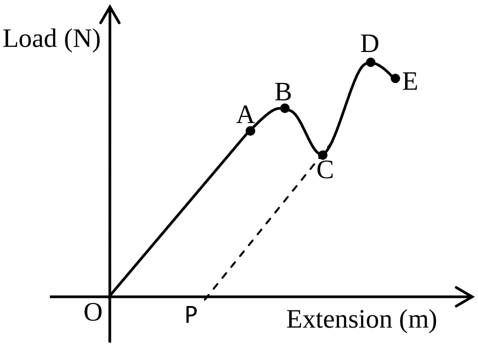
Load(N)	l_n (m)	e(m)
-	-	-
-	-	-

- A graph of load against extension is drawn, and a straight-line graph is obtained whose slope is equal to the spring constant.



- Thus, the load is directly proportional to the extension "e". This verifies Hooke's law.

A graph of load against extension(or A graph of stress against strain).



A = Proportionality limit
B = Elastic limit
C = Yield point (minimum stress)
D = Hecking point (maximum stress)
E = Breaking point
OP = Permanent deformation

Explanation
Along **OA**, the load is proportional to extension in that the extension increases as the load increases. It is called Hooke's law region. Point "A" is called proportionality limit.

Curve ABC: Beyond point A, the graph is not a straight line meaning that the extension is no longer proportional to the force. However, the material is still elastic and a small force produces a large extension. Point "B" is called elastic limit. Along OB, the material under goes elastic deformation.

Beyond point B,. The material becomes plastic. This is indicated by a kink at C, which is called yield point. The yield point is a point beyond which the material becomes plastic and does not contract at all.

Beyond C, the material undergoes plastic deformation. i.e. it does not regain its shape and size when the deforming force is removed. This goes on to the breaking point E.

Point D represents the maximum stress (Breaking stress) the material can withstand fracturing.

Explanation of sketch of load against extension according to kinetic theory.
OB the molecules are pulled slightly farther apart but can move back to original position when stretching force is removed. The deformation is called elastic.

Beyond C, layers of atoms slip over each other. The molecule move farther apart but cannot move back to original position when stretching force is removed.

Applications of Hooke's.
- ❖ Foundations of seismology, acoustics and molecular mechanics.
- ❖ Fundamental principle behind manometer, spring scale, balance wheel of a clock.

STRESS, STRAIN AND YOUNG'S MODULUS.

(i) Stress:
Is the force acting per unit cross section area of a material. Its S.I unit is Nm^{-2} or Pa.

$$\text{Stress} = \frac{\text{Force}}{\text{Cross section area}} = \frac{F}{A}$$

***Tensile stress** is the stretching or compressing force per unit cross section area of a material*

(ii) Strain:
Is the ratio of extension to original length of a material. It has no units.

$$\text{Strain} = \frac{\text{Extension}}{\text{Original length}} = \frac{e}{l_o}$$

***Tensile strain** is the ratio of extension or compression produced by a stretching or compressing force to the original length of the material.*

(iii) Young's modulus:
This is the ratio of tensile stress to tensile strain.
It is the gradient of the straight line in the elastic region. Its S.I unit is Nm^{-2} or Pa.

$$\text{Young's modulus} = \frac{\text{stress}}{\text{strain}} = \frac{F\,l_o}{Ae}$$

Note: This holds only when the elastic limit of a material is not exceeded.

Example 3:
A wire of cross section area $3m^2$ increases in length from 20cm to 25cm, when a force of 5N is applied. Calculate the;
- (i) tensile strain.
- (ii) tensile stress
- (iii) Young's modulus.

Solution:
(i) Given; l_o=20cm, l_n=25cm, F=5N, $A = 3m^2$
$e = l_n - l_o \Leftrightarrow e = (25-20) = 5\text{cm}$

$e = \frac{5}{100}$ = 0.05m

(i) Tensile train= $\frac{e}{l_o}$ Tensile train= $\frac{5}{20}$ =0.25 (ii) Tensile stress= $\frac{F}{A}$ Tensile stress= $\frac{5}{3}$ Tensile stress=1.67Nm^{-2}	(iii) Young's modulus= $\frac{\text{stress}}{\text{strain}}$ Young's modulus= $\frac{1.67}{0.25}$ Young's modulus=6.67Nm^{-2}

Example 4:
Calculate the tensile stress when a force of 25N acts on a wire of cross sectional area $5m^2$.

Given; A = $5m^2$, F=25N

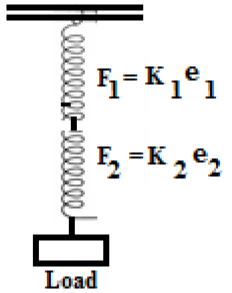
Tensile stress $= \frac{F}{A} = \frac{25}{5} = 5\text{Nm}^{-2}$

Example 5:
An elastic wire of length 4m has a force of 100N acting on it. If the final length is 4.5m and cross section area is 0.5m^2. Find the:
(i) Extension (ii) Strain (iii) stress

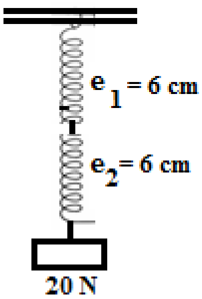
Example 6:
A piece of wire 1.0 m long and of cross-sectional area 2.0×10^{-8} m^2 is acted upon by a tensile force of 50 N. Calculate the tensile stress on the wire.

SPRINGS IN SERIES AND IN PARALLEL

(i) Springs in series
These are springs together to form a longer spring. The same force acts on both springs.

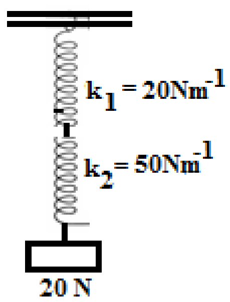


Example: 1. A load of 20N is hang on a spring and stretches it by 6cm. Find the extension produced when two similar springs are arranged in series and the same load is suspended at the free end.



Total extension $= e_1 + e_2$
$= 6\text{ cm} + 6\text{cm}$
$= 12\text{ cm}$

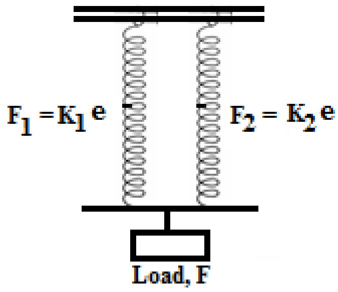
Example: 2. Two springs of force constants 20Nm^{-1} and 50Nm^{-1} are connected in series to form a long continuous spring .Find the extension produced in the combined spring when a load of 100N is suspende nd on the composite spring.



$F_1 = k_1e_1 \Rightarrow 100 = 20e_1$
$\Rightarrow e_1 = 5\text{m}$
$F_2 = k_2e_2 \Rightarrow 100 = 50e_2$
$\Rightarrow e_2 = 2\text{m}$

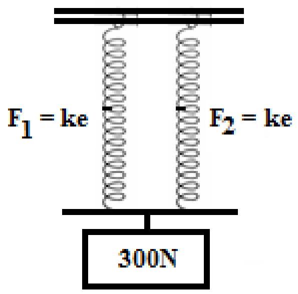
Total extension $= e_1 + e_2$
Total extension $= 5\text{m} + 2\text{m}$
Total extension $= 7\text{m}$

(ii) Springs in parallel
When springs are connected in parallel as shown below, they produce the same extension when a load is applied on the system.



$F = F_1 + F_2$
$F = K_1e + K_2e$
$F = (K_1 + K_2)e$

Example: 1
Two springs of force constant 500Nm^{-1} are placed parallel to each other and a force of 300N is suspended on them as shown below .



$F_1 = k_1e = 500e$
$F_2 = k_2e = 500e$

$F = F_1 + F_2$
$F = 500e + 500e$
$300 = 1000e$
$e = 0.3\text{ m}$

Question 1
Two springs A and B are connected in series to form a composite spring. Given that the spring constants of A and B 5000Nm^{-1} and 3500Nm^{-1} respectively, determine the total extension produced in the composite spring when a force of 200N is applied at the free end**.**
(Ans: 0.097m)

Question 2
Two springs with spring constants of 250Nm^{-1} and 200Nm^{-1} are connected in parallel and a 200g mass suspended at the free end of the combination. What is the extension produced in each spring when a force of 200N is applied at the free end**. (Ans: 0.004m).**

CRYSTALS:

A crystal is a solid that consists of particles arranged in an orderly and repetitive manner.
It can be defined as a solid that has solidified in a definite regular shape.

Crystals have hard, flat sides and straight edges. Crystals of the same substance have the same shape. This will be observed when salt crystals grow as water evaporates from the salt solution on glass slide as seen through a microscope.

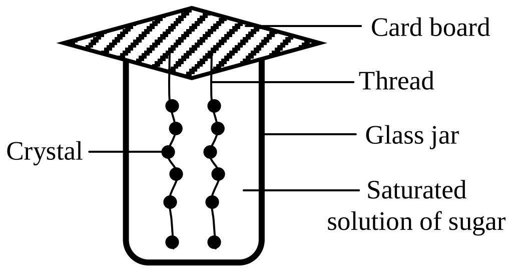
This fact suggests that crystals are made of small particles called atoms or molecules arranged in orderly way in planes. Metals consist of tiny crystals.

(a) Cleavage (or breaking of a crystal):
Cleavage is the hitting of a crystal softly by a blunt object so as to break it and not cutting it.
Cleavage line is the line a long which a crystal is split. Crystal cleavage is the splitting of the crystal to form other crystals.

(b) Growing Crystals
(i) Faster rate method of growing crystals.

Add **copper II sulphate** to little warm water in a test tube and shake.
Smear a little solution of **Cu SO_4** on a microscopic slide and observe through a microscope to see how the crystals grow.
Note: Crystals grown by faster method are of very small particles.

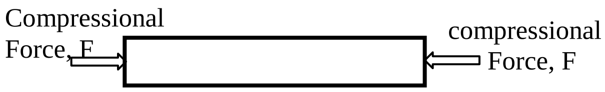
(ii) Slow rate method of growing crystals.



- ❖ Warm water is poured in a glass jar and some sugar added. The mixture is stirred.
- ❖ A card board with several threads protruding from it is placed on top of the glass jar.
- ❖ The process is repeated until the water cannot dissolve any more sugar at this temperature. The sugar solution is said to be saturated.
- ❖ The glass jar is left un disturbed for at least a day.
- ❖ When the threads are pulled out of the solution, crumbs or crystals are seen lining up on the threads.

Why different crystals have different shapes and sizes
This depends on 2 factors:
(i) The internal symmetry of the crystal, and
(ii) The relative growth rates along the various directions in the crystal.
Question 2007 PP1:
(a) What is a **crystal**.
(b) A potassium permanganate crystal is carefully placed at the bottom of a beaker containing clear water. Explain what is observed

Tensile, shear and compression force.
(i) Compression force
Compression is when the force acts as in the diagram below. This results in the particles to be pressed more closely together. So the length of the material decreases but the thickness of the material increase.

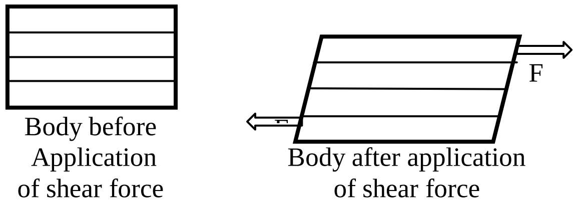


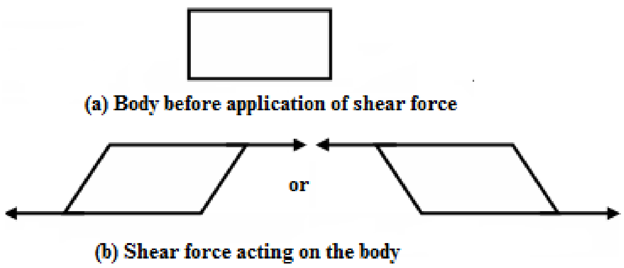
(ii) Tensile force
Tensile force is when the force acts as in the diagram below. This result in the particle of the material to be pulled further apart from one another. So tensile forces increase the length of the material but its thickness decreases.

Differences between tensile and compression force.

Tensile force	Compression force
i) Particles are pulled further apart	i) Particles are pulled close together
ii) Length of the material increases	ii) Length of material decreases
iii) Thickness of the material decreases	iii) Thickness of the material increases

(iii) Shear force
Shear force is the force needed to fracture the material in a direction parallel to the applied force in that one section (or layer) of the material slides over its neighbours.
A shear is produced when two equal but opposite forces are applied to a body. The effect depends on the turning effect or movement of the force.





Important materials used for construction.

(a) Metals:
Large varieties of metals are available from which different alloys or combinations of these metals are made into various shapes. Metal can be rolled, pressed, and drawn into various shapes, and are usually strong, rigid and elastic.

Some of the common metals are; copper, Zinc, Lead, Tin, Nickel, Chromium. e.t.c.

(b) Alloys:
Alloys are made by mixing one metal with one or more other metals and in some cases with non metals.

- ❖ *Steel alloys*: Steel is an alloy of Iron and carbon. Iron is alloyed with a variety of the other materials like:-

Examples of steel
- Mild steel (Iron and carbon) used in making cars, ships etc.
- Stainless steel has high corrosion resistance due to its composition of chromium and nickel. It is used in making knives, watch casing etc.
- Lead and sulphur steel. It is used in the making of screws because it is easy to cut.

- ❖ *Duralium* is an alloy of aluminium and is used in the making of aircrafts because of its lightness and strength.

- ❖ *Nickel-Chromium alloys*
  i) Have good resistance to corrosion
  ii) The electrical conductivity is independent of temperature
  iii) Have a high melting point.

For these properties, nickel-chromium alloys are useful for making elements of electrical heaters.

- *Invar:* is a nickel-iron alloy with low expansivity. It can be used to make accurate measuring tape and parts of watches.

- *Brass:* Is copper-zinc alloy? It is ductile and with high tensile strength. It is used in stamping, pressing or drawing. It is used in the making plumbing fittings.

- *Bronze:* Is an alloy of copper and tin is harder and stronger than brass. It is useful in ornamental work.

- *Solder:* Is an alloy of lead and tin. It is used to create a permanent bond between metal work pieces, especially in electronics.

(c) Stony materials

- Bricks: Are made by moulding a mixture of clay and water and beating the mixture strongly.
- Concrete: A concrete is a stony material which is a mixture of cement, sand gravel and water. This is left to harden in desired form.

Properties of concrete which makes it a suitable building material

(i) It is resistant to weather
(ii) It is resistant to compression
(iii) It is very durable.
(iv) It is resistant to fire

Concrete can be primarily subjected to compression like column and arches because its compression strength is high. However, concrete is relatively a brittle material whose tensile strength is small compared to its compression strength. This makes concrete unsuitable for use in structure membranes which are subjected to tension like tie rod, beams.

In order to overcome the limitation of low tensile strength, steel (with high tensile strength) is interlocked and completely surrounded by hardened concrete mass to form an integral part of the membranes called ***reinforced concrete.***

Reinforced concrete is a combination of steel rods, Cement, sand, gravel and water which is left to harden. Concrete is reinforced by interlocking and surrounding the steel rods with the hardened concrete mass.

Advantages of reinforced concrete.

(i) It has high compressive strength
(ii) It has high tensile strength
(iii) It has much greater ductility
(iv) It is tough
(v) It is weather and fire resistant

*However, the **disadvantage** of concrete is its volume instability caused by shrinkage of concrete, which results in cracks.* The cracks can be filled with mixture of special tar, sand, cement and water.

Cement Mortar: Cement mortar is composed of sand, cement mixed with water in right proportions and left to harden.

Reinforcement: sisal-fibre, bamboo stripes, wood strands are also used in reinforcing concrete and cement mortars.

The reinforcing improves on tensile strength and weather resistance of the materials.

(d) Glass:

Glass can be melted and formed into various shapes.

Advantages of glass which makes it useful as construction material.

i) It is transparent
ii) Its surface quite harder
iii) Very few chemicals react with glass.
iv) Can be melted and formed into various desired shapes.

Safety glass: Is used in motor vehicle windscreen. Safely glass is made by heating plate glass, and cooling the two surfaces in a stream of air.

These layers contract and compress the glass in the middle resulting into a very strong glass which when hit hard enough, simply breaks into small fragment that are less dangerous than large pieces.

(e) Wood:

Wood is a poor conductor of both heat and electricity.
The hardness and strength of wood varies from one sample to another.

Thin sheets of wood are glued together to form a laminate (or plywood) which is stronger than solid wood of the same thickness.

BEAMS AND STRUCTURES

Beams:

A beam refers to a large, straight piece of material with uniform cross section capable of withstanding loads by resisting bending.

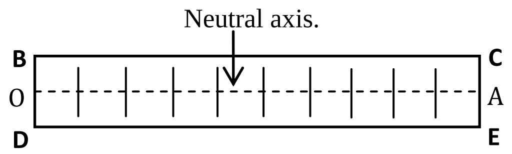
Beams are used as major structural items or elements in a building or structure. **A beam** is a large and long straight piece of materials (e.g wool, metals, concrete, e.t.c) with uniform cross-sectional area *capable of withstanding loads by resisting bending.*

Girders:

These are the smaller pieces of materials used to strengthen a structure.
In any structure, some girders are under tension while others are undercompression.
Girders under compression bend or buckle and those under tension become thin and may break.

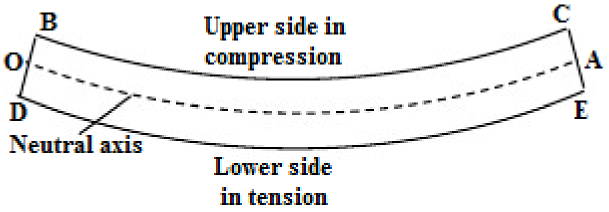
When a beam bends, one side is compressed, the other is stretched (tensile) and the centre is unstretched **neutral plane.**

(i) When Free



Above is the diagram of rubber marked with lines as shown. When the rubber is bent as shown below,

(ii) When Loaded

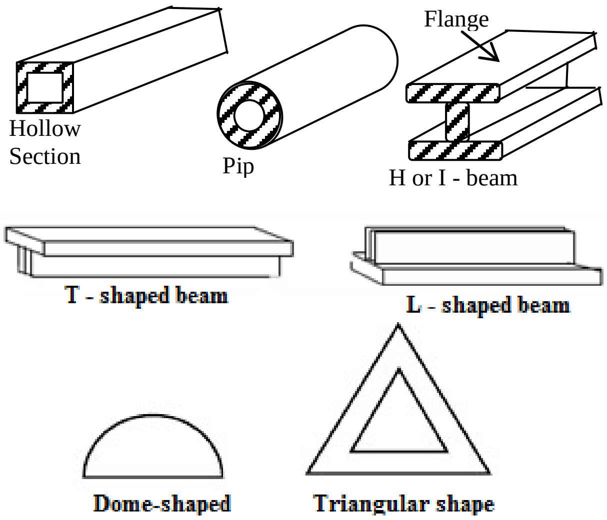


The lines above OA move further apart. Showing that the upper parts are in tension.
The lines below OA move closer showing that the lower parts are in compression.

Along OA (neutral axis) the lines are at the same distance apart as before implying that this region has not been affected by the tensional and compression forces.

From above it can be noted that materials from neutral plane can withstand compression and tensile force due to loading.

In engineering, the following shapes have been found to resist very high stresses:



Because they are beams that have had material removed from the neutral plane, so can with stand compression and tensile forces due to loading.

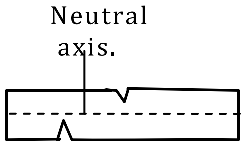
Advantages of hollow beams
In general, pipes for construction of structures like bicycles, bridges are made hollow for the following advantages.

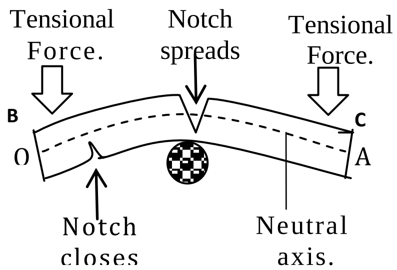
- Notches cannot spread easily hence less risk of breaking.
- Less material is used for construction
- The finished structure is lighter
- Provide room for expansion and contraction.
- They can with stand compression and tensional forces due to loading.

THE NOTCH EFFECT:

Cracks and fractures:
A **notch** is a cut or weak point in the surface of a material.

When a notch is made in the reinforcing material, the fibres, stripes and strands in the length of concrete or mortar are broken down.
This result in such materials to fail to withstand compression or tensile force.





Glass tubes are easily broken after notch is made on the side.

A notch, crack or scratch on the surface of brittle material like concrete and glass, spreads more readily under tensile force than under compression.

Reducing notch effect:

(a) <u>For concrete and cement mortar;</u>
Notch effect can be reduced by; pre-stressed concrete containing steel rods that are in tension because they were stretched while the concrete was poured on them.

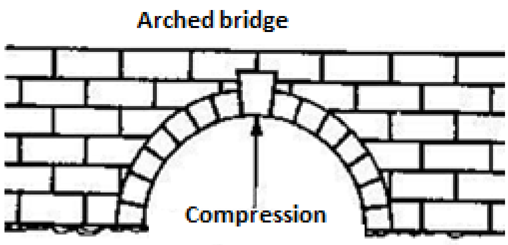
This is advantageous in that as well as resisting tension forces they keep the concrete in concrete in compression even if the whole structure is not.

(b) <u>For glass:</u>
Notches can be removed from glass
i) By making the surface of glass as smooth as possible. So glass is usually made smooth to reduce the breaking due to notches.
ii) For safety glass used in motor vehicle screen is made by heating plate glass and cooling the two surfaces of glass in a stream of air where they contract and compress the glass in the middle. This is called <u>thermal toughening.</u>
iii) By reinforcing glass with transparent polythene.

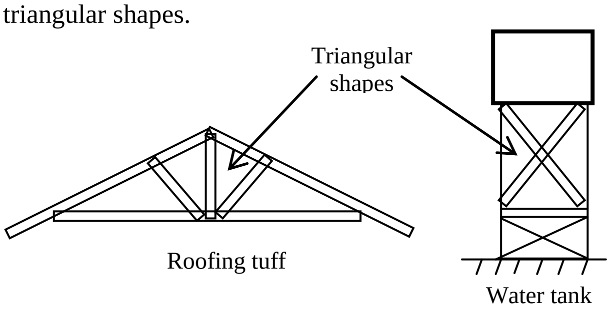
(c) <u>For wood;</u>
Thin sheet of wood are glued together to form a laminated structure which is able to resist notches more than solids because for solid structures, the crack or a notch goes right through while in a laminated structure it may be stopped by one of the layers.

STRUCTURES:

A structure is rigid meaning that it can support weight.



Triangular structures are more rigid than others. So a rectangular structure can be made rigid by adding a diagonal piece so that the rectangular change into a triangular structure, which is more rigid. This is why doors, water tanks and roofing tuffs are made with triangular shapes.



Ties and Struts

In any structure, there are parts, which are under action of tensional forces and others under action of compressional forces.

Ties are girders, which are under tension.
This occurs when a girder results in the points it joins to moves further apart on the removal of such girder in a tie.

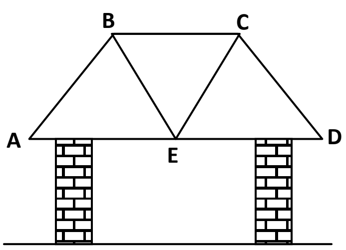
Properties of ties:

- ✓ It is under tension
- ✓ When removed, the point it joins move further apart.
- ✓ It can be replaced by a rope or strong string.

Struts are girders, which are under compression.
This occurs when a girder result in the point to move closer together on removal girder in struts.

Properties of struts:

- ✓ It is under compression
- ✓ When removed, the point it joins move closer to each other.
- ✓ It cannot be replaced by a rope or strong string.

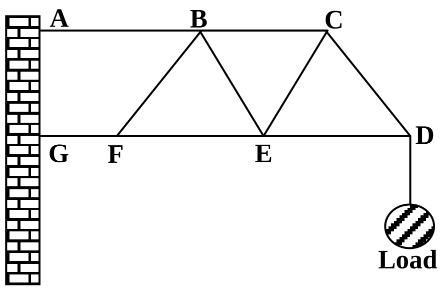


In order to determine each of the girders whether its a tie or a strut, each of the girders is removed and the effect is noted.

- ❖ If the points move further apart then the girder is tie and if the points move closer together then the girder is strut.
- ❖ When BC is removed, point B moves close to point C showing that girder BC is strut.
- ❖ When AB is removed, point A moves close to B. so girder AB is strut and similary CD.
- ❖ When AE is removed, point A moves further apart from E meaning that girder AE is tie. Similarly, girder ED is tie.

For structures

When BE is removes point B move further apart from E meaning the girder BE tie.



AB, BC, CD, BF are ties

CE, AD, DE, AG, are struts

When BF is removed, the structure turns about point G. B will move further away from F hence BF is a tie.
When BC is removed, the structure will bend at E. Thus, C will move in the direction of the load, far away from B. This means BC is under tension and hence it is a tie.

When CD is removed, point D moves down wards with the load. Point D moves away from C, so CD is a tie.

When DE is removed, CD will be vertical due to the load. Thus, point D moves nearer to E meaning that girder DE is a strut. Similarly, girder EG is a strut.

When CE is removed, the load moves down wards and part BCD will be straight due to the load. Thus, point C moves nearer to E meaning that girder CE is a strut. Similarly, girders BE and AB are struts.

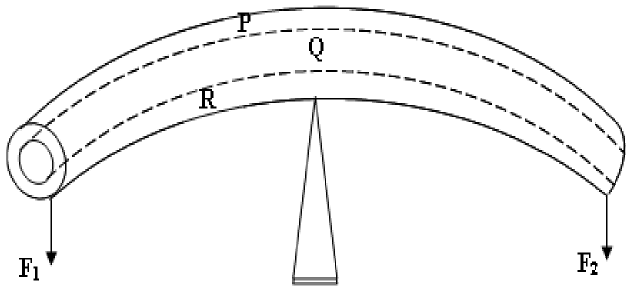
Check UNEB 2010 PP1 No. 37, for a related question**.**

SECTION A

1. Roofing structures and many bridges are made designed triangular sections to;
   (i) Minimize the material used
   (ii) Withstand compression forces
   (iii) Minimize tensile force under compression.

A. (ii) only B.(ii) and (iii) only.
C. (i) and (iii) only. D. (i) , (ii) and (iii)

2. The beam shown below is being acted upon by forces F_1 and F_2 as shown.



The regions **P**, **Q** and **R** are respectively,

A. tension, compression, neutral axis
B. neutral axis, compression, tension
C. tension, neutral axis, compression

D. compression, neutral axis, tension

3. A notch on a material spreads more rapidly when the material is;
A: reinforced B: in tension
C: pre stressed D: in compression

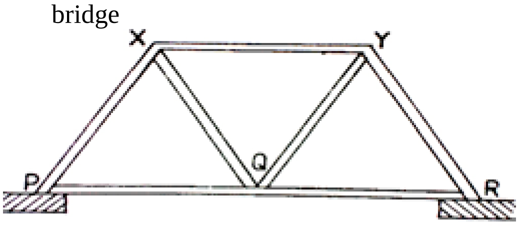
1. The strength of a material depends on the:
(i) Nature of the material (ii) Diameter of the material (iii) Length of the material
A. (i) only B. (i) and (ii) only
C. (ii) and (iii) only D. (i), (ii) and (iii)

2. A mass of 0.2 kg produces an extension of 8 cm in a spring. The force required to produce an extension of 6cm is
A. 0.75 N B. 1.50 N
C. 2.70 N D. 24.00 N

3. A ductile material is that which
A. Is fragile
B. Is not elastic
C. Can be molded into any shape
D. Easily breaks under compression.

4. In a wire supporting a load, stress is given by
A. $\frac{strain}{area}$ B. Force x area
C. $\frac{area}{force}$ D. $\frac{force}{area}$

5. The diagram in figure 6 shows a framework of a bridge

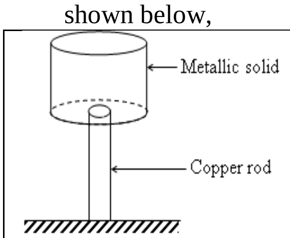


. Which of the girders are **ties**?
A. XQ, QY, PX, YR B. PQ, QR, XY
C. XQ, QY D. PX, YR

6. Which of the following are all brittle materials?
A. Leather, rubber, thread.
B. Clay, glass, wood.
C. Glass, cast iron, stone.
D. Rubber, polyester, copper wire.

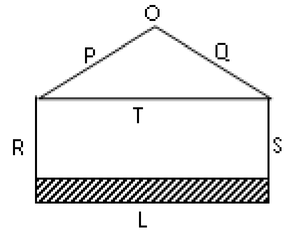
7. The diagram below shows a structure of wooden beams P, Q, R, S and T supporting a heavy road L. Which of the beams can be replaced by ropes if the same shape is to be maintained?

8. A metallic solid of mass 45kg rests on a copper rod of cross sectional area 0.5 cm^2 standing vertically as shown below,

	Calculate the stress in the rod. A. $9.0 \times 10^2 \text{Nm}^{-2}$ B. $9.0 \times 10^5 \text{Nm}^{-2}$ C.$9.0 \times 10^6 \text{Nm}^{-2}$ D. $9.0 \times 10^8 \text{Nm}^{-2}$

9. A notch on a material spreads more rapidly when the metal is;
A. in tension B. in compression
C. pre-stressed D. reinforced

10. The curve in the figure shows the force versus extension graph for a copper wire.



A. P, R, S and T B. P, Q, S and T
C. Q, R, S and T D. P, Q, R and S
(**Ties**: **P**, **Q**, **R**, **S**. **Struts**: **T**.)

11. A rod of cross-sectional area 40cm^2 needs a tensile force of 2N to break it. What is its breaking stress?
A. 0.005 Nm^{-2} B. 0.05 Nm^{-2}
C. 5 Nm^{-2} D. 500 Nm^{-2}

12. A mass of 0.5kg causes a spiral spring to extend by 4cm. The force that would cause an extension of 6cm would be
A. 2.0 N B. 3.3 N C. 4.8 N D. 7.5 N

13. If a load 1N extends a spring by 5cm, what extension will a load of 0.6 N produce?
A.1.2 cm B. 3.0 cm
C. 8.3 cm D.30.0 cm

14. Which of the following are brittle substances?
A. Dry clay, steel, chalk, wood
B. Chalk, steel, plastic, glass.
C. Glass, chalk, concrete and steel
D. Dry clay, glass, chalk and concrete.

15. Reinforced concrete is stronger than ordinary concrete because concrete and the steel are
A. Both brittle materials.
B. Strong in tension and compression respectively.
C. Both ductile materials.
D. Strong in compression and tension respectively.

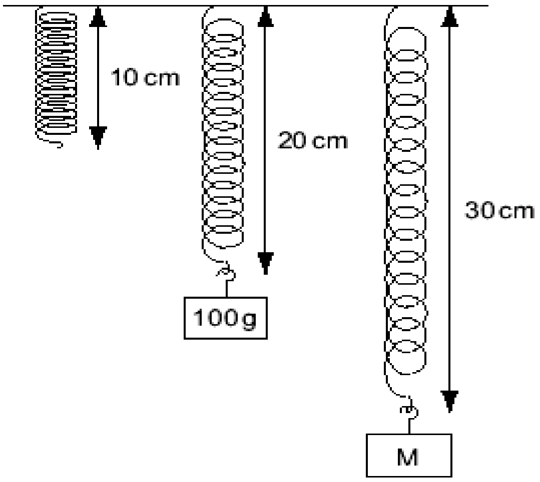
16. The graph above represents the extension of a wire with increasing load. Where does the yield point occur?
A. between point P and Q
B. between point Q and R
C. between point R and S
D. at point S

17. A load of 4 N stretches a spring by 0.5 cm. Calculate the extension when a load of 8 Nis applied.
A. 0.25 cm B. 1.0 cm
C. 2.0 cm D. 4.0 cm

18. The strength of a material is its ability to resist
(i) Compression.
(ii) Shearing forces.
(iii) Change in size or shape.
A. (i) only. B. (ii) only.
C. (i) and (ii) only. D. (i), (ii) and (iii).

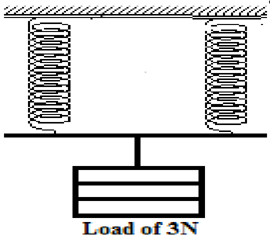
19. Which of the following are all brittle materials?
A. Leather, rubber, thread.
B. Clay, glass, wood.
C. Glass, cast iron, stone.
D. Rubber, polyester, copper wire.

20. Objects with different masses are hung on a 10 cm spring. The diagram shows how much the spring stretches.



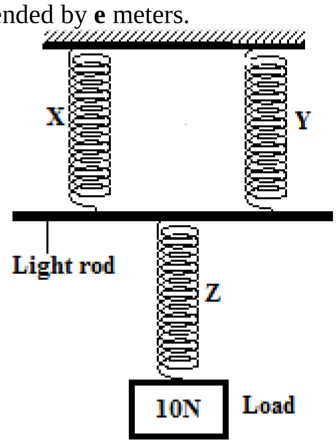
The extension of the spring is directly proportional to the mass hung on it. What is the mass of object M?
A: 110 g B: 150 g C: 200 g D: 300 g

21. An experimenter applies a force of 6N to a helical spring and it extends by 12cm. She then hangs the spring in parallel with an identical spring and attaches a load of 3N as shown in the figure below.



The resulting extension of the system in cm, will be
A: 3 B: 4 C: 12 D: 36

22. The diagram shows three identical spring balances X, Y, and Z arranged as shown in the figure below supporting a load of 10N. At equilibrium, the spring Z is extended by **e** meters.



The extension of X and Y are:

	X(m)	Y(m)		X(m)	Y(m)
A	e/2	e/2	C	e	e
B	2e	2e	D	3e	3e

Paper II Questions

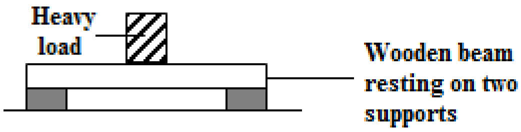
23. (a) With the aid of a diagram, describe the effect of a shear force on a body.
(b) (i) What is meant by strength as applied on a material?
(ii) State the factors on which strength on a material depends.
(c) (i) Describe a simple experiment to describe Hooke's law using a spring.
(ii) State any three characteristics of concrete which make it a desirable building material.

24. (a) Define the following terms
(i) Strain. (ii) Stress.

(b) Explain with the aid of a sketch diagram, how a notch weakens a beam of a brittle material.
(c) Sate two ways in which concrete may be made stronger.

(d) A force of 100 N stretches an elastic spring by 2 cm. what force would stretch the same spring by 3.5 cm?

(e) The diagram in the above figure shows a simple bridge on a stream.



(i) Mark the neutral axis
(ii) Label the part that will be in tension
(iii) Indicate on the diagram how the bridge can be strengthened.

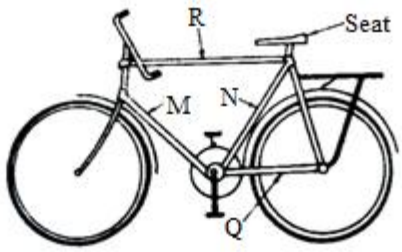
25. A spring constant of natural length 8.0×10^{-2}m extends by 2.5×10^{-2}mmwhen a weight of 10N is suspended on it.
(i) Find the spring constant.
(ii) Determine the extension when a weight of 15N is suspended on the spring

26. A force of 500N extends a wire by 2mm. If the force is reduced by a half, what will be the new length of the wire, if the original length is 10 cm.

.

27. A vertical spring of length 30 cm is stretched to 36 cm when an object of mass 100g is place in the pan attached to it. The spring is stretched to 40 cm when a mass of 200g is placed in the pan. Find the mass of the pan.

28. (a) Define the terms **strain** and **stress**.
(b) The figure below shows a diagram of a bicycle.

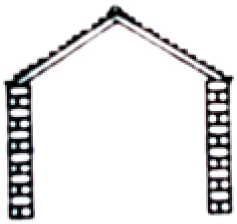


Which of the parts labelled M, N, Q and R would be
(i) in tension.
(ii) in compression when a heavy person sits on the seat.

(c) Give four reasons why bicycle frames are made of hollow cylindrical structures

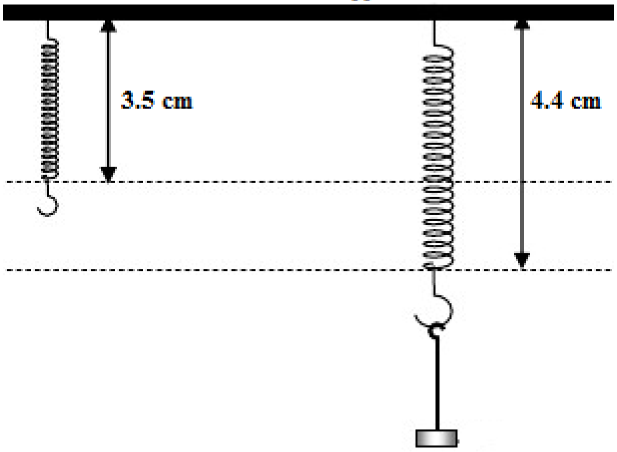
(d) Explain why the lower part of the second floor of a building is made of reinforced concrete while the upper part is not reinforced.

(e) The figure below shows a part of a roof structure.



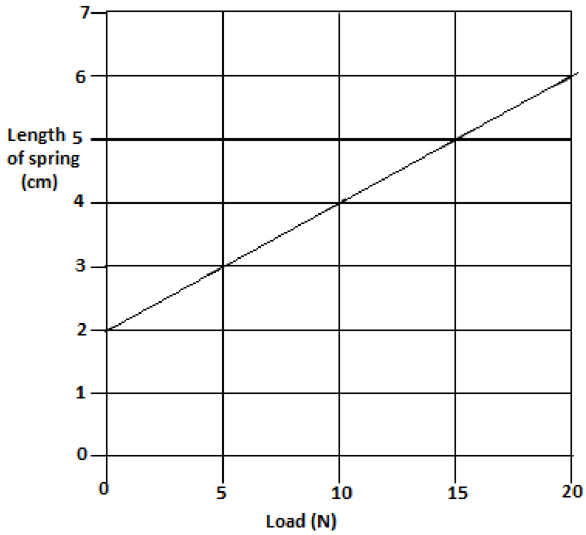
(i) Copy the diagram and on it show how the structure can be strengthened by using two other girders.
(ii) Label one tie and one strut on your diagram.

19. The figure below, shows a spring of length 3.5 cm when hanging freely,and length of 4.4 cm when a mass of 200g is attached to its free end.



What will be the new length of the spring if a 400g is attached to its free end.

20.A spring balance is calibrated to give readings in newtons. The graph shows how the length of the spring varies with the load.



(i) What is the balance reading if a load causes the spring of the balance to extend by 13cm.
(ii) What extension would be produced by a load of 12N.
(iii) Determine the spring constant.

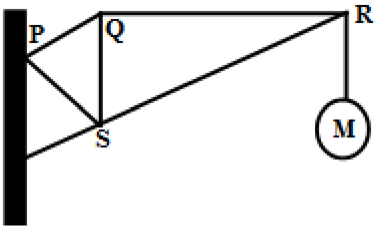
21. **UNEB 2011 No. 5C.** When a boy of 50kg stands at the end of the spring board board, it is depressed by 15cm. What would be the depressession of the same spring board when a man of 80kg stands at the end. **(Ans: 0.24m)**

22. A road of cross sectional area 40cm^2 needs a tensile force of 2N to break it. What is the breaking stress. **(Ans: 500Nm^{-2})**

23. To cut a glass rod, a scratch (a notch) is made on it and then bent suddenly. Explain why the scratch made on the glass rod.

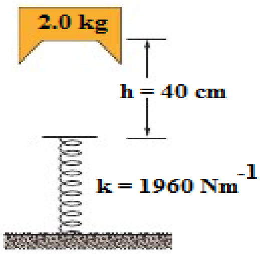
24. A spring has an un stretched length of 15.0cm and a length of 15.6cm when a load of 3N is put at the bottom of the spring. The load on the spring when the stretched length is 15.8cm in newtons is:
A: 10 B: 8 C: 4 D: 6

25. The figure shows a structure supporting a load M.



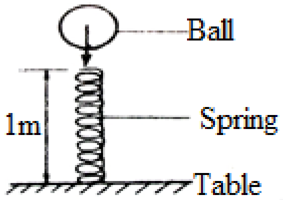
Which of the girders can be replaced by strings.

26. A block of mass m 2.0kg is dropped from height h 40 cm onto a spring of spring constant, k = 1960 Nm^{-1}.



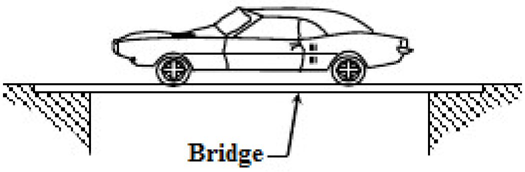
Find the maximum distance the spring is compressed.

27. A ball of mass 100g falls from rest through a height of 2m on to the top of a spring of length 1m placed on the table as shown in the figure below.



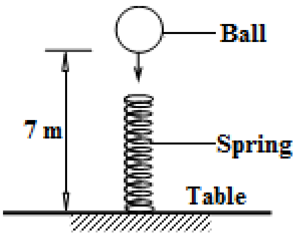
(i) How much energy is passed onto the spring by the ball.
(ii) If the elastic constant of the spring is100Nm^{-1}, what will be the compression in the spring.

28. The diagram in the figure below shows a simple bridge on a stream.



(i) Mark the **neutral axis**
(ii) Describe the mechanical state of the beam.
(iii) Indicate on the diagram how the bridge can be strengthened.
(iv) Explain what is likely to happen to the bridge if a notch is made on the beam at the:
(a) Upper surface.
(b) Lower surface

29. What is meant by **kinetic** energy and **potential** energy?



(b) A ball of mass 100 g falls from rest through a height of 7 m onto the top of a spring of length 1m, placed on a table as shown in figure above. How much energy is passed onto the spring

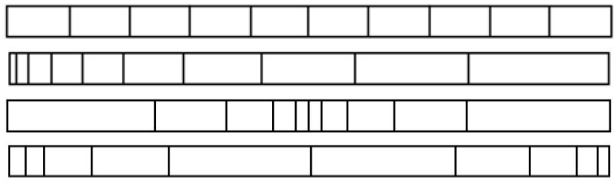
30. An iron wire and a brass wire, of equal lengths and cross sectional area, are joined at one end. A tensile force **F** is applied to the free ends as shown.

If the Young modulus of iron is twice that of brass, which statement is true?

A	The extension of the brass wire is twice that of the iron wire.
B	The extension of the iron wire is twice that of the wire.
C	The stress of the brass wire is twice that of the iron wire.
D	The stress of the iron wire is twice that of the wire.

31. A uniform strip of rubber, marked with equal divisions, is fixed at end **P** and pulled by force *F* applied at end **Q**, as shown in the diagram.

Which diagram shows the separation of the divisions when the elastic is extended to twice its original length?



32. The following readings were obtained in an experiment to verify Hooke's law, when a spring was extended by hanging various masses on it.

Mass(g)	0	25	50	75	100	125
Reading (cm)	10.0	11.5	12.5	13.5	14.4	16.0

Plot a graph of extension against mass and use it to determine the:
(a) Weight of a bottle of ink hung from the spring when the reading obtained is 12 cm.
(b) Spring reading for a mass of 0.02Kg hang on it.

TURNING EFFECT OF FORCE (MOMENTS)

Moment of a force is also called the measure of the turning effect of a force.

__**Moment of a force**__*__is a product of a force and the perpendicular distance of the line of action of the force from the fulcrum (pivot).__*

$$\begin{pmatrix}\textbf{Moment of}\\ \textbf{a force}\end{pmatrix} = \textbf{Force} \times \begin{pmatrix}\textbf{Perpendicular distance of}\\ \textbf{the line of action of the}\\ \textbf{force from the pivot}\end{pmatrix}$$

SI unit of moment is a ***newton meter,*** (***Nm***). Moment of a force is a vector quantity.

Examples of the turning effects of a force;

- Opening or closing a door, window, tin, etc
- Children playing on a see-saw
- Bending of the fore arm of a hand

Factors affecting moments

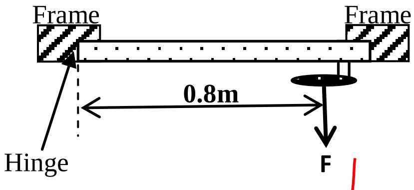
The moment of the force depends on the:-

i) magnitude of a force

ii) Perpendicular distance from the turning point (fulcrum).

Example;1

A force of 12N is applied to open a door using a handle, which is 0.8m from the hinges of the door. Calculate the moment of the force produced.



Solution

__Taking moments about the Hinge;__

$Moment\ of\ Force\ = Force, F \times Perp.distance$

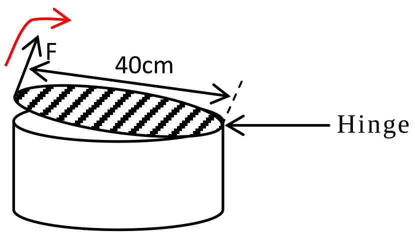
$Clockwise\ moment = 12 \times 0.8$

$\underline{Clockwise\ moment = 9.6Nm}$

Example;2

The moment of a force is 4Nm in the clockwise direction when the lid of a tin is opened. Calculate the vertical force applied, if the perpendicular distance from the hinges is 40cm.

Solution



__Taking moments about the Hinge;__

$\text{Moment of Force} = \text{Force, F} \times \text{Perp. distance}$

$4 = \text{F} \times 0.4$

$\text{F} = \frac{4}{0.4}\text{N}$

$\text{F} = 10\text{N}$

__Thus the vertical force applied is 10N__

From above, it can be noted that:

❖ The greater turning effect of a force occurs when the force acts on an object at a right angle.

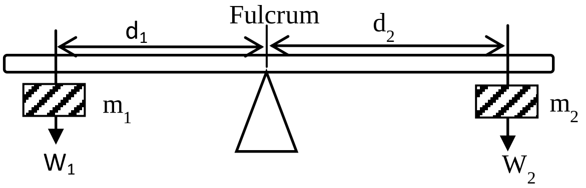
❖ **It is easier to close the door by pushing it at a point as far away from the hinges as possible.** Because the force applied can easily balance with the reaction at the hinges.
In other words increasing the distance between the pivot and the effort allows a small effort to be used to produce a larger moment of the effort applied.

Law or principle of moments

This states that when body is in a state of equilibrium the sum of clockwise moments about any point is equal to the sum anticlockwise moments about the same point.

$$\begin{pmatrix}\textbf{Sum of clockwise}\\ \textbf{moments}\end{pmatrix} = \begin{pmatrix}\textbf{Sum of anticlockwise}\\ \textbf{moments}\end{pmatrix}$$

Experiment to verify the principle of moments.



The metre rule is balanced horizontally on a knife-edge and its centre of gravity, G noted.

Un equal masses m_1 and m_2 are hung from cotton loops on either sides of the rule.

The distances of the masses are then adjusted until the rule balances horizontally once again. The distances d_1 and d_2 from m_1 and $m_2$respectively are measured from the fulcrum and recorded.

The experiment is repeated several times and the results tabulated including values of $\mathbf{w_1 = m_1g, w_2 = m_2g}$, w_1d_1 and w_2d_2.

W_1(N)	W_2(N)	d_1(m)	d_2(m)	w_1d_1(Nm)	w_2d_2(Nm)

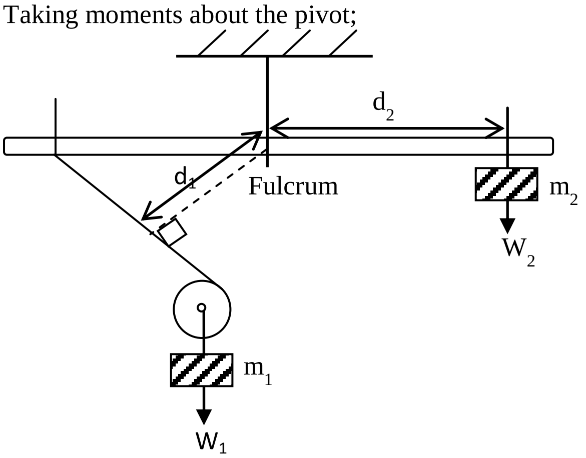
It is found that; $\mathbf{w_2d_2 = w_1d_1}$. Where w_2d_2 is the clockwise moment and w_1d_1 is the anticlockwise moment. This verifies the principle of moments.

Note: The points from which moments are being taken acts as the pivot and the moments of force at that point is zero (0).

$$\begin{pmatrix}\text{Clockwise}\\ \text{moments}\end{pmatrix} = \begin{pmatrix}\text{clockwise}\\ \text{force}\end{pmatrix} \times \begin{pmatrix}\text{Perpendicular}\\ \text{distance from pivot}\end{pmatrix}$$

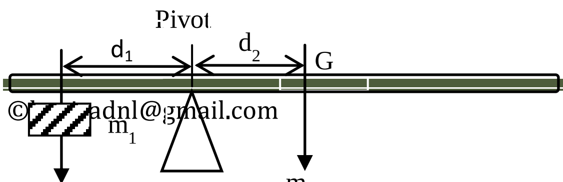
$$\begin{pmatrix}\text{Anti}-\\ \text{clockwise}\\ \text{moments}\end{pmatrix} = \begin{pmatrix}\text{Anti}-\\ \text{clockwise}\\ \text{force}\end{pmatrix} \times \begin{pmatrix}\text{Perpendicular}\\ \text{distance from pivot}\end{pmatrix}$$

Taking moments about the pivot;



Clockwise moments $= W_1 \times d_1 = W_1d_1$
Anticlockwise moments $= W_2 \times d_2 = W_2d_2$
And by the law of moment;
Sum of clockwise moments = sum of anti-clock moment about any point. Thus, $W_1d_1 = W_2d_2$

Experiment to determine the mass of a metre-rule using the principle of moments.



The metre rule is balanced horizontally on a knife-edge and its centre of gravity, G noted.

A known mass $m_1$is hung from cotton loops on one side of the metre-rule.

The metre-rule is then adjusted until it balances horizontally once again. The distances d_1 and d_2 from m_1 and G respectively are measured from the pivot and recorded.

The mass of the metre rule is then calculated by using the principle of moments.;

$$\boldsymbol{mg \times d_2 = m_1g \times d_1}$$

$$\boldsymbol{m = \frac{m_1 \times d_1}{d_2}}$$

Condition for Body to be in Equilibrium Under action of parallel forces.

When a number of parallel forces act on a body such that the body attains equilibrium, then the following conditions must be met or fulfilled:

(i) *The sum of the clockwise moment about any point is equal to sum of the anti-clockwise moments about the same point.*
(ii) *The sum of the forces in one direction is equal to the sum of forces in the opposite direction.*

The above conditions are useful in calculations involving two unknown forces. The following steps should be taken.

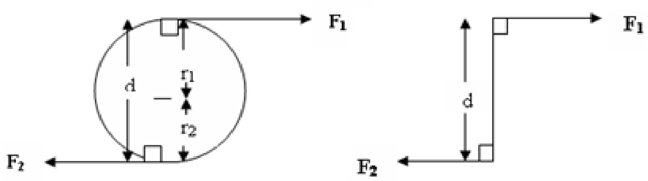
(i) An equation for sum of force in one direction equaling to sum of forces in the opposite direction is written.
(ii) Moments should be taken about one of the unknown force. Where by the sum of anticlockwise moment is equal to sum of the clockwise moments.

Note:
- ✓ *When calculating moments about a point (pivot) all distances should be measured from that point.*
- ✓ *When solving problems involving the law of moments, identify the force(s) which has/have clockwise moment(s) and anti-clock wise moment(s). So that you substitute them correctly. Experience has shown that many students tend to forget this as such they put clockwise moments under anti-clock wise moments and vice versa.*

A Couple or (Parallel forces)

A couple refers to two equal and opposite parallel forces whose lines of action do not meet.

A couple produces rotation and can only be stopped or balanced by an equal and opposite couple.



Where: $r_1 = r_2$ = radius of the circle

$r_1 + r_2 = d$ = diameter of the circle

$$F_1 = F_2$$

Characteristics of a body under the action of a couple

(i) The resultant force on the body is zero.

(ii) The turning effects of the forces cause a rotational effect.

(iii) The forces act in opposite directions.

Examples of couples

- ✓ Steering wheel of cars
- ✓ Pedals of bicycles
- ✓ Opening and closing of the caps of bottles or doors keys

Moment of a couple (Torque)

The moment of a couple is equal to the product of one force and the perpendicular distance between the two forces of a couple.

The moment due to the couple in figure above is given by the formula:

Moment of a couple = *One force* x *the perpendicular distance between the forces*

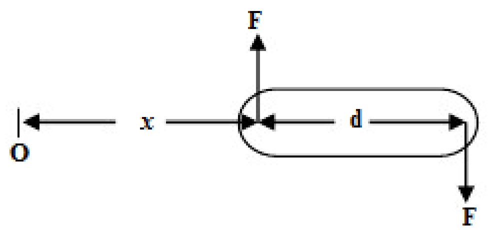
$= F_1 \text{x } d$ Nm

Or *Moment of a couple* = *One force* x *the perpendicular distance between the forces*

$= F_2 \text{x } d$ Nm

Or *Moment of a couple* $= (F_1r_1 + F_2r_2)$ Nm

Imagine two parallel forces, each of magnitude F, separated by a distance d and acting on a body as shown.



Then, taking moments about any point O we have,

Sum of moments about point O = moment of the couple

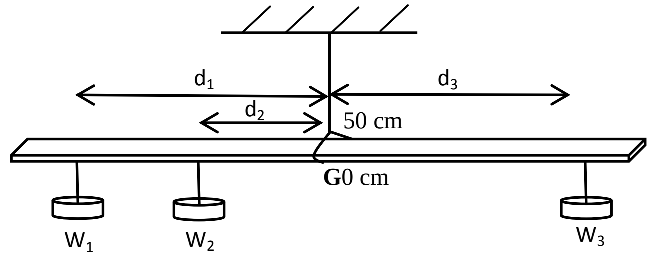
F (d+x) – Fx = Fd

The moment of a couple is called the **torque**

Example 2:

A metre-rule suspended from the centre of gravity is in equilibrium, i.e balanced at G, when forces of W_1, W_2 and W_3, act at distances of a, b and c respectively from the pivot.

(i) Draw a labeled diagram to show all the forces acting on the metre-rule.



(ii) Write an expression for the sum of the moments.

Taking moments about the pivot;

Sum of Anticlockwise moments $= W_1 \times d_1 + W_2 \times d_2$

Sum of Clockwise moments $= W_3 \times c$

Applying the principle of moments;

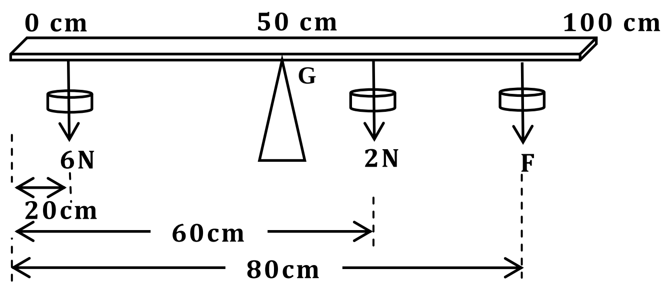
Sum of clockwise moments = Sum of anticlockwise moments

$$W_3 \times c = W_1 \times a + W_2 \times b$$

Example 3:

A uniform metre rule is pivoted at its centre and three forces of 6N, 2N and F act at distances of 20cm, 60cm, and 80cm respectively from the zero mark. If the metre rule balances horizontally, find the value of F.

Solution



Taking moments about the pivot;

Sum of Anticlockwise moments $= 6 \times 30 = 180$Ncm

Sum of Clockwise moments $= 2 \times 10 + F \times 30$

$= (20+30F)$ Ncm

Applying the principle of moments;

Sum of clockwise moments = Sum of anticlockwise moments

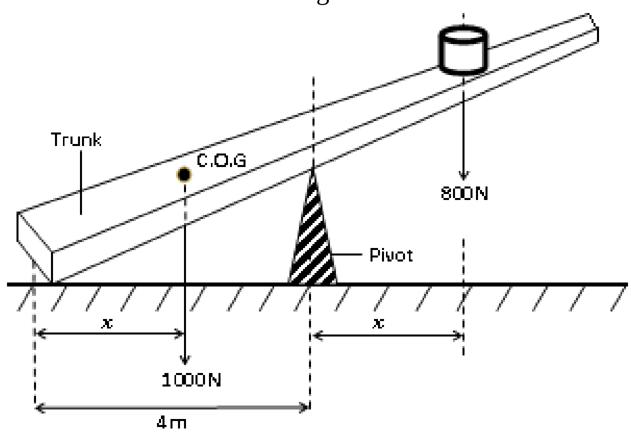
$(20+30F)$ Ncm $= 180$Ncm

$30F = 160$

$F = 5.3$ N

Example 4:

A non-uniform tree trunk of weight 1000N is placed on a pivot, 4m from the thick end. A weight of 800N is placed on the other side of the pivot, at a distance equal to that from the thick end to the centre of gravity, just tips off the tree trunk. How far is the weight from the thick end?



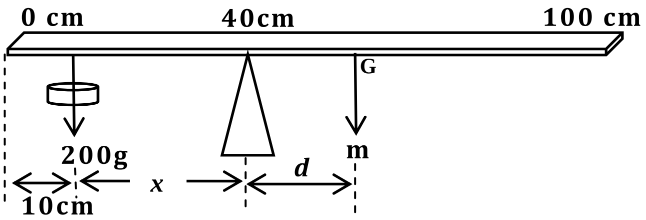
Solution:
Let the distance from the thick end to the Centre of gravity (C.O.G) be $\boldsymbol{x}$.
- ✓ Taking moments about the pivot;
- ✓ Applying the principle of moments;

Sum of clockwise moments = Sum of anticlockwise moments

$$(800 \times x) \text{ Nm} = 1000 \times (4 - x) \text{ Nm}$$
$$800x = 4000 - 1000x$$
$$1800x = 4000$$
$$\frac{1800x}{1800} = \frac{4000}{1800}$$
$x = 2.2$m

Thus the heavy weight, is (4+2.2) m = 6.2m from the thick end.

Example: 5
A uniform metre rule is suspended from 40cm marking as shown in the diagram below. Find the mass of the metre rule if it's in equilibrium.



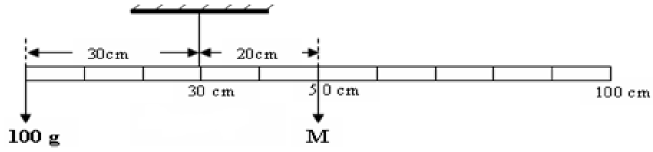
Taking moments about the pivot;
$\boldsymbol{x} = (40 - 10) = 30cm$
$\boldsymbol{d} = (50 - 40) = 10cm$

Applying the principle of moments;
Sum of clockwise moments = Sum of anticlockwise moments

$$(200 \times x) = \text{m} \times \text{d}$$
$$200\,(30) = 10\text{m}$$
$$6000 = 10\text{m}$$
$$\frac{10\text{m}}{10} = \frac{6000}{10}$$
m = 600g

Thus, the mass of the metre rule is 600g

Example: 6
Consider the diagram in the figure below to find, M.



Applying the principle of moments

Clockwise moment = Anti-Clockwise moments

M x (50 – 30) cm = 100 g x (30 – 0) cm

M x 20 cm = 100 g x 30 cm

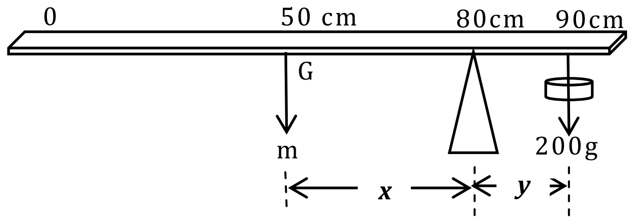
$$\frac{M \text{ x } 20cm}{20cm} = \frac{100g \text{ x } 30cm}{20cm}$$

M = 150 g

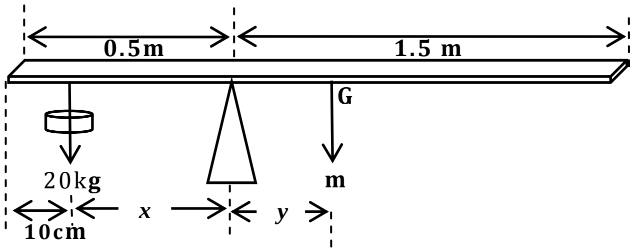
NB: *To get the weight (W) of the object, we use the formula:* ***W = mg***
Where: ***g*** *= Acceleration due to gravity and*
m *= mass of the object in kg.*

Example 7: A uniform metre rule pivoted at 10cm mark balance when a mass of 400g is suspended at 0cm mark. Calculate the mass of the metre rule. **(Ans: m=100g)**

Example 8: The diagram below is a metre rule pivoted at 80cm mark. Calculate the mass of the metre. **(Ans: m = 67g)**



Example 9:
A uniform beam 2m long is suspended as shown below. Calculate the mass of the metre. **(Ans: m=16kg)**



Interpreting the question in word form.
- ✓ The diagram for the body should be drawn and all the forces acting on it indicated in the right positions.
- ✓ The mass or weight of the body will always act at the centre of gravity. If the body is uniform, then its centre of gravity is at a position which is half way its total length, which is obtained by,

$$\text{C.o.g} = \frac{\text{L}}{2}$$

i.e. For a uniform metre rule, which is marked from 0-100cm, the centre of gravity from which the mass or weight acts is,

$$\text{C.o.g} = \frac{\text{L}}{2} = \frac{100\text{cm}}{2} = 50.0\text{cm}$$

- ✓ Then the required value is calculated by applying the principle of moment.

Example: 10A uniform metre rule is pivoted at 30cm mark. It balances horizontally when a body of mass 20g is suspended at 25cm mark.
a) Draw a force diagram for the arrangement.
b) Calculate the mass of the metre rule

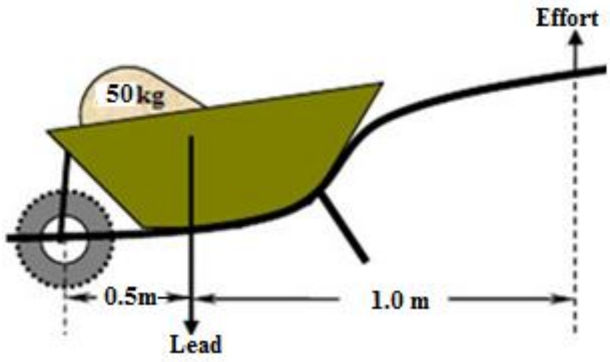
(Ans: m = 5g)

Example:11 A uniform half-metre rule is pivoted at 15cm mark and balances horizontally when a body of 40g is hanging from 2cm mark.
i) Draw a diagram of the arrangement.
ii) Calculate the mass of the metre rule.

(Ans: m = 52g)

Example:12 A uniform rod AB of length 5cm is suspended at 2m from end A. if the mass of the rod is 10kg. Calculate the mass of the body, which must be suspended at 1m from end A so as for the rod to balance horizontally. **(Ans: m = 5kg)**

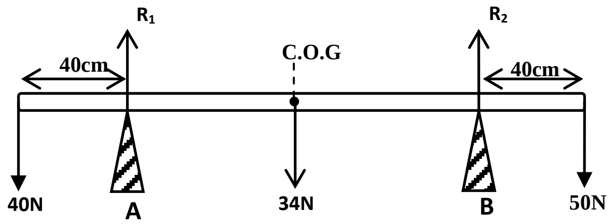
Example: 8. A hand cart of length 1.5 m, has the centre of gravity at length 0.5 m from the wheel when loaded with 50kg of sand as shown below.



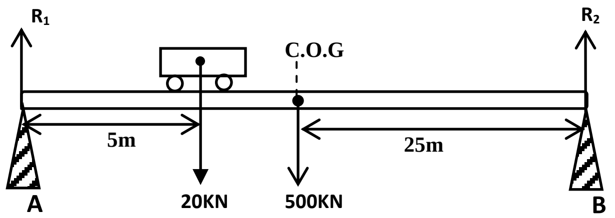
If the mass of the hand cart is 10 kg, find the effort needed to lift the hand cart. **(Ans: E = 200N)**

Example: 13
A uniform wooden beam of length 2m and weight 34N rests on two supports A and B placed at 40cm from either end of the beam. Two weights of 40N and 50N are suspended at the end of the beam.
(i) Draw a diagram to show the forces acting on the beam.
(ii) Calculate the reactions at the supports.

Solution:
(a)



Example 14: A truck of weight 20KN is driving across a uniform 50m long bridge of weight 500KN as shown below.



Calculate the reactions at "A" and "B" if the bridge is in equilibrium sum of forces in one direction = sum of forces in opposite direction.

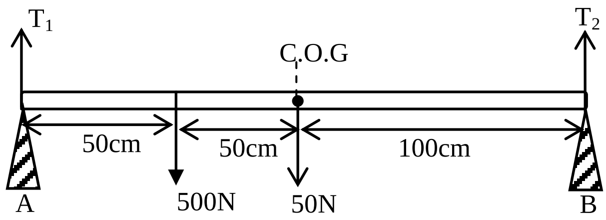
Solution
Sum of upward forces=sum of downward forces
$R_1 + R_2 = 20KN + 500KN$
$R_1 + R_2 = 520KN$……………………….(i)

Since R_1 and R_2 are, unknown forces, moments can be taken about either R_1 or R_2 .

Taking moments about R_1:
Sum of clockwise moments = Sum of anticlockwise moments
$(20 \times 5)+(500\times25) = R_2\times 50$
$100+12500= 50R_2$
$12600= 50R_2$
$R_2 = 252KN$
Substituting for $R_2 = 252KN$ into equation (i), gives;
$R_1 + 252 = 520$
$R_1 = 268KN$

Thus, the Reactions R_1 and R_2 respectively are 268KN and 252KN.

Example 2:
Two labourers "A" and "B" carry between them a load of 500N on a uniform pole of weight 50N. if the pole is 2m long, and the load is 50cm from A towards B.
(a) Draw a diagram to show the force acting on the poles.



(b) Find the tension on A and B

Solution
Sum of upward forces=sum of downward forces
$T_1 + T_2 = 500N + 50N$
$T_1 + R_2 = 550N$……………………….(i)

Since T_1 and T_2 are, unknown forces so moments can be taken about either T_1 or T_2 .

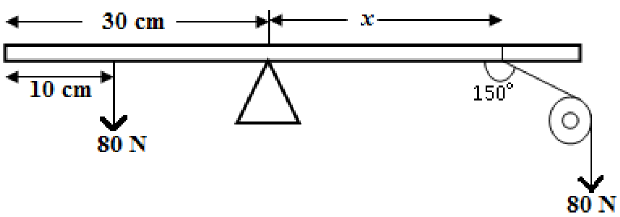
Taking moments about R_1:
Sum of clockwise moments = $\left(\begin{matrix}\text{Sum of anticlockwise} \\ \text{moments}\end{matrix}\right)$
$(500 \times 50)+(50\times100) = T_2\times 200$
$25000+5000 = 200T_2$
$30000 = 200T_2$

$$\frac{\cancel{200}T_2}{\cancel{200}} = \frac{30000}{200} \Leftrightarrow T_2 = 150N$$
Substituting for $T_2 = 150N$ into equation (i), gives;
$T_1 + 150 = 550$
$T_1 = 400N$
Tensions T_1 and T_2 respectively are 400N and 150N .

(c) Find the fraction of the total weight that is supported by B.

$$\text{Fraction} = \frac{\text{Weight supportd by B}}{\text{Total weight}} = \frac{150}{550} = \frac{3}{11}$$

Example 3:
A uniform metre rod AB is pivoted at 30cm. A load of 80N is hang at 10cm mark. Another 80N weight is attached to the string and passed over a smooth pulley shown below. The system is now at equilibrium.



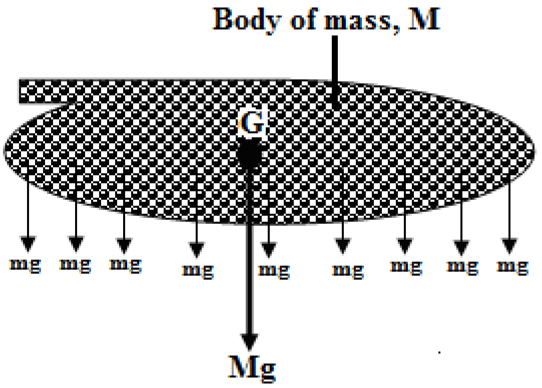
Find the distance 'x' given that the weight of the metre rule is 2N. (03marks)

CENTRE OF GRAVITY

***Centre of gravity** is the point of application of the resultant force due to the earth's attraction on a body*.
It can also be defined as the point where the resultant weight of a body appears to be concentrated.

***Resultant force** is a single force which has the same effect as two or more forces acting on a body.*

All bodies are made of a large number of tiny equal particles each of mass "m" and pulled towards the earth with a force "**mg**". If the total mass of the entire particles in a body is "**M**" then the resultant force of gravity on the body is **Mg** and it acts vertically downwards at the point G, which is the centre of gravity of the body.



The centre of gravity or centre of the mass is a fixed point in the object where the resultant weight, (force of gravity) seems to act.

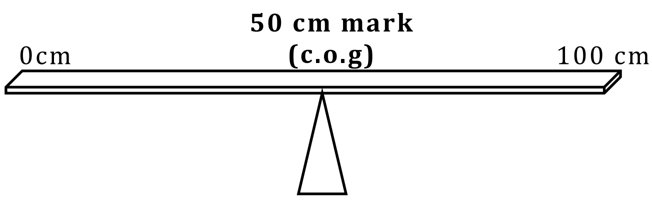
Methods to locate the Centre of gravity of a body
The method chosen to determine the centre of gravity of a body depends on the following factors:
- ✓ The nature and
- ✓ The shape of the body.

The shape may either be regular or irregular.

(a) A regular body
The mass or weight is evenly distributed and its centre or gravity is in the middle, which is at the geometric centre of the shape.

The centre of gravity of a regular body is found by using:
(i) Balancing and
(ii) Intersection of diagonal method.

(i) Balancing method

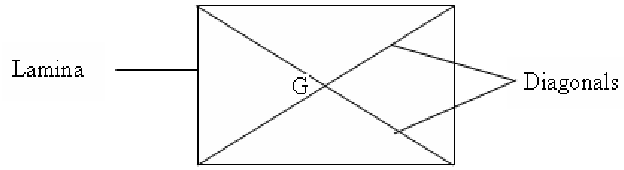


The centre of gravity of a long uniform object such as a metre rule may be determined by balancing method.
In this method, the metre rule may be balanced on a knife edge or hang from a loop of thread and then adjusted until it balances horizontally.
The point at the knife edge is the centre of gravity.

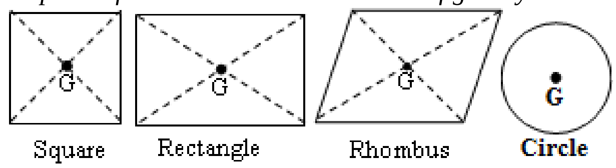
Note: *A uniform metre rule or a uniform body is one in which the particles are:*
- ✓ *uniformly distributed.*
- ✓ *The centre of gravity of a uniform body is always at its centre.*

(ii) Intersection of diagonals method
This method applies mostly to two dimensional figures e.g a rectangular lamina or cardboard.

Experiment:To determine the centre of gravity of a regular lamina
Procedure
Draw straight lines along the diagonals of the lamina as shown in the diagram below.

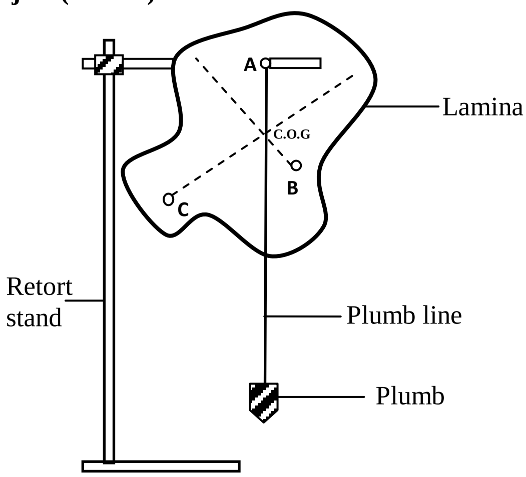


*The point of intersection **G** is the centre of gravity.*



(b) Irregular Body
The centre of gravity of irregular body is determined by using *plumb line method.*

Finding the centre of gravity of an irregularly shaped object (lamina).



- ✓ Marking holes: Three holes "A", "B" and "C" are made in the object at the edges far away from each other.
- ✓ Marking the cross lines: The object is suspended on a retort stand from each of the holes and plumb (or pendulum bob) is used to trace the centre of gravity by marking a line on the object tracing the plumb line thread when swinging stops.
- ✓ Repeating: The experiment is repeated with the object hung at B and C and cross lines marked. The point C.O.G at which all the lines cross is the centre of gravity of the body.

Note:
(i) *In the laboratory, the plumb can be replaced by a pendulum bob.*
(ii) *Not always that the centre of gravity of a body lies within the material, it may alsobe at a point in the air nearby.*
The best examples are:
- ✓ tripod and

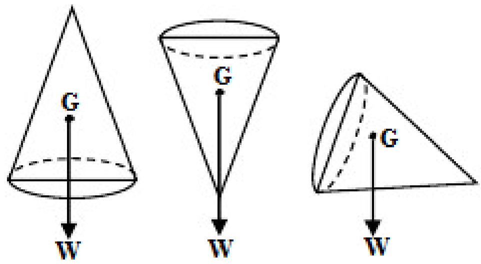
✓ laboratory stool.

STABILITY:

Stability is the difficulty with which a body topples.
When a body is at rest, it is said to be in a state of equilibrium or stability.

Types or states of stability or Equilibrium
Some bodies are in a more stable state than others.
There are three types or states of equilibrium or stability:

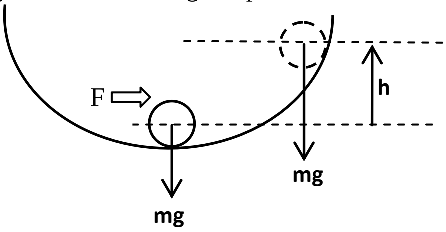
a) stable equilibrium
b) unstable equilibrium
c) neutral equilibrium

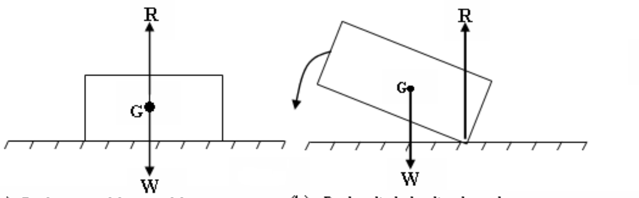


(i) Stable (ii) Un stable (iii) Neutral

(a) Stable equilibrium:
Stable equilibrium is a state of a body in which on a slight displacement it returns to its original position.
It does not topple because the line of action of its weight remains within the base e.g a cone resting on its base.

Is the type of equilibrium where, if the body is slightly tilted or displaced and then released:
(i) the centre of gravity of the body is raised.
(ii) the body returns to its original position.

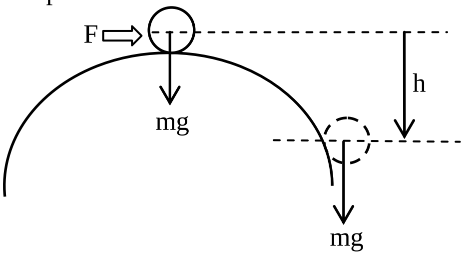


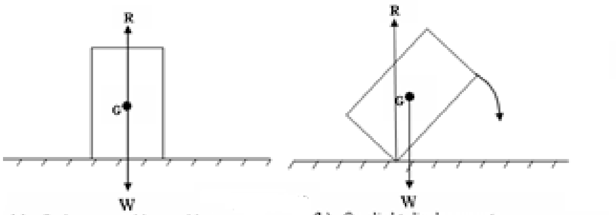


(a) *Body in stable equilibrium:*
-Centre of gravity is at the lowest point
(b) *Body slightly displaced:*
- the center of gravity rises and the block returns to its original position

(b) Unstable equilibrium:
Unstable equilibrium refers to a state of a body in which on a slight displacement it does not return to its original position.
This is because, the line of action of its weight falls outside the base. It cannot stay in this configuration without support. In this case the body continues to fall. e.g. a cone resting on its apex.

It is the type of equilibrium where, if the body is slightly tilted or displaced and then released:
(i) the centre of gravity of the body is lowered.
(ii) the body moves farther away from its original position.



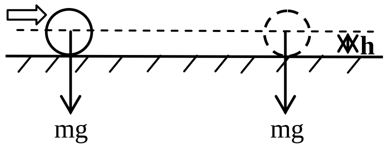


(a) *Body in unstable equilibrium:*
-Centre of gravity at highest point
(b) *On slight displacement:*
- the centre of gravity is lowered and
- the block topples over.

(c) Neutral equilibrium:
This is a state of a body in which on slight displacement its centre of gravity is neither raised nor lowered.
In this configuration the body simply remains in its new position when displaced. The line of action of its weight always passes through the line of support whatever the displacement, e.g. a cone or cylinder resting on its side.

It is the type of equilibrium where, if the body is slightly tilted and then released:
(i) the centre of gravity of the body is neither raised nor lowered.
(ii) the body stays in its new position or it just rolls on before stopping.

<u>Example:</u>
A ball on a flat surface.

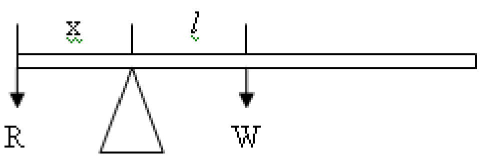


Ways of increasing the stability of a body.
The stability of a body can be increased by:
(i) Lowering the centre of gravity by putting more weights at the base.
E.g London double decker buses have the chesis, engine at its bottom while its top half is empty space to lower its centre of gravity and hence increase its stability.

(ii) Increasing the area of the base.
E.g racing cars (Formula 1 cars) are made short with a wide base.

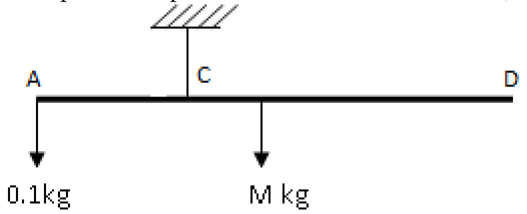
EXERCISE (SECTION A)

1. The Figure shows a uniform beam in equilibrium when a force R acts on it at one end. Find the weight W of the beam.



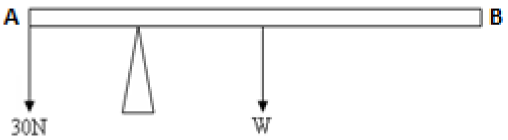
A. $\frac{x}{Rl}$ B. $\frac{Rl}{x}$ C. $\frac{l}{Rx}$ D. $\frac{Rx}{l}$

2. The diagram in the figure shows a uniform half-meter rule suspended at point C. The mass of the rule is;



A. .020 kg B. 0.025 kg C. 0.100 kg D. 0.125 kg

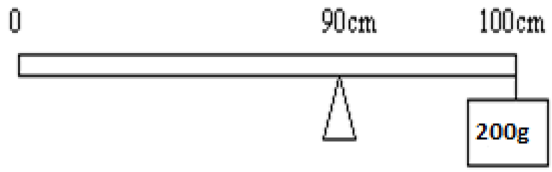
3. A uniform wooden beam of weight W is pivoted at a distance $^1/_5$ of its length from the end A and kept in equilibrium by applying a force of 30 N as shown in figure below.



The force exerted by the pivot on the beam is;

A. 50 B. 40 C. 30 D.20

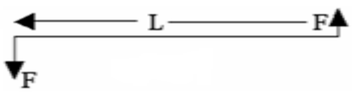
4. A uniform rod 100cm long pivoted at the 90 cm mark, balances horizontally when a mass of 200 g is suspended at the 100cm mark as shown in the figure.



The mass of the rod is;

A. 40 g B. 50 g C.400 g D. 800 g

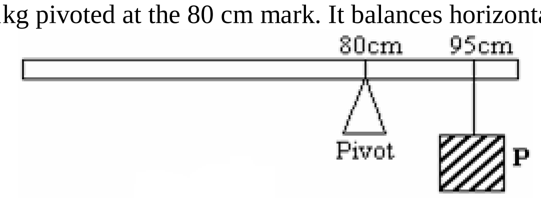
5. Which one of the following statements is true about two equal forces acting on a bar of length L shown in the figure below.



(i) The resultant force on the bar is zero.
(ii) The forces cause a rotational effect.
(iii) The forces act in opposite directions.
(iv) The forces produce different turning effects.

A. (i) only B. (i) and (ii) only
C. (i),(ii) and (iii) only D. All

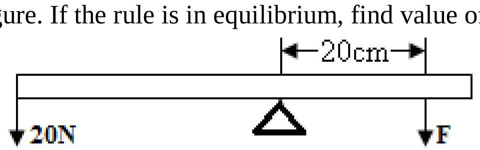
6. The figure below shows a uniform metre rule of mass 0.1kg pivoted at the 80 cm mark. It balances horizontally.



When a mass P is hanging at the 95 cm mark. Find P.

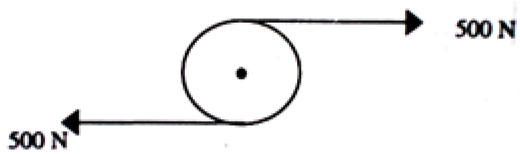
A. 0.08 kg B. 0.2Kg C. 0.4 kg D. 1 kg

7. A uniform metre-rule is pivoted at its centre shown in the figure. If the rule is in equilibrium, find value of F.



A. 4 N B. 33.3 N C. 50 N D. 100 N.

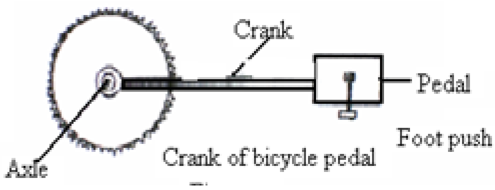
8. The shaft in an engine is subjected to two parallel but opposite forces of 500N each as shown in the figure.



The rotation is best stopped by applying

A. Two forces of 500 N acting at right angles to each other
B. A single force of 1000 N.
C. Two parallel but opposite forces of 500 N
D. A single force of 250 N.

9. The above figure shows a crank of a bicycle pedal.
The force a cyclist exerts on the pedal varies from a minimum to maximum.



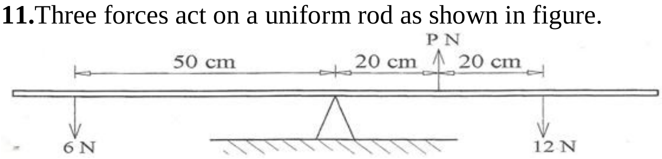
When does thecyclist exert maximum turning effort?

A. crank makes 90^0 with the foot push
B. crank makes 0^0 with the foot push
C. cyclist is climbing a hill
D. cyclist is turning a corner

10. Find the weight, w, of a uniform metre rule if a force of 60N at one end balances it as shown figure.

A. 24 N B. 40 N C. 90 N D. 100 N

11. Three forces act on a uniform rod as shown in figure.



If the rod balances horizontally, determine the value of p

A. 3N B. 9N C. 16N D. 24N

12. It is easier to use a claw hammer to remove a nail from a piece of wood if the handle is longer because the;

A. effort applied becomes bigger.
B. turning effect becomes bigger
C.anticlockwise moments will balance clockwise moments.
D. fulcrum is between the effort and the load.

13. A pole AB of length 10.0m and weight 800N has its center of gravity 4.0m from the end A and lies on a horizontal ground .The end B is to be lifted by a vertical force applied to B. Calculate the least force required to do this.

14. An object in unstable equilibrium continues to fall when slightly displaced because its;

(i) Centre of gravity is lowered.
(ii) Center of gravity is raised.
(iii) Potential energy is reduced
(iv) Potential energy is increased.

A (i), (ii) and (iii) only. B. (i) and (iii) only.
C. (ii) and (iii) onlyD. (iv) only

15. Two weights are balanced on a rule of negligible mass as shown above. What is the value of W?

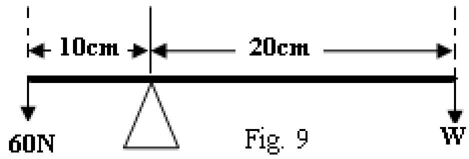


Fig. 9

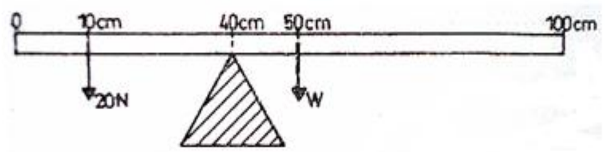
A. 2.5N B. 10N C. 30N D. 40N

16. A uniform metre rule is suspended with a string at the 20cm mark and is kept horizontal by a mass of 120g from one end as shown above. Find the mass of the metre rule

A. 80g B. 30g C. 24g D. 120g

Paper II Questions.

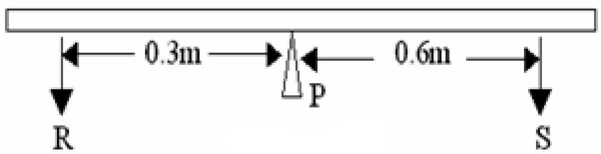
17. (a) (i) Define moment of a force and state its SI unit.
(ii) State the principle of moments.
(iii) State the conditions for a body to be in equilibrium.
(b) A uniform meter ruler is pivoted at the 40 cm mark as shown in the figure below.



The meter ruler is the equilibrium under its weight W and a 20 N force acting at the 10 cm mark. Calculate:
(i) The weight W of the metre rule.
(ii) The reaction at the knife edge.

18. (a) What is meant by **centre of gravity**?
(b) (i) Describe an experiment to determine the centre of gravity of an irregular lamina.
(ii) Describe how you would measure the mass of a metre rule using aknown mass and a knife-edge only.

19. (a) State the (i) types of equilibrium.
(ii) Characteristics associated with the types of equilibrium you have stated in (a) (i) above.
(b) Explain giving reasons whether it is advisable to load a bus on the rack.
(c) Describe how you would design a given structure to have a high stability.
(d) A uniform beam of weight 2.5 N is pivoted at its mid-point P, as shown in figure below.



The beam remains in equilibrium when force R and S act on it. If R is 5N, find the:
(i) Value of S. (ii) Reaction at the pivot

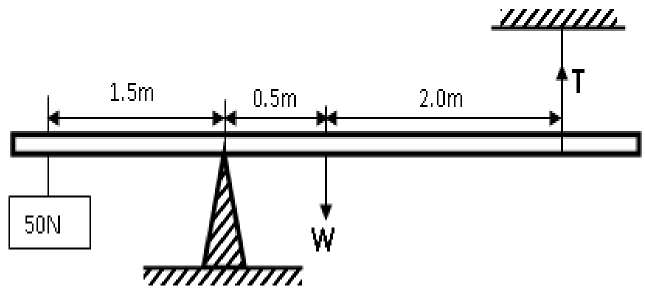
20. A uniform rod AB of length 5cm is suspended at 2m from end A. if the mass of the rod is 10kg. Calculate the mass of the body, which must be suspended at 1m from end A so as for the rod to balance horizontally. **(Ans: m=5kg)**

21. A uniform wooden beam of length 2m and weight 34N rests on two supports A and B placed at 40cm from either end of the beam. Two weights of 40N and 50N are suspended at the end of the beam.
(i) Draw a diagram to show the forces acting on the beam.
(ii) Calculate the reactions at the supports.

22. A truck of weight 20KN is driving across a uniform 50m long bridge of weight 500KN as shown below. Find the reactions on the wedges.
[Reactions R_1 and R_2 respectively are 2**68KN** and **252KN**.]

23. (i) What is meant by **centre of gravity** of a body?
(i) Given a uniform metre rule, a known mass M_o, a knife edge and apiece of thread, describe how the mass of the metre rule can be determined. (*04 mark*)

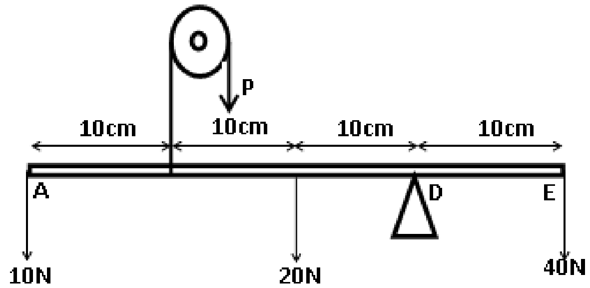
b) (i) State the conditions for a body to be in equilibrium.
(ii) A uniform beam of weight 500N is made to balance horizontally on a knife edge by a string tied near one end and a weight of 50N hanged near the other end as shown below.



If the weight of the beam is **W**, find the tension and the reaction of the knife edge on the beam.(*04 mark*)

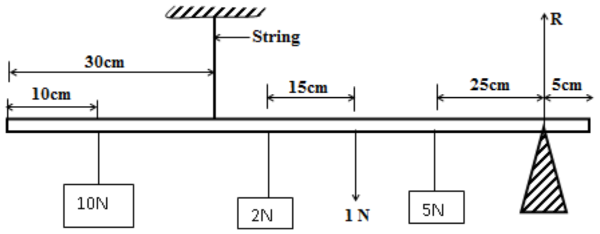
24. (a) Briefly describe a simple experiment to determine the mass of a metre rule using a knife edge, a metre rule and a known mass only.

25. (b) A rod AE of negligible weight, 40cm long, is pivoted at point D. Weights of 10N, 20N, 40N and P newtons act on the rod as shown bellow.



Find the value of P and the reaction at pivot D.

26. A uniform metre rule of weight 1N is pivoted on a wedge 5cm away from one end and suspended by a string 30cm from the other end.
If the metre rule is in equilibrium when weights of 10N, 2N and 5N are attached to it as shown in the figure below,



calculate the:

(i) Tension in the string.

(ii) Normal reaction, **R** at the wedge.

27. A uniform half-metre rule is freely pivoted at the 20 cm mark and it balances horizontally when a weight of 10 N is suspended at the 4 cm mark.

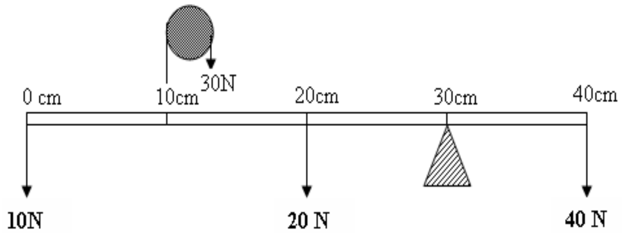
(a) Draw a sketch diagram showing all the forces acting on the metre rule.

(b) Calculate:

(i) the weight of the metre rule.

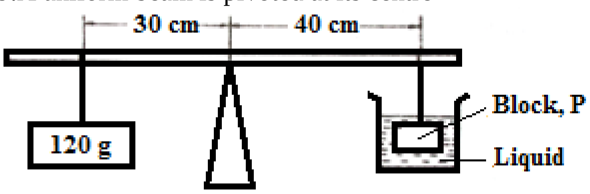
(ii) the reaction at the knife edge.

28. Four forces, 10 N, 20 N, 40 N, act downward and 30 N acts upward on a body which is 40 cm long. The 10 N is hung at 0 cm mark, the 30 N acts at 10 cm mark, 20 N acts at 20 cm mark and 40 N acts at 40 cm mark. If the knife edge is placed at 30 cm mark, calculate the resultant moment on the body.



(Ans: ***5 Nm acting in a clockwise direction*****)**

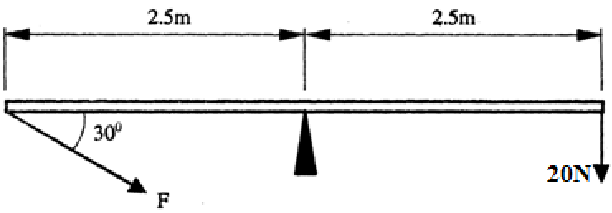
29.A uniform beam is pivoted at its centre



A mass of 120g is suspended at 30cm from the centre of the beam. The beam remains horizontal when a block P suspended at the 40cm mark form the centre of the beam, is immersed in a liquid of density 800kgm^{-3} as shown above. If the volume of the liquid displaced by the block is 10cm^{3}, find the;

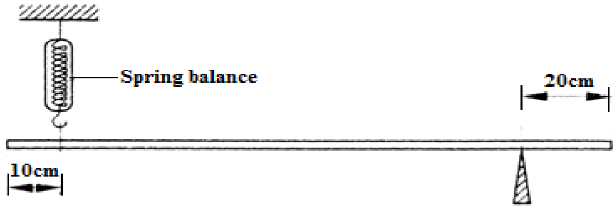
(i) mass if the liquid displaced. (ii) weight of P in air.

30. The figure shows a uniform bar in equilibrium under action of two forces.



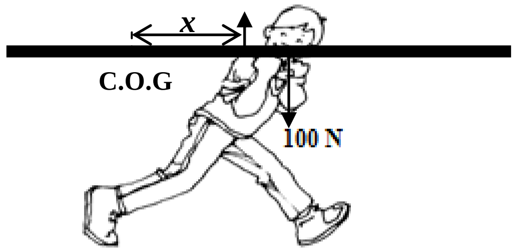
Determine the value of F. (03marks)

31. The figure below shows a uniform bar of length 1.0m pivoted near one end. The bar is kept in equilibrium by a spring balance as shown below.



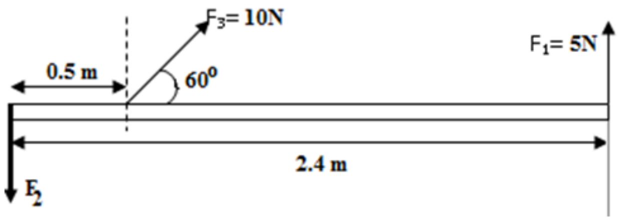
Given that the reading of the spring balance is 0.60N, determine the weight of the bar. (03marks)

32. Mr. Bagira carried a uniform post of weight 200N horizontally on his shoulder as shown in the figure. He placed the post on his shoulder such that the centre of gravity, C.O.G is ***x*** cm behind him. He balanced the post by applying a downward force of 100N at a point 50cm on the part of the pole in front of him as shown.



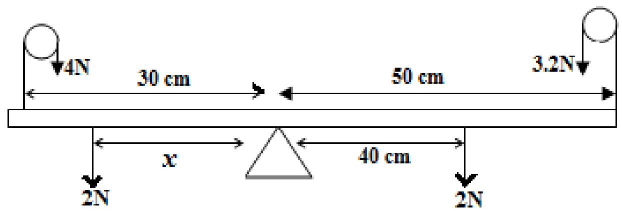
Determine the value of the distance *x*. (03marks)

33. The forces F_1, F_2 and F_3 act on a uniform light bar as shown. sketch on the same diagram the fourth force F_4 necessary to keep the bar in equilibrium. (01mark)



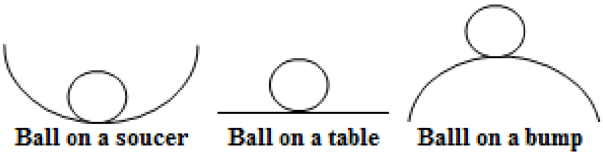
34. A boy of mass 40kg sits at apoint 2.0 m from the pivot of a see- saw. Find the weight of a girl who can balance the see-saw by sitting at a distance of 3.2m from the pivot. (02marks)

35. The figure below shows a system at equilibrium under several forces. Find distance ***x***. (03marks)



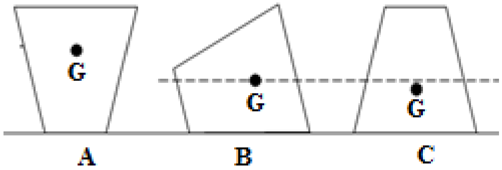
36. A uniform wooden block PQ of length 2.0m and weighing 9kg rests on two sharp edge supports A and B placed 10cm and 15cm from the ends P and Q respectively. A 150N weight is hung 20cm from the end P and a 100N force is hung 10cm from Q. Calculate the forces acting at the supports A and B. (04marks)

37. The Figure below shows a ball resting on different shaped surfaces. They represent three different types of equilibrium, which are:



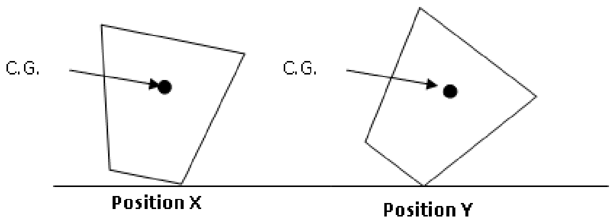
	Ball on a saucer	Ball on a table	Ball on a bump
A	Stable	Unstable	Neutral
B	Unstable	Neutral	Stable
C	Stable	Neutral	Unstable
D	Neutral	Stable	Unstable

38. An object can be placed in 3 different position on a table. Assume object has uniform thickness (not shown).



a) State 2 reasons why Position A is more unstable than Position C.

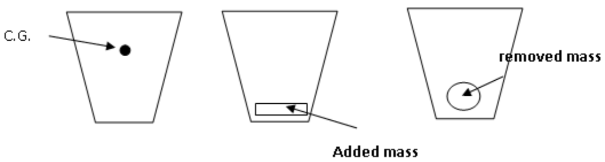
39. (a) What is meant by **Centre of Gravity** ?
(b) The object is inclined at an angle .



i) Draw and label the forces acting on the object at position X.
ii) State and explain what happen when object is released at position X.
iii) Draw and label the forces acting on the object at position **Y**. [2]
iv) State and explain what happen when object is released at position **Y.** [2]

40. (a) State 2 ways that can increase the stability of an object. [2]

(b) Mark the new positions of the C.G when a mass is added and removed from the bottom. [2]



(c) Which action makes the object more stable? [1]

40. A pole AB of length 10.0 m and weight 800N has its centre of gravity 4.0 m from end A and lies on a horizontal ground. The end B is lifted by a vertical force applied at B. Calculate the least force required to do this. **(Ans: 320N)**

41. A uniform metre rule AB of weight 2N supports 5N at a point 20cm from end A and 3N at a point 10cm from end B. Find;
(i) how far from the mid-point of the rule must a spring balance be fixed for the rule to
balance horizontally.
(ii) the reading of the balance

42. Two spring balances P and Q support a uniform metre rule of weight 0.8N at the 10cm mark and 80cm mark respectively. A weight of 0.2N is hung at the 90cm mark. Find
a) the readings of the spring balances
b) where the 0.2N must be shifted to for the balances to read the same.

MACHINES

A machine is a device on which a force applied at one point, is used to overcome a force at another point.
***A machine** is a device, which simplifies works by magnifying the effort.*
.

Principle of machines:
It states that a small force (effort) moves over a large distance to produce abigger force that moves the load over a small distance.
Effort: Is the force applied at one point of a machine to overcome the load.

Load: Is the force, which is overcome by the machine using the effort.

Mechanical Advantage (M.A):
This is the ratio of the load to the effort.
i.e; $\text{M.A} = \frac{\text{Load}}{\text{Effort}}$

Note:-Mechanical advantage has no units.
-M.A is the number of times the load is greater than the effort.
Alternatively, it gives the number of times the machine magnifies the effort.

Velocity ratio (V.R):
It is the ratio of the velocity of the effort to the velocity of the load in the same time. It is independent of friction.

It is defined as the ratio of the distance moved by the effort to the distance moved by the load in the same time.

i.e; $\text{V.R} = \frac{\text{Distance moved by effort}}{\text{Distance moved by load}}$

Efficiency (η):
This is the ratio of the useful work output to the work input expressed as a percentage.

i.e; Efficiency $(\eta) = \frac{\text{Work output}}{\text{Work input}} \times 100\%$
$\text{Work out put} = \text{Load} \times \text{load distance}$
$\text{Work input} = \text{Effort} \times \text{Effort distance}$

$$\text{Efficiency} = \frac{\text{Load} \times \text{load distance}}{\text{Effort} \times \text{Effort distance}} \times 100\%$$

$$= \frac{\text{Load}}{\text{Effort}} \times \frac{\text{Load distance}}{\text{Effort distance}} \times 100\%$$

$$= \text{M.A} \times \frac{1}{\text{V.R}} \times 100\%$$

Efficiency (η) = $\frac{\textbf{M.A}}{\textbf{V.R}} \times \mathbf{100}\%$
This equation is useful I working out numerical problems but it cant replace the fundamental definitions above.

less than 100% because of;
- ❖ Friction in the moving parts of the machine.
- ❖ Work wasted in lifting useless weights like movable parts of the machine.

The efficiency can be improved by;
- ❖ Oiling or greasing the movable parts.
- ❖ Using lightweight materials for movable parts.

SIMPLE MACHINES:
A simple machine is a device that work with one movement and change the size and direction of force.

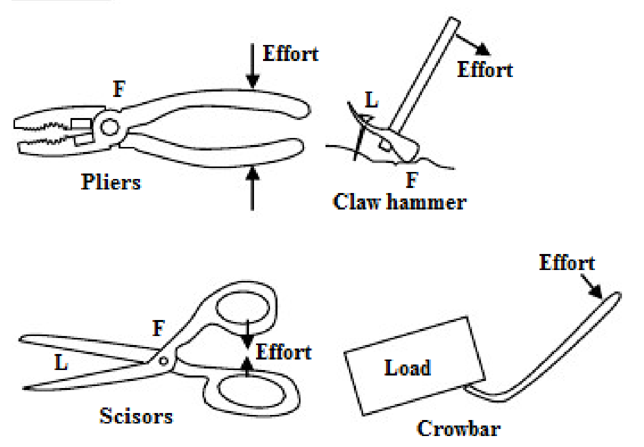
Examples of simple machines:

1.Lever system 2.Wheel and Axle machine 3. Gear system 4. Pulley systems	5.Screws 6.Inclined Planes 7. Wedges

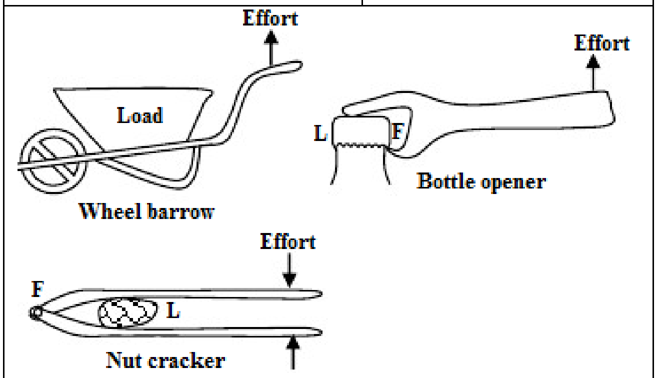
(a) LEVER SYSTEM:
A lever is a rigid bar, which is free to move about a fixed point called fulcrum or pivot.
It works on the principle of moments.

Classes of levers:

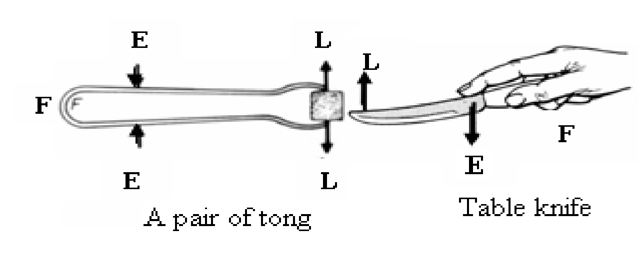
Class of lever	Examples
(i) First class lever: Is a lever system where the fulcrum (or pivot) is between the load and the effort.	• See-saw • Pair of scissors • Pair of pliers • Weighing scale • Claw Hummer



(ii) <u>Second class lever:</u> Is a lever system where the load is between the fulcrum (or pivot) and the effort.	• Wheel barrow • Nutcracker • Bottle opener

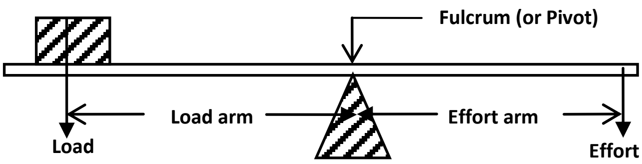


(iii) <u>Third class lever:</u> Is a lever system where the Effort is between the fulcrum (or pivot) and the load.	• Fishing rod • Pair of tongs • Human arm • Spade • Forceps

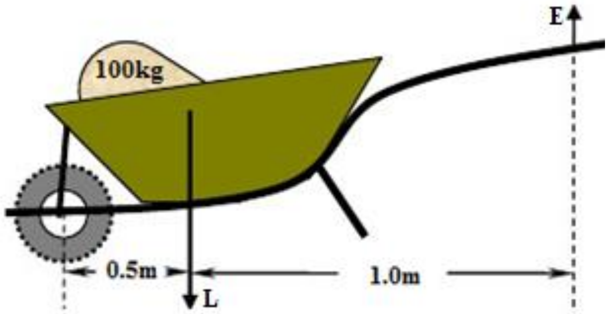


NOTE: -Load arm is the distance of the load from pivot.
-Effort arm is the distance of effort from pivot.
-$\mathbf{M.A} \approx \mathbf{V.R} \Rightarrow \frac{\text{Load}}{\text{Effort}} \approx \frac{\text{Effort arm}}{\text{Load arm}}$

Hence, a lever system is more efficient compared to other machines.



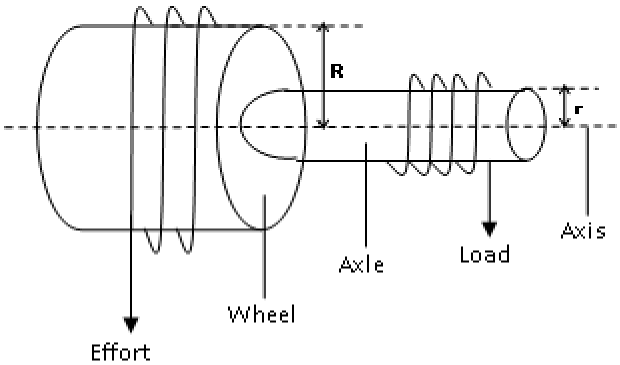
Example: The wheel barrow below is 20kg when empty. It is used to lift a sack of 100kg.



Calculate the efficiency of the wheel barrow.

(b) WHEEL AND AXLE MACHINE :

This consists of two wheels of different radii on the same axis. The axle has the same attachment on the wheel. The effort is applied to the wheel and a string attached to the axle raises the load.



For a complete turn or rotation;

❖ The effort moves through a distance equal to the circumference of the wheel. $\mathbf{C = 2\pi R}$, R= radius of wheel.

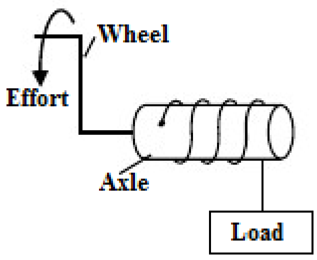
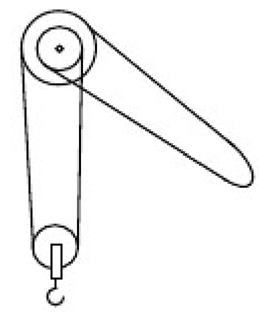
❖ The load moves through a distance equal to the circumference of the axle. $\mathbf{C = 2\pi r}$, r = radius of axle.

❖ Thus, from; $\text{V.R} = \frac{\text{Distance moved by effort}}{\text{Distance moved by load}}$

$$= \frac{2\pi R}{2\pi r}$$

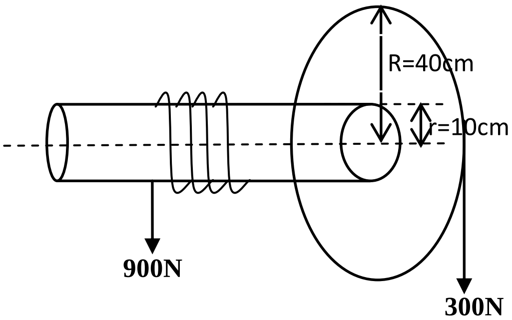
$$\mathbf{V.R} = \frac{\mathbf{R}}{\mathbf{r}}$$

Examples

(i) Windlas	**(ii) Weston differential pulley**
	
$\text{V.R} = \frac{R}{r}$	$\text{V.R} = \frac{2R}{R-r}$

Example1:

The figure below shows a wheel land axle system, which uses an effort of 300N to raise a load of 900N using an axle of radius 10cm.



Calculate the; (i) velocity ratio
(ii) Efficiency of the system

Solution:

R=40cm, r=10cm; L=900N, E=300N;

Thus, from; $V.R = \frac{\text{Distance moved by effort}}{\text{Distance moved by load}} = \frac{2\pi R}{2\pi r}$

(i)
$V.R = \frac{R}{r} = \frac{40}{10} = 4$

Thus, the velocityratio is 4.

(ii).
$M.A = \frac{Load}{Effort} = \frac{900}{300} = 3$

M.A = 3

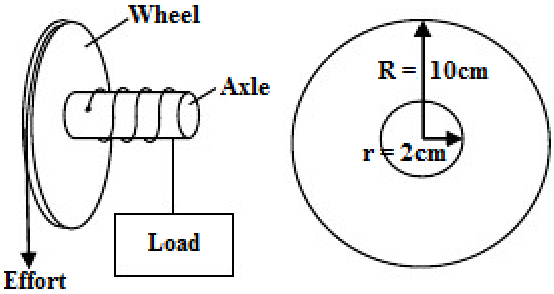
$\text{Efficiency } (\eta) = \frac{M.A}{V.R} \times 100\%$

$\eta = \frac{3}{4} \times 100\%$

$\eta = 75\%$

Thus, efficiency is 75%

Example2:
A wheel and axle machine is constructed from a wheel of diameter 20cm and mounted on an axle of diameter 4cm.



(a) Calculate the;
(i) Velocity ratio of the machine
(ii) Greatest possible value of mechanical advantage.

(b) Explain why the mechanical advantage is likely to be less than this value.

Solution:
D =20cm$\Longrightarrow$ R = 10cm, d = 4cm$\Longrightarrow$ r = 2cm

(a)(i)

$V.R = \frac{\text{Distance moved by effort}}{\text{Distance moved by load}} = \frac{2\pi R}{2\pi r}$

$V.R = \frac{R}{r} = \frac{10}{2}$

$V.R = 5$

Thus, the velocityratio is 5.

(a) (ii)

For the greatest (or maximum) mechanical advantage, the system is 100% efficient.
Hence M.A=V.R= 5

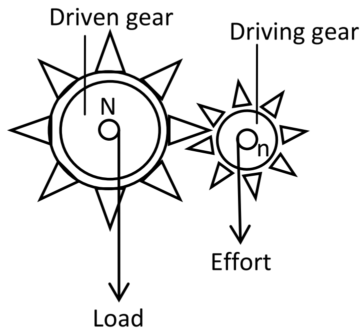
(b) The M.A is likely to be less than 5 because work needs to be done against friction

Example3:
A common windlass is used to raise a load of 480N by application of an effort 200N at right angles to the handle.If the crank is33cm from the axis and the radius of the axle is 11cm, calculate the;

(i) Velocity ratio. (Ans: V.R=3)
(ii) Efficiency of the windlass. (Ans: η =80%)

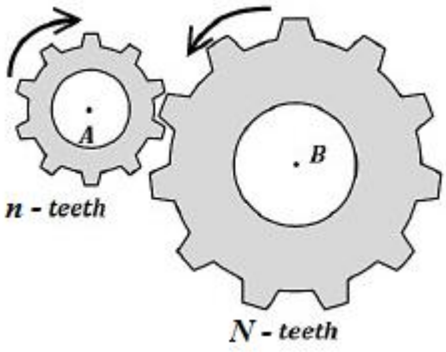
(c) GEAR SYSTEM:

A gear is device consisting of toothed wheels.
These are rigidly fixed to the axis and turn with their axis.



They change direction and speed of rotation when the effort applied is not changed.
The direction of the driven gear is opposite to that of the driving gear.
The number of rotations of the gear wheels depends on the ratio of number of teeth and the radii of the wheels.

The effort and the load are applied on the shafts connected to the gear wheels. A large V.R is obtained only when the effort is applied on a small gear so that it drives the large gear.



$V.R = \frac{\text{Number of teeth on driven gear}}{\text{Number of teeth on driving gear}} = \frac{\mathbf{N}}{\mathbf{n}}$

Example 1:
Two gearwheels A and B with 20 and 40 teeth respectively lock into each other. They are fastened on axles of equal diameters such that a weight of 400N attached to a string wound around one-axle, raises a load of 600N attached to a string wound around the other axle. Calculate the:
(a) Velocity ratio of the system when; (i) A drives B
(ii) B drives A

(b) Efficiency when; (i) A drives B
(ii) B drives A

Solution:

(a) N = 40cm, n = 20cm
L = 600N, E = 400N.

(i)Thus, from; $V.R = \frac{\text{Number of teeth on driven gear}}{\text{Number of teeth on driving gear}} = \frac{N}{n}$

$V.R = \frac{N_B}{n_A} = \frac{40}{20}$

$\underline{V.R = 2.}$

The velocityratio is 2.

(ii)

$V.R = \frac{N_A}{n_B} = \frac{20}{40}$

$\underline{V.R = 0.5}$.

The velocity ratio is 0.5.

(iii) M.A = $\frac{\text{Load}}{\text{Effort}} = \frac{600}{400} = 1.5$

$V.R = 2.$

Efficiency (η) = $\frac{M.A}{V.R} \times 100\%$

$\eta = \frac{1.5}{2} \times 100\%$

$\underline{\eta = 75\%}$.

(ii) M.A =1.5
V.R =2

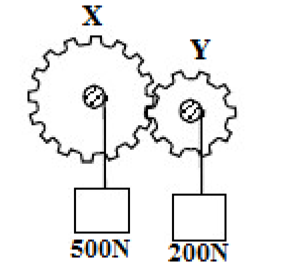
Efficiency (η) = $\frac{M.A}{V.R} \times 100\%$

$\eta = \frac{1.5}{0.5} \times 100\%$

$\underline{\eta = 300\%}$

Example

Two gear wheels X and Y having 100 and 25 teeth respectively, mesh with each other. They are fastened on axles of equal diameters such that a weight of 200 N attached to a string wound round one axle raises a load of 500 N attached to a string wound round the other axle as shown.



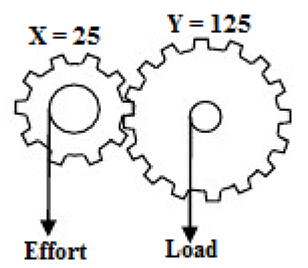
Find
(i) the velocity ratio
(ii) the efficiency of the system

Example

A screw jack with a tommy bar of length 50 cm and a pitch of 2.5 mm is used to raise a load of 1200 N. If the efficiency is 40%, find
(i) the velocity ratio
(ii) the mechanical advantage

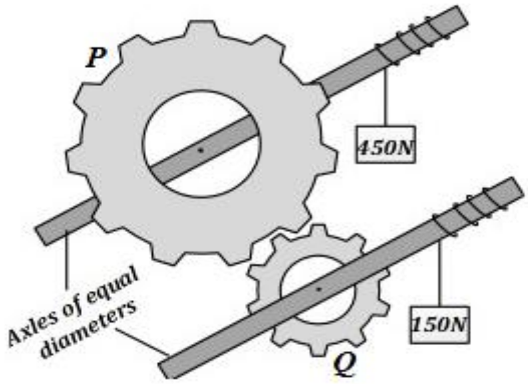
Example:

In the gear system shown below the wheels X and Y have the number of teeth shown. If the
shaft diameters are 20 cm and 10 cm respectively, and the efficiency is 30%.



find
(i) the velocity ratio
(ii) the effort required to lift a load of 900 N.

Example 2:



Two gear wheels P and Q with 80 and 20 teeth respectively, lock each other. They are fastened on axles of equal diameters such that a weight of 150 N attached to a string wound around one-axle raises a load of 450N attached to a string wound around the other axle. Calculate the;
(i) Velocity ratio of the gear system. (Ans: V.R=4)
(ii) Efficiency of the system. (Ans: η =75%)

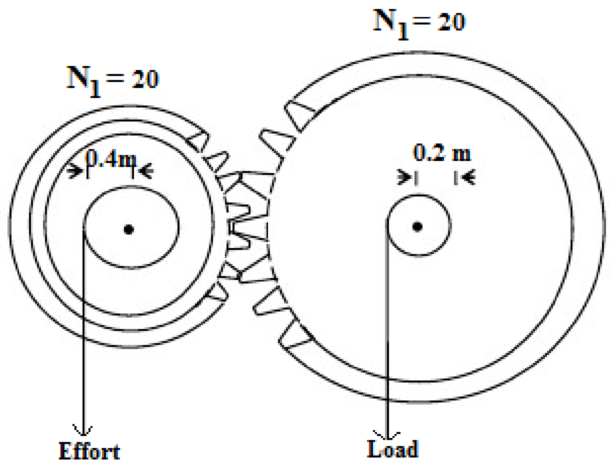
Example: 3

Two gear wheels P and Q with 25 and 50teeth respectively lock into each other. They are fastened on axles of equal diameters such that a weight of 400N attached to the string wound around one axle raises a load of 600N attached to a string wound around the other axle. Calculate the:
(i) Velocity ratio and efficiency when Q drives P.
[Ans: V.R = 0.5, Efficiency = 300%]

(ii) Velocity ratio and efficiency when P drives Q.
[Ans: V.R = 2, Efficiency = 75%]

Example:

In the gear system sketched in the figure below, N1 and N2 are the number of teeth on the wheels.



If the shaft radii are 0.4 m and 0.2 m respectively and the efficiency is 30%, find
(i) the velocity ratio.
(ii) the load that can be raised by an effort of 200 N.

Example 4:

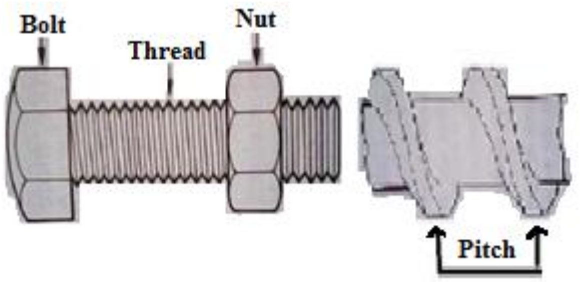
A bicycle has wheels which are 66cm in diameter. Its crank wheel has 44 teeth and its rear sprocket has 16 teeth. If the crank radius is 16.5 cm. Find the;
(i) V.R (V.R = $\left(\frac{16}{44}\right) \times \left(\frac{16.5}{16}\right) = 0.18$)

(ii) efficiency of the bicycle whose M.A is 0.14.

(d) SCREW MACHINE :

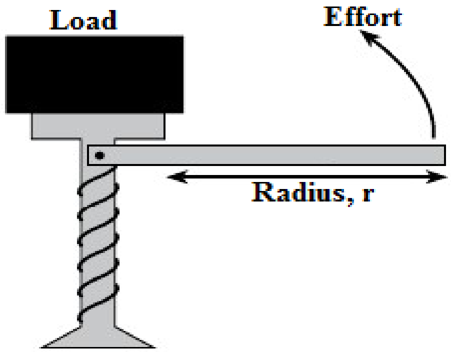
A screw is a nail or bolt with threadlike windings.
It is like a spiral stair case.

Pitch: This is the distance between any two successive threads of a screw.

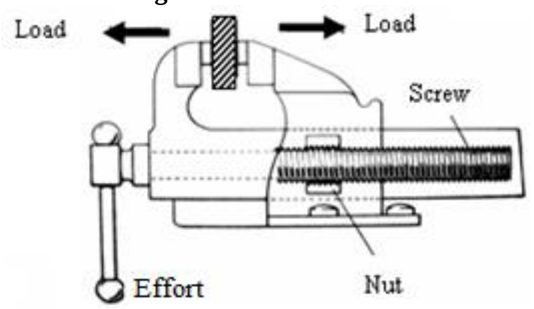


A screw is an essential feature of machines like the **vise** and the **screw jack**.

Below is a diagram of a screw jack.



Below is a diagram of a vise



- ❖ An effort is applied on a handle like in a vice or in a car jack.
- ❖ For a complete turn (or rotation) of the effort, the load moves through a distance equal to 1pitch while the effort moves a distance equal to the circumference of the handle

.

$$\text{V.R}=\frac{\text{Distance moved by effort}}{\text{Distance moved by load}}=\frac{\text{circumference of handle}}{\text{1Pitch}}$$

$$\textbf{V.R} = \frac{\mathbf{2\pi l}}{\textbf{1Pitch}}$$

Note: For the screw the velocity ratio is very high because the length of the handle is very big compared to the pitch of the screw. However the efficiency is very low. Usually lower than 50%. This is because friction is very high so the screw cannot run back if left.

Example 1:
In a screw jack, the length of the handle is 56cm and a pitch of 2.5mm. It is used to raise a load of 2000N. Calculate the;
(i) Effort required to raise the load. (Ans: E = 1.42N).
(ii) V.R (Ans: V.R = 1408).
(iii) Efficiency of the screw, hence explain the significance of your value of efficiency.
(Ans: η =100%)

Example 2:
A load of 800N is raised using a screw jack whose lever arm is 49cm has a pitch of 2.5cm.If it is 40% efficient, Find the
(i) V.R
(ii) M.A

Example 3:
A certain screw machine has apitch of 3.5mm. The effort is applied using a handle, which is 44cm long. Calculate its velocity ratio. (Ans: V.R = 790.1)

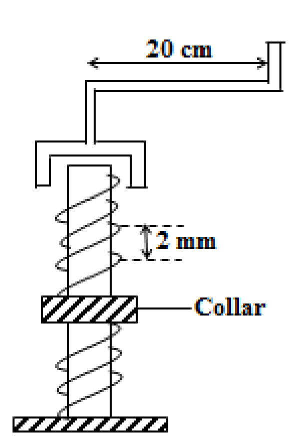
Example 4:
A screw jack with a lever arm of 56 cm, has threads which are 2.5mm apart is used to raise a load of 800N. If its 25% efficient, find the;
(i) Velocity ratio (Ans: V.R = 1408)
(ii) Mechanical advantage (Ans: M.A = 352)

Solution:
(a) Radius (lever arm),l =56cm, Pitch of a screw $=\frac{2.5}{10}=$ 0.25cm
L= 800N.

$$\text{V.R of a screw} = \frac{2\pi l}{\text{1Pitch}}$$

$$\text{V.R of a screw} = \frac{2\times 3.14\times 56}{0.25}$$
$= 1406.72$

Example: 5
The diagram below shows a screw jack being used to lift a car in order that a wheel may be changed.
If the car bears down on the jack with a force of 5000N and that efficiency of a screw jack is 15%. Calculate the;
a) V.R.



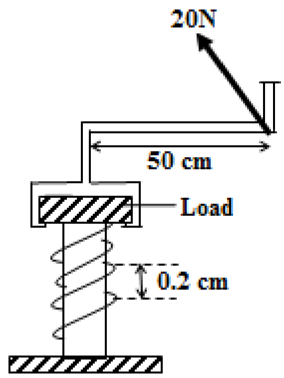
Given; Radius, $r = 2\text{cm} = \frac{2}{100} = 0.02\text{m}$
Pitch, $P = 2\text{mm} = \frac{2}{1000} = 0.002\text{m}$

Then;
$$\text{V.R}=\frac{\text{Effort Distance}}{\text{Load Distance}}$$

(b)The effort required to turn the handle

V.R= $\frac{2\pi r}{Pitch}$ V.R = $\frac{2(3.14)(0.02)}{0.002}$ V.R = 62.8 Mechanical Advantage Given;Efficiency=15 %, V.R= 62.8 Then; Effi = $\frac{M.A}{V.R} \times 100\%$ 15%= $\frac{M.A}{62.8} \times 100\%$ $0.15 = \frac{M.A}{62.8}$ $M.A = 0.15(62.8)$ $M.A = 9.42$	M.A= $\frac{Load}{Effort}$ $9.42 = \frac{5000}{E}$ 9.42E = 5000 $\frac{9.42E}{9.42} = \frac{5000}{9.42}$ E = 530.79N (c) Work done by the operator in order to raise the side or the car by 25cm. $Eff = \frac{\text{Work output}}{\text{Work input}} \times 100\%$ Work output=Load×Load distance Work output=5000× $\left(\frac{25}{100}\right)$ Work output=1250J

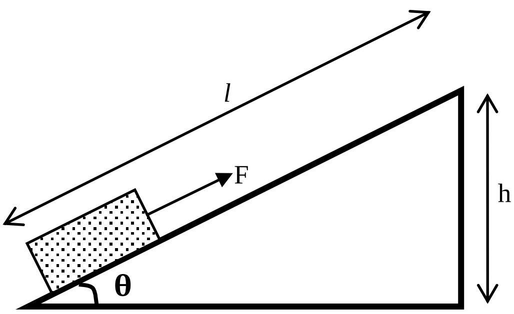
Example 6:
In the figure below, a screw is used to raise a load. Determine the mechanical advantage given the machine is 100% efficient.



A. $\frac{50}{20}$ B. $\frac{100\pi}{20}$. C. $\frac{50}{0.2}$ D. $\frac{50\pi}{20}$.

(e) INCLINED PLANE

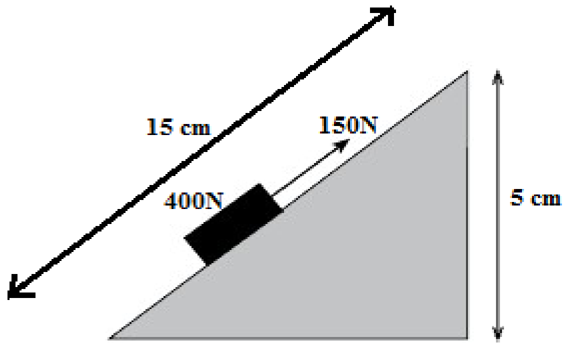
An inclined plane is a slope, which allows a load to be raised more gradually by using a smaller effort than when lifting vertically upwards.



V.R= $\frac{\text{Distance moved by effort}}{\text{Distance moved by load}} = \frac{\text{length of the plane}}{\text{height of the plane}}$

$V.R = \frac{\mathbf{l}}{\mathbf{h}}$ OR: $V.R = \frac{\mathbf{1}}{\mathbf{\sin\theta}}$

Example:
A load of 400N is pulled along an inclined plane as shown below.



Calculate the;
Solution:

(i) V.R (=3)
l=15cm, h=5cm
(i)Thus, from;
V.R = $\frac{\text{length of the plane}}{\text{height of the plane}} = \frac{l}{h}$
$V.R = \frac{l}{h}$
$V.R = \frac{\mathbf{15}}{\mathbf{5}} = 3$
Thus, the velocity ratio is 3.

(iii) M.A(=5N)
L=400N, E=150N
M.A = $\frac{Load}{Effort} = \frac{400}{150}$
= 2.67

(iv) Efficiency
(η) = $\frac{M.A}{V.R} \times 100\%$
η = $\frac{2.67}{3} \times 100\%$
η = 88.9%

(v) Work input
Work input = Effort × Effort distance
Work input = 150 × 15
= 2250J

(vi) Work out put
Work out put = Load × load distance
Work out put = 400 × 5
= 2000J

EXERCISE.

Practice Question:

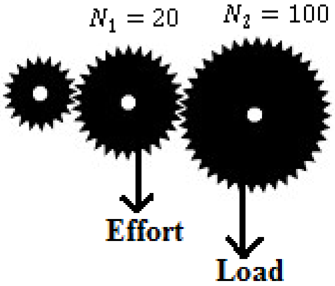
1. A force of 600N is applied to pull a trolley up a ramp of 6m at a constant velocity. If the trolley is vertically raised by 4m and the weight of the trolley is 500N. What is the:
   (i) Work done on the load.
   (ii) Work done by the effort.
   (iii) Efficiency of the system.

2. A wooden plank, 3m long is used to raise a load of 1200N through a vertical height of 60cm. If the friction between the load and the plane is 40N, calculate the:
   (i) effort required [Ans: E = 280N]
   (ii) Mechanical advantage [Ans: M.A = 4.29]

3. A driving gear wheel having 25 teeth engages with a second wheel with 100 teeth. A third wheel with 30 teeth on the same shaft as the second engages with

the fourth having 60 teeth. Find the total velocity ratio of the gear system.

4. In the gear system in figure below N_1 and N_2 are the number of teeth on the wheels. The efficiency of the gear system is 60%.

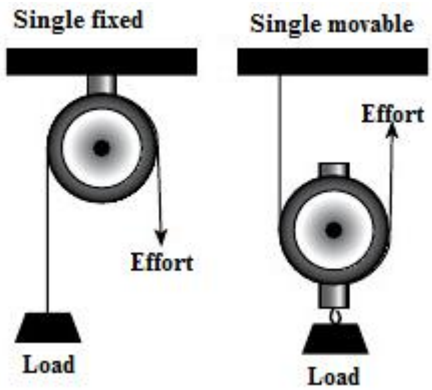


Find the;
- (i) Velocity Ratio.
- (ii) Load that can be raised by an effort of 200N.
- (iii) Explain why its preferred to use a longer ladder to a shorter ladder when climbing a tree.

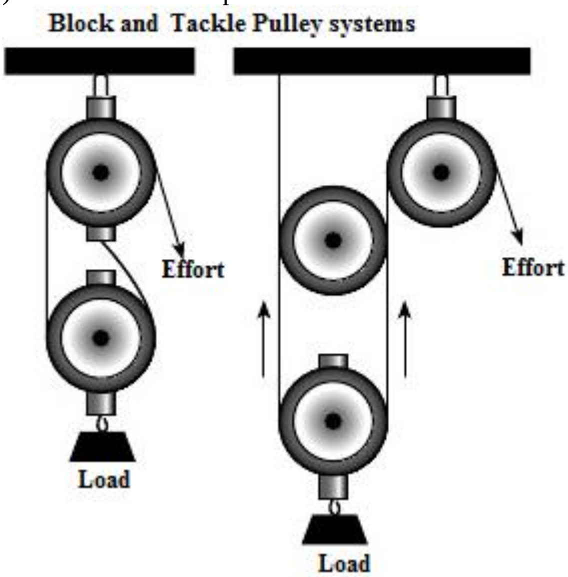
(f) PULLEY SYSTEM:

A pulley is a wheel with a grooved rim over which a string passes.

(a) Single Pullies



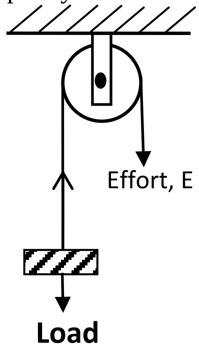
(b) Block and Tackle pulies



Types of pulleys.
- (i) Single fixed pulley
- (ii) Single movable pulley
- (iii) Block and tackle pulley system

(i) **Single fixed pulley**

This is the type of pulley fixed on a rigid support.

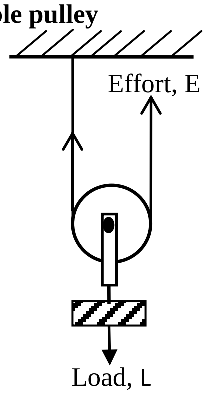


It is applied in:
- ❖ Raising a flag
- ❖ Lifting building materials during construction

Here, -load distance = effort distance
-tension is the same throughout the string.
-If no friction is considered, Load = Effort. Hence, **M.A** = $\frac{\textbf{Load}}{\textbf{Effort}} = \frac{\textbf{E}}{\textbf{E}} = \mathbf{1}.\ (\textbf{since L} = \textbf{E})$

However, in practice the mechanical advantage and V.R of a single fixed pulley is less than **one**. Because of the following;
- (i) Some energy is wasted in overcoming friction.
- (ii) Some energy is wasted in lifting useless loads like threads.

(ii) Single movable pulley



Here, the effort distance is twice the load distance.
Here,-load distance = 2 x effort distance
-tension is the same throughout the string.
-If no friction is considered, Load = Effort. Hence,**M.A** = $\frac{\textbf{Load}}{\textbf{Effort}} = \frac{\textbf{2E}}{\textbf{E}} = \mathbf{2}.\ (\textbf{since L} = \textbf{2E})$

At balancing;
Sum of upward force = sum of downward forces
$L = E + E$
$\underline{\mathbf{L = 2E}}$

$$\text{M.A} = \frac{\text{Load}}{\text{Effort}} = \frac{2\text{E}}{\text{E}} = 2.\ (\text{since L} = 2\text{E})$$

M.A and V.R of a single movable pulley is two
However, in practice, the M.A. of a single movable pulley is less than **two**. Because of the following reasons;
(i) Some energy is wasted in overcoming friction.
(ii) Some energy is wasted in lifting useless loads like threads.

A single movable pulley is more advantageous than a single fixed pulley. In that, for a single movable pulley the effort required to raise a load is less that the load.

(ii) Block and tackle pulley system

This is consists of two blocks each having one or more pulleys, combined together to form a machine. This is done in order to have high velocity ratio and a higher mechanical advantage.

It is applied in:

- ❖ Cranes
- ❖ Brake downs
- ❖ lifts

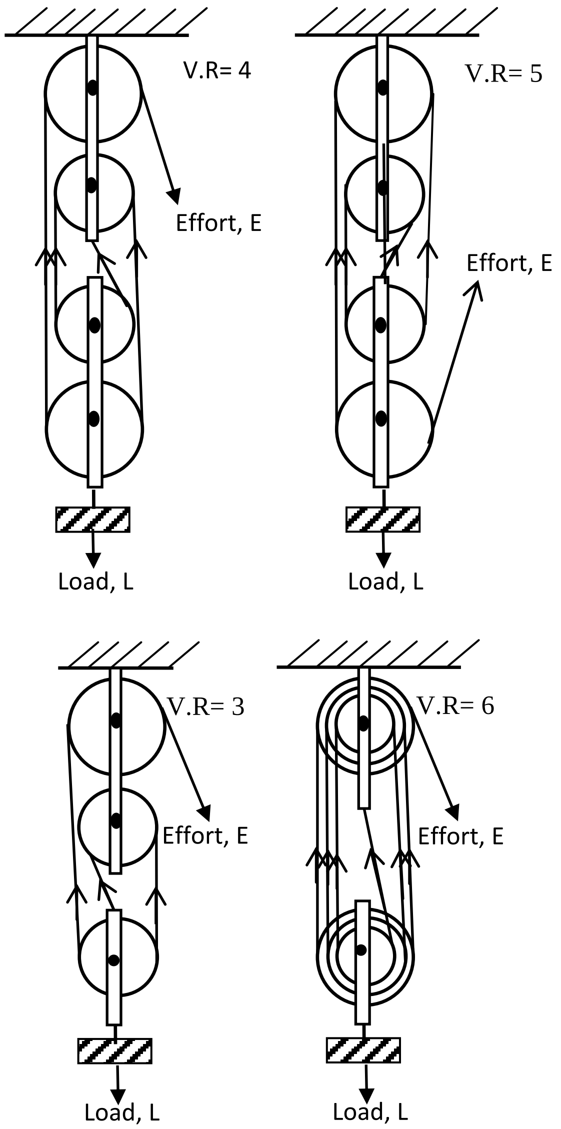
} For raising heavy loads

Note: (i) The number of portions of the string supporting the lower block is equal to the velocity ratio of the system.

(ii) The effort applied is equal to the tension in each string supporting the movable block.

E.g. If the effort is 6N, the tension in each string is also 6N.

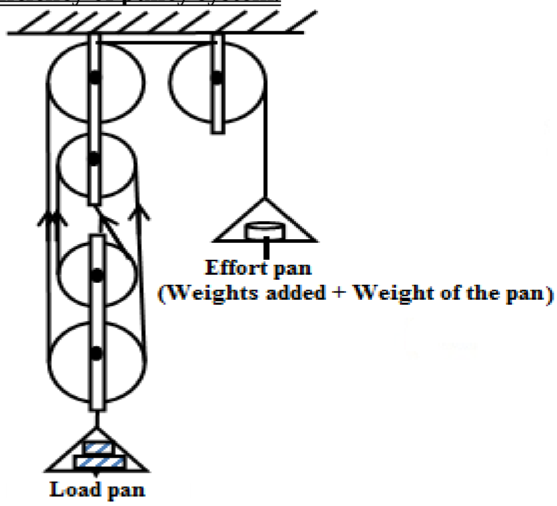
(iii) For an odd number of pulleys in a system, the upper block contains one more pulley than the lower block. In addition, the string starts from the lower block.



Passing the string

- ❖ If the number of pulley wheels is odd, then the string should be tied down to the movable block.
- ❖ For even number of pulley wheels, the string should be tied up to the fixed block

<u>**Experiment to measure mechanical advantage and efficiency of pulley system.**</u>



<u>Determining effort:</u> A known load is placed on the load pan and known weights are added to the effort pan until the load just rises steadily when given a gentle push.

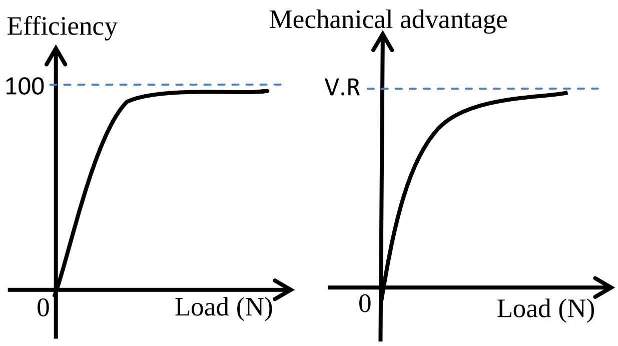
<u>Repeating:</u> The experiment is repeated with different loads and the results are recorded in table shown below:

V.R = ……….

Load (N)	Effort (N)	$M.A=\frac{Load}{Effort}$	**Efficiency=** $\frac{M.A}{V.R}\times 100$
-	-	-	-
-	-	-	-
-	-	-	-

<u>Drawing the graph:</u>

From the table a graph of efficiency or mechanical advantage against the load is plotted.



Explanation of the shape of the graphs:

- ❖ As the load increases, the efficiency also increases
- ❖ This is because the weight of the movable pulley block and friction become very small compared to the load.

Note:

In practice, the movable block has some weight (w) and there is friction (F). These two together with the load (L) act downwards and they become part of the total downward forces.

<u>Thus, the efficiency do not increase beyond 100% because;</u>

i) some energy is wasted on overcoming friction

ii) Some energy is wasted on lifting useless loads like movable pulley blocks.

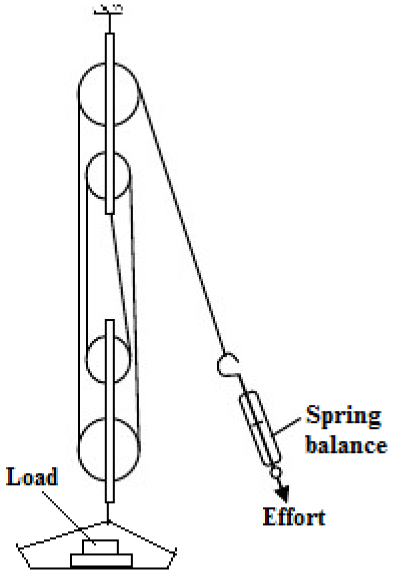
Therefore at Equilibrium**;**

Sum of upward forces = sum of downward force

$$\begin{bmatrix}\text{Sum of tensions}\\ \text{suporting lower}\\ \text{block}, (V.R)E\end{bmatrix} = \text{Load}(L) + \text{Weight}(W) + \text{Friction}(F)$$

$$(V.R)E = L + W + F$$

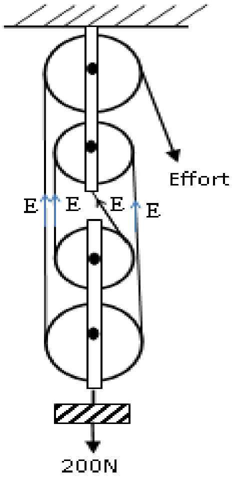
Experiment: To investigate the variation of M.A of a Pulley System with the load.



The pulley system is arranged with the string appropriately assembled.
A load is fixed to the lower block and a spring balance is fixed at the free end of the string.
By pulling on the spring balance, the minimum effort E, required to lift the load, is found and noted.
The procedure is repeated for several other values of the load and a table as shown below is filled.
V.R = ……….

Load (N)	Effort (N)	M.A= $\frac{\text{Load}}{\text{Effort}}$	**Efficiency=** $\frac{\textbf{M.A}}{\textbf{V.R}} \times \textbf{100}$
-	-	-	-
-	-	-	-
-	-	-	-

Example 1:
Below is a pulley system of mass 0.4kg, and there is friction of 5N
(a) Calculate the;
 (i) Velocity ratio of the system.
 (ii) Effort required to raise the load.



(a) Calculate the;
(i) Velocity ratio of the system

$$V.R = \begin{pmatrix}\text{Number of portions of the string}\\ \text{suporting the movable block}\end{pmatrix}$$

$V.R = 4$

(ii) Effort required to raise the load.

Solution
Data
L= 200N, m = 0.4Kg, F = 5N, E =?,
W = mg = 0.4 x 10
W = 4N

Sum of upward forces = sum of downward force
$E + E + E + E = L + W + F$
$4E = L + W + F$
$4E = 200 + 4 + 5$
$4E = 209$
$\frac{4E}{4} = \frac{209}{4}$
$E = 52.25N$

(iii) Mechanical advantage of the system
$M.A = \frac{\text{Load}}{\text{Effort}}$
$= \frac{200}{52.25}$
$M.A = 3.83$

(b) If the load is raised through 6m, calculate the distance the effort moves at the same time.

Example 2:
Data
L.D = 6m, E.D = ?

$V.R = \frac{\text{Effort distance}}{\text{Load distance}}$

$4 = \frac{E.D}{6}$
$E.D = 4 \times 6$
$E.D = 24m$

Example 2:
A pulley system has two pulleys on the bottom block. A load of 1000N is hung from the bottom block, it is found that an effort of 300N to raise the load.
(i) How much energy is supplied, if the effort moves through 5m?
Solution
Data
L=1000N, E=300N, E.D =5m
$\text{Work in put} = \text{Effort} \times \text{Effort distance}$
$= 300 \times 5$
$= 1500N$

(ii) If the effort moves through 5m, find how far the laod rises.
Solution
Data
E.D =5m, V.R=4, L.D=?

$V.R = \frac{\text{Effort distance}}{\text{Load distance}}$

$4 = \frac{5}{L.D} \Rightarrow 4L.D = 5 \Rightarrow L.D = \frac{5}{4} \Rightarrow \mathbf{L.D = 1.25m}$

(iii)Find how much energy is gained by the load if the effort moves through 5m.

Work out put $=$ Load $\times$ distance

$= 300\times5$

$= 1500N$

Example 2:
A pulley system of velocity ratio 3 is used to lift a load of 100N. The effort needed is found to be 60N.

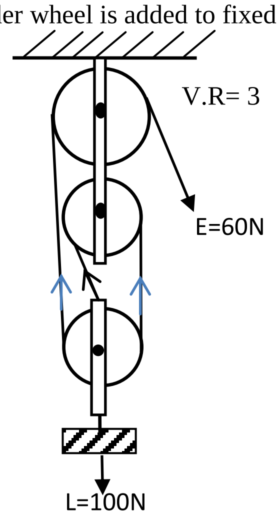
(a) Draw the arrangement of the pulley system.

Solution

Velocity ratio is odd. then;

$\left(\begin{matrix}\text{Number of pulley wheels}\\ \text{on each block}\end{matrix}\right) = \frac{\text{Velocity ratio}}{2} = \frac{3}{2} = 1$ remainder 1.

The remainder wheel is added to fixed block.



(b) Calculate the efficiency of the system.

Solution

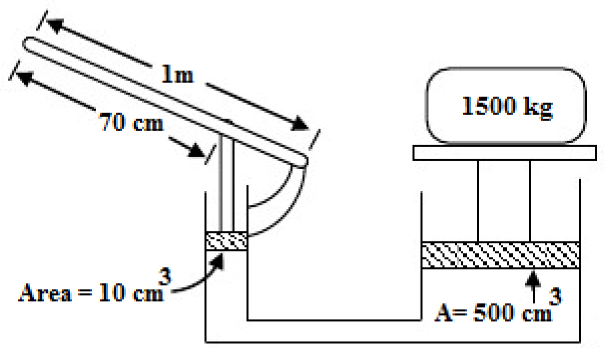
V.R =3 $M.A = \frac{\text{Load}}{\text{Effort}}$ $= \frac{100}{60}$ $M.A = 1.67$	$\text{Efficiency} = \frac{M.A}{V.R} \times 100\%$ $\text{Efficiency} = \frac{1.67}{3} \times 100\%$ $\text{Efficiency} = 55.56\%$

Combination of simple machines

V.R = Product of the individual velocity ratios

$$V.R = \frac{a}{b} \times \frac{c}{d}$$

For the hydraulic press shown , find the



(i) Velocity ratio

(ii) Efficiency

Solution

(i) $V.R = V.R \text{ of lever} \times V.R \text{ of hydraulic pressure}$

$$V.R = \frac{\text{Effort distance}}{\text{Load distance}} \times \frac{\text{Load piston area}}{\text{Effort piston area}}$$

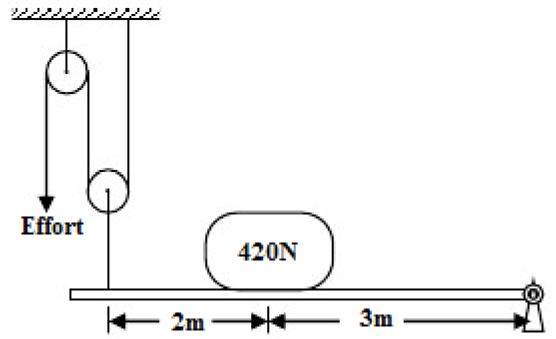
$$V.R = \frac{100}{30} \times \frac{500}{10} = \frac{500}{3} = 166.7$$

(ii) Efficiency

$$\text{Efficiency} = \frac{M.A}{V.R} \times 100\%$$

$$\text{Efficiency} = \frac{(420 \times 3)}{E \times 10} \times 100\% = 90\%$$

Example:
An effort E is used to just lift a load of weight 420 N using the arrangement shown below.



If the efficiency of the arrangement is 70%, find

(i) the velocity ratio of the system

(ii) the effort E.

Solution:
Overall velocity ratio = velocity ratio of the pulley system x velocity ratio of the lever

$$V.R = 2 \times \frac{5}{3} = \frac{10}{3} = 3.33$$

$$V.R = \frac{10}{3} = 3.33$$

Efficiency =

$$\text{Efficiency} = \frac{M.A}{V.R} \times 100\%$$

$$\text{Efficiency} = \frac{\left(\frac{1500\times10}{100\times\frac{500}{3}}\right)}{166.7} \times 100\% = 90\%$$

$$\text{Efficiency} = \frac{M.A}{V.R} \times 100\%$$

$$70\% = \frac{(420 \times 3)}{E \times 10} \times 100\%$$

$$E = 180N$$

Exercise

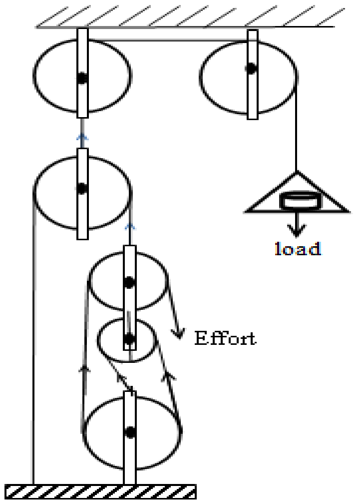
1. A load of 600 N is placed at 1.5 m from the pivot of a sea saw. Find the distance from the pivot at which a weight of 300 N should be placed to balance the sea saw.

COUPLED MACHINES

If two or more machines are, coupled machines such that the output of one is connected to the input of the other, the over all performance is summed up by:

Overall **-V.R = V.R1 + V.R2**

-M.A. = M.A1 + M.A2
-Eff = Eff1 + Eff2



The diagram above shows a pulley system used by a sailor for hoisting. Calculate the:
(a) Velocity ratio of the system

<u>Solution</u>
Velocity ratio of lower block = 4
Velocity ratio of middle = 2
Velocity ratio of upper block = 1
<u>Overall V.R = **4 + 2+ 1 = 7**</u>

(b) The effort required to lift the load if the efficiency of the system is 75%.
<u>Solution</u>

$\text{Efficiency}=\frac{\text{M.A}}{\text{V.R}}\times 100\%$	Then from;
$75\%=\frac{\text{M.A}}{7}\times 100\%$	$\text{M.A}=\frac{\text{Load}}{\text{Effort}}$
$0.75=\frac{\text{M.A}}{7}$	$5.25=\frac{1500}{\text{E}}$
$\text{M.A}=0.75\times 7$	$5.25\text{E}=1500$
$\underline{\text{M.A}=5.25}$	$\underline{\text{E}=285.7\text{N}}$

NB: Work input is the work done by the effort. Sometimes it is considered as the work done by operator.

$$\text{Efficiency}=\frac{\text{Work output}}{\text{Work input}}\times 100\%$$

$$15\%=\frac{1250}{W_{in}}\times 100\%$$

$$0.15=\frac{1250}{W_{in}}$$

$$0.15W_{in}=1250$$

$$\underline{\underline{W_{in}=8333.33\text{J}}}$$

In general;
Work wasted = work input - work output
= 8333.33 – 1250
=<u>7083.33J</u>

From above, it is noted that work input is greater than workout put due to;
i) some work wasted in lifting useless loads,
ii) Some work wasted in reducing friction.

Note: For the screw the velocity ratio is very high because the length of the handle is very big compared to the pitch of the screw.
However the efficiency is very low. Usually lower than 50%. This is because friction is very high so the screw cannot run back if left.

Qn1:
A pulley system of V.R six is used to lift a load of 250N through a distance of 3m. If the effort applied is 50N, calculate how much energy is wasted.

Qn 2:
A student wants to compare the efficiency of a petrol engine and a diesel engine.
(i) The student provides 150 J of energy to each engine. The petrol engine gives an output of 30J whereas the diesel engine gives an output of 40J. What is the efficiency of boththe engines?

(ii) Give two reasons for the greater efficiency of one engine over the other.

(iii) In what form is energy wasted in the two engines?

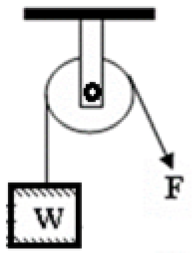
SECTION A

1. Which one of the following are true for simple machines?
(i) If there is a gain in force, there is a loss in distance.
(ii) The mechanical advantage is the ratio of the load to the effort.
(ii) There is a gain in work.
A. (i) and (ii) B. (ii) and (iii)
C. (i) and (iii) D. (i), (ii) and (iii)

2. Which one of the following below is an example of a 3rd class lever?
A. tweezers B. equal –arm balance
C. see- saw D. fixed pulley

3. The system that uses fixed and movable pulleys is called
A. windlass B. inclined plane
C. block and tackle D. lever

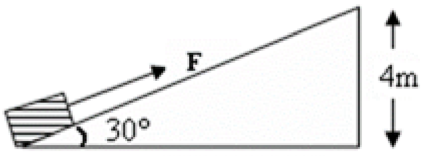
4. Which one of the following describes the type of pulley, and the lever that the pulley represents.



A. Fixed Pulley, First Class
B. Fixed Pulley, Third Class
C. Movable Pulley, Second Class
D. Movable pulley, Third Class

5. In a windlass, which changes decrease the force needed to pull up the load
(i) Increasing the radius of the wheel.
(ii) Decreasing the radius of the wheel
(ii)Decreasing the radius of the axle.
A. (i) and (ii) only B. (i) and (iii) only
C. (ii) only D. (iii) only

6. A force F is acting on a block of mass 2 kg to push it on an inclined plane. If F = 5 N, what is the length of the plane?



A. 4 m B. 8 m C. 12 m D. 16 m

7. A screw of length 5 cm enters totally into a wooden block after 25 turns. What is the pitch of the screw?
A. 0.1 cm B. 0.2 cm
C. 0.4 cm D. 0.5 cm

8. The maximum efficiency that can be obtained with four pulleys and a mechanical advantage of 3 is?
A. 100% B. 75%
C. 12% D. 1.33%

9. Calculate the effort when a load of 72 N is raised using a block and tackle system of 5 pulleys and efficiency 80%.
A. 11.52N B. 18N
C. 57.6N D. 288N

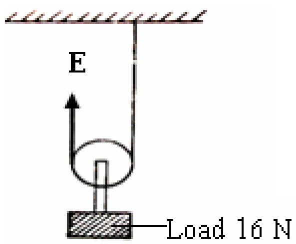
10. The block and tackle system in the figure has an efficiency of 80%. The load, which can be lifted by an effort of 10N, is
A. 4N B. 8N C. 40N D. 50N

11. A machine which is 80% efficient is run by an engine with an output of 40 watts. The time taken to raise a load of 1500 N through 0.15 m may be
A. 4.5s B. 5.6 s C. 7.0s D. 28.1s

12. Which of the following statements is true of a wedge used as a simple machine?
A. Very small force is required to lift a big load.
B. Work done is always so much.
C. Effort on the wedge is applied vertically.
D. There is no frictional force.

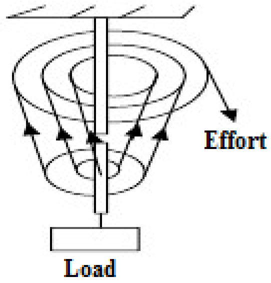
13. Calculate the effort when a load of 72 N is raised using a block system of 5 pulleys and efficiency 80%.
A. 11.52N B. 18N C. 57.6N D. 288N

14. The figure shows a light, smooth pulley used to lift a load of 16 N with an effort E. The mechanical advantage of the system is



A. 128 B. 2 C. 1 D.½

15. The block and tackle pulley system in the above figure has an efficiency of 80%. The load which can be lifted by an effort of 10N is



A. 4N B.8N C. 40N D. 50N

16. Which one of the following is not a correct formula for calculating velocity ratio?

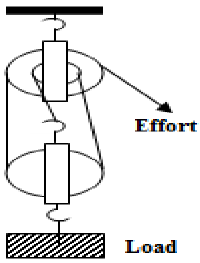
A. $V.R = \frac{1}{h}$ B. $V.R = \frac{\text{Load distance}}{\text{Effort distance}}$

C. $V.R = \frac{R}{r}$ D. $V.R = \frac{\text{No. of teeth on driven wheel}}{\text{No. of teeth on driving wheel}}$

SECTION B

16. (a) What is meant by a **first class leve**r?
(b) Give two examples of first class lever.
(c) By means of a lever, an effort of 50 N moves a load of 200 N through a distance of 3m. If the effort moves a distance of 16 m, calculate:
(i) the mechanical advantage
(ii) the efficiency of the system.

17. (a) Define **efficiency** of a machine.
(b) The diagram in the figure below represents a pulley system in which an effort E is applied to raise the load.

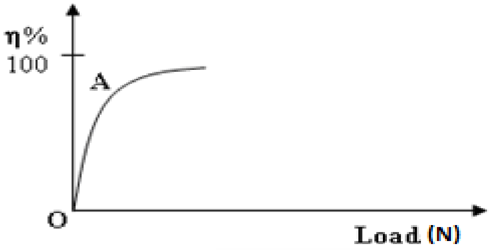


(i) Copy the diagram and indicate the forces acting on the string
(ii) Find the velocity ratio of the system?
(iii) How far will the load move if the effort moves 2.4m.
(iv) What effort would just raise a load of 960 N, if the mechanical advantage is 2.4?
(v) Use your results above to calculate the efficiency of the pulley system.

(c) (i) Draw a sketch graph to show how the mechanical advantage of the pulley system in (b) varies with the load.
(ii) Explain the features of the sketch in (c) (i).

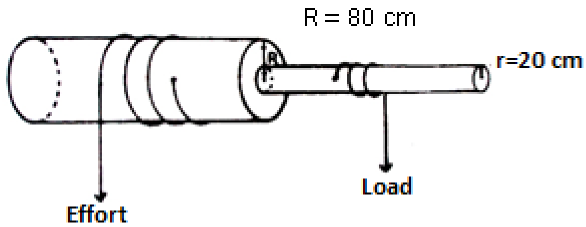
(d) Give two practical examples where pulley systems are used.

19. (a) Draw a labeled diagram to illustrate the lever principle as applied to a wheelbarrow.
(b) The graph in the figure shows the variation of the efficiency of a pulley system with load.



(c) Explain why:
(i) Part OA of the graph is almost a straight line
(ii) From A, the graph curves and finally levels off before reaching 100%.

19. The figure 8.25 shows a wheel and axle system. When an effort of 300 N is applied, a load of 900 N is raised through a distance of 1.0 m.

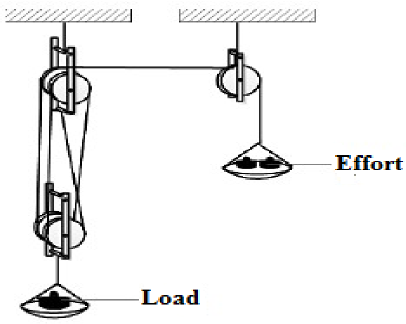


Calculate;
(a) the velocity ratio
(b) the efficiency of the system

21. (a) State what is meant by each of the following terms as applied to simple machines:
(i) Mechanical advantage (ii) Pitch

(b) (i) Give two reasons why the efficiency of any simple machine is always less than 100%.
(ii) Give two ways in which the efficiency of a Machine can be increased.

(c) The figure shows a load of 10 N raised slowly by a simple frictionless pulley system.



(i) What is the velocity ratio of the system?
(ii) Calculate the effort required to lift the load if the mass of the pulley is 0.2 kg.

(iii) Explain what happens to the efficiency of the system if the;
(a) Load is less than 2N
(b) Load is more than 2N

(iv) If the load is raised through a distance of 5 m in 5 s, calculate the efficiency of the system.

23. A smooth wooden board 3.6 m long is used to raise a box of 600 N to a height of 1.2 m. Calculate:
(a) The effort required
(b) The M.A of the system.

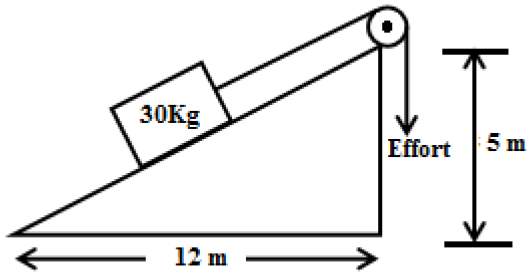
24. A pulley system has two pulleys on the bottom block. A load of 1000N is hung from the bottom block, it is found that an effort of 300N is needed to raise the load.
(i) How much energy is supplied, if the effort moves through 5m? [**1500N**]

(ii) If the effort moves through 5m, find how far the load rises. [**1.25m**]

(iii) Find how much energy is gained by the load if the effort moves through 5m. [**1500N**]

25. A pulley system of velocity ratio 3 is used to lift a load of 100N. The effort needed is found to be 60N.
(a) Draw the arrangement of the pulley system.
(b) Calculate the efficiency of the system. [**55.56%**]

26. The figure below shows a mass of 30Kg being raised to the top of an inclined plane.



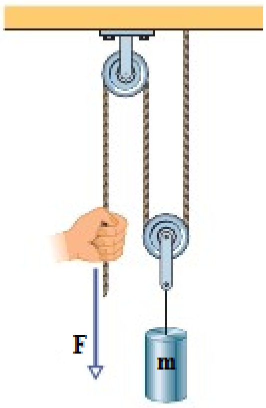
If the effort applied is 160N, calculate the:
(i) Efficiency of the machine. (4 marks)
(ii) Frictional force. (3 marks)

27. The following results were recorded in an experiment to using a set of pulleys.

L(N)	25	50	75	100	125	150	175	200
E(N)	20	38	54	68	82	92	106	120

(a) Plot a graph of **L** against **E.**
(b) Find the slope of your graph and state what it signifies**. [1.8]**

(c) A cord runs around two mass less, frictionless pulleys. A canister with mass m 20 kg hangs from one pulley, and you exert a force F on the free end of the cord.



(i) What must be the magnitude of Fif you are to lift the canister at a constant speed?

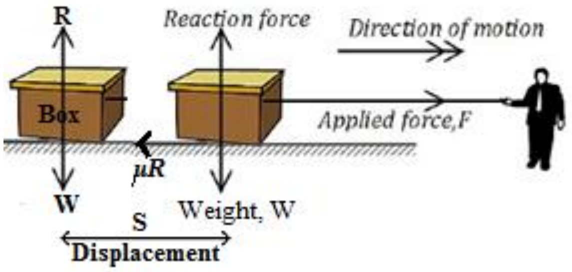
(ii) To lift the canister by 2.0 cm, how far must you pull the free end of the cord? During that lift, what is the work done on the canister by your force (via the cord) and the gravitational force? (Hint: When a cord loops around a pulley as shown, it pulls on the pulley with a net force that is twice the tension in the cord.)

WORK, ENERGY AND POWER

(a) WORK

Work is the product of the force applied on a body and the distance moved by the point of application of the force in the direction of the force.

Work is the product of the force applied on a body and the distance moved by the body in the direction of the force.



Note that the distance moved has to be in the direction of the applied force. It is common that a force may be applied to move an object to the right, but instead the object moves to the left. The force in this case has not done any work.

Work done, W = Force, F × Displacement, S
W = FS

The S.I unit of work done is a **joule** (J)

Definition:
A **joule** *is the work done when the point of application of a force of 1N, moves through a distance of 1m in the direction of the force*.

Example:1
1. Calculate the work done when a force of 9000N acts on a body and makes it move through a distance of 6m.

Solution
Force, F= 9000N
Distance, s = 6m

Work done = Force, F × Displacement, S
W= F×S
W= 9000×6
W= 54000J

Note:
If an object is raised vertically or falling freely, then the force causing work to be done is weight.
Force = Weight = mass, m × acceleration due to gravity, g
Force = Weight= mg

Thus, the work done against gravity is given by;
Work done = Weight × height
Work done = mgh

Where m is mass in kg, h is distance in metres and some times, it is height.

Example:2
A block of mass 3kg held at a height of 5m above the ground is allowed to fall freely to the ground. Calculate the work done.

Solution
Given, mass, m = 3Kg, Distance, s = 5m
Force F = Weight, W =mass × g
F = mg = 3×10 = 30N
Work done = Force, F × Displacement, S
W= F×S
W= 30×5
W= 150J

Example: 3
A man of mass 80kg runs up a staircase of 10stairs, each of vertical height 25cm. Find the work done against gravity.

Solution:
Given, mass m = 80Kg,
$\text{Distance, h} = 25\text{cm} = \frac{25}{100} = 0.25\text{m}$
$\text{Total Distance, } h_T = 0.25\text{m}\times10\text{stairs}$
$\text{Total Distance, } h_T = 2.5\text{m}$
Then;
Work done = Weight × height
Work done = mgh
= 80×10×2.5
Work done =2000J

Example: 4
A crane is used to raise 20 tonnes of concrete to the top floor of a building 30m high. Calculate the total work done by the crane.
Solution:
Given, mass m = 20tonnes = 20×1000=20,000Kg,
Distance, h = 30m, Then;
Work done = Weight × height
Work done = mgh
= 20,000×10×30
Work done = 6,000,000J

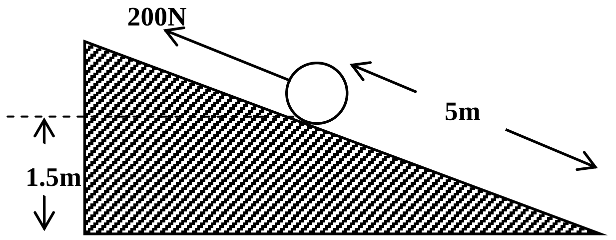
Example 5
A train travelling on level ground is subject to a resistive force (from the brakes and air resistance) of 250 kN for a distance of 5 km. How much kinetic energy does the train lose?
Note: Work and energy have the same units.

Solution
The forward force is: = −250 000 N.

The work done by it is = -250000×5000
$= -1250000\ 000$ J.

So $-1\ 250\ 000\ 000$ J of kinetic energy are gained by the train. In other words, $+1\ 250\ 000\ 000$ J of kinetic energy are lost and the train slows down. This energy is converted to other forms such as heat and perhaps a little sound.

Example: 6
The figure bellow shows a 50kg bale of hay being pulled up an inclined plane with a force of 200N.
(a) If the bale moves down the incline a distance of 5m.



(i) Calculate the work done by the force.

Solution:
Work done = Force, F × Displacement, S
= 200N × (-5m)
Work done = -1000J

(ii) Explain your answer.
The distance moved by the bale, was in a direction opposite to that of the force applied hence a negative displacement.
The negative in the answer therefore means that the bale did the work instead of the force applied.

(b) If the bale moves up the incline a distance of 5m, Calculate the:
(i) Efficiency of the inclined plane.
(ii) Frictional force.

(i) Efficiency

$$\textbf{Work in put} = \textbf{Effort} \times \textbf{Effort distance}$$
$$\text{Work in put} = 200 \times 5$$
$$\text{Work in put} = 1000\text{J}$$

$$\textbf{Work out put} = \textbf{Load} \times \textbf{Load distance}$$
$$\text{Work out put} = 500 \times 1.5$$
$$\text{Work out put} = 750\text{J}$$

$$\textbf{Efficiency} = \frac{\textbf{Work out put}}{\textbf{Work in put}} \times \textbf{100\%}$$
$$\text{Efficiency} = \frac{750}{1000} \times 100\%$$
$$\text{Efficiency} = 75\%$$

Alternatively: We can use M.A and V.R

$$\textbf{V.R} = \frac{\textbf{Effort Distance}}{\textbf{Load Distance}} = \frac{5}{1.5} = 3.3333$$
$$\textbf{M.A} = \frac{\textbf{Load}}{\textbf{Effort}} = \frac{500}{200} = 2.5$$

$$\textbf{Efficiency} = \frac{\textbf{M.A}}{\textbf{V.R}} \times \textbf{100\%}$$
$$\text{Efficiency} = \frac{2.5}{3.3333} \times 100\%$$
$$\text{Efficiency} = 75\%$$

(ii) Frictional force.
$$\textbf{Work wasted} = \textbf{Work in put} - \textbf{Work out put}$$
$$\text{Work wasted} = 1000\text{J} - 750\text{J}$$
$$\text{Work wasted} = 250$$

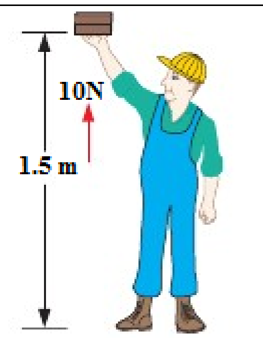
But also, work wasted here is due to friction, thus:
$$\textbf{Work wasted} = \textbf{Frictional force} \times \textbf{Effort distance}$$
$$250 = \text{F} \times 5$$
$$\text{F} = 50\text{N}$$

(b) ENERGY

Energy *is the ability or capacity to do work.*

In order to do work, a body must have energy. A body with energy supplies the force needed to do work. In the process of doing work, the body which does the work exchanges energy with that upon which work is being done. When work is done upon a body, that body gains energy. If the energy gained makes the body change position, then it is called mechanical energy.

In an energy transfer, work is done. The work done is a measure of the amount of energy transferred.



For example, if you have to exert an upward force of 10 N to raise a stone steadily through a vertical distance of 1.5 m, the work done is 15 J. This is also the amount of chemical energy transferred from your muscles to potential energy of the stone.

The S.I unit of work done and energy is a **joule,** (**J**). All forms of energy, as well as work, are measured in joules.

(i) SOURCES OF ENERGY:
The raw material for the production of energy is called the energy source.
There are two types of energy sources.

(a) **Non-renewable sources of energy**
These are sources of energy which use the earth's finite resources which were formed in the earth's crust millions

of years ago. These energy sources cannot be replaced when they get used up.

Examples of non- renewable sources of energy
(i) Fossil fuels; these are formed from plant remains that died million years ago. They include; coal, petroleum oil, natural gas, e.t.c.
(ii) Nuclear fuels; these are fuels found in radioactive elements which may be occurring naturally such as Uranium. These fuels can be used in nuclear reactions to produce electricity.

Advantages of non-renewable source of energy.
- They have high energy density. I.e. a lot of energy can be produced from a small quantity.
- They are readily available as demand increases.

Disadvantages of non-renewable source of energy.
- They are highly polluting.

(b) **Renewable sources of energy**
These are sources of energy which do not use the earth's finite resources.
These are energy sources which can be replaced when they get used up. They can never be exhausted.

Advantage:
They are non-polluting.

Examples of renewable sources of energy.
(i) Sun which provides solar energy: Solar energy is the form of energy which reaches the earth in form of heat and light.
It can be harvested using solar panels and transformed into electrical energy, which is used for many purposes.
It is also used in direct low temperature heating.

(ii) Wind: Wind provides mechanical energy which can be harvested using giant windmills, which can turn electrical generators to produce electrical energy, which is a more useful form.
(iii) Running water: Running water is used in hydro-electricity plants to turn giant turbines, which produce electrical energy.
The water will always flow hence a renewable source. Tides can also be used to generate electricity in this way.

(iv) Geothermal energy: Water is pumped to hot under ground rocks where it's heated and then forced out through another shaft where it can turn turbines.

(ii) FORMS OF ENERGY
Energy can exist in the following forms;

Form of energy	Definition	Example
Mechanical energy -Potential (gravitational) -Potential (elastic) -Kinetic energy	Is the type of energy possessed by a body by a reason of its position at rest or in motion.	- Energy stored in a book resting on a table. -A stretched spring or catapult -A shot fired from a gun.
Chemical energy	The type of energy released during a chemical reaction.	-Energy stored in fuels and energy giving foods that becomes active when oxidized by oxygen. - Energy stored in battery cells.
Nuclear (atomic) energy	Is the energy released by nuclei of heavy atoms of disintegrating radioactive elements.	- Energy stored in the nucleus of an atom
Electrical energy	The type of energy produced by electric cells, generators etc.	-Energy produced in electric appliances such as cooker,
Radiant energy (heat and light)	a) Heat energy: Is a form of energy, that results from random movement of the molecules in the body. b) Light energy: Is the form of energy which enables us to see. Light is part of the electromagnetic spectrum.	- Infra-red rays. -Visible spectrum
Sound energy	Type of energy produced by vibrating objects.	-Vibrational energy.

c) Chemical energy:
Chemical energy is the form of energy a body has due to the nature of its atoms and molecules and the way they are arranged.
In the combination of atoms to form compounds, there is gain or loss of energy. This energy is stored in the compound as chemical energy.
If the atoms in such compounds are rearranged to form a new compound, this energy is released. E.g If sugars in the human body are burnt, a lot of chemical energy is released.

d) Nuclear energy:
This is the energy released when atomic nuclei disintegrate during nuclear reactions.
In nuclear reactions, the energy, which holds the nuclear particles together (Binding energy), is released.
There are two types of nuclear reactions i.e. fission (Where large nuclei break to form smaller ones) and fusion (Where smaller nuclei combine to form larger ones). In both cases, large amounts of energy are released.

e) Electrical energy (Electricity):
This is the form of energy which is due to electric charges moving from one point of a conductor to another.
This form of energy is most easily converted to other forms, making it the most useful form.

f) Light energy:
This is the form of energy which enables us to see. Light is part of a wider spectrum of energy called the electromagnetic spectrum. Light consists of seven visible colours, of red, orange, yellow, green, blue, indigo and violet. We are able to see because the eye is sensitive to the colours.

g) Heat energy:
Heat is a form of energy, which results from random movement of the molecules in the body.
It is responsible for changes in temperature.
When a body is heated or when heat energy of the body increases;
(i) The internal kinetic energy of the molecules increases leading to a rise in temperature.
(ii) The internal potential energy of molecules increases leading to expansion and change of state of the body.

h) Sound energy:
This is the energy which enables us to hear.
Like light, sound is also a form of wave motion, which makes particles to vibrate. Our ears are able to detect sound because it produces vibrations in the ear.

i) Mechanical energy:
This is the energy of motion.
Mechanical energy=kinetic energy + Potential energy

There are two forms of mechanical energy.
(i) Kinetic energy:- This is the energy possessed by a body due to its velocity or motion.

Kinetic energy=$\frac{1}{2}$(mass)×(velocity)^2

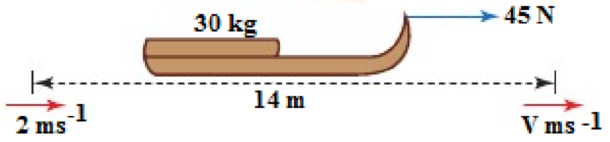
$$\mathbf{K.E = \frac{1}{2}mv^2}$$

If the speed of a body increases from **u** to **v** ms^{-1}, then**:**

$$\boldsymbol{Work\ done = F \times S}$$
$$Work\ done = ma \times S$$
$$From, V^2 = u^2 + 2aS \Leftrightarrow a = \frac{V^2 - u^2}{2S}$$
$$Work\ done = m\left(\frac{V^2 - u^2}{2S}\right) \times S$$
$$\boldsymbol{Work\ done = \frac{1}{2}mv^2 - \frac{1}{2}mu^2}$$
$$\boldsymbol{FS = \frac{1}{2}m(v^2 - u^2)}$$
Thus, work done is equal to the change in the kinetic energy of the body.

The work–energy principle or Theorem
The aobove expression illustrate the work–energy principle which states that:
The total work done by the forces acting on a body is equal to the increase in the kinetic energy of the body.

Example:
A sledge of total mass 30 kg, initially moving at 2 m s–1, is pulled 14 m across smooth horizontal ice by a horizontal rope in which there is a constant tension of 45 N. Find its final velocity.



Solution
Since the ice is smooth, the work done by the force is all converted into kinetic energy and the final velocity can be found by using;
$$\begin{pmatrix} work\ done \\ by\ force \end{pmatrix} = \begin{pmatrix} final\ kinetic \\ energy \end{pmatrix} - \begin{pmatrix} initial\ kinetic \\ energy \end{pmatrix}$$
$$45 \times 14 = \frac{1}{2} \times 30 \times v^2 - \frac{1}{2} \times 30 \times 2^2$$
$So\ v^2 = 46$ and the final velocity of the sledge, v is 6.8 ms^{-1} (to 2 s.f.).

Example:
The combined mass of a cyclist and her bicycle is 65 kg. She accelerates from rest to 8 m s–1 in 80 m along a horizontal road.
(i) Calculate the work done by the net force in accelerating the cyclist and her bicycle.
(ii) Hence calculate the net forward force (assuming the force to be constant).

Solution
(i) The work done by the net force F is given by
$$\text{work} = \text{final K.E.} - \text{initial K.E.}$$
$$\begin{pmatrix} \text{work done} \\ \text{by force} \end{pmatrix} = \begin{pmatrix} \text{final kinetic} \\ \text{energy} \end{pmatrix} - \begin{pmatrix} \text{initial kinetic} \\ \text{energy} \end{pmatrix}$$
$$\text{Work} = \frac{1}{2} \times m \times v^2 - \frac{1}{2} \times m \times u^2$$
$$\text{Work} = \frac{1}{2} \times 65 \times 8^2 - \frac{1}{2} \times m \times 0^2$$
$$\text{Work} = 2080\text{J}$$

(ii) $\text{Work done} = Fs$
$\text{Work done} = F \times 80$
Now using the Work – Energy Theorem,
$$80F = 2080$$
$$F = 26\ N$$
The net forward force is 26 N.

(ii) Potential energy:- This is the energy possessed by a body due to its position or condition.
It is equal to the work done in putting the body in that position or condition.
A body above the earth's surface has an amount of gravitational potential energy equal to the work done against gravity.
Weight is the force of gravity acting on a body.
Weight = mg.

Gravitational Potential energy, G. P. E is calculated from:
$$(\text{G. P. E}) = (\text{mass}) \times \begin{pmatrix} \text{acceleration} \\ \text{due to} \\ \text{gravity} \end{pmatrix} \times \begin{pmatrix} \text{Height} \\ \text{above} \\ \text{the} \\ \text{ground} \end{pmatrix}$$
$$\mathbf{G.P.E = mgh}$$

$$\begin{pmatrix}\text{Elastic}\\ \text{Potential energy}\end{pmatrix} = \frac{1}{2}\begin{pmatrix}\text{Material}\\ \text{constant}\end{pmatrix} \times (\text{Extension})^2$$

$$\textbf{E.P.E} = \frac{\mathbf{1}}{\mathbf{2}} \times \mathbf{k} \times \mathbf{e^2}$$

(iii) ENERGY TRANSFORMATIONS

By means of suitable mechanisms and apparatus, energy can be transformed from one form to another. This is shown in the table below.

Activity	Energy Transformation
1. A boy running up a stair case	Chemical energy in the muscles is converted to K.E and then to p.e. (C.E → K.E → P.E)
2. Running water at a hydroelectric power station (water turning turbine which finally drives a generator)	P.E is converted to K.E and then electrical energy. (P.E → K.E → E.E)
3. A stone dropped from rest at a certain height until it hits the ground.	P.E is converted K.E then to heat and sound energy. (P.E → K.E → H.E → S.E)
4. A moving car	Chemical energy due to the burning of fuel in the engine is converted to heat energy which is converted by pistons to kinetic energy. (C.E → H.E → K.E)
5. A coal fired engine drives a dynamo which lights a bulb.	Chemical energy is converted to heat energy, kinetic energy, electrical energy and lastly to light energy. (C.E → H.E → K.E → E.E → L.E)
6. A torch bulb flashing.	Chemical energy is converted to electrical energy, light energy and heat energy. (C.E → E.E → L.E → H.E)

Transducers (Energy Converters)

As energy is changed from one form or state to another, an energy converter (Device) is required to ease the conversion. Examples of such devices are shown in the table below.

Energy Change	**Converter**
Chemical to electrical	Cells or Batteries
Chemical to light	Candle
Light to Electrical	Solar cell / Photo cell
Electrical to light	Electric lamps e.g bulbs
Electrical to heat	Cooker or flat iron, etc.
Heat to Electrical	Thermocouple
Electrical to sound	Loud speakers
Sound to Electrical	Microphones
Electrical to Kinetic	Electric motors
Kinetic to Electrical	Electric generators, Dynamos

(iv) CONSERVATION OF ENERGY.

The principle of conservation of energy:

It states that 'energy is neither created nor destroyed' but can be changed from one form to another.

In any system, the total original energy is equal to the total final energy. For example, electrical energy is changed to light energy in the bulb. However, the bulb also feels hot because some of the energy is changed to heat.

Therefore, light energy plus the heat energy is equal to the electrical energy supplied.

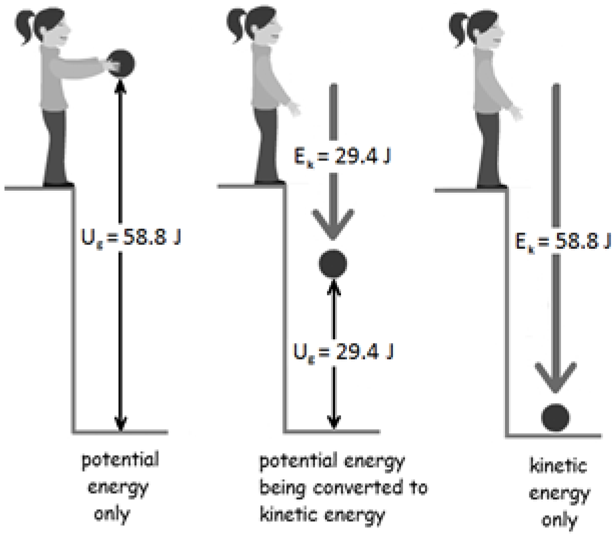
Thus from this principle, we conclude that;

- No new energy is created
- Total existing energy is not destroyed
- Energy is only changed from one form to another.

Conservation of mechanical energy:

(a) A falling body

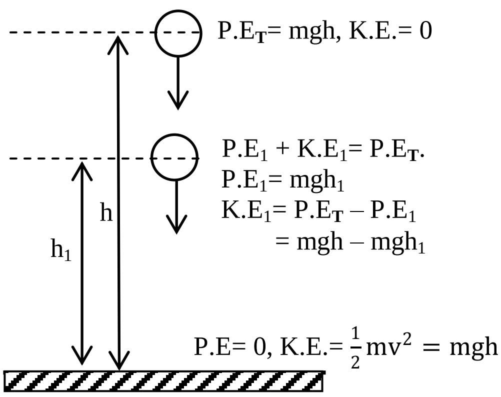
In the following diagram, suppose that the girl drops a ball with a mass of 2 kg from a height of 3 m.



Before the girl lets go of the ball, it has 58.8 J of potential energy. As the ball falls to the ground, potential energy is gradually converted to kinetic energy.

The potential energy continuously decreases and the kinetic energy continuously increases, but the total energy is always 58.8 J.

After the ball hits the ground, 58.8J of work was done by gravity, and the 58.8 J of kinetic energy is converted to other forms, such as thermal energy (the temperatures of the ball and the ground increase infinitesimally), sound, etc.



A body of mass m at a height h above the ground, has a potential energy, P.E = mgh. At this point, the velocity of the body is $0ms^{-1}$ hence it has no kinetic energy. (K.E. = 0J).

When the body is released, it begins to fall with an acceleration g. The velocity of the body thus increases as the height, h decreases. The body therefore gains kinetic energy at the expense of potential energy.

When the body is just reaching the ground, the height, h is zero (h = 0m) while its velocity is given by;

$v^2 = u^2 + 2as$; where $s = h, a = g$ and $u = 0$

$v^2 = 0^2 + 2gh$

$v^2 = 2gh$

$\mathbf{v = \sqrt{2gh}}$

Thus, its kinetic energy as it reaches the ground is given by; $K.E = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\sqrt{2gh}\right)^2 = mgh$

Hence, $\mathbf{K.E = \frac{1}{2}mv^2 = mgh}$

Therefore; **Gain in K.E = Loss in P.E.**

The above illustration shows that energy is conserved. Mechanical energy is continually transformed between kinetic and potential energy.

(b) Aswinging simple pendulum.

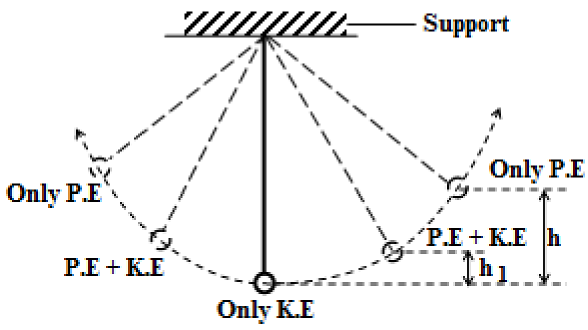
A simple pendulum consists of a pendulum bob tied on a thread. If the thread is fixed and the pendulum is displaced, it moves in a to and fro motion called an **oscillation**.

The time taken for one complete oscillation is called **periodic time**, T. The periodic time depends on:

- ✓ Length, ***l*** of the thread; the longer the length of the pendulum the longer the periodic time.
- ✓ Air resistance; in windy environment the periodic time is longer.
- ✓ Acceleration due to gravity, ***g***; in places where it is great, the periodic time is small.
- ✓ The relationship between the period time, acceleration due to gravity and the length of the pendulum an be deduced from the following expression.

$$\boldsymbol{T = 2\pi\sqrt{\frac{l}{g}}}$$

The transformation of energy between kinetic and potential energy can also be seen in a swinging pendulum.



Mechanical Energy = P.E + K.E

At the end (extremes) of the swing, the energy of the pendulum bob is only potential.

As the bob falls from the left towards the central position, it gains K.E at the expense of P.E.

As it passes the central position, it has only kinetic energy.

As it rises from the central position towards the left end, it gains P.E at the expense of K.E.

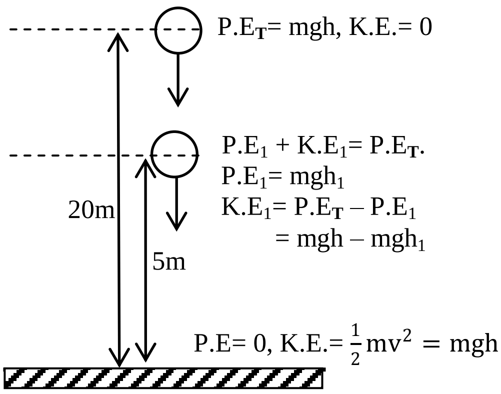
In other positions between the extreme ends and the central position, the body has both potential and kinetic energies.

Example:

A ball of mass 200g falls freely from a height of 20m above the ground and hits a concrete floor and rebounds to a height of 5m. Given that $g = 10ms^{-1}$, find the;

(i) P.E of the ball before it fell.
(ii) Its K.E. as it hits the concrete.
(iii) Velocity with which it hits the concrete.
(iv) K.E as it rebounds.
(v) Velocity with which it rebounds.
(vi) Velocity when it has fallen through a height of 15m.

Solution:



(i) Assuming negligible air resistance through out the motion of the body; Then

P.E = mgh (h=height from which the ball is dropped)

P.E = 0.2×10×20

P.E = 40J

Alternatively, Considering the motion of the body to the ground;

$\boldsymbol{u = 0}$, $(body\ from\ rest)$, $\boldsymbol{a = g = 10ms^{-2}, s = 20m}$

Then, using the 3rd equation of motion, we have:

$\boldsymbol{v^2 = u^2 + 2as}$

$v^2 = 0^2 + 2 \times 10 \times 20$

$v^2 = 400$

Then, $K.E = \frac{1}{2}mv^2$

$K.E = \frac{1}{2} \times 0.2 \times 400$

$K.E = 40J$

(ii)

As it hits the concrete, Total P.E is converted to K.E

K.E= $\frac{1}{2}mv^2$= mgh

(h=height from which the ball is dropped)

K.E=0.2×10×20

K.E=40J

(iii)
As it hits the concrete, Total P.E is converted to K.E
K.E= $\frac{1}{2}mv^2$ = mgh
(h=height from which the ball is dropped)
$\frac{1}{2}mv^2$ = mgh
v^2 = 2gh.

$v = \sqrt{2gh}$
$v = \sqrt{2(10)(20)}$
$v = \sqrt{400}$
$v = 20ms^{-1}$

(iv) As the ball bounces from the concrete, the K.E used to move the it from the bottom to the height h_1 is converted to P.E at h_1 and it is momentarily at rest. However, some energy is changed to heat and sound on hitting the ground.
$K.E_1 = \frac{1}{2}mv_1^2 = mgh_1$
(h_1=height to which the ball bounces).
$K.E_1$ = 0.2(10)(5)
$K.E_1$ = 10J

(v)
As the ball bounces from the concrete, the K.E used to move it from the bottom to the height h_1 is converted to P.E at h_1 and it is momentarily at rest.
$K.E_1 = \frac{1}{2}mv_1^2 = mgh_1$
(h_1=height to which the ball bounces).
$\frac{1}{2}(0.2)v_1^2 = 0.2(10)(5)$
$0.1v_1^2 = 10$
$v_1^2 = 100$
$v_1 = 10ms^{-1}$

(vi) As it falls from the top, Total P.E at the top is converted to some K.E and some P.E in falling to the height h_1.
$K.E_T = \frac{1}{2}mv_1^2 + mgh_1$
(h_1= height of the ball from ground).
$40 = \frac{1}{2}(0.2)v_1^2 + 0.2(10)(5)$
$40 = 0.1v_1^2 + 10$
$30 = 0.1v_1^2$
$v_1^2 = 300$
$v_1 = \sqrt{300}$
$v_1 = 17.32ms^{-1}$

Example 1:
Calculate the kinetic energy of a 2Kg mass trolly traveling at 400m per second.
Given; $m = 2kg, v = 400ms^{-1}$

$K.E = \frac{1}{2}mv^2 \Leftrightarrow K.E = \frac{1}{2}(2)(400)^2$
K.E = 160,000J

Example 2:
A 5Kg mass falls from a height of 20m. calculate the potential energy lost.
$Given; m = 5kg, h = 20m$
P.E=mgh
P.E=5(10)(20)
P.E=1000J

Example 3:
A 200g ball falls from a height of 0.5m. Calculate its kinetic energy just before hiting the ground.
$Given; m = 200g = \frac{200}{1000} = 0.2kg, h = 0.2m$
K.E gained = P.E lost
K.E=mgh
K.E=0.2(10)(0.5)
K.E=1J

EXERCISE:

1. A block of mass 2 kg falls freely from rest through a distance of 3m.
   (i) Find the K.E of the block. (**Ans: =60J**).
   (ii) Potential energy. (**Ans: =60J**).
   (iii) The velocity with which the body hits the ground. (K.E gained = P.E lost).

2. A body falls freely through 3m. Calculate the velocity with which it hits the ground.
   (Ans: = $7.75ms^{-1}$)
3. 100g steel ball falls from a height of 1.9m on a plate and rebounds to a height of 1.25m. Find the;
   (i) P.E of the ball before the fall. (Ans: =1.8J)
   (ii) K.E. as it hits the plate. (Ans: =1.8J)
   (iii) velocity on the plate. (Ans: $=6ms^{-1}$)
   (iv) K.E as it leaves the plate on rebound. (Ans: =1.25J)
   (v) velocity of rebound. (Ans: $=5ms^{-1}$)

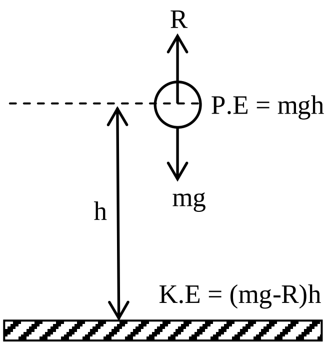
Effect of air resistance.
For a body not falling freely but as it falls it experiences air resistance then the kinetic energy gained by the body just before it hits the ground is calculated from:

$$\mathbf{K.E\ gained = (mg - R)h}$$

Where mg is the weight of the body, R is the air resistance and h is the height above the ground.

Example 4:
A 20kg body falls from 1.8m above the ground. If the air resistance is 0.9N.
(i) Calculate the kinetic energy just before hitting the ground.

Solution
Given; $m = 20kg, R = 0.9N, h = 1.8m, K.E. = ?$



K.E gained=(mg-R)h
K.E gained=(20×10 - 0.9)×1.8
=(200 - 0.9)×1.8
=(199.1)×1.8
K.E gained=358.38J

(ii) Calculate energy lost due to air resistance

Total energy at h, $= mgh$

$= 20 \times 10 \times 1.8$

Total energy at h, $= 360J$

Energy lost due to air resistance=360J-358.38J

Energy lost due to air resistance=1.62J

Note: Energy lost due to air resistance can also be calculated from;

Energy lost due to air resistance=Work done against R

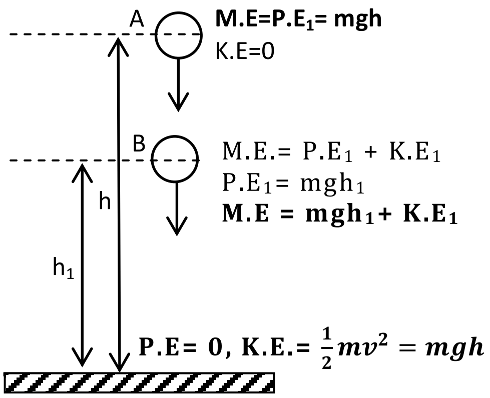
Energy lost due to air resistance=Force×Height

Energy lost due to air R = Air resistance × Height

= 0.9×1.8

Energy lost due to air R = 1.62J

Calculating the kinetic energy at any point for a body falling freely.



At A the body has all potential energy. So the energy at A is mgh = Total energy.

At **B** the body has a mixture of kinetic energy and potential energy.

$P.E_T = K.E_1 + P.E_1$

$mgh = K.E_1 + mgh_1$

$$\mathbf{mgh = \frac{1}{2}mv_1^2 + mgh_1}$$

Where "$\mathbf{h_1}$" is the height above the ground.

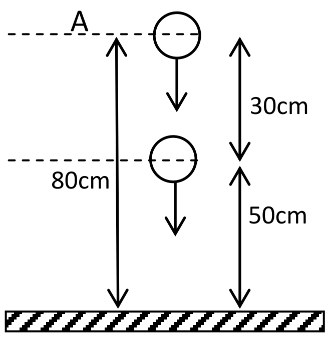
Example 5:

A stone of 150g is dropped from a height of 80m. Calculate the;

(i) Kinetic energy when it is 50m above the ground.

Solution:

$m = 150g = \frac{150}{1000} = 0.15kg$, $h_1 = 50m$, $h = 80m$.



(i)	Method 2 :
$mgh = K.E_1 + mgh_1$ $0.15(10)(80) = K.E_1 + 0.15(10)(50)$ $120 = K.E_1 + 75$ $K.E_1 = 120 - 75$ $K.E_1 = 45J$ (ii) Its velocity when its 50m above the ground. Method 1 : $K.E_1 = \frac{1}{2}mv_1^2$ $45 = \frac{1}{2} \times 0.15 \times v_1^2$ $\sqrt{600} = v_1$ $v_1 = 24.49ms^{-1}$	Given; $a = 10ms^{-2}$, $u = 0ms^{-1}$ Where h is the height fallen through. Then using the third equation of motion, we have; $\square^2 = u^2 + 2ah$ $v^2 = 0^2 + 2(10)(30)$ $v^2 = 600$ $v = \sqrt{600}\ ms^{-1}$ $v = 24.49\ ms^{-1}$

(iii) Its kinetic energy when it has fallen through 50m.

Given; $g = 10ms^{-2}$, $h = 80m$, $h_1 = (80-50) = 30m$, K.E=?

Where h is the height above the ground.

Then from;

$mgh = K.E_1 + mgh_1$

$0.15(10)(80) = K.E_1 + 0.15(10)(30)$

$120 = K.E_1 + 45$

$K.E_1 = 120 - 745$

$K.E_1 = 75J$

Example 6:

A boulder of mass 4 kg rolls over a cliff and reaches the beach below with a velocity of 20 m/s. Find:

(a) the kinetic energy of the boulder as it lands **(= 800 J)**

(b) the potential energy of the boulder when it was at the top of the cliff.(Applying the principle of conservation of energy (and neglecting energy lost in overcoming air resistance),

p.e. of boulder on cliff = k.e. as it lands

∴ $\Delta E_p = E_k = 800$ J

(c) the height of the cliff.

(If h is the height of the cliff: $\Delta E_p = mgh$: $h = 20$ m)

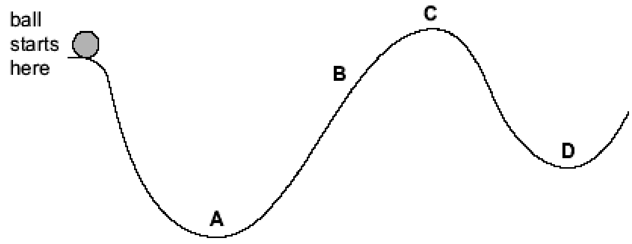
Question:

(a) A ball has a mass of 5 kg and is placed on the edge of a table 1 m tall. What is its gravitationalpotential energy? If the ball is pushed over the edge what would the kinetic energy of the ballbe one-third of the way to the ground?

(b) Why is it important to determine the efficiency of a machine? Machine A performs 900 J ofwork when supplied with 1000 J of energy. Machine B performs 800 J of work when supplied with 900 J of energy. Which machine wastes less energy?

(c) In part (b) above machine A performs the work in one hour and machine B performs workin 45 minutes. Which machine gives the greater power output?

(d) A ball is released from rest and rolls down a track from the position shown. What is the furthest position the ball could reach?



(c) POWER

Power is the rate of doing work. Or Power is the rate of transfer of energy.
Note: Work done is the same as energy transferred.

$$\textbf{Power} = \frac{\textbf{Work done}}{\textbf{Time taken}} = \frac{\text{Energy transfered}}{\text{Time taken}} = \frac{\text{Mgh}}{\text{t}}$$

Where work done = Force × Displacement.
Where **Mg** is the weight of the body and h the height.

$$\text{Power, P} = \frac{\text{F} \times \text{d}}{\text{t}} = \text{F} \times \frac{\text{d}}{\text{t}} \Rightarrow \quad \text{P} = \text{FV}$$

$\textbf{Power} = \textbf{F.V}$; W here V is the velocity of the body.

The S.I unit of power is **watt** (W).
1watt=1Js^{-1}

Definition:
A watt is the rate of transfer of energy of one joule per second.
Or It is the rate of doing work of 1joule in one second.

Measurement of Personal Power
Any one can find the power developed when running upstairs by measuring the total vertical height of the stair way and using a stop watch to measure the total time taken to run up it.

Example:
A boy of mass 40 kg finds that he can run up a flight of 45 steps each 16 cm high in 5.2s. Find the power developed by the boy.

$\text{Force overcome, F:} = mg = 40 \times 10 = 400\text{N}$
$\text{Distance moved:} = \text{nd} = 45 \times 16\text{cm} = 720\text{cm} = 7.2\text{m}$

$\text{Energy transfered} = \text{Work done} = \text{FS} = 400 \times 7.2 = 2880 \text{ J}$

$$\text{Power , P} = \frac{\text{Work done}}{\text{Time taken}} = \frac{400 \times 7.2}{5.2} = 554\text{W} = 0.554\text{KW}$$

Example 1:
An engine raises 20kg of water through a height of 50m in 10 seconds. Calculate the power of the engine.

Solution:
$$\text{Power} = \frac{\text{mgh}}{\text{t}} = \frac{20(10)(50)}{10}$$

$\text{Power} = 1000\text{W}$

Example 2:
An electric bulb is rated 100W. How much electrical energy does the bulb consume in 2hours.

Solution:
$$\text{Power} = \frac{\text{Energy used}}{\text{time taken}}$$

$$100 = \frac{\text{Energy used}}{2 \times 60 \times 60}$$

$\text{Enery used} = 100(2 \times 60 \times 60)$
$\text{Energy used} = 720{,}000\text{J}$

Example 3:
A man uses an electric motor whose power output is 3000W for 1hour. If the motor consumes 1.44×10^7J of electricity in that time, find the efficiency of the motor.

Solution:
Given; P_{out}= 3000W, t =1hr =1×60×60 =3600s.
$\text{Energy}_{input} = 1.44\times10^7$ J

$$\text{power input} = \frac{\text{Energy input}}{\text{time taken}}$$

$$P_{in} = \frac{E_{in}}{t} = \frac{1.44\times10^7}{36000} = 4000\text{W}$$

$$\text{Efficiency} = \frac{\text{Power output}}{\text{Power input}} \times 100\%$$

$$\text{Efficiency} = \frac{3000}{4000} \times 100\% = 75\%$$

For machines
Power input is the power created by effort.

$$\text{Power input} = \frac{\text{Work input}}{\text{Time taken}} = \frac{\text{Effort}\times\text{Effort Distance}}{\text{Time taken}}$$

Power output is the power created by the load.

$$\text{Power output} = \frac{\text{Work output}}{\text{Time taken}} = \frac{\text{Load}\times\text{Load Distance}}{\text{Time taken}}$$

Example 4:
An effort of 250N raises a load of 1000N through 5m in 10 seconds. If the velocity ratio is five, Calculate the:
i) Power input
ii) Efficiency

Solution:

(i) Given;
Effort=250N, Load=1000N, V.R=5, L.D=5m, t=10s

$$\text{V.R} = \frac{\text{E.D}}{\text{L.D}} \Leftrightarrow 5 = \frac{\text{E.D}}{5}$$
E.D=25m

$$\begin{pmatrix}\text{Power}\\ \text{input}\end{pmatrix} = \frac{\text{Work input}}{\text{Time taken}}$$

$$= \frac{\text{Effort}\times\text{Effort Distance}}{\text{Time taken}}$$

$$= \frac{250\times25}{10}$$
Power input = 625 W

$$\begin{pmatrix}\text{Power}\\ \text{input}\end{pmatrix} = \frac{\text{Work output}}{\text{Time taken}}$$

$$= \frac{\text{Load}\times\text{Load Distance}}{\text{Time taken}}$$

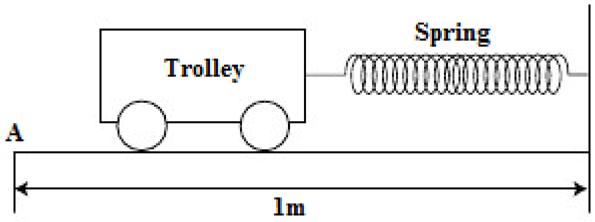
$$= \frac{1000\times5}{10}$$
Power output=500 W

(ii)
$$\text{Eff} = \frac{\begin{pmatrix}\text{Power}\\ \text{output}\end{pmatrix}}{\begin{pmatrix}\text{Power}\\ \text{input}\end{pmatrix}} \times 100\%$$

$$\text{Eff} = \frac{500}{625} \times 100\%$$

Efficiency = 80%

Example 5:
The figure below shows a trolley attached to a spring fixed at one end.



Calculate the work done on the trolley when it is pulled to point A with a force of 5 N. [1mrk]
(ii) Assuming spring constant k = 0.1, how much potential energy is stored in the trolley atpoint A? (**Elastic PE = ½ k** x^2**.** Where x is extension). [1mrk]

(iii) Draw diagrams to show the positions of the block where the potential energy would be:
- ❖ Maximum and where it would be Minimum

(iv) Draw diagrams to show the positions of the block where the kinetic energy would be:
- ❖ Maximum and where it would be Minimum

(v) Identify two forces acting on the trolley during its motion**.**

(vi) Which of the two forces in part (v) would be greater / lesser if the trolley were replaced by a wooden block of the same mass**.**

6. The engine of a high speed train, travelling at 50 ms^{-1}, delivers a power of 2 MW. What is the force exerted by the engine?

A	4×10^4 N
B	1×10^5 N
C	4×10^7 N
D	1×10^8 N

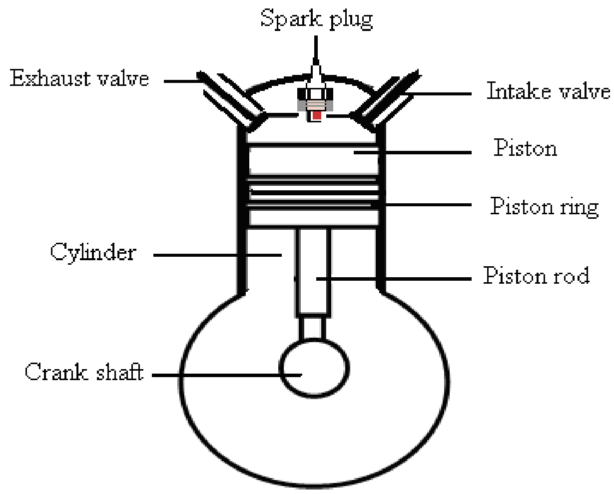
7. A force of 1000 N is needed to lift the hook of a crane at a constant velocity. The crane is then used to lift a load of 10000 N at a velocity of 0.50 ms^{-1}. How much power does the motor of the crane need to develop to lift the hook and load?

A	5.0 kW
B	5.5 kW
C	20 kW
D	22 kW

INTERNAL COMBUSTION ENGINE

A Heat engine is a machine, which changes heat energy obtained by burning fuel to kinetic energy (Mechanical energy).
Engines are always less than 100% efficient because.
(i) Some of the energy is lost in overcoming friction between walls of the cylinder and pistons.
(ii) Some heat energy is lost to the surrounding due to conduction.
(iii) Some of the energy is also wasted in lifting useless loads like pistons.

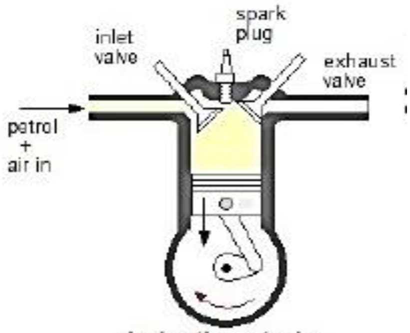
Petrol engine
A Petrol engine gets its energy from an exploded mixture of air and petrol vapour.
Petrol engines are also called four stroke cycle engines because four piston stroke or monuments inside the cylinder repeat themselves continuously. The piston strike is in the order intake, compression, power and exhaust.



Action of a four-stroke Engine

Stoke	Activity
1.**Intake** (Piston moves down)	• Inlet valve opens • Fuel air mixture is drawn into the cylinder.
2. **Compression** (Piston moves up)	• Both valves close • Fuel air mixture is compressed to a sixth of its volume.
3. **Power** (Piston moves down)	• Spark plug produces a spark which ignites and burns the fuel. • Pressure of the gasses produced pushes the piston down.
4. **Exhaust** (Piston moves up)	• Exhaust valve opens. • Exhaust gases are let out • Pressure reduces and the piston moves up

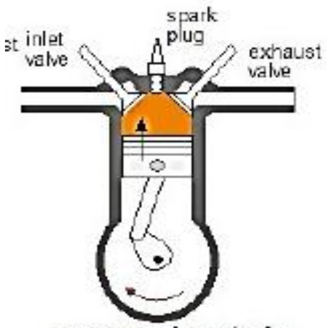
a) Intake.
-As the piston moves down the cylinder due to the starter motor in a car (or kick-start in a motor cycle) it reduces the pressure inside the cylinder.
-The inlet value opens and the petrol air mixture from the carburetor is forced into the cylinder by atmospheric pressure.



induction stroke

In short, intake involves the piston moving down the cylinder, inlet valve opening and allowing petrol – air mixture into the cylinder.

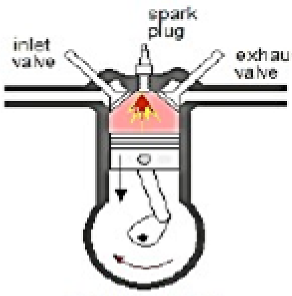
b) Compression



compression stroke

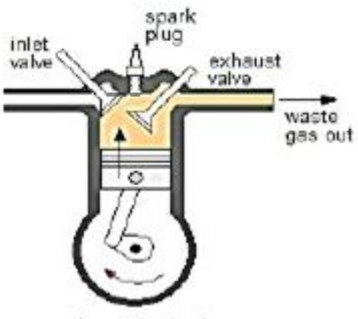
-Both valves close and the piston moves up compressing the mixture to about a sixth of its original volume.
-Near the end of the stroke, the fuel is ignited by a spark from the spark plug.

c) Power stroke



- ✓ Spark plug, produces an electric spark.
- ✓ Fuel-air mixture ignites and burns.
- ✓ Expanding gases exert a pressure on the piston and moves it down.
- ✓ A spark jumps across the points of the sparking plug and explodes the mixture, forcing the piston to move down.

d) Exhaust stroke



The outlet value opens and the piston rises, pushing the exhaust gasses out of the cylinder.

DIESEL ENGINE

The operation of a diesel engine is similar to that of a petrol engine. However, there are some **differences.**

Diesel engine	**Petrol engine**
-Diesel is used as fuel	-Petrol is used as fuel
-No spark plug	-Has a spark plug
-Has a fuel injector	-Has a carburettor
-Reliable and economical because its 40% higher	-Not reliable and economical
-Heavier	-Lighter

In a diesel engine air is drawn into the cylinder on down stroke of the piston. On upstroke of the piston, it compresses reducing the volume of the cylinder. The very high compression increase the stroke, oil is pumped into the cylinder by a fuel injector, it ignites automatically. The resulting explosion drives the piston down on its power stroke.

Note: Diesel engine is also called compression ignition (CI). It is heavier than a petrol engine. Diesel engine is reliable and economical. The efficiency is about 40% higher than any other heat engine.

EXERCISE

1. A crane raises a mass of 500 kg vertically upwards at a speed of 10 ms^{-1}. Find the power developed
A. 5.0×10^0 B. 5.0×10^1
C. 5.0×10^2 D. 5.0×10^4

2. A girl whose mass is 50 kg runs up a staircase 25 m high in 4 s. Find the power she develops.
A. $\frac{50 \times 4}{25} W$ B. $\frac{50 \times 10}{25 \times 4} W$
C. $\frac{50 \times 25}{4} W$ D. $\frac{50 \times 10 \times 25}{4} W$

3. A train traveling at a constant speed of 20 m/s overcomes a resistive force of 8 kN. The power of the train is
A. (8 x 20) W B. (8x10x20) W
C. (8 x 100 x 20) W D. (8 x 1000 x 20) W

4. A pump is rated at 400W. How many kilograms of water can it raise in one hour through a height of 72m?
A. 0.8kg B. 5.6kg
C. 33.3kg D. 2000kg

5. A boy carrying a load of 6 kg runs upstairs. If the work that the boy does is 300 J, find the height of the stairs.
A. 3m B. 5m
C. 6m D. 10m

6. Tony can pull a box 2m in 5 sec. Ever (Tony's sister) can pull the same box in 10 sec. Assuming both apply the same force, what is the ratio of Tony's power to the sister's power = ?
A. 1 B. 2
C. ½ D. 4

7. An engine exerts a force of 2000N at a speed of $15ms^{-1}$. Find the power developed by the engine in kW.

A. 30 000 B. 3 000
C. 300 D. 30

8. A constant force of 5N acts on a body and moves it through a distance of 20m in 10 seconds. Calculate its power.

A. 2.5W B. 10W
C. 40W D. 100W

9. A mouse of mass 0.03 kg climbs through a distance of 2 m up a wall in 4 s. The power expended in watts is

A. 0.03 x 2 x 4 x 10 B. $\frac{0.03 \text{ x } 4 \, x \, 2}{10}$

C. $\frac{0.03 \text{ x } 4 \, x \, 10}{2}$ D. $\frac{0.03 \text{ x } 10 \text{ x } 2}{4}$

10. A bullet of mass 0.02kg is fired with a speed of 40m s^{-1}. Calculate its kinetic energy.

A. 0.4 J. B. 0.8 J.
C. 16 J. D. 32 J.

11. Which of the following statements is true about an electric motor? It changes

A. Kinetic energy to electric energy
B. Electrical energy to light energy
C. Electrical energy to kinetic energy
D. Chemical energy to electrical energy.

12. A body pulls a block of wood with a force of 30N through a distance of 300m in 2 minutes. Find the power he develops, if he pulls the block at a constant speed.

A. $\frac{30 \text{ x } 300}{2}$ B. $\frac{30 \text{ x } 300}{2 \text{ x } 60}$

C. $\frac{30 \text{ x } 2 \text{ x } 300}{300}$ D. $\frac{300}{2 \text{ x } 60 \text{ x } 30}$

13. A ball of 1kg bounces off the ground to a height of 2m after falling from a height of 5m, find the energy lost.

A. 5 J B. 20 J
C. 30 J D. 50 J

14. A man weighing 800N climbs a vertical distance of 15m in 30s. What is the average power out put?

A. 80/3 W **B**. 800/15 W
C. 400 W **D**. 5 kW

15. In which action(s) below is there a work done?

(i) Pushing a wall without moving it.
(ii)Taking a book from a table to a higher shelf.
(iii) Walking on a bridge for 50 m

A. (i) only B. (ii) only
C. (iii) only D. (ii) and (iii) only

16. A bullet of mass 5g is fired at a speed of $400ms^{-1}$. How much energy does it have?

A. ½ x 5 x 10^2 x 400J B. ½ x 5 x 10^3 x 400J
C. ½ x 5 x 10^{-3} x 400 x 400J
D. ½ x 5 x 10^2 x 400 x 400J

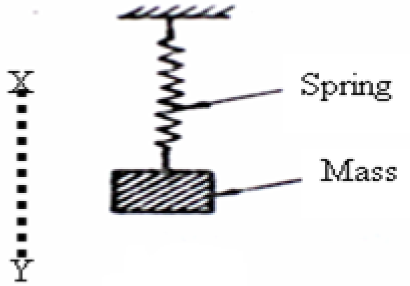
17. Which of the following forms mechanical energy?

A. Electrical energy and kinetic energy
B. Potential energy and nuclear energy
C. Nuclear energy and kinetic energy
D. Potential energy and kinetic energy

18. An object, of mass 2kg, dropped from the top of a building hits the ground with kinetic energy of 900J. The height of the building is

A. 30m B. 45m C.90m D. 180m.

19. A mass attached to the end of a string moves up and down to maximum and minimum points X and Y as shown in the figure below. When the mass is at X the



A. kinetic energy is maximum, potential energy is minimum
B. kinetic energy is zero, potential is maximum
C. kinetic energy is equal to potential energy
D. kinetic energy and potential energy are both zero

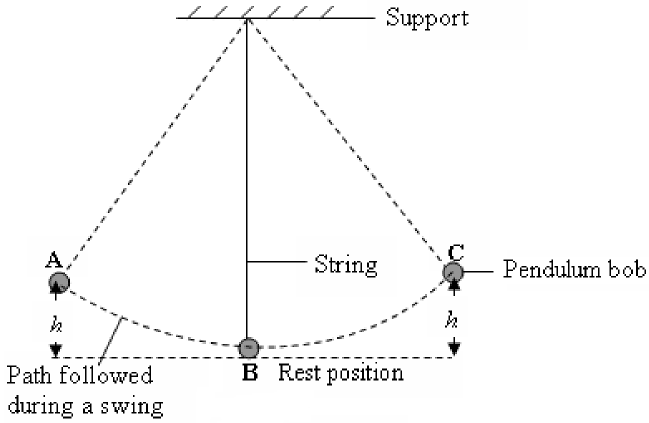
20. An electric motor of power 500 watts lifts an object of 100 kg. How high can the object be raised in 20 sec?

A. 40m **B**. 30m **C**. 20m **D**. 10m

21. A motor can pull a 400 kg box up to a height of 10m in 4 sec. What is the power of the motor in kW?

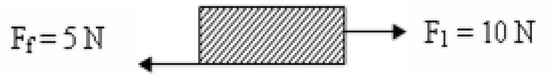
A. 10 **B**. 20 **C**. 30 **D**. 40

22. The diagram in the figure 3 shows an oscillation pendulum lob. Which of the following statements is true about its motion?



A. the K.E at B is equal to the K.E at A
B. the K.E at B is less than the P.E at A
C. the K.E at B is equal to the P.E at A.
D. the K.E at B is greater than the P.E at Z.

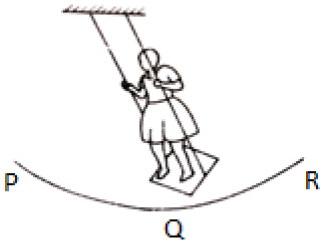
23. A toy car is pulled with a force of 10 N for 5m. If the friction force between the block and the surface is 5N, what is the net work done on the toy car?



A. 50 J B. 100 J C. 200 J D. 25 J

24. Allen and Vanessa move identical boxes equal distances in ahorizontal direction. Since Allen is a weak child, the time needed for her to carry the box is two times longer than for Vanessa. Which of the following is true for the two girls.
A. Allen does less work than Vanessa.
B. Vanessa does less work than Allen.
C. Each does the same work.
D. Neither Allen nor Vanessa do any work

25. The below figure shows a child on a swing. The child will have;

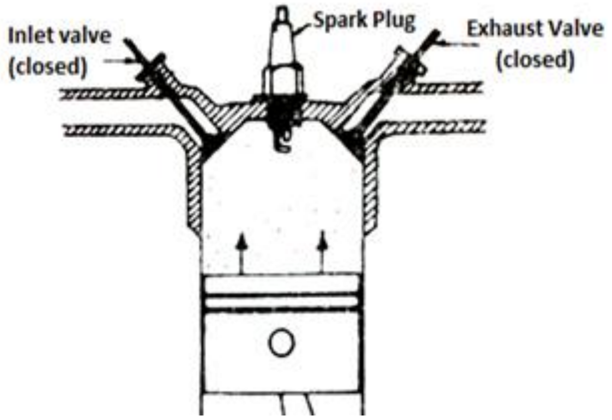


A. maximum potential energy at P and R
B. Maximum potential energy at Q
C. maximum kinetic energy at P
D. No kinetic energy at Q

26. Which of the following represents the firing order of a four-stroke petro engine?
A. exhaust, inlet , compression and power strokes
B. inlet, power, compression and exhaust strokes
C. power, compression, inlet and exhaust strikes
D. inlet, power, exhaust and compression strokes

27. A crane lifts a load of 1000 N through a vertical height of 3.0 m in 10 s. The input power to the crane is 500J/s. What is the efficiency of the crane?
A. 0.17 **B. 0.50** **C. 0.60** **D. 0.67**

28. The diagram above shows part of a combustion engine. What is the likely stroke in the cycle?

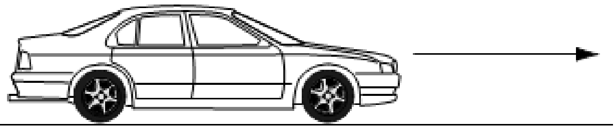


A. Inlet stroke B. Power stroke
C. Exhaust stroke D. Compression stroke

29. The energy changes that take place when a stone falls freely from rest to the ground can be orderly arranged as:
A. Kinetic energy ➔ Potential energy ➔ Sound energy ➔ Heat.
B. Sound energy ➔ Potential energy ➔ Kinetic energy ➔ Heat.
C. Potential energy ➔ Sound energy ➔ Kinetic energy ➔ Heat.
D. Potential energy ➔ Kinetic energy ➔ Heat energy ➔ Sound.

30. In a four stroke internal combustion engine, the work required for initial induction and compression comes from the:
A: movement of the steering wheel
B: rotation k.e. stored in the fly wheel
C: sparking plug
D: separate starter motor

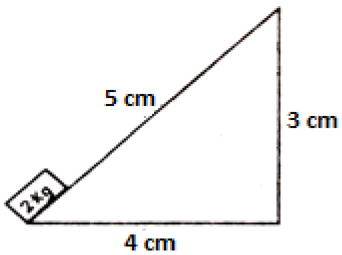
31. A car is driven along a level road. The total energy input from the petrol is 60kJ, and the car wastes 45kJ of energy.



What is the efficiency of the car?
A.15% B.25% C. 45% D. 75%

32. A ball of 1kg bounces off the ground to a height of 2m after falling from a height of 5m, find the energy lost.
A.5 J B.20 J C.30 J D.50 J

33. A brick of mass 2kg is lifted to a height of 3m along a smooth, inclined plane 5m long, as shown above. The work done is



A. 10J B.60J C. 6J D. 100J

34. A man of mass 50kg climbs 40 steps up stairs. If each step is 0.2m high. The potential energy gained is;
A. 100J. B. 400J. C. 4000J. D. 20,000J

35. Water flows at a rate of $6{\cdot}25 \times 10^8$kg per minute over a waterfall.The height of the waterfall is 108 m.The total power delivered by the water in falling through the 108 m is;
A . $1{\cdot}13 \times 10^9$W B . $1{\cdot}10 \times 10^{10}$ W
C . $6{\cdot}62 \times 10^{11}$W D . $4{\cdot}05 \times 10^{12}$W
E. $3{\cdot}97 \times 10^{13}$W.

36. A body of mass 25 kg falls freely from a height of 10 metres to the ground. Calculate its velocity as it hits the ground.
A. 4.47 ms^{-1} B. 10.0 ms^{-1}
C. 2500 ms^{-1} D. 14.14 ms^{-1}

SECTION B

35. (a) Define the following terms.

(i) Work. (ii) Power.

(b) State and define the SI units of the terms you have defined above.

(c) A crane lifts a load of 3500 N through a vertical height of 5 m in 5 second. Calculate:
(i) the work done.
(ii) the power developed by the crane.

36. (a) Define the term energy and state the SI unit for measuring it.

(b) Distinguish between potential energy and kinetic energy.

(c) A block of mass 2 kg falls freely from rest through a distance of 3m. Find the kinetic energy of the block.

37. (a) Define a **joule.**
(b) Describe briefly how you can measure your power.
(c) A boy of mass 45 kg runs up a flight of 60 steps in 5 seconds. If each step is 12 cm.Calculate the:
(i) work done against gravity by the boy.
(ii) power developed by the boy.

38. (a) (i) State the types of heat engines you know.
(ii) Describe the mechanism of operation of a four stroke petrol engine.
(b) (i) What are the factors that affect the efficiency of an engine?
(ii) State how the factors you have stated in (c) above are minimized in a heat engine.

More Practice Question

1. Calculate the kinetic energy of a 2Kg mass trolley traveling at 400m per second. .[K.E=160,000J]

2. A 5Kg mass falls from a height of 20m. Calculate the potential energy lost. .[P.E=1,000J]

3. A 200g ball falls from a height of 0.5m. Calculate its kinetic energy just before hitting the ground.[K.E=1J]

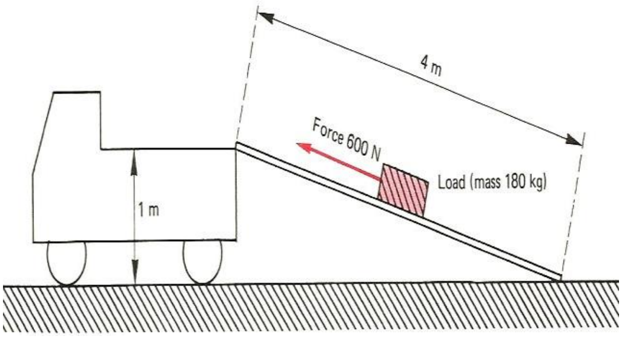
4. A block of mass 2 kg falls freely from rest through a distance of 3m. Find the;
(i) K.E of the block. (Ans: =60J)
(ii) Potential energy (Ans: =60J)
(iii) The velocity with which the body hits the ground.

5. A body falls freely through 3m. Calculate the velocity with which it hits the ground. (Ans: = $7.75ms^{-1}$)

6. A 100g steel ball falls from a height of 1.9m on a plate and rebounds to a height of 1.25m. Find the;
(i) P.E of the ball before the fall. (Ans: =1.8J)
(ii) Its K.E. as it hits the plate. (Ans: =1.8J)
(iii) Its velocity on the plate. (Ans: $=6ms^{-1}$)
(iv) Its K.E as it leaves the plate on rebound. (Ans: =1.25J)
(v) Its velocity of rebound. (Ans: $=5ms^{-1}$)

7. A stone of 150g is dropped from a height of 80m.Calculate the;
(i) Kinetic energy when it is 50m above the ground.[$v = 24.49\ ms^{-1}$]
(ii) Its kinetic energy when it has fallen through 50m. [$K.E_1$=75J]

9. The figure below shows a ramp used to get a load which has a mass of 180kg.onto a lorry. The ramp is 4m long and the end of the lorry is 1m above the ground. A force of 600N is needed to pull the load up the ramp.



Calculate
(a) The gravitational potential energy gained by the load as it goes from the bottom to the top of the ramp.
(b) The work done by the 600N force in pulling the load up the ramp. (02mks)

10. An arrow of mass 25g is released from a bow with a kinetic energy of 31.25J. The energy transferred from the bow to the arrow is 60% of the energy stored in the stretched bow. Find the,
(i) Initial velocity of the arrow.
(ii) Energy stored in the stretched bow.

11. A girl of mass 40kg runs up a staircase in 16 seconds. If each stair is 20cm and she uses $100Js^{-1}$, find the number of stairs in the staircase.

12. A crane can lift 600kg through a vertical height of 12m in 16 seconds.
(i) Find the power output of the motor driving the crane.
(ii) If the motor is 80% efficient, what is the power in put required?

13. A man of mass 50kg climbs 40steps up stairs. If each step is 0.2m high, find the potential energy gained.

14. (a) Define the following terms.
(i) Work.
(ii) Power.

(b) State and define the SI units of the terms you have defined above.
(c) A crane lifts a load of 3500 N through a vertical height of 5 m in 5 second.

15. Calculate: (i) the work done.
(ii) the power developed by the crane.

16. (a) Define the term energy and state the SI unit for measuring it.
(b) Distinguish between potential energy and kinetic energy.
(c) A block of mass 2 kg falls freely from rest through a distance of 3m. Find the kinetic energy of the block.

17. (a) Define a **joule**.

(b) Describe briefly how you can measure your power.

(c) A boy of mass 45 kg runs up a flight of 60 steps in 5 seconds. If each step is 12 cm.Calculate:

(i) the work done against gravity by the boy.

(ii) the power developed by the boy.

18. (a) (i) State the types of heat engines you know.

(ii) Describe the mechanism of operation of a four stroke petrol engine.

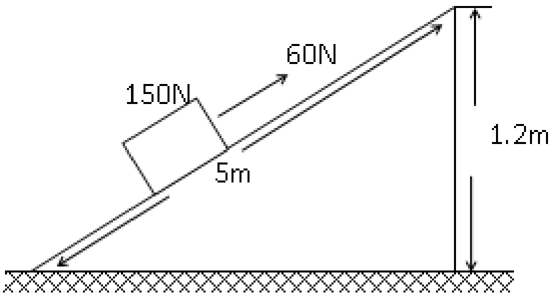
(b) (i) What are the factors that affect the efficiency of an engine?

(ii) State how the factors you have stated in (c) above are minimized in a heat engine.

19. A ball of mass 1kg falls from a height of 20m above the ground and bounces to a height of 4.05m. Calculate the change in momentum after bouncing of the ball.

20. A house pipe is delivers water at a rate of 100 litters per minute at a speed of 20 ms^{-1}. Calculate the power of the pump used to do this.

21. The diagram in the figure below shows a load of 150N being raised by pulling it along an inclined plane of length 5.0m by a force of 60N.



Determine:

(i)	The work done by the effort.	(2 mrks)
(ii)	The work done on the load	(2 mrks)
(iii)	The efficiency of the machine	(3 mrks)

PRESSURE

Pressure is the force acting normally per unit area of the surface.

i.e $$\textbf{Pressure}, \rho = \frac{\textbf{Force(N)}}{\textbf{Area}(\mathbf{m^2})}$$

The S.I unit of pressure is a newton per square metre, (N/m^2 or $\mathbf{Nm^{-2}}$) or a pascal, (**Pa**).

***A pascal** is the pressure exerted when a force of **1N** acts normally on an area of* $\mathbf{1\ m^2}$.

Other units of pressure include:

- Atmospheres
- Millimetres or centimetres or metres of mercury
- Bars

(a) PRESSURE IN SOLIDS:

Pressure in solids depends on;

- Magnitude of force applied
- Cross sectional area in contact

Maximum and Minimum Pressure

Pressure increases when the area decreases and decreases when the area increases. Thus;

$$\text{Maximum Pressue} = \frac{\text{Force or weight}}{\text{Minimum Area}}:$$

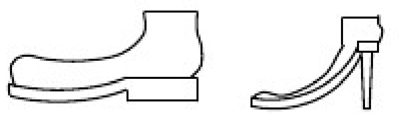
i.e. $$\mathbf{P_{max}} = \frac{\mathbf{F}}{\mathbf{A_{min}}}$$

$$\text{Minimum Pressue} = \frac{\text{Force or weight}}{\text{Maximum Area}}:$$

i.e. $$\mathbf{P_{min}} = \frac{\mathbf{F}}{\mathbf{A_{max}}}$$

The pressure exerted by a solid is due to its weight and depends on what area of it is resting on the supporting surface and also the angle of application of the force. It should be obvious that the smaller the area the greater is the pressure.

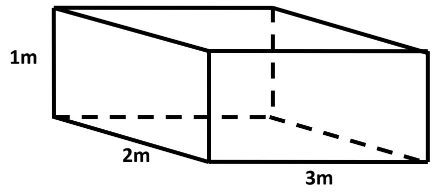
This is why a shoe with a narrow sole sinks more easily in mud than a flat one, or a cow sinks more easily in mud than a hippopotamus which is heavier.



(i) Wide Flat sole **(ii) Narrow sole**

Example 1:

The box below weighs 60N. Determine the maximum and minimum pressures it exerts on the ground.



Solution

Given:
-Dimensions**;** 1m x 2m x 3m
-Force, F=W = 60N
-Acceleration due to gravity, g = $10ms^{-2}$
Force, F = Weight
F = 60N

$$\begin{pmatrix}\text{Smallest}\\ \text{Area}\end{pmatrix} = \begin{pmatrix}\text{Smallest}\\ \text{length}\end{pmatrix} \times \begin{pmatrix}\text{Next smaller}\\ \text{length}\end{pmatrix}$$

$$A_{min} = (1 \times 2) = 2m^2$$

$$\text{Then: } P_{max} = \frac{F}{A_{min}} = \frac{60}{2} = 30\ Nm^{-2} \text{ or } 30\ Pa$$

$$\text{Largest Area} = \begin{pmatrix}\text{Longest}\\ \text{length}\end{pmatrix} \times \begin{pmatrix}\text{Next longer}\\ \text{length)}\end{pmatrix}$$

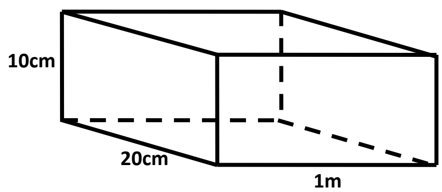
$$A_{max} = (3 \times 2) = 6m^2$$

$$P_{min} = \frac{F}{A_{max}} = \frac{60}{6} = 10\ Nm^{-2} \text{ or } 10\ Pa$$

Example 2:

A box of dimensions 20cm by 1m by10cm weighs 30kg. Determine the maximum and minimum pressures exerted by the box on the ground.

Given: -Dimensions**;** cm x 10cm x 20cm
-Mass, m = 30kg
-Acceleration due to gravity, g = $10ms^{-2}$



Given:
-Dimensions**;** 1m x 2m x 3m
-Mass, m = 30kg
-Acceleration due to gravity, g = $10ms^{-2}$
Force, F = Weight
= mg
F = 30 × 10
F = 300N

$$\begin{pmatrix}\text{Smallest}\\ \text{Area}\end{pmatrix} = \begin{pmatrix}\text{Smallest}\\ \text{length}\end{pmatrix} \times \begin{pmatrix}\text{Next smaller}\\ \text{length}\end{pmatrix}$$

$$A_{min} = \left(\frac{10}{100} \times \frac{20}{100}\right) = 0.02m^2$$

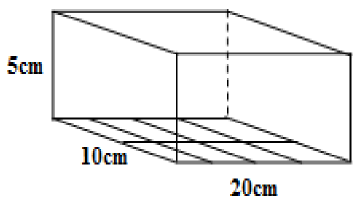
$$\text{Then: } P_{max} = \frac{F}{A_{min}} = \frac{300}{0.02} = 15000\ Nm^{-2} \text{ or } 15000\ Pa$$

$$\text{Largest Area} = \begin{pmatrix}\text{Longest}\\ \text{length}\end{pmatrix} \times \begin{pmatrix}\text{Next longer}\\ \text{length}\end{pmatrix}$$

$$A_{max} = \left(1 \times \frac{20}{100}\right) = 0.2\text{m}^2$$

$$P_{min} = \frac{F}{A_{max}} = \frac{300}{0.2} = 1500\ \text{Nm}^{-2} \text{ or } 1500\ \text{Pa}$$

Example 3:
The dimension of a cuboid are 5cm x 10cm x 20cm and the mass of the cuboid is 6kg. Calculate the maximum and minimum pressures the cuboid exerts on the ground.
Solution
Given: - Dimensions**;** 5cm x 10cm x 20cm
-Mass, m = 6kg
-Acceleration due to gravity, g = 10ms^{-2}



$$\text{Then: } P_{max} = \frac{F}{A_{min}}$$

$$\text{Force, } F = \text{Weight}$$
$$F = mg$$
$$F = 6(10)$$
$$F = 60\text{N}$$

$$\begin{pmatrix}\text{Smallest}\\ \text{Area}\end{pmatrix} = \begin{pmatrix}\text{Smallest}\\ \text{length}\end{pmatrix} \times \begin{pmatrix}\text{Next smaller}\\ \text{length}\end{pmatrix}$$

$$A_{min} = \left(\frac{5}{100} \times \frac{10}{100}\right) = \frac{1}{200}\text{m}^2 = 0.005\ \text{m}^2$$

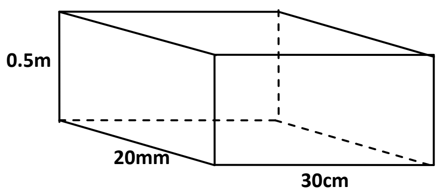
$$P_{max} = \frac{F}{A_{min}} = \frac{60}{0.005} = 12000\ \text{Nm}^{-2} \text{ or } 12000\ \text{Pa}$$

$$\text{Largest Area} = \begin{pmatrix}\text{Longest}\\ \text{length}\end{pmatrix} \times \begin{pmatrix}\text{Next longer}\\ \text{length}\end{pmatrix}$$

$$A_{max} = \left(\frac{20}{100} \times \frac{10}{100}\right) = \frac{1}{50}\text{m}^2 = 0.02\ \text{m}^2$$

$$P_{min} = \frac{F}{A_{max}} = \frac{60}{0.02} = 3000\text{Nm}^{-2} \text{ or } 3000\ \text{Pa}$$

Example 4:
The tank below has a mass of 2.5kg. Determine the minimum and maximum pressure exerted by the tank on the ground; When it is;
(i) empty
(ii) filled with water up to the brim.
(iii) half filled with water. (Density of water =1000kgm^{-3})



Solution
(i) When empty
Given: - Dimensions**;** 5cm x 10cm x 20cm
-Mass, m = 2.5kg
-Acceleration due to gravity, g = 10ms^{-2}

$$\text{Force, } F = \text{Weight}$$
$$F = mg$$
$$F = 2.5 \times 10$$
$$F = 25\text{N}$$

$$\begin{pmatrix}\text{Smallest}\\ \text{Area}\end{pmatrix} = \begin{pmatrix}\text{Smallest}\\ \text{length}\end{pmatrix} \times \begin{pmatrix}\text{Next smaller}\\ \text{length}\end{pmatrix}$$

$$A_{min} = \left(\frac{20}{1000} \times \frac{30}{100}\right) = 0.006\text{m}^2$$

$$P_{max} = \frac{F}{A_{min}} = \frac{25}{0.006} = 4166.67\text{Nm}^{-2} \text{ or } 4166.67\ \text{Pa}$$

$$\text{Largest Area} = \begin{pmatrix}\text{Longest}\\ \text{length}\end{pmatrix} \times \begin{pmatrix}\text{Next longer}\\ \text{length}\end{pmatrix}$$

$$A_{max} = \left(0.5 \times \frac{30}{100}\right) = 0.15\text{m}^2$$

$$P_{min} = \frac{F}{A_{max}} = \frac{25}{0.15} = 166.67\text{Nm}^{-2} \text{ or } 166.67\ \text{Pa}$$

(ii) When filled with water to the brim

$$\text{Force, } F = (\text{Weight of empty tank}) + (\text{weight of water})$$
$$F = m_t g + m_w g$$
$$F = m_t g + V_w \rho_w g$$

$$\text{Where Volume of water, } V_w = l \times w \times h$$
$$V_w = \frac{30}{100} \times \frac{20}{1000} \times 0.5$$
$$V_w = 0.003\text{m}^{-3}$$

$$F = 2.5 \times 10 + (0.003) \times (1000) \times 10$$
$$F = 25 + 30$$
$$F = 50\text{N}$$

$$P_{max} = \frac{50}{0.006} = \frac{50}{0.006} = 8333.33\text{Nm}^{-2} \text{ or } 8333.33\ \text{Pa}$$

$$P_{min} = \frac{50}{0.15} = 333.33\ \text{Nm}^{-2} \text{ or } 333.33\text{Pa}$$

(iii) When half filled with water.

$$\text{Force, } F = (\text{Weight of empty tank}) + (\text{weight of water})$$
$$F = m_t g + m_w g$$
$$F = m_t g + V_w \rho_w g$$
$$\text{Where Volume of water, } V_w = l \times w \times h$$
$$V_w = \frac{30}{100} \times \frac{20}{1000} \times 0.25$$
$$V_w = 0.0015\text{m}^{-3}$$

$$\text{Then, } F = 2.5 \times 10 + (0.0015) \times (1000) \times 10$$
$$F = 25 + 15$$
$$F = 40\text{N}$$

$$P_{max} = \frac{40}{0.006} = 666.67\text{Nm}^{-2} \text{ or } 666.67\text{Pa}$$

$$P_{min} = \frac{40}{0.15} = 266.67\text{Nm}^{-2} \text{ or } 266.67\text{Pa}$$

Note: when calculating pressure, the unit of area of base should always be in m^2. From the above calculations it is noted that: the greater the area over which the force acts normally the less is the pressure.

- ❖ A tractor with wide wheels can pass over soft ground because the greater area of wide wheel exerts less pressure.
- ❖ Ahippopotamus of wide feet is able to walk on soft grounds without sinking because the greater area of wide hooves exerts less pressure.

- ❖ When the **same force** is applied on a needle and nail, both placed on the hand, one tends to feel more pain from the needle because the small area of needle exerts greater pressure.

- ❖ The skiis used when skiing over snow have large surface area in order to exert the minimum pressure on the snow.

- ❖ A sharp knife cuts well than a blunt one.

Exercise:

1. Explain the following observations;

(i) A large reservoir is much wider at the base than at the top

(ii) In supply of water, smaller pipes are preferred to larger ones.

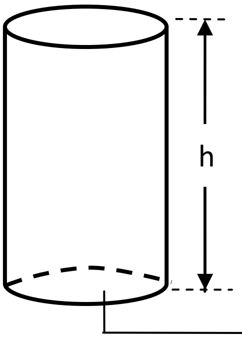
2. A rectangular block of metal weighs 5 N and measures 2 cm × 3 cm × 4 cm. What is the least pressure which it can exert on a horizontal surface?

A. 2.10×10^{-7} Pa B. 4.17×10^{-5} Pa
C. 6.25×10^{-5} Pa D. 8.30×10^{-5} Pa

(b) PRESSURE IN FLUIDS:

Defining pressure in fluids

Fluids refer to gas or liquids. These take up the shape of the container, so the volume of the liquid filling a cylindrical container is equal to the volume of that cylindrical container.



Area of base $= \pi r^2$
Volume of liquid $= \pi r^2 h$
Mass of liquid $= \pi r^2 h\rho$
Weight of liquid $= \pi r^2 h\rho g$

Area of base $= \pi r^2$

Then from the definition of pressure:

$$\text{Pressure} = \frac{\text{Force(N)}}{\text{Area}(\text{m}^2)} = \frac{(\pi r^2)h\rho g}{(\pi r^2)} = h\rho g$$

$$\textbf{Pressure} = \mathbf{h\rho g}$$

Factors affecting pressure in fluids

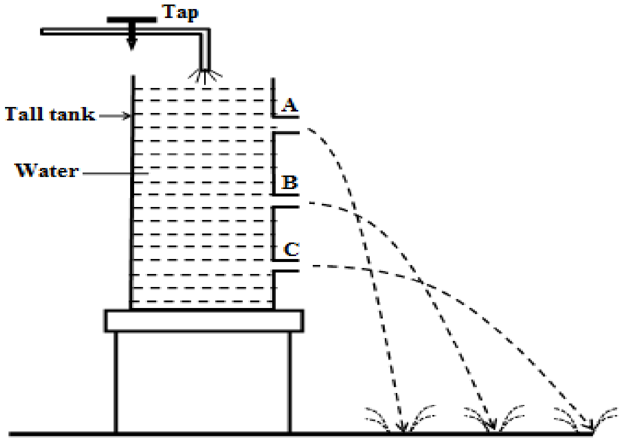
Generally, pressure at any point in a liquid is the same in all direction and depends on the following factors:

i) Depth "***h***" below the surface of the liquid
ii) Density **ρ** of the liquid

Other factors that are normally ignored include;

i) A acceleration due to gravity
ii) Pressure exerted on the surface of the liquid.
iii) Temperature

Experiment to* show *that pressure increases with depth



Procedures:

Equally, spaced holes A, B and C of the same size are drilled at different depths along one vertical side of a cylindrical can.
The holes are then closed using corks.
Water is then poured into the can to full capacity.
The corks are then removed at the same time and the distance from the can to where water fom each hole lands noted.

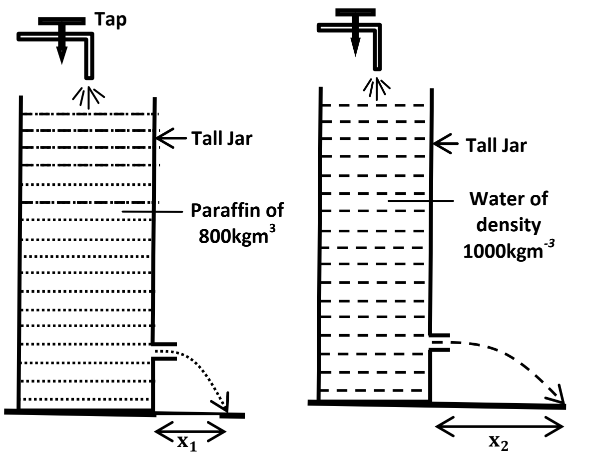
Observation:

Water comes out fastest and lands furthest from the lowest hole C followed by B and then least from A.
This means that pressure is highest at C, which is deepest.
Hence, pressure in liquids increases with depth.

Water supply system:

Water supply often comes from reservoirs at a higher ground level. In a very tall building, it is necessary to pump water to a large tank in the roof. All the above are done because the lower the place supplied the greater the water pressure at it.

Experiment to show that pressure depends on density



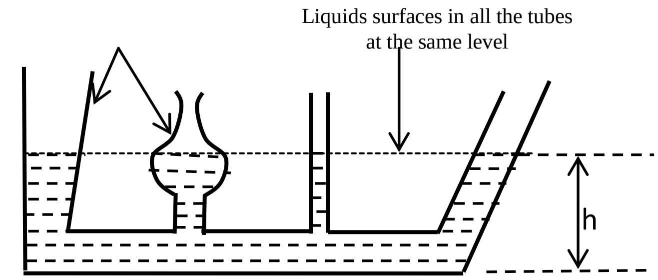
- ❖ A tall jar with a hole punched at some depth is used.
- ❖ The jar is then filled with liquids of different densities e.g paraffin and water one after the other.
- ❖ The distance to which the liquids jet out is observed, measured and compared.
- ❖ It is observed that water jets furthest compared to paraffin i.e; $\mathbf{x_2} > \mathbf{x_1}$.Thus the higher pressure is exerted by water than paraffin at the same depth.
- ❖ Therefore, the higher the density, the higher the pressure.

Properties of fluids related to pressure

(i) A liquid finds its own level:

Pressure in liquids does not depend on cross sectional area and shape of vessel containing the liquid.

This can be illustrated by an experiment using a communicating tube as shown below.



A liquid is poured into the communicating tubes of different cross-sectional areas.

The liquid is found to stand at the same level in each tube. This shows that pressure at same level is the same.

This is because the same atmospheric pressure acts on the surface of water in each tube.

(ii) Pressure at a given depth acts equally in all directions:

Pascal`s principle of transmission of pressure in fluids

It states that *pressure in an enclosed fluid is equally transmitted through out the fluid in all directions.*

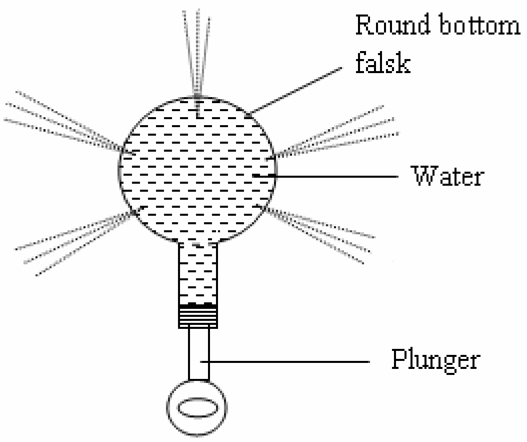
Pascal`s principle works because *liquids are incompressible*. That is to say, their volumes can`t be reduced by squeezing.

Assumptions on which the principle is based.

(i) Fluids (Liquids and gases) are incompressible.

(ii) Pressure at a point is transmitted equally in all directions in an enclosed fluid.

An experiment to verify Pascal`s principle.



Holes of equal size are drilled in a round bottomed flask at the same height and covered with cork.

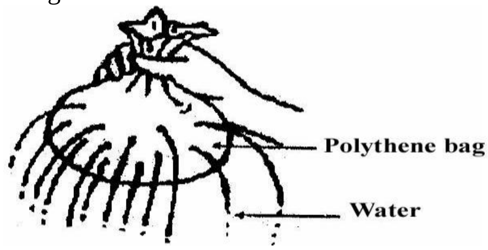
The flask is then filled with water and the piston pushed inside the flask.

Water shoots out equally in all directions, and travels equal distances. This verifies Pascal`s principle.

Alternatively

Procedure:

- ✓ Take a polythene bag and fill it with water and close its mouth with a piece of thread.
- ✓ Hold this polythene bag gently where it is tied by thread.
- ✓ Make many holes of same size at the same height with the help of needle. And apply force slowly to the bag.



- ✓ Observe the water coming out through these different holes.

Interpretation:

Since the height of all the holes is same water comes out with same pressure.

Conclusion:

From the above experiment it is found that the pressure exerted by the liquid is same

in all the direction at the same height.

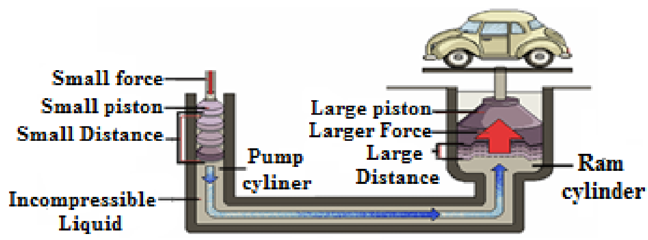
HYDRAULIC MACHINES

Pascal's principle *states that: When a force exerted on a liquid, pressure is produced which is transmitted equally throughout the liquid.*

The above principle is applied in hydraulic press, hydraulic brakes and hydraulic jacks. Liquids are almost uncompressible so they can pass on any pressure applied to them.

In hydraulic press a small force is applied to a small piston in order to raise, large force (load) placed on large piston.

(a) Hydraulic press



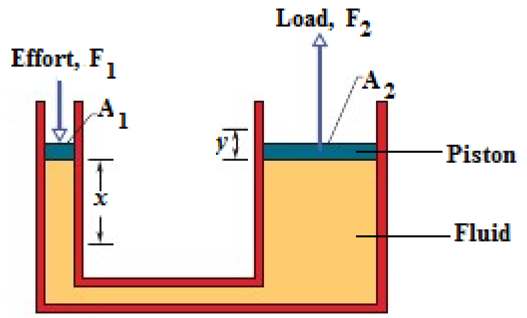
It consists of two interconnected cylinders of different diameters enclosed by means of pistons which fit tightly in the cylinders.

A high-density liquid like oil is used to fill the system.

Effort applied on the smaller piston can be used to overcome a larger load on the bigger piston.

When a force (effort) is acting on the smaller piston, exerts pressure on the liquid. According to Pascal's principle, the pressure will be transmitted equally to every point of the liquid since the system is enclosed by the cylindrical pistons.

The same pressure then acts on the bigger piston, where it overcomes a bigger force (heavy load) because of the large area of the piston.



Thus assuming a hydraulic press, which is 100% efficient, then,

$$\frac{\textbf{Load}}{\textbf{Effort}} = \frac{\textbf{Area of Larger piston}}{\textbf{Area of Smaller piston}}$$

$$\frac{\mathbf{F_2}}{\mathbf{F_1}} = \frac{\mathbf{A_2}}{\mathbf{A_1}} \Leftrightarrow \frac{F_2}{F_1} = \frac{\pi R^2}{\pi r^2} \Rightarrow \frac{\mathbf{F_2}}{\mathbf{F_1}} = \frac{\mathbf{R^2}}{\mathbf{r^2}}$$

Where **r** and **R** are the radius of the smaller (**Pump**) and bigger (**Ram**) pistons respectively**.**

If x is the distance moved by the **Pump piston** and y is the distance moved by the **Ram piston,** then equating the volumes gives:

$$\text{Volume of the Pump} = \text{Volume of the Ram}$$
$$x \times \text{Area of the Pump} = y \times \text{Area of the Ram}$$

$$\text{Velocity ratio, V.R} = \frac{x}{y} = \frac{\text{Area of the Ram Piston}}{\text{Area of the Pump Piston}}$$

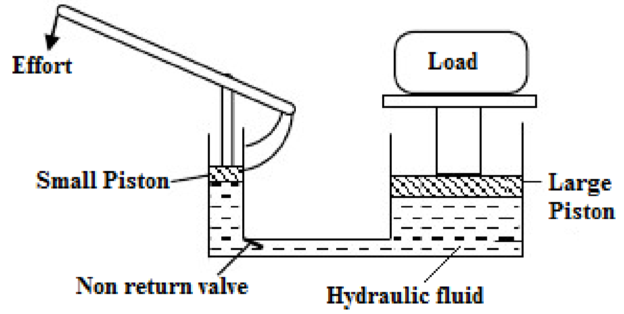
$$\textbf{Velocity ratio, V.R} = \frac{\boldsymbol{x}}{\boldsymbol{y}} = \frac{\pi R^2}{\pi r^2} = \frac{\mathbf{R^2}}{\mathbf{r^2}}$$

This gives the velocity ratio between the two pistons only. If the total velocity ratio of the whole press, is required, then we multiply $\frac{R^2}{r^2}$ by the velocity ratio of the handle (treated as a lever).

Advantage
A small force applied on small piston can overcome a large place load placed on a large piston.

Applications and uses of the Hydraulic Press
(i) It is used to shape motor car bodies.
(ii) It is used to compress materials such as waste paper and cotton into compact bales.
(iii) It is used in forging of steel armour plate and light alloys.

Example 1:
A hydraulic press is made of two cylinders of cross-section areas $20cm^2$ and $120cm^2$ respectively fitted tightly with pistons A and B. A force of 10N applied on A is used to raise a load on piston B. Calculate the maximum possible force that can be raised on piston B.



Solution:

$$\text{Then from } \frac{F_1}{F_2} = \frac{A_1}{A_2}$$

$$\frac{10}{F_2} = \frac{20}{120}$$
$$20F = 1200$$
$$F = 60N$$

Example 2:
A hydraulic press requires an effort of 100N acting on a piston of area $20cm^2$ to press a bale of cotton placed on a piston of area $240cm^2$. If the percentage efficiency of the press is 80%, calculate the force applied on the bale.

Solution:
Then from; $\frac{F_1}{F_2} = \frac{A_1}{A_2}$

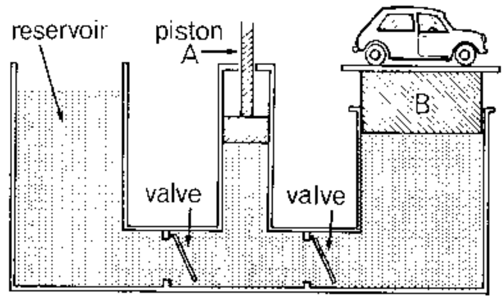
$$\frac{100}{F_2} = (\frac{80}{100} \times \frac{20}{240}) \Rightarrow \frac{100}{F_2} = \left(\frac{16}{240}\right) \Rightarrow F_2 = 1500N$$

Example 3:
In a hydraulic machine, the larger cylinder is 20 times the diameter of the smaller one and has a pump which is operated by a lever system of velocity ratio 6.
(i) Find the velocity ratio of the whole machine. **(Ans: V.R= 2400).**
(ii) If the machine is 90%, calculate the force exerted by the machine when a force of 100N is applied to the handle. **(Ans: F= 216KN)**

Example 4:
A hydraulic press has cylindrical pistons of of radii 2cm and 4cm respectively. Calculate the maximum force at the smaller piston to overcome a force of 78 N applied at the larger piston.

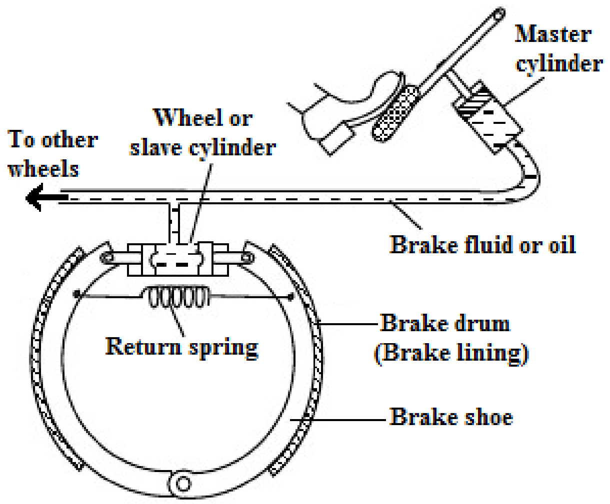
Example 5:
In a hydraulic press, the smaller piston has a diameter of 14cm while the larger one has a diameter of 280cm. Find the force exerted by the larger piston if the smaller one is pushed by a force of 77N. **(Ans: F= 30800N)**

Hydraulic lift



This is commonly used in garages; it lifts cars so that repairs and service on them can be done easily underneath the car.
A force applied to the small piston, raises the large piston, which lifts the car. One valve allows the liquid to pass from
The small cylinder to the wider one, a second valve allows more liquid (usually oil) to pass from oil reservoir on the left
to the small cylinder. When one valve is open, the other must be shut.

(b) **Hydraulic brake:**



When the brake pedal is placed, the pressure exerted inside the master cylinder is transmitted equally to all the slave cylinders.

At the slave cylinder, the pressure acts on the pistons which are connected to the brake shoes (pads).

This presses the brake shoes against the brake drum (disc) hence creating friction, which opposes the rotation drum and therefore the wheel. This results in the stopping of the car.

EXERCISE:

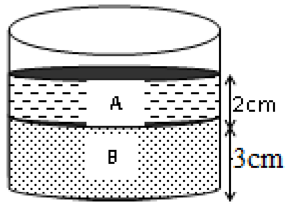
1. A hydraulic press machine is used to raise a load W placed on a piston of cross-sectional area of $100cm^2$ by using an effort of 20N at a piston of cross-sectional area of $2cm^2$.
Calculate the;
(i) Pressure transmitted through out the liquid [P=100000Pa]
(ii) Load, W. [W=1000N]

2. A force of 100N is applied on a small piston of area $0.002m^2$. Find the maximum load that can be lifted by a piston of area $0.8m^2$.

3. Calculate the pressure at the bottom of a swimming pool 1000cm deep.{density of water = $1000kgm^{-3}$}

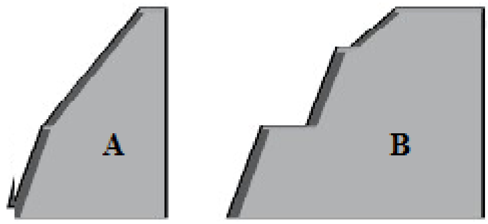
4. A diver dives to a depth of 20m below the surface of sea water of density $1200kgm^{-3}$. Calculate the pressure Experienced.

5. The tank below contains mercury and water. Find the total pressure experienced at the bottom.
{Density of mercury = $13600kgcm^{-3}$, Density of water = $1000kgm^{-3}$}



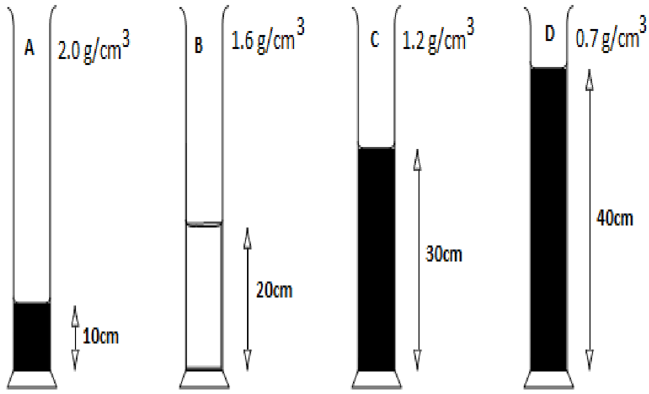
6. (a) (i) Define Pressure and state its S.I unit.
(ii) Describe how a hydraulic car Brake system works.
(b) A hydraulic press has cylindrical pistons of radii 0.2m and 0.4m respectively. Calculate the maximum Load at that can be overcome by a force of 78N.

7. An engineer has come up with two designs for a dam. Which of these would you recommend? Why?

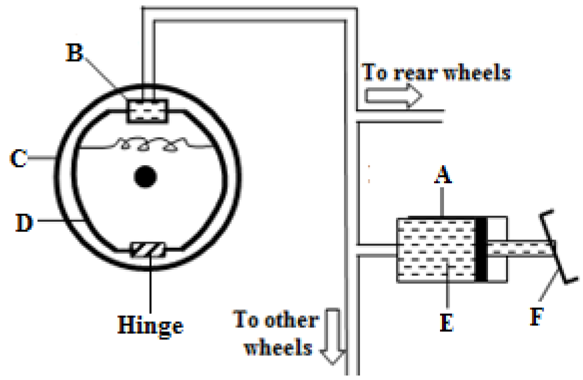


(*B, because the thick base would be able to withstand the greater pressure at the bottom of the Water*)

8. Four different liquids are poured into identical measuring cylinders. The diagrams show the depths of the liquids and their densities. Which liquid causes the largest pressure on the base of its measuring cylinder?



8. The figure below shows part of a Hydraulic braking system. Name the parts labeled A, B, C, D, E, and F.



MEASURING FLUID PRESSURE

(a) Using a bourdon gauge

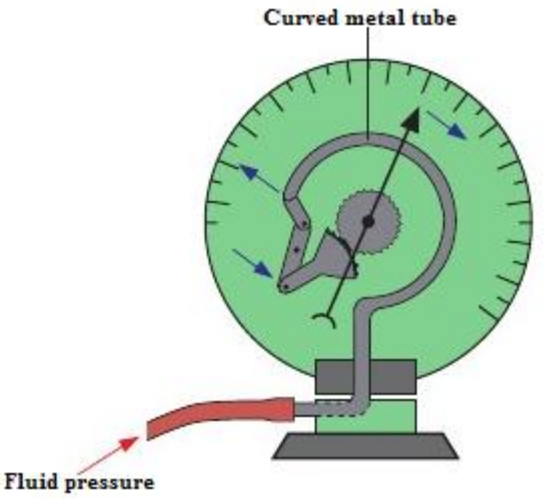
This gauge measures the very high pressures of liquids or gases, e.g. the pressure of steam in boilers.

It is a hollow curved tube of springy metal closed at one end. The tube straightens slightly when pressure acts on the inside.

The closed end of the tube is joined to a series of levers and gear wheels which magnify the slight movement.

A pointer moving over a scale (usually graduated in 10^5 pa, which is about 1 atmosphere pressure) records

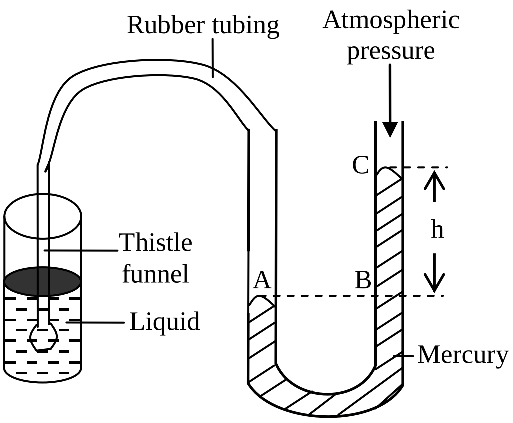
Then, the recorded pressure is the excess pressure of liquid or gas over atmospheric pressure, but some gauges can record the actual pressure.



Bourdon gauges are commonly used at filling stations.

Using a manometer

(i) Measurement of Liquid pressure

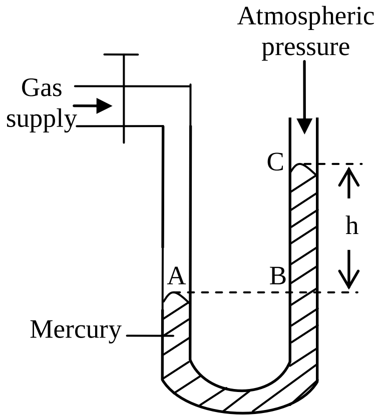


One arm of the manometer is connected to a thistle funnel whose base is covered with a thin membrane and the other end remains open to the atmosphere.

The difference in the liquid surface levels, h gives the pressure at point A and it is called the gauge pressure or absolute pressure.

$$\textbf{Absolute pressure} = \quad \mathbf{H} \quad + \quad \mathbf{h\rho g}$$

(ii) Measurement of Gas pressure



-Connect a manometer to a gas supply as shown above

-Turn on the gas.

-The gas exerts a pressure at a point A. This causes the liquid to rise in the opposite arm until the pressure in both arms is the same.

-The gas pressure in one arm (limb) is equal to the pressure in the opposite limb.

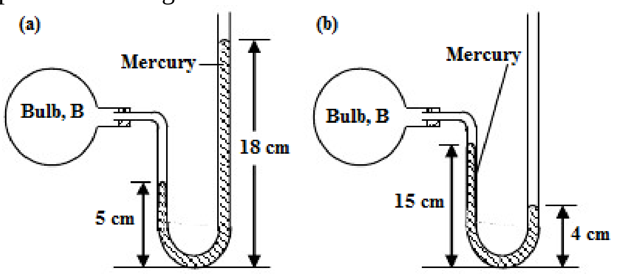
$$\text{Pressure at A} = \text{Pressure at B}$$

$$\text{Pressure at A} = \begin{pmatrix}\text{Atmospheric} \\ \text{pressure}\end{pmatrix} + \begin{pmatrix}\text{pressure due} \\ \text{to mercury} \\ \text{column}\end{pmatrix}$$

$$\textbf{Gas pressure} = \quad \mathbf{H} \quad + \quad \mathbf{h\rho g}$$

Example

Given that the density of mercury is 13600 kg m^{-3} and the atmospheric pressure is 1.01 x 10^5 Nm^{-2}, calculate the pressure of the gas in bulb B in each case.



Solution

(a) Gas pressure = Atmospheric pressure + pressure due to extra mercury column

The extra mercury column has height = (18 – 5) x 10^{-2} m
= 0.13 m

Pressure due to mercury column = 0.13 x 13600 x 10
= 1.768 x 104 N m^{-2}

Gas pressure = 1.01 x 105 + 0.1768 x 10^5
= 1.19 x 10^5 N m^{-2}

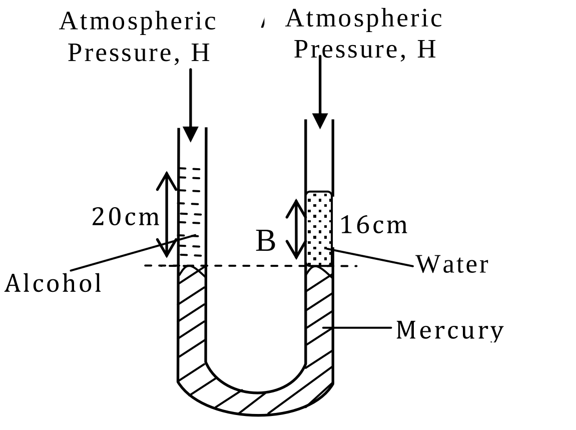
(b) The mercury level in the open limb is (15 – 4) x 10^{-2} m below

Gas pressure = atmospheric pressure – 0.11 x 13600 x 10
= 1.01 x 105 - 1.496 x 104
= 8.6 x104Nm-2

Example:1

Mercury was poured in a U- tube such that it finds its own level. When a column of 20cm of alcohol was poured on one side of the tube, it was necessary to pour 16cm of water on the other side to maintain equal mercury levels on both sides as shown below. Find the density of alcohol.

Solution



From; $P = h\rho g$,

$h_a \rho_a g = h_w \rho_w g$

$\rho_a(20)(10) = 1000 \times 16 \times 10$

$\rho_a = 800 \text{kgm}^{-3}$

Expressing cmHg or mmHg pressure in Nm^{-2} or Pa

This is done by applying of formula **pressure = hρg** where **h** is the liquid column which should be in meters, **ρ** is the density of the liquid and it should be in kgm^{-3} and $g$is theacceleration due to gravity ($g = 10ms^{-2}$).

Example 1

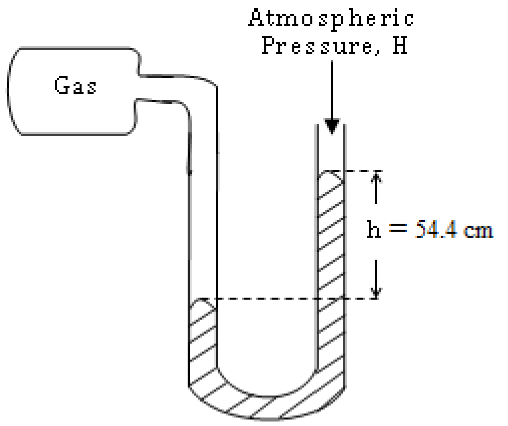
Express a pressure of 75cmHg given that the density of mercury (Hg) is $13600kgm^{-3}$.

Solution

Given: h =75cm, $= \frac{75}{100}$ m $= 0.75$m. $\rho = 13600 Kgm^{-3}$ $g = 10ms^{-2}$	Then from, Pressure = hρg Pressure = (0.75) × (13600) ×10 =102000Pa Thus, 75cmHg =102000Pa.

Example 2

The manometer contains mercury so the atmospheric pressure is 76cm Hg. Calculate the gas pressure in cm Hg and Nm^{-2}.

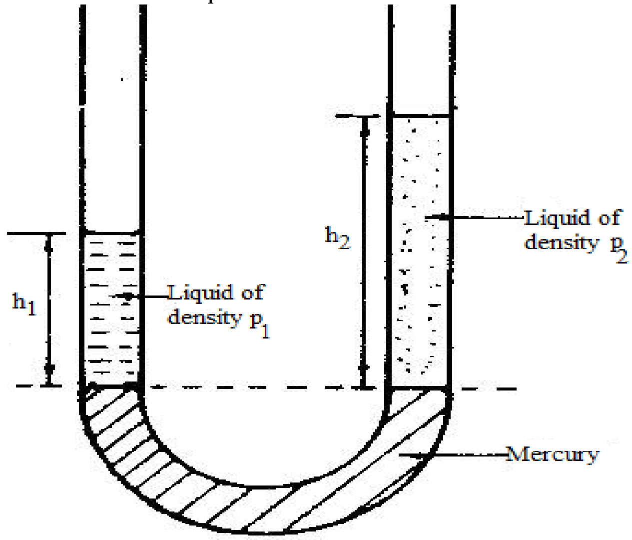


Gas pressure $= H_{atm} + h$ Gas pressure $= 76 + 54.4$ $= 130.4$cmHg	**Expressing in Nm^{-2}** Gas pressure $= (H_{atm} + h)\rho g$ $= \left(\frac{130.4}{100}\right) \times 13600 \times 10$ $= 177344 Nm^{-2}$

Comparison of densities of liquids

(i) Miscible liquids

Here, a third liquid usually mercury is used to separate the two miscible liquids.

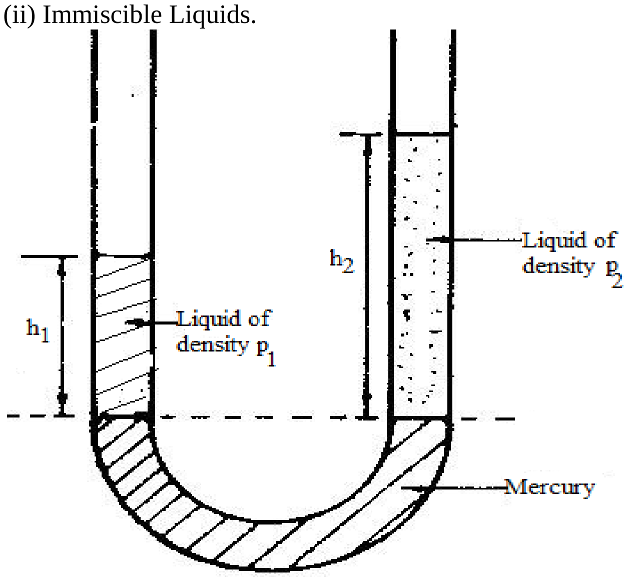


-One liquid is poured in one arm of a manometer and the second liquid poured in the other arm.

-The height of the liquids in the two arms, h_1 and h_2 are measured and recorded.

$$P_A = P_A$$
$$H + h_1\rho_1 g = H + h_1\rho_1 g$$
$$h_1\rho_1 = h_1\rho_1$$

(ii) Immiscible Liquids.

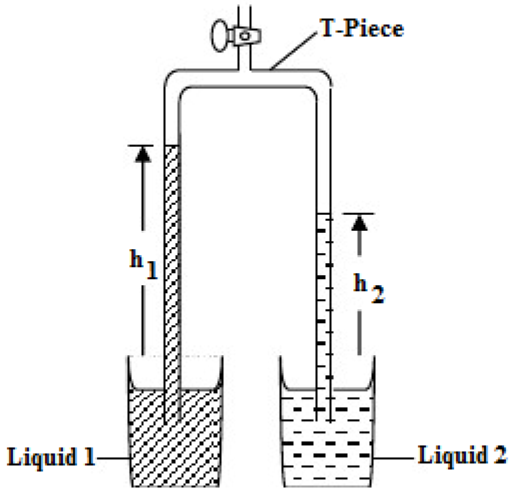


-Pour one liquid in one arm of a manometer and pour the second liquid in the other arm.

-Measure the height of the liquids in the two arms, h_1 and h_2.

$$P_A = P_A$$
$$H + h_1\rho_1 g = H + h_1\rho_1 g$$
$$h_1\rho_1 = h_1\rho_1$$

Comparison of densities of liquids using Hare's apparatus



Liquids of different densities are placed in glass pots as shown above.

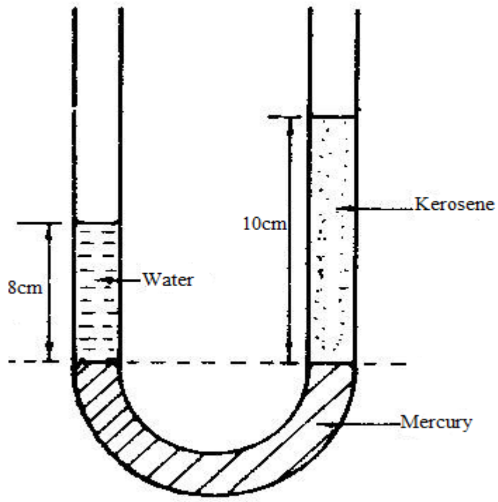
When the gas tap is opened each liquid rises to different height h_1 and h_2.Since they are subjected to the same gas supply,

-The height of the liquids in the two arms, h_1 and h_2 are measured.

$$P_A = P_A$$
$$H + h_1\rho_1 g = H + h_1\rho_1 g$$
$$h_1\rho_1 = h_1\rho_1$$

Example 1

Water and kerosene are placed in U-tube containing mercury as shown above. Determine the density of kerosene?



Pressure of kerosene= Pressure of water (since both tube are open to the atmosphere)

$$P_A = P_A$$
$$H + h_1\rho_1 g = H + h_1\rho_1 g$$
$$h_1\rho_1 = h_1\rho_1$$
$$8(1000) = 10\rho_1$$
$$\rho_1 = 800\ \text{kgm}^{-3}$$

Example 2

The diagram below shows heights to which liquids A and B have risen in an inverted U-tube, when some air has been pumped at P. Find the density of liquid B if that of A is 800 kgm^{-3}.[Ans: $\rho = 640\ \text{kgm}^{-3}$]

Example 3

The atmospheric pressure at the bottom of a mountain is 100000Pa. If the mountain is 800m high, and the density of air is1.25 kgm^{-3}. Find the pressure at the top of the mountain.

Solution:

$$\mathbf{P_{bottom} = P_{top} + h\rho g}$$
$$100000 = P_{top} + 800(1.25)(10)$$
$$P_{top} = 90000\ \text{Pa}$$

EXERCISE:

1. In an experiment to compare density of two liquids, water and spirit were used. The height of water was found to be 8cm and that of spirit was 12cm. Given that the density of water is 1000kgm^{-3}. Find the density of the spirit. [Ans: **666.67kgm^{-3}]**

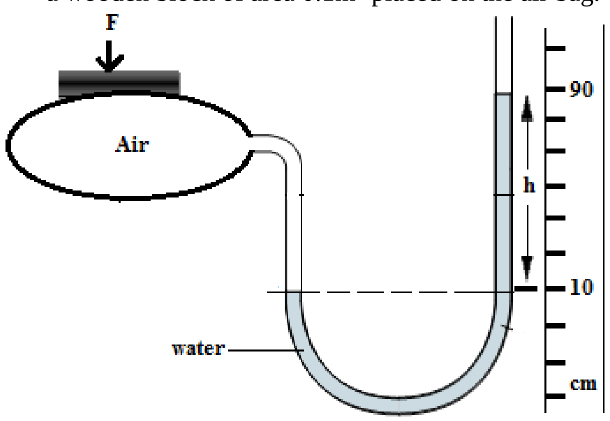
2. An aquarium maker wants to decide between making a glass aquarium and a fibre glass one. The customer prefers a glass aquarium 0.5 m tall. The glass aquarium can withstand a pressure of 4800 Pa and the fibre glass one can withstand 5200 Pa. Which material should the aquarium maker use assuming the density of water is 1000 kg m^{-3} and g = 10 N kg^{-1}?

(*Pressure = ρgh = 1000 x 10 ms^{-2} x 0.5 m = 5000 Pa; he should use fibre glass because it can withstand the pressure*)

3. A mercury barometer shows a reading of 760 mm at sea level. When it is taken to the top of a mountain, the barometer reads 800 mm. Why might the barometer be defective?

(*The barometer should show a lower reading at high altitude because of lower atmospheric pressure. Since the barometer shows a higher reading it is probably defective.*)

4. The diagram below shows an air bag connected to a manometer and used to measure the force F acting on a wooden block of area 0.1m^2 placed on the air bag.



How does h change when:

(i) The manometer is made narrower.

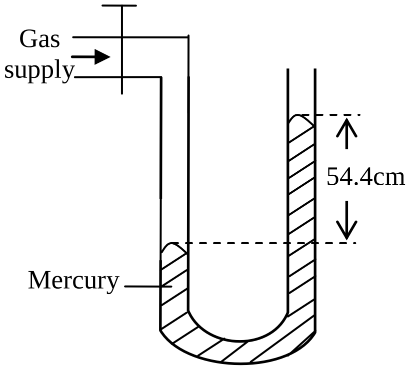
(ii) The liquid is denser than water

(iii) Calculate the value of F

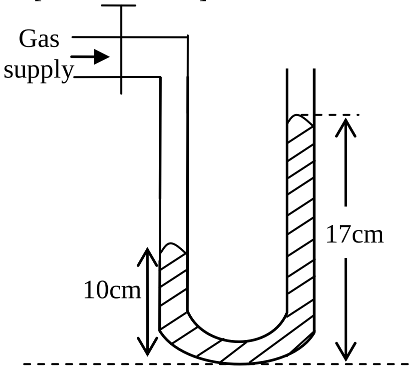
5. (a) How does a manometer help to measure pressure difference?

(b) The manometer tubes below contain mercury and connected to a gas supply. Find the gas pressure.

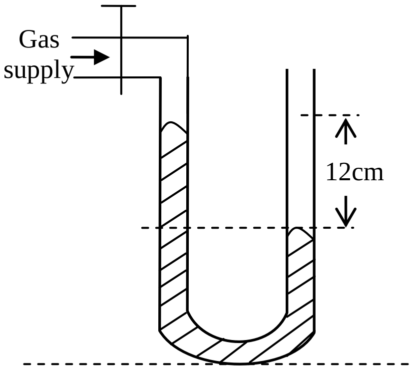
[Atmospheric pressure=103360Pa].[Ans:177344Pa]



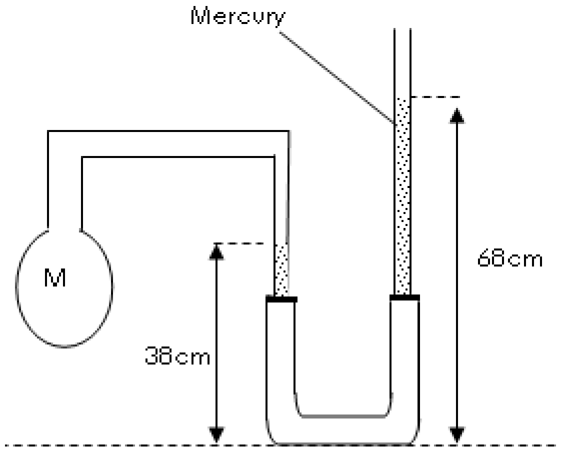
(i) [Ans:109620Pa]



(c)



6. In the figure below, a fixed mass of dry gas is trapped in bulb M.



Determine the total pressure of the gas in M, given that the atmospheric pressure is 760mm of mercury.

A) 114cm Hg B) 106cm Hg
C) 30cm Hg D) 46cm Hg

(c) ATMOSPHERIC PRESSURE

The layer of air surrounding the earth is called the atmosphere.

Atmospheric pressure is the pressure exerted by the weight of air on all objects on the earth's surface.

Atmospheric Pressure depends on altitude.

Atmospheric pressure is inversely proportional to altitude.The density of air above the earth decreases as the altitude increases leading to the decrease of atmospheric pressure at high altitude such as mountain peaks and the viceversa.At sea level, the atmospheric pressure is1.0×10^5Pa or 0.76 mHg.

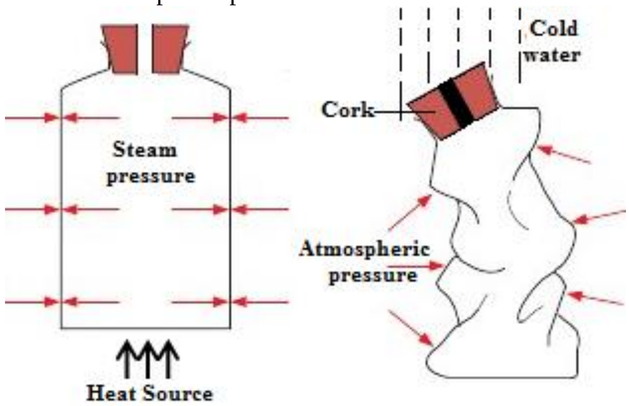
Though the value of atmospheric pressure is large we do not normally feel it because:

(i) Blood pressure is slightly greater than atmospheric pressure.
(ii) Atmospheric pressure acts equally in all directions.

Experiments to Demonstrate Existence of Atmospheric Pressure.

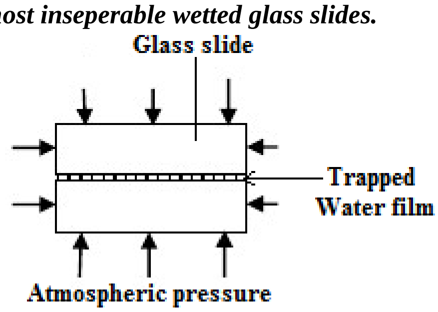
(a) Collapsing Can or Crushing Can Experiment.

If air is removed from the can by a vacuum pump, the can collapses because the air pressure inside becomes less than the atmospheric pressure.



- A small quantity of water is boiled in a can until steam forms.
- The steam drives out all the air inside the can, hence reducing the pressure inside the can.
- The stopper is then tightly fitted onto the can and the heat source removed.
- Cold water is then poured over the can. This causes the steam inside to condense producing water and water vapour at very low pressure.
- The excess atmospheric pressure outside the can causes it to collapse inwards.

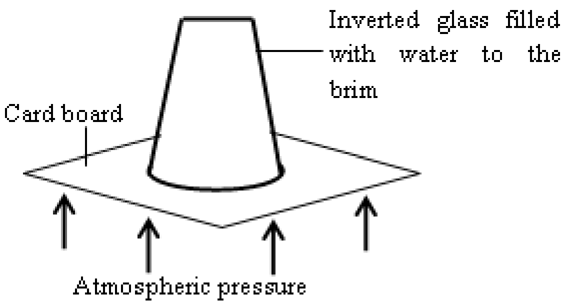
(b) Almost inseperable wetted glass slides.



- One face of a glass block is wetted with a liquid and a second one is intimately placed on it.

- Attempt to move them apart proves difficult. This is because the atmosphere is pressing them together.
NB: The liquid in between helps to expel any air that might be trapped in there.

(c) Inverted glass full of water cover with a card board



Procedure:
- A glass is filled with water to the brim.
- Slide a paper card over the top so that no air is trapped between the card and the water.
- Firmly place your hand over the card, invert the glass and remove your hand carefully.

Observation:
- Water does not pour out of the glass.

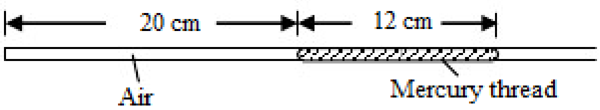
Conclusion:
- Atmospheric pressure keeps the card in place against the weight of water inside.

MEASUREMENT OF ATMOSPHERIC PRESSURE
Atmospheric pressure is measured using the following instruments.
(i) Barometer
(ii) Bourdon gauge

Types of barometers
(b) Simple mercury barometer
(c) Fortin barometer
(d) Aneroid barometer

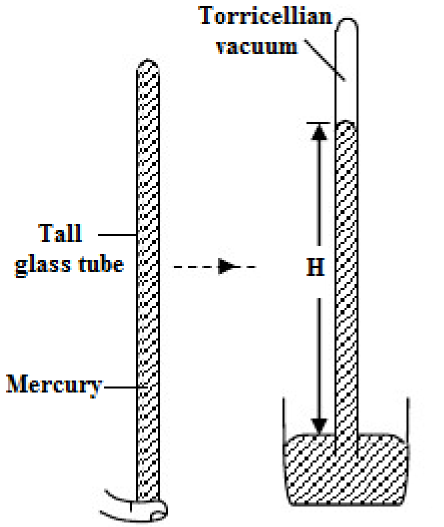
A simple mercury barometer
A barometer is an instrument which measures atmospheric pressure.

Question
The diagram shows a horizontal tube of uniform cross-section closed at one end containing dry air which is trapped by a thread of mercury of length 12 cm.



When the tube is inverted, the length of the air column becomes 23.8 cm. Calculate the atmospheric pressure.

<u>**How to set up a simple mercury barometer in the laboratory**</u>**.(How to measure atmospheric pressure).**

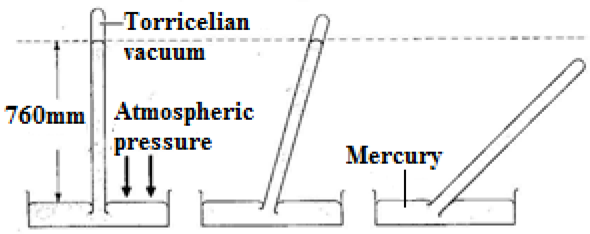


(i) Tube filled with mercury and then inverted **(ii) Tube inveted into a trough of mercury**

- ❖ Fill a graduated glass tube with mercury up to the brim.
- ❖ Cover the open end of the glass tube with a finger and shake the tube to drive out any trapped air bubbles.
- ❖ Invert the glass tube and placed vertically with its open end below the surface of mercury in a beaker or trough and then remove the finger.
- ❖ When the finger is removed, the mercury column falls until it is constant.
- ❖ Measure the vertical height h, of the mercury column in the glass tube above that in the trough and is equal to atmospheric pressure at that place.
- ❖ From the above apparatus, when the air above the mercury in the glass tube is pumped out, the column falls.

Testing the vacuum
If the vacuum is faulty and contains air or water-vapour, the barometer readings are less than the true atmospheric pressure.

Testing for the vacuum of a mercury barometer.
This is done by tilting the tube until at a position when the vacuum either remains or disappears.
If the **vacuum remains**, then **it is faulty** and contains air or water-vapour.



When the tube is tilted as in the diagram, the vertical height of column "h" of mercury remains the same but the length of mercury increases.

When a mercury barometer is taken from sea level to the top of a mountain i.e. low altitude to high altitude, the mercury column falls.
This is because the atmospheric pressure decreases at the top of the mountain. The decrease in atmospheric

pressure is due to density of air decreasing because air is less compressed above.

Effects of Atmospheric pressure.

❖ **Boiling point of liquids.**

Boiling of liquids occur when the vapour pressure from the liquid is equal to the atmospheric pressure. The boiling point of liquids is directly proportional to the atmospheric pressure.

Therefore at high altitudes like mountain peaks, liquids boil at a low boiling point. As a result, cooking takes longer at a high altitude.

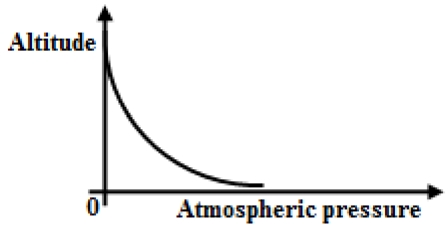
❖ Deep-sea divers must return slowly to the surface because the sudden decrease in pressure when they return fast from deep water is very painful.

❖ Pilots operating at great heights and mountain climbers must have protective headgear to prevent nose bleeding because atmospheric pressure at great height is much smaller tan blood pressure.

Note:

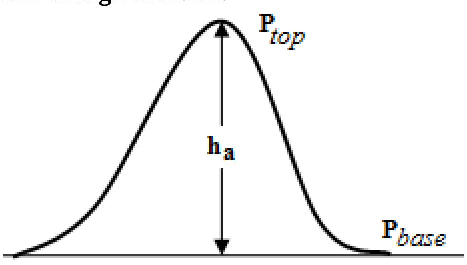
(a) The vertical height of the mercury column remains constant even when the tube is tilted at an angle.
At sea level, $h = 0.76\text{m}$. Thus, atmospheric pressure at sea level is;

$$\textbf{Atm. Pressure} = \mathbf{0,76mHg} = \mathbf{1.014 \times 10^5 Pa}$$
$$= \mathbf{1atm.} \quad = \mathbf{1bar}$$



(b) *It is more convenient to use mercury in barometers than water. This is because the density of water is very low. Therefore in order to sustain the atmospheric pressure, a high volume of water is required and to read the water level would require the use of a ladder.*

Calculating the height of the reading of the mercury barometer at high altitude:



This is calculated from;

Pressure change for air = Pressure change for mercury

$$P_{air} = P_{base} - P_{top}$$

$$h_a\rho_a g = (H_{atm} - h_m)\rho_m g$$

Where: $\mathbf{h_a}$ is the height of altitude or height of the mountain, $\boldsymbol{\rho_a}$ is the density of air, $\mathbf{h_m}$ is the mercury column barometer at that altitude and $\mathbf{H_{atm}}$ is atmospheric pressure at the base of the mountain before rising and $\boldsymbol{\rho_m}$ is the density of mercury.

Example; 1

A barometer is taken to the top of a mountain 440cm high. If the atmospheric pressure is 76cm Hg at sea level, the average density of air = 1.2Kg/m^3 and mercury is 13600Kg/m^3. Calculate the barometer reading.

Solution:

$P_{atm} = 76\text{cm} = \frac{76}{100} = 0.76\text{mHg}$ $\rho_{mer} = 13600\,\text{kgm}^{-3}$ $\rho_{air} = 1.2\,\text{kgm}^{-3}$ $h_{Hg} = ?$ $h_{air} = 440\text{m}$	$\begin{pmatrix}\text{Pressure change}\\ \text{for air}\end{pmatrix} = \begin{pmatrix}\text{Pressure change}\\ \text{for mercury}\end{pmatrix}$ $h_a\rho_a g = (H_{atm} - h_m)\rho_m g$ $h_a\rho_a = (H_{atm} - h_m)\rho_m$ $440 \times 1.2 = (0.76 - h) \times 13600$ $528 = 13600 \times (0.76 - h)$ $\frac{528}{13600} = 0.76 - h$ $h = 0.7212\text{m}$

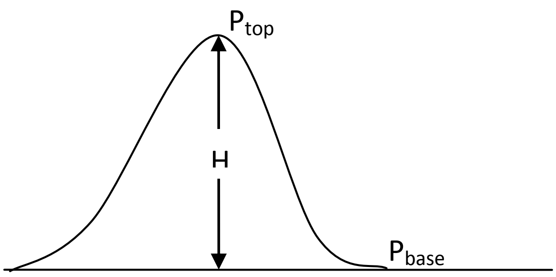
Example; 2

(a) A heavy can full of air at atmospheric pressure sinks in water of density $1000kgm^{-3}$. If the can has a valve that opens at a pressure of 80000Pa. Calculate the depth at which the valve opens.

From; $\mathbf{P = h\rho g}$

$$80{,}000 = 1000 \times 10 \times h$$
$$h = \frac{80{,}000}{10{,}000} \Rightarrow h = 8\text{m}$$

(b) The air pressure at the base of a mountain is 75.0cmHg and that at the top is 60.0 cmHg. Calculate the height of the mountain.



Pressure of air, =Pressure difference due to mercury.

$P_a = P_{base} - P_{top}$
$= 75\text{cmHg} - 60\text{cmHg}$
$= 15\text{cmHg}$
$= 0.15\text{mHg}$

From; $P = h\rho g$
$P_a = 13600 \times 10 \times 0.15$
$= 20400\text{Nm}^{-2}$

But also; $P = \rho_a h_a g$
$20400 = H\rho_a g$
$20400 = 1.25 \times 10 \times H$
$20400 = 12.5H$
$H = 1632\text{m}$

EXERCISE:

1. The pressure difference between the top and the bottom of a mountain is $1.0 \times 10^4\text{Nm}^{-2}$. If the density of air is 1.25kgm^{-3}. Find the height of the mountain. [Ans: 800m]

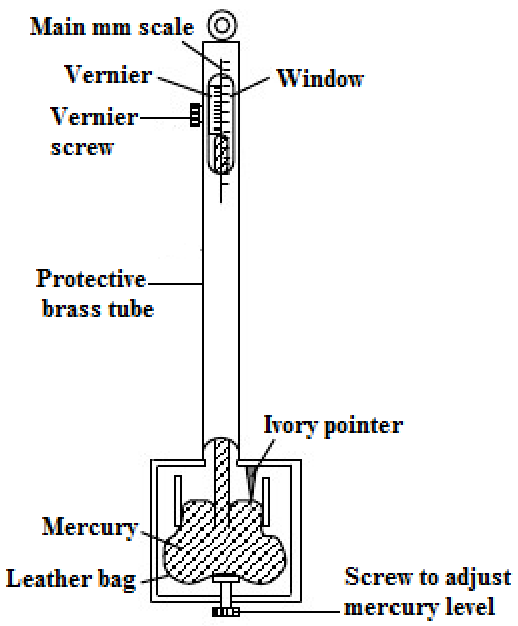
2. A barometer reads 780mmHg at the foot of the mountain which is 450m high. What is the barometer

reading at the top of the mountain.(Density of air is $1.25kgm^{-3}$ and that of mercury is $13600kgm^{-3}$). [Ans: 738.9mmHg]

3. See UNEB 2016P2 Qn.3 (c).
A simple barometer is raised from sea level to a height of 2.5 km. Given that the average air density is 1.25 kg m -3, find the new length of the mercury column in the barometer.

<u>Other types of Barometers.</u>

1) Fortin Barometer

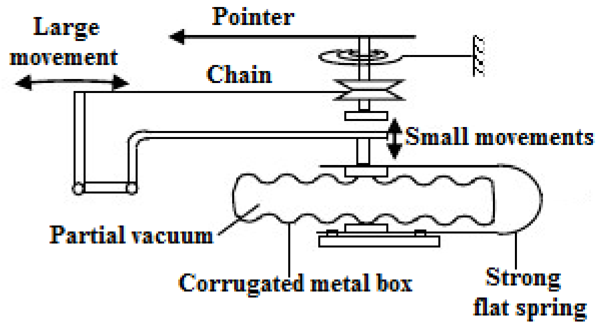


It is constructed like a simple mercury barometer but with a provision for accurate determination of atmospheric pressure.
There is a vernier scale for accurate reading of the mercury level.

2) Aneroid Barometer

It does not use any liquid.

Note: The fact that an aneroid barometer is portable makes it a useful altimeter device to measure altitude in aeroplanes.



- It consists of a sealed flat box (chamber) with flexible walls.
- The box is evacuated but prevented from collapsing by means of a spring.
- The box expands and contracts in response to changes in atmospheric pressure.
- The movements of the box are magnified by a system of levers and transmitted to a fine chain attached to a pointer, which moves along a suitably calibrated scale.

Variation of Atmospheric pressure with Altitude
Atmospheric pressure decreases as altitude increases. However, the decrease is not uniform all through since the density of the air is not uniform. It is higher towards the Earth's surface.

Uses of Barometers
1. Measurement of Altitude: Since atmospheric pressure varies with altitude, barometer can be used to measure altitude (as **an altimeter**).

2. Weather forecast: dry air is denser than humid air and hence exerts higher atmospheric pressure. So, by measuring the atmospheric pressure, weather forecast is possible. High pressure would indicate dry weather while lower pressure would be associated with impending rain.

High Altitude Flying and Deep Diving
When flying at high altitude, one may not breathe properly or may have bleeding in the nose due to reduced atmospheric pressure. In fact, the inside of a high flying plane must be pressurized, i.e kept at 1 atmosphere pressure artificially.
On the other hand, a diver under water experiences a higher pressure than normal and at a great depth nitrogen may be forced into the circulatory system and cause bubbles in the blood on returning to the surface and finally cause death.
So, deep divers should have protective suits with cylinders of compressed air for breathing.

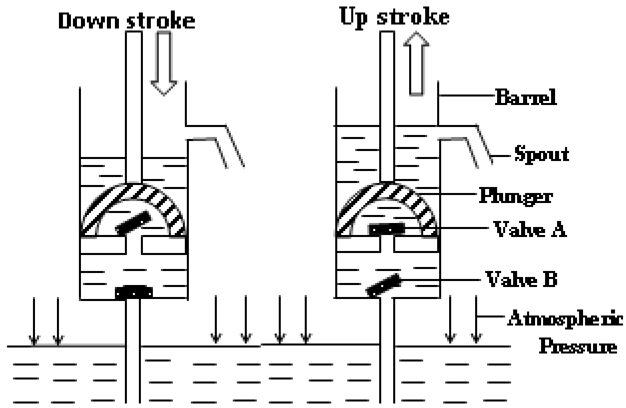
<u>APPLICATIONS OF ATMOSPHERIC PRESSURE:</u>

Importance of atmospheric pressure and Applications of atmospheric Pressure include:

(i) Drinking straw	(ii) Siphon
(iii) Rubber sucker	(iv) Tyre pressure pump
(v) Lift pump	(vi) Water supply system
(vii) Force pump	(viii) Sanction pad

1.<u>THE LIFT PUMP:</u>
Lift pumps are used to raise water from deep underground wells.

<u>Structure</u>
It consists of a long cylindrical barrel, inside which is a plunger (piston). It has two valves one at the entry point to the barrel and the other at the plunger.



<u>Action</u>

The action of the lift pump is explained in terms of what happens when the plunger is moving upwards (up stroke) and when moving downwards (down stroke).

Down stroke.

- Valve B closes due to the pressure on it, while valve A opens due to the pressure exerted by water in the burrel.
- Water the passes upwards through valve A into the area above the plunger.

Up stroke.

- Valve A closes due to the weight of water above it.
- The weight above valve B reduces. This causes the atmospheric pressure acting on the surfsce of water in the well, to push the water up through the pipe into the burrel.
- Consquently, water above the plunger is lifted upwards and it flows out through the spout.

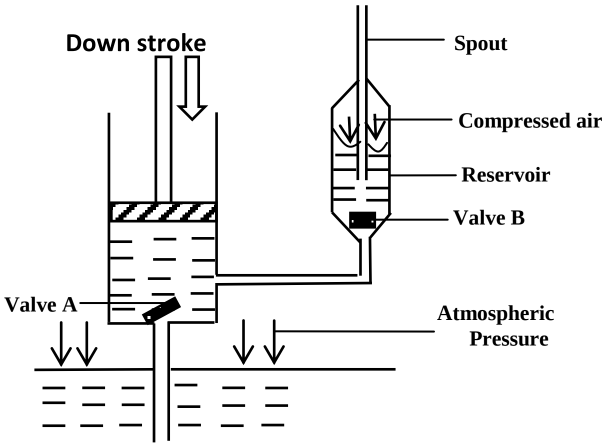
Limitations of the lift pump

It can only raise water to a maximum height of 10 metres. This is because the atmospheric pressure can only support a water column of 10 metres.

2.THE FORCE PUMP:

The force pump is designed to overcome the limitations of the lift pump. It can raise water to heights greater than 10metres.

Structure



Action

The action of the force pump is also explained in terms upstroke and down stroke.

Up stroke.

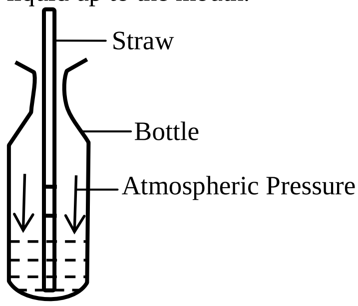
- Valve B closes and the atmospheric pressure forces the water into the barrel through valve A.

Down stroke.

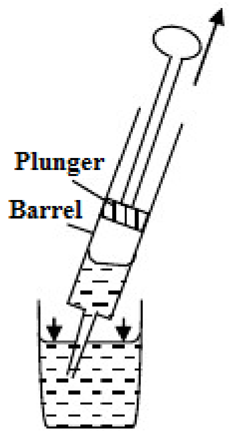
- Valve A closes due to the weight of the water above it.
- The water in the barrel is forced through valve B into the reservoir, C and out of the spout D.
- The air trapped in the reservoir is compressed and as a result, it keeps on pushing the water out of the reservoir through the spout even when in upstroke.

3. DRINKING STRAW

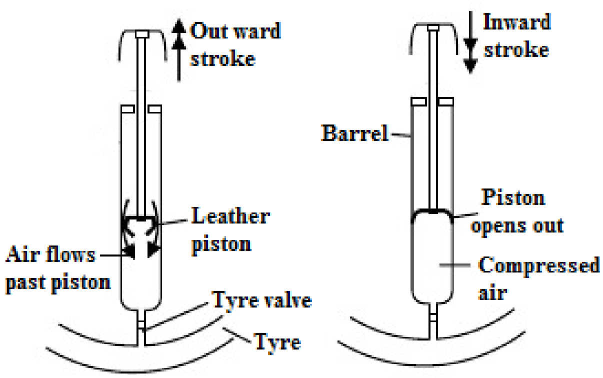
When sucking, lungs expand and air is driven out from the inside of the straw to the lungs.
This reduces the pressure inside the straw.
Then atmospheric pressure acting on surface of the liquid in the bottle is greater than air pressure in straw and so it forces the liquid up to the mouth.



4. SYRINGE

	- When the plunger is pulled outwards, a partial vacuum is created inside the barrel. - So, the atmospheric pressure forces up the liquid into the barrel.

5. BICYCLE PUMP

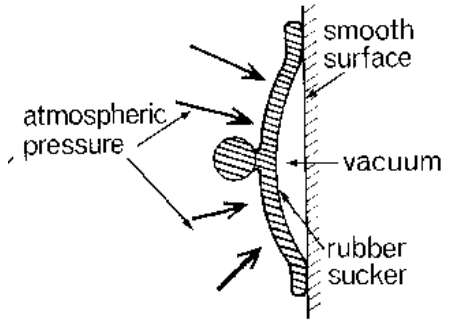


During the outward stroke a partial vacuum is formed between the tyre valve and the piston. So, the atmospheric pressure forces the flexible leather piston to curve in and air is pushed past it into the enclosed part of the barrel, mean while, the air already in the tyre is prevented from flowing out by a tyre valve.

During the inward stroke the compressed air in the barrel opens out the piston and this air is pushed through the tyre valve to the tyre.

6. RUBBER SUCKER

This is circular hollow rubber cap before it is put to use it is moisturized to get a good air seal and firmly pressed against a small flat surface so that air inside in pushed out then atmospheric pressure will hold it firmly against surface as shown below

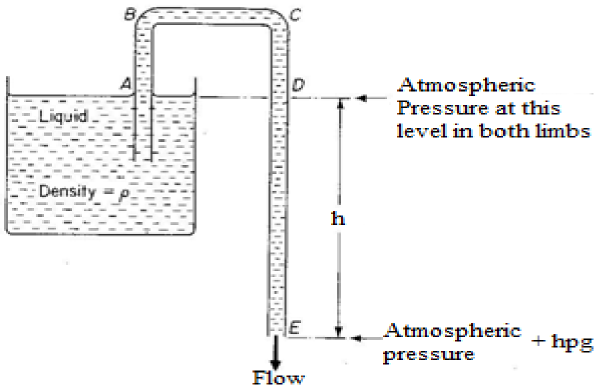


Uses of rubber sucker;

-It is used printing machines for lifting papers to be fed into the printer.

5. THE SIPHON;

This is used to take the liquid out of vessels (eg. Aquarium, petrol tank)



How a siphon works

The pressure at A and D is atmospheric, therefore the pressure at E is atmospheric pressure plus pressure due to The column of water DE. Hence, the water at E can push its way out against atmospheric pressure..

NB: To start the siphon it must be full of liquid and end A must be below the liquid level in the tank.

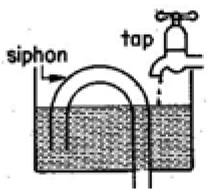
Applications of siphon principle

(a) **Automatic flushing tank**:

This uses siphon principle.

Water drips slowly from a tap into the tank.The water therefore rises up the tube until it reaches and fills the bend

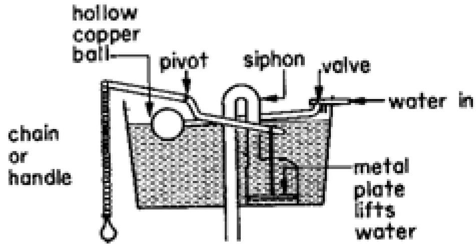
In the pipe siphon action starts and the tank empties (the water level falls to the end of the tube).The action Is then repeated again and again.



(b) **Flushing tank of water closet:**

This also uses the siphon principle.

When the chain or handle is pulled, water is raised to fill the bend in the tube as shown below:



The siphon action at once starts and the tank empties.

EXERCISE:

1. Using Hare's apparatus, with water another liquid A in a container, water rises to a height of 60cm and liquid A rises to a height of 48cm. If liquid A weighs 5g, determine the volume of liquid A.

2. A tank is filled with water to a depth of 3 m. What is the pressure at the bottom of the tank due to the water alone? (d_{water} = 1000kgm^{-3}).
   A. 30 kPa B. 15 kPa
   C. 3 000 Pa D. 1 500 Pa

3. A diver is searching for treasure at a depth of 40m below the surface. What is the pressure exerted on the diver. (P_{atm} = 100,000 N/m^2; d_{water} = 100 kg/m^3)
   A. 400 000 N/m^2 B. 200 000 N/m^2
   C. 500 000 N/m^2 D. 50 000 N/m^2

4. What is the pressure at the bottom of a 3 km deep oil well filled with oil of density 860kg/m^2?
   A. 5 400 kPa B. 1 080 kPa
   C. 10 800 kPa D. 25 800 kPa

5. What is the total pressure on a fish swimming in the sea at a depth of 2 m below the surface? (d_{sea} = 1 125 kg/m^3, P_{atm} = 101 300 Pa)
   A. 22.5 kPa B. 123.8 kPa
   C. 32.6 kPa D. 132.5kPa

6. The piston of a hydraulic automobile lift has 0.48 m^2 area. What pressure is required to lift a car of mass 1 200 kg?
   A. 25 kPa B. 12 kPa
   C. 30 kPa D. 60 kPa

7. In the hydraulic lift, the area of the smaller piston is one fourth that of the larger piston. If 40 N force is applied on the smaller piston, what is the force on the bigger piston?
   A. 640 N B. 160 N
   C. 10 N D. 320 N

8. In a hydraulic press a force of 40 N is applied to a piston of area 0.1m^2. The area of the other piston is 4m^2. What is the pressure transmitted through the liquid and the force on the other piston?
   A. 800 N/m^2; 3 200 N B. 400 N/m^2; 1 600 N
   C. 400 N/m^2; 400 N D. 800 N/m^2; 1 600 N

9. A hydraulic jack is made with a small piston 12 cm^2 that is used to move a large piston 108 cm^2. If a man can exert a force of 270 N on the small piston, how heavy a load can he lift with the jack?
   A. 1 215 N B. 2 430 N
   C. 4 860 N D. 3 645 N

10. A hydraulic press has a large piston with a cross-sectional area of 250 cm^2 and a small piston with a cross-sectional area of 1.25 cm^2. What is the force on the large piston when a force of 1 250 N is applied to the small piston?
A. 375 000 N   B. 125 000 N
C. 500 000 N   D. 250 000 N

11. In a liquid, pressure is,
A. Transmitted in a specific direction
B. Transmitted in all direction.
C. Decreased with depth
D. Decreased with density

12. Pressure in a liquid is independent of the,
A. density of the liquid
B. depth below the surface of the liquid
C. pressure exerted on the surface of the liquid above
D. cross-sectional area and the shape of the vessel containing the liquid.

13. A rectangular block of metal weighs 3N and measures (2 x 3 x 4) cm^3. What is the greatest pressure it can exert on a horizontal surface.
A. 5.0×10^3 Nm^{-2} B. 3.75×10^3 Nm^{-2}
C. 2.5×10^3 Nm^{-2} D. 7.5×10^{-1} Nm^{-2}

14. The mass of a cuboid of dimensions 4 m x 2 m x 3 m is 48 kg. The minimum pressure it can exert is,
A. 20 Nm^{-2} B. 40 Nm^{-2}
C. 60 Nm^{-2} D. 80 Nm^{-2}

15. In a hydraulic machine,
A. an object displaces its own weight of fluid
B. the pressure transmitted in the fluid is the same in all directions.
C. the volume of fluid compressed is proportional to the applied force.
D. an object experiences an upthrust equal to the weight of fluid displaced.

16. Which one of the following is true about a manometer?
(i) It uses mercury because mercury is a good conductor of heat.
(ii) It is used for measuring gas pressures.
(iii) The maximum height of mercury it can support is 760mm.
A. (i) and (ii) only   B. (i) and (iii) only
C. (ii) only   D. (ii) and (iii) only.

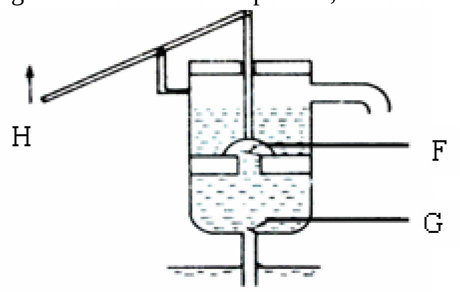
17. What is 730mm Hg in Nm^2 ?
A. $\frac{13600 \times 1000 \times 10}{730}$ B. $\frac{13600 \times 730x10}{1000}$
C. $\frac{13600 \times 730}{1000 \times 10}$ D. $\frac{13600 \times 10}{1000 \times 730}$

18. A metal cylinder contains a liquid of density 1100 kg/m^3. The area of the base of the cylinder is 0.005 m^2 and the height of liquid is 5m. Calculate the force exerted by the liquid on the base of the cylinder.
A. 27.5 N   B. 55 N
C. 220 N   D. 275 N

19. Which one of the following are true about a hydraulic brake?
(i) It uses water.
(ii) The brake pedal is connected to the master cylinder.
(iii) The return spring returns the brake drum in position.
(iv) The return spring returns the brake shoe in position.
A. (i) (ii) and (iii)   B. (ii) (iii) and (iv)
C. (ii) and (iv)   D. (iii) and (iv) only.

20. Which one of the following statements is false? The pressure in a liquid.
A. at any one point in a liquid would not change even when more liquid is added.
B. at any one point depends only on the depth and density.
C. at any one point acts equally in all directions.
D. increases with depth.

21. When the handle, H, of the force pump shown in figure below is moved upwards, the valves at.



A. F and G will both close
B. F and G will both open
C. F will close, and G will open
D. F will open and G will close

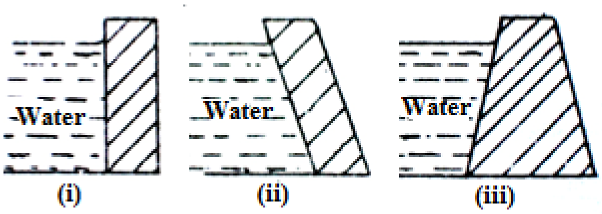
22. A rectangular block of dimensions 4 cm x 2 cm x 1cm exerts a maximum pressure of 200 Nm^{-2} when resting on a table. Calculate the mass of the block.
A. 4 g   B. 16 g
C. 40 g   D. 400 g

23. Calculate the increase in pressure which a diver experience when he descends 30m in sea water of density 1.2×10^3.
A. 3.0×10^2 Nm^{-2} B. 1.2×10^4 Nm^{-2}
C. $3.6x10^4$ Nm^{-2} D. 3.6×10^5 Nm^{-2}

24. In a hydraulic press, the area of the piston on which the effort is applied is made smaller in order to,
A. facilitate the movement of the piston downwards
B. transmit a force as large as possible to the load
C. transmit pressure equally through out the liquid
D. obtain a pressure as large as possible.

25. Which of the following is true about pressure in liquids? It
A. increases with the surface area of the liquid
B. is directly proportional to the depth
C. depends on the shape of the container
D. is the same at equal depths in all liquids.

26. The diagrams below show the possible shapes of water dams.



Which shape(s) is /are preferable?

A. (i) and (ii) only B. (ii) and (iii) only
C. (i) and (iii) only D. (iii) only

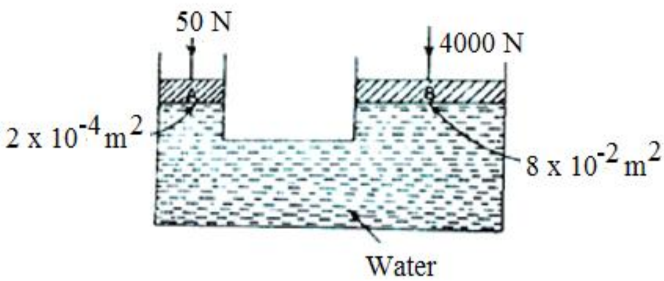
29. Calculate the increase in pressure which a diver experiences when he descends 30m in the sea water of density $1.2x10^3kgm^{-3}$

A. $3.0 \times 10^2Nm^{-2}$ B. $1.2 \times 10^4Nm^{-2}$
C. $3.6 \times 10^4Nm^{-2}$ D. $3.6 \times 10^5Nm^{-2}$

30. The pressure exerted by a gas decreases when its volume is increasing at a constant temperature because the molecules

A. move faster
B. move closer to one another
C. hit the walls more often
D. hit the walls less frequently

31. Forces of 50N and 400N are applied to pistons A and B respectively as shown below.



The areas of cross-section of A and B are 2×10^{-4} m^2 and8 x $10^{-2}m^2$ respectively. Which of the following is not true?

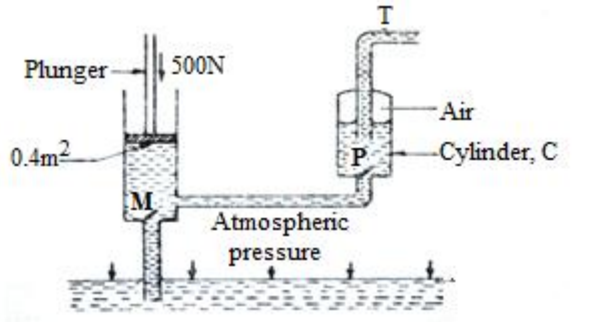
A. Both pistons A and B remain at the same level
B. The upthrust on piston B is equal to 20000N.
C .The pressure exerted on the water by piston B is $5x10^4Nm^{-2}$.
D. Piston B is going to move upwards

Paper II Questions.

1. **(a)** **(**i) State the **principle of transmission of pressure** in fluids.
(ii) Give one assumption on which the principle is based.
(iii) State two application of the principle.
(iv) In a hydraulic press the smaller piston has a diameter of 14 cm while the larger has a diameter of 280 cm. If a force of 77 N is exerted on the smaller piston, calculate the force exerted the larger piston.

(b) With a help of diagram, describe how hydraulic brake works.

27. (a) Explain why large water reservoirs are much wider at the base than at the top.
(b) The Figure below shows the structure of a force pump.



(i) Describe the action of the pump.
(ii) If a downward of 500 N is exerted of the plunger whose surface area is 0.4 m^2, calculate the pressure which forces water into cylinder C.

28. **(a)**Define term **pressure** and state its unit.
(b) (i) Describe how a simple mercury barometer can be set up to measure the atmospheric pressure.
(ii) The difference between the atmospheric pressure at the top and bottom of a mountain is 1×10^4 N m^{-2}. If the density of air is 1.25 kgm^{-3}, calculate the height of the mountain.

29. Hydraulic press machine is used to raise a load W placed on a piston of cross-sectional area of $100cm^2$ by using an effort of 20N at a piston of cross-sectional area of $2cm^2$.Calculate the;
(i) Pressure transmitted through the liquid [P=100000Pa]
(ii) Load, W. [W=1000N]

30. A force of 100N is applied on a small piston of area $0.002m^2$. Find the maximum load that can be lifted by a piston of area $0.8m^2$.

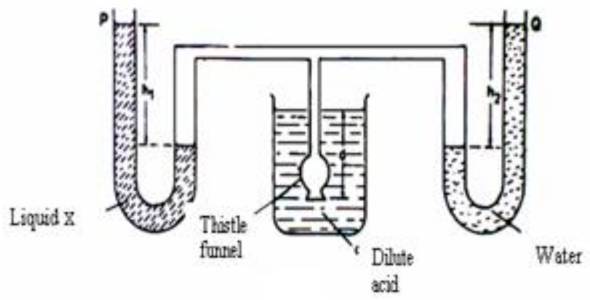
31. Calculate the pressure at the bottom of a swimming pool 1000cm deep.{density of water = $1000kgm^{-3}$}

32. A diver dives to a depth of 20m below the surface of sea water of density $1200kgm^{-3}$. Calculate the pressure experienced.

SECTION B

33. **(a) (i)**Define **pressure** and state its units.
(ii) With the aid of a diagram, describe how you would show that the pressure of a liquid is in dependent of cross-sectional area and shape of a container.

(b) Two manometers P and Q contain a liquid X, and water respectively at the same level. They are then connected to a thistle funnel covered with a rubber membrane as shown in figure 9.23.



34. When the thistle funnel is lowered into a beaker containing a dilute acid of density 1200 kgm^{-3}, the heights h_1 and h_2 are 15 cm and 12 cm respectively. Find the:
(i) Ratio of the density of liquid X to that of water,
(ii) Depth d of the thistle funnel below the surface of the dilute acid.

35. Explain why a ship floats in water although it is made mainly of metal.

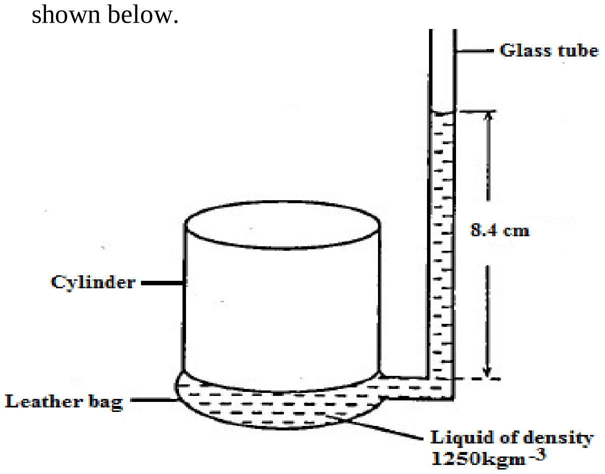
36. **(a) (**i) State the principle of transmission of pressure in fluids.
(ii) Give one assumption on which the principle is based.
(iii) State two application of the principle.

37. **(a)** In a hydraulic press the smaller piston has a diameter of 14 cm while the larger has a diameter of 280 cm. If a force of 77 N is exerted on the smaller piston, calculate the force exerted the larger piston.
(b) With a help of diagram, describe how hydraulic brake works.
(c) Explain why large water reservoirs are much wider at the base than at the top.

38. **(a)** Define term pressure and state its unit.
(b) (i) Describe how a simple mercury barometer can be set up to measure the atmospheric pressure.
(ii) The difference between the atmospheric pressure at the top and bottom of a mountain is 1×10^4 Nm^{-2}. If the density of air is 1.25 kgm^{-3}, calculate the height of the mountain.

39. (a) With a diagram, demonstrate how pressure in liquids increases with increase in depth. (3 marks)
(b) Describe with the aid of a labeled diagram, how a force pump works. (4 marks)
(c) State one factor that determines the height to which water is risen in a force pump. (1 mark)
(d) Explain why it may be difficult to suck a soda using a straw which is a hole along its column. (2 marks)

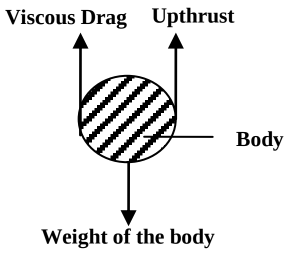
(e) A leather bag is filled with a liquid of density 1250kgm^{-3} and attachedto a vertical glass tube. When a cylinder of radius 0.78m is placed on theleather bag, the liquid rises in the glass tube by 8.4cm as shown below.



Calculate the weight of the cylinder.(4 marks)

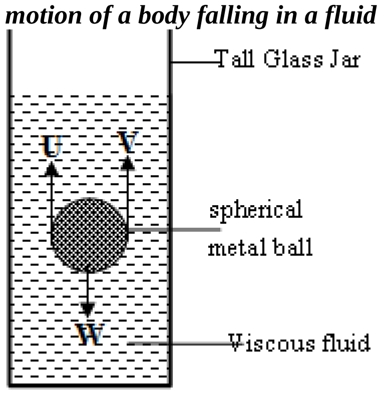
MOTION IN FLUIDS

When a body falls through a fluid it will be acted on by three forces namely:
(i) Weight of body: down ward direction towards earth.
(ii) Up thrust: upward direction.
(iii) Viscous force; direction opposite to that of motion



Direction of motion
The direction of motion is determined by direction of the viscous force, which is a force that opposes motion like in the above body the direction of motion is down ward because the viscous force is acting in upward direction.

Describing motion of a body falling in a fluid



-At first,$\mathbf{W > (U + V)}$**.** The body thus experiences a net down ward force(resultant force, F) which makes it accelerate down wards. This accelerating force is given by the equation: $\mathbf{F = W - (v + u)}$ **Or** $\mathbf{F = W - v - u}$

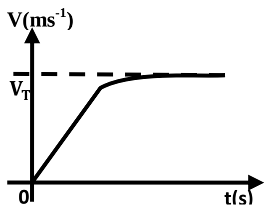
-As the body continues to fall, its velocity increases, the viscous drag increases and reduces the acceleration.
A point is reached when, $\mathbf{W = (U + V)}$ and the resultant force on the body becomes zero:

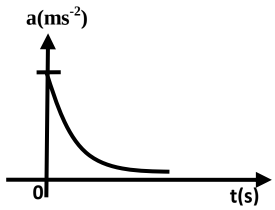
$$\mathbf{0 = W - (v + u)} \text{ Or } \mathbf{0 = W - v - u}$$

- By Newtons 1st law, the body attains a maximum uniform velocity called **terminal velocity** and falls with this constant velocity called until it lands.
Terminal velocity is the uniform velocity attained by a body falling through a fluid when the net force on the body is zero such that:
Weight = Viscous force + up thrust

Note: The same process occurs when a **parachutist** jumps from a high flying plane.

Velocity and acceleration graphs for a body falling in a fluid.





BERNOULLI'S PRINCIPLE

It states that when the speed of the fluid increases, the pressure in the fluid decreases and vice versa.

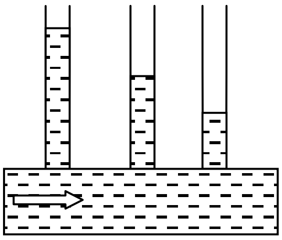
For an incompressible non viscous liquid, the kinetic energy per unit volume plus the potential energy per unit volume plus the pressure is constant assuming stream line flow.   K.E + P.E + Pressure = constant

Liquids flowing in a pipe have three kinds of energies, namely;
- ✓ kinetic energy
- ✓ potential energy
- ✓ pressure energy

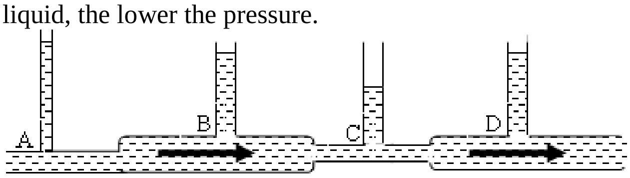
the sum of these three energies is a constant.

a) Liquid

The speed of a liquid e.g. water is greater at the narrow part of the pipe (constriction) and lower at the wider part. This is because since liquids are incompressible the same volume of liquid flows at a wider part as that at a narrower part at the same time. Hence it has to flow faster at a narrower part to cover the longer distance at the same time.
Since potential energy is constant at the constriction the speed is higher and hence kinetic energy is also higher and the pressure falls.
At the wider part water flows slower and the pressure is high.



When the liquid flows through the uniform tube, the level goes on decreasing as shown in the diagram, the faster the liquid, the lower the pressure.



Pressure is highest at the wider part B since the velocity at B is lowest.
Pressure falls at C (constriction) because the speed is highest. That is why water flows very fast out of tap partly blocked by a finger.
Also that is why a river even on a horizontal ground flows faster in some places and slower in others.

The pressure falls in the in the narrow part C but rises again in the wider part D. This is because, since C is narrow, the speed at which the liquid moves through it is higher, hence the fall in pressure.

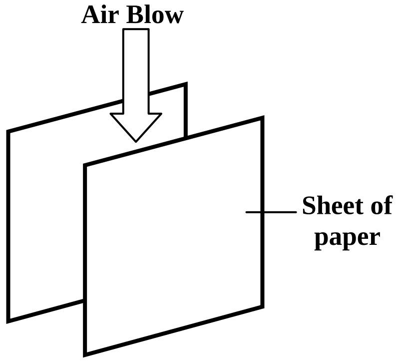
Note:

	Wide section	Narrow section
Stream lines	Far apart	Close together
Velocity	Low	High
Pressure	High	Low

b) Gases

Moving air has a lower pressure than still air. When two large vehicles pass each other, a force is experienced. This is because the moving air between them is at lower pressure, then the pressure outside pushes them.

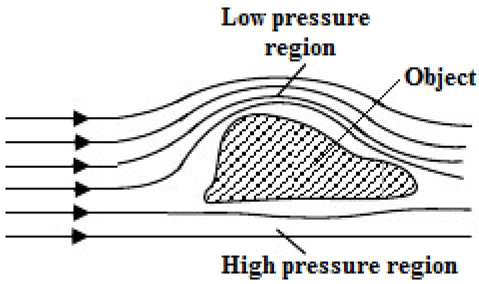
Bernoulli Effect in an air stream can be shown by blowing air between two sheets.



When air is blown the two sheets come together because the air between them moves faster resulting in decrease of pressure between them. This illustrates the **sunction effect.**

Relationship between Pressure, Velocity and Closeness of streamlines

A streamline is a path where molecules have steady speed and each molecule retraces the path of the one directly ahead of it. Where the streamlines are close, the velocity of the fluid is high but the pressure is low, and vice versa. This was discovered by a scientist known as **Bernoulli.**



The diagram below shows air flowing past an object. The shape of the object makes the air above it to flow faster and at reduced pressure than that passing below. So the streamlines above are closer.

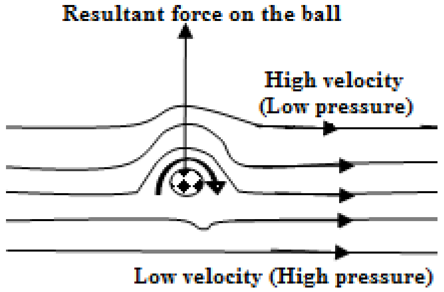
Application of Bernoulli's principle

(i) **Pressure Sprays:** When the fluid comes out of a jet, the speed increases as the pressure decreases.

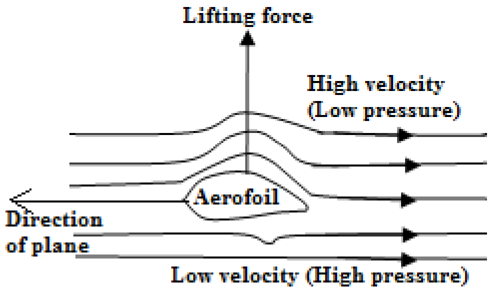
At the jet the gas comes out at high speed so the pressure is low at the jet. This results in air to be drawn in.

Inside a container of sprays e.g. perfumes, insecticides etc there's a very large pressure. This forces the liquid through a narrow opening (jet) producing low pressure at the jet, since the liquid flows faster at the jet. Atmospheric pressure from outside forces air at the jet to equalize pressure.
The air breaks the liquid into fine drops which are driven forward.
Other applications of low pressure at the jet include; the carburetor, Filter pump, inject pump and Bunsen burner.

(ii) **Spinning ball**: As the ball rotates or spins, it opposes air at the lower surface creating low velocity air of high pressure. The air above the ball is dragged by the ball spin creating high velocity air of low pressure. The pressure difference makes the ball to curve upwards and rise.



(iii) **Taking off of an air craft (Aero foil):** An aero plane wing called aero foil is shaped so that air has to travel farther and so faster on the top than underneath. This results in a pressure difference that causes a resultant up ward force on the wing, thus enabling the aero plane to take off.



(iv) **Attraction between two large highly speeding vehicles passing each other**. **(<u>The Sunction Effect</u>).**

When two large vehicles pass each other, a force of attraction is experienced. **This is because**:
The speeding vehicles drag layers of air along with them. As these layers of air pass each other at high speed, they cause a pressure decrease.
This results in the vehicles being pushed towards each other.

FLUID FLOW

A **fluid** is a liquid or gaseous substance that can flow.

Fluid Friction

Fluid Friction is a retarding force which acts on a body moving through a fluid.

It is due to the internal friction existing between layers of fluids of a liquid in motion. It is caused by the attraction between the molecules of one layer and the molecules of another layer. The frictional resistance of a fluid (liquid or gas) opposing motion of a body moving through it is called viscosity.

Factors which determine the magnitude of fluid friction.

(i) Unlike friction between solids' viscosity is proportional to the surface area and the velocity of the object moving through the fluid.

(ii) *Nature of fluid*. Viscosity depends on the type of fluid for example glycerin, engine oil, and natural honey flow much less easily from a vessel than liquids such as petrol, paraffin and water.

(iii) *Temperature*: Viscosity of liquids decreases as a temperature of liquid increases while that of gases increases with temperature.

NB: *Liquids which have high viscosity e.g. glycerin, engine oil are called vicious liquids and are used to make lubricants.*

Types of fluid flow.

There are two types of fluid flow namely:

i) Stream line flow
ii) Turbulent flow

When a water tap is opened slightly, the water oozes out slowly in form of a thin smooth orderly stream. As the tap is opened further, eventually the water flows fast and the order disappears. Thus, by changing the velocity, the flow changes from one kind to another.

The orderly flow is termed the **streamline flow**. In such flow the liquid molecules move in layers and do not cross from layer to another. This happens at low speeds of flow. The disorderly flow at high speeds is termed as **turbulent flow**. Here the liquid no longer flows in layers and the movement of the molecules is in all directions.

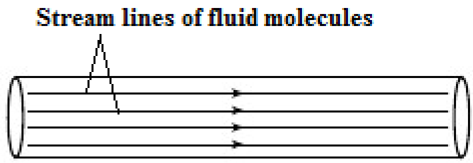
(i) Stream line flow or Steady flow or Laminar flow

<u>Is the type of fluid flow where all the fluid particles that pass a given point follow the same path at the same speed.</u>

A streamline is a direction of motion of molecules in a given layer. Stream line flow occurs where the slope falls gently so that the fluid flows slowly and uniformly.

It is obtained by making the;

✓ Diameter of the pipe wide
✓ Fluid flow slowly and uniformly.

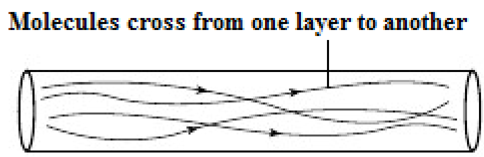


(ii) Turbulent flow

<u>Is type of fluid flow in which the speed and direction of the fluid particles passing any given point vary with time.</u>

Turbulent flow occurs where the slope is so steep, such as at a water fall and when there is a constriction.
Due to constriction or steep slope, water tends to flow very fast and so disorderly.
It is obtained by making the;

✓ Diameter of the pipe narrow.
✓ Fluid flow very fast and disorderly, by lying the pipe steeply.

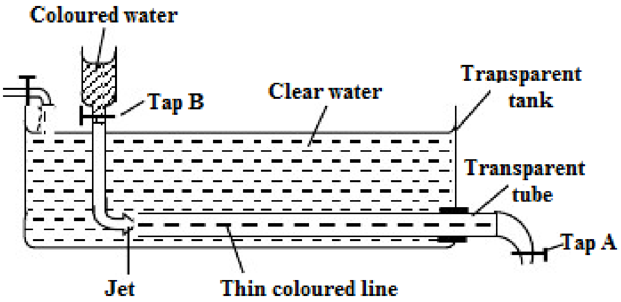


Differences between streamline and turbulent flow.

Stream line flow	Turbulent flow
The fluid flows very slowly	The fluid flows very fast
The fluid layers or	The fluid layers mix

planes do not mix	
The velocity of each layer is uniform in terms of direction and magnitude at any point.	The velocity varies at any point in terms of magnitude and direction.
Is due to slope falling gently so that the fluid flows slowly and uniformly throughout.	Is due to steep slope or constriction so that water flows very fast and disorderly throughout.

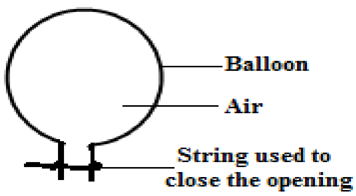
Demonstration of Streamline and Turbulent Flow



- A transparent tank, fitted with a horizontal transparent tube is filled with water from a tap. Tap A controls the rate of flow through the horizontal tube while tap B opens for the coloured liquid.
- Tap A is opened, first slightly and then B is opened to release some coloured liquid.
- Tap A is progressively opened further.

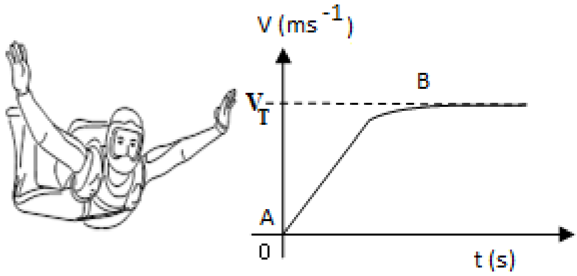
Observation:
At first a thin coloured line is seen in the horizontal tube. This is streamline flow. However, as A is opened further, the coloured line disappears and instead the colour fills the whole tube. The flow has now become turbulent.

Question 1:
(a) What is meant by the term **Upthrust**?
(b) The figure below shows an inflated balloon moving downwards with uniform velocity in air. The forces acting on it are, its weight (W), up thrust (U) and air resistance (F).



(i) Copy the diagram and on it, show all the forces acting on the balloon.
(ii) Write an equation for the net force on the balloon.
(iii) If the string is cut and the air is allowed to escape, explain how the resulting motion of the balloon comes about.

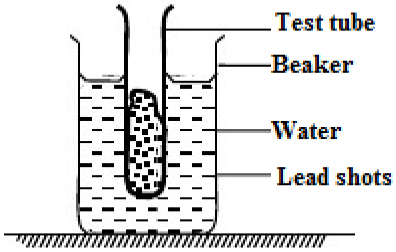
Question 2:
Fig. (a) Shows a free-fall parachutist falling vertically downwards. Fig. (b) Shows how the speed of the parachutist varies with time.



(a)
(i) State the forces acting on the parachutist.
(ii) State the initial value of the acceleration of the parachutist.

(b) (i) Explain why the acceleration decreases from A to B.
(ii) Explain why the parachutist falls at a constant speed after B.

Question 3:
The figure below shows a tube whose cross-section area is 50×10^{-4} m^2 loaded with lead shots till its total mass is 3×10^{-2} kg.

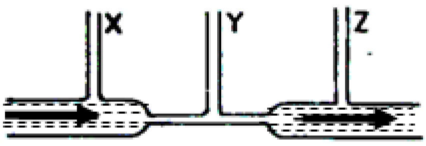


(a) To what depth will the tube sink?
(b) The length of the tube submerged and the level of the water are noted. State what happens to the length of the tube submerged and the level of the water in the beaker when
(i) some lead shots are removed from the beaker.
(ii) the temperature of the water is increased.

Question 4:
In a river, turbulent flow occurs:
(i) At the water falls
(ii) Where there is a narrow opening.
(iii) Where the river is wide and deep.

A. (i) only. B. (iii) only.
C. (ii) and (iii) only. D. (i) and (ii) only.

Question 5:
A uniform tube with a narrowed middle part has three identical manometers attached to it as in the figure below.



If a steady flow of a liquid is maintained in the direction indicated by the arrows, the height of the liquid will be.
A. greatest in X and Y B. greatest in Y
C. greatest in Z D. equal in X, Y and Z

SINKING AND FLOATING

(a) ARCHIMEDE'S PRINCIPLE

Upthrust is an upward force due to the fluid resisting being compressed. When any object is immersed or submerged into fluid its weight appears to have been reduced because it experiences an up thrust from the fluid.

Upthrust is also referred to as the apparent loss of weight in the body.

***The apparent weight** (weight of the body in a fluid) is less than the actual weight of the body(weight of the body in air) because when the body is immersed it experiences an up thrust.*

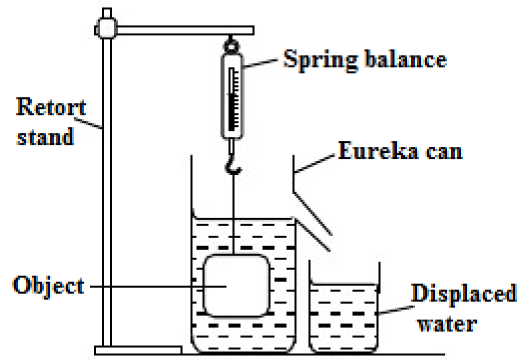
$$\begin{bmatrix}\text{Apparent loss}\\ \text{in weight}\end{bmatrix} = \begin{bmatrix}\text{Weight of}\\ \text{body in air}\end{bmatrix} - \begin{bmatrix}\text{Weight of}\\ \text{body in fluid}\\ \text{or } \begin{pmatrix}\text{Apparent}\\ \text{weight}\end{pmatrix}\end{bmatrix}$$

$$\mathbf{Upthrust, U} = \mathbf{W_a - W_f}$$

Archimede's principle states that when a body is either wholly or partly submerged in a fluid the up thrust is equal to the weight of fluid displaced.i.e

$$\boldsymbol{Upthrust} = \begin{pmatrix}\textbf{Weight of}\\ \textbf{displaced fluid}\end{pmatrix} = (\boldsymbol{V_f \rho_f})\boldsymbol{g}.$$

Experiment: To verify Archimedes principle



❖ Weight W_a of object in air

An object is weighed in air using a spring balance to obtain Wa.

❖ Weight W_w of object in water

The object is weighed when completely immersed in water using a spring balance to obtain W_w and the displacement water collected in beaker as shown below.

❖ Weight of displaced water

By using a spring balance the beaker is weighed with the displaced water when it's empty

❖ Up thrust "U" = $W_a - W_w$

It is found that weight of displaced water is equal to up thrust. Thus Archimedes' principle.

Calculations involving Archimedes principle

For any calculation involving Archimedes' principle the following should be noted:

(i) The body should be completely immersed or submerged.

(ii) The weight of the body when completely immersed or submerged is called its apparent weight, $\boldsymbol{W_f}$.

(iii) According to Archimedes Principle;

$$[\text{Upthrust}] = \begin{bmatrix}\text{Weight of}\\ \text{displaced fluid}\end{bmatrix} = \begin{bmatrix}\text{Apparent loss}\\ \text{in weight}\end{bmatrix}$$

$$[\boldsymbol{Upthrust}] = \boldsymbol{V_f \rho_f g} = \boldsymbol{W_a - W_f}$$

Where V_f *and* ρ_f are the volume and density of the displaced fluid.

For a body completely immersed or submerged fully, according to the displacement method,

$$\begin{bmatrix}\textbf{Volume of}\\ \textbf{immersed boddy}\end{bmatrix}; \mathbf{V_b} = \begin{bmatrix}\textbf{Volume of}\\ \textbf{displaced fluid}\end{bmatrix}; \mathbf{V_f}$$

Weight = mg and m = $V\rho$ where "m" is mass in kg, V is volume, and ρ is density.

But up thrust = weight of displaced fluid.

= m_f g (where m_f is mass of displaced fluid)

Up thrust = $\boldsymbol{(V_f \rho_f)\, g}$

Where "$\mathbf{V_f}$" is volume of displaced fluid "ρ" is density of fluid.

Example: 1

A glass blocks weight 25N. When wholly immersed in water, the block appears to weigh 15N. Calculate the Up thrust.

<u>Solution</u>

$W_a = 25N; W_f = 15N;$

$\text{Upthrust} = W_a - W_f$

$= 25 - 15$

<u>Upthrust = 10N</u>

Example 2:

A metal weighs 20 N in air and 15N when fully immersed in water Calculate the:

(i) Up thrust;

(ii) Weight of displaced water

(iii) Volume of Displaced Water

<u>Solution</u>

$W_a = 20N; W_f = 15N;$

i) Up thrust;

$\text{Upthrust} = W_a - W_f$

$= 20 - 15$

<u>Upthrust = 5N</u>

ii) Weight of displaced water

Weight of displaced fluid

= up thrust

<u>= 5N</u>

iii) Volume of Displaced Water

Weight of displaced fluid = up thrust

Weight of displaced fluid = up thrust = $\boldsymbol{V \rho_f g}$.

$Upthrust = V_f \rho_f g$.

$5 = V_f \times 1000 \times 10.$

$V_f = 5 \times 10^{-4} m^3$

iv) Volume of the metal

Volume of the metal = Volume of displaced fluid

<u>$= 5 \times 10^{-4} m^3$</u>

v) Density of the metal

$W_a = 20N$

$W_a = V_b \rho_b g$
$20 = (5 \times 10^{-4}) \times \rho_b \times 10$
$20 = 0.005\rho_b \Leftrightarrow \rho_b = \frac{20}{0.005}$
$\rho_b = 4000\ kgm^{-3}$

Example 3:
An iron cube of volume 800cm^3 is totally immersed in (a)Water (b) oil of density 0.8gcm^{-3}.Calculate the up thrust in each case. Density of water =1000 kgm^{-3}
$V_b = 800cm^{-3}$ = 800/(100x100x100) kgm^{-3};

Solution
(a) Upthrust in water
ρ_f =1gcm^{-3}=1000 kgm^{-3}
$V_f = V_b = 800cm^{-3}$ = 800/(100x100x100) kgm^{-3};
Up thrust = weight of displaced water
$Upthrust \ = V_f \rho_f g$
$$\text{Upthrust} = \left(\frac{800}{100 \times 100 \times 100}\right) \times 1000 \times 10$$
Upthrust = 8 N

(b) Upthrust in the oil
ρ_f = 0.8 gcm^{-3} = 0.8x1000kgm^{-3} = 800 kgm^{-3}

Up thrust = weight of displaced water
Upthrust = $V_f \rho_f g$
$$\text{Upthrust} = \left(\frac{800}{100 \times 100 \times 100}\right) \times 800 \times 10$$
Upthrust = 6.4 N

Note: the greater the density, the greater the up thrust. The apparent weight of a body is less in fluids of greater density.

Example 3:
An iron cube, mass 480g and density 8g/cm^3 is suspended by a string so that it is half immersed in oil of density 0.9gcm^{-3}. Find the tension in string.

Solution
m = 480g, ρ_b = 8 gcm^{-3}
W_a= mg = $(\frac{480}{1000}) \times 10$ = 4.8N
ρ_f =0.9gcm^{-3} = 0.9 x 1000 = 900 kgm^{-3}

$$V_b = \frac{m_b}{\rho_b} = \frac{480}{8} = 60\ m^3$$
Since its half –immersed then: V_f of oil = $\frac{1}{2} \times 60$ = 30cm^3
Up thrust = weight of displaced fluid
Upthrust = $V_f \rho_f g$
$$\text{Upthrust} = \left(\frac{30}{100 \times 100 \times 100}\right) \times 900 \times 10$$
Upthrust = 0.27 N

Tension in string = Apparent weight (W_f)
$$Upupthrust = W_a - W_f$$
$$0.27 = 4.8 - W_f$$
$$W_f = 4.8 - 0.27 \Leftrightarrow W_f = 4.53\ N$$
Thus Tension in string = 4.53 N

Application of Archimedes principle

(a) Relative density of a solid
By Archimedes principle, the apparent weight is equal to the weight of water displaced by the solid. The volume of this water displaced is the same as the volume of the solid.
But ***apparent loss in weight of solid in water = Wa – Ww***

$$\mathbf{R.D} = \frac{\text{Weight of solid in air}}{\text{Apparent loss in weight of solid in water}}$$

$$= \frac{\text{Weight of solid in air}}{Upthrust\ in\ water} = \frac{\mathbf{w_a}}{\mathbf{W_{a-w_w}}}$$

W_a - W_w = Upthrust: Where; W_a is weight of solid in air. W_w is weight of solid in water.

Example
A glass block weighs 25N. When wholly immersed in water the block appears to weigh 15N. Calculate the relative density.

Solution

$W_a = 25N; W_f = 15N;$ $\text{Upthrust} = W_a - W_f$ $= 25 - 15$ Upthrust = 10N	$R.D = \frac{w_a}{W_{a-w_w}}$ $R.D = \frac{25}{10} = 2.5$

(b) Relative density of liquid
This is determined by using a solid. This solid sinks in water and in the liquid for which the relative density is to be determined.
A solid of weight W_a is weighed when completely immersed in the liquid to obtain W_l. The solid is then weighed when completely immersed in water to obtain Ww.
So $Relative\ Density\ of\ the\ liquid\ (R.D)$ is given by;

$$\text{R.D} = \frac{\text{Apparent loss in weight of solid in liquid}}{\text{Apparent loss in weight of solid in water}}$$

$$= \frac{\text{Upthrust in liquid}}{\text{Upthrust in water}} = \frac{\mathbf{w_a - w_l}}{\mathbf{w_a} - \boldsymbol{w_w}}$$

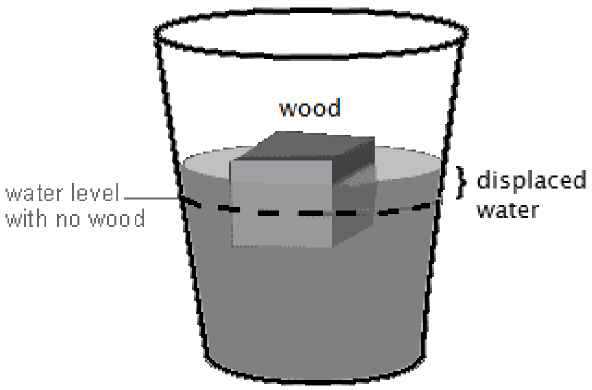
Example
A metal weighs 25N in air. When completely immersed in liquid it weighs 15N and it weighs 20N when completely immersed in water. Calculate the relative density of the liquid.

Solution
$W_a = 25N; W_l = 15N; W_w = 20N$:
$$\text{Relative density of liquid} = \frac{w_a - w_l}{W_{a-w_w}}$$
$$= \left(\frac{25-15}{25-20}\right)$$
$$= 2.0$$

(b) FLOATATION
When a stone is placed on water, it sinks because its weight is greater than the up thrust. When a cork is held below the surface of water, it rises on release. This is

because the up thrust on the cork is greater than its weight.

A piece of wood neither rises nor sinks but floats because the up thrust on the piece of wood and its weigh just balance so it experiences no net force.



In general a body floats because up thrust is equal to weight of the body. A body will sink because up thrust on it is less than the weight of the body.

The principle of flotation: *It states that, a floating body displaces its own weight of fluid i.e. for a floating body; weight of body = weight of displaced fluid*

$$\boldsymbol{W_b = W_f}$$

Where W_a is weight of body floating, W_f is weight of displaced fluid.

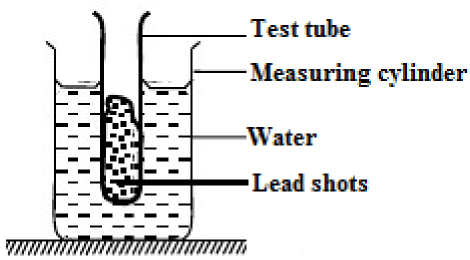
$$\boldsymbol{W_f = V_f \rho_f g \quad and \quad W_b = V_b \rho_b g}$$

Where V_f is volume of displaced fluid and V_b is volume of floating body, $\boldsymbol{\rho_b}$ is density of floating body "g" is acceleration due to gravity.

In general: $\boldsymbol{V_b \rho_b g = V_f \rho_f g}$

Thus: $\boldsymbol{m_b = m_f}$

Experiment: ***To verify the Law of Flotation***



Procedure

- ❖ A test tube is placed in a measuring cylinder containing water and the original reading of the water level (V_1) is noted.
- ❖ Lead shots are added to the test tube until it floats up right and the new water level (V_2) is noted.

  $\text{Volume of displaced water} = (V_2 - V_1)\text{cm}^3$

  $\text{Weight of displaced water} = \rho_w (V_2 - V_1) g$
- ❖ The test tube together with the shots is removed from the cylinder and weighed using a spring balance. (The cotton loop helps to attach it to the balance hook). Their weight is recorded, $\mathbf{W_a}$.

  $(\text{Weight of lead shots} + \text{testtube}) = W_a$

Observation

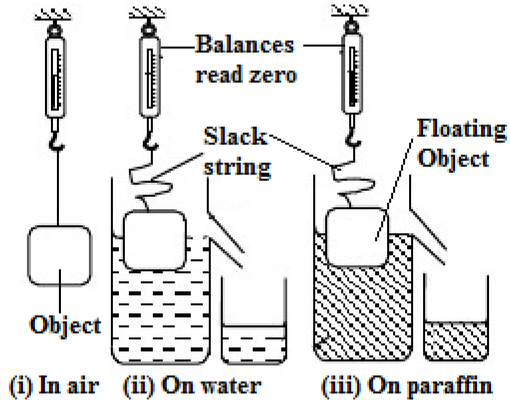
- ❖ The weight of lead shots and test tube is equal to the weight of displaced water.

$$\begin{pmatrix} Weight\ of\ lead \\ shots + testtube \end{pmatrix} = \begin{pmatrix} \text{Weight of} \\ \text{displaced water} \end{pmatrix}$$

Conclusion

- ❖ From the above observation, it is noticed that the law of floatation is verified.

Alternatively: We verify the law of flotation as follows.



- A suitable object is first weighed in air.
- Then it is floated on a liquid and the weight of the displaced liquid is found.

Observation:

In each case the weight of the displaced liquid is equal to the weight of the solid in air. This verifies the law.

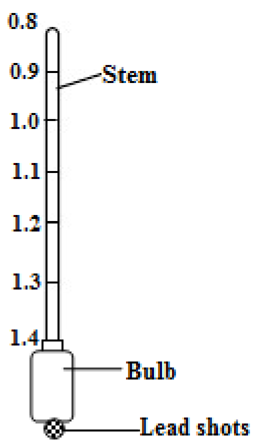
Application of the law of floatation

(i) Ahydrometer (ii) Submarines	(iii) Ships (iv) Balloons

(i) A hydrometer

It is used to measure the relative density (or specific gravity) of a liquid. Since a body displaces its own weight of the fluid in which it floats, it always displaces a volume of the fluid that will make up the weight of the object.

Consequently if it floats in a denser liquid, it displaces a smaller volume of that liquid than if it floated in a less dense liquid.



Thus a hydrometer sinks more in a less dense liquid. i.e a greater fraction of the body gets submerged in a less dense liquid. Hence, calibrations on the stem of a hydrometer increase downwards. (see the diagram)

- The stem carries the scale and is narrow to increase its accuracy as it easily sinks and rises in the specimen liquid.Sensitivity of the hydrometer to small changes in the density of the liquid increased by making the stem very thin.

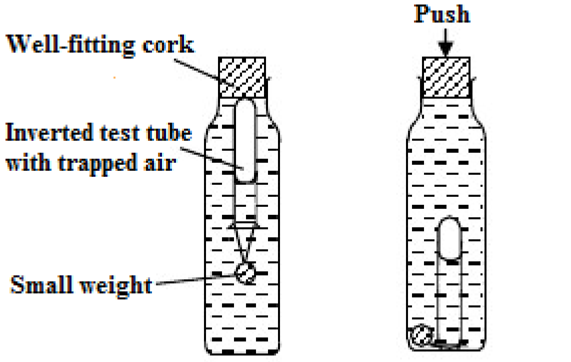
- The buoyancy is increased by making the bulb large. The bulb is wide such that it displaces sufficient volume of water whose weight can balance the up thrust on it. I.e, it increases the buoyancy of the hydrometer.

- A heavy weight (lead shots) is placed beneath the float to keep the hydrometer up right (Vertically).

  The smaller scales are at the top and the bigger scales are at the bottom. This is because the hydrometer floats deeper in lighter liquids than in denser liquids.

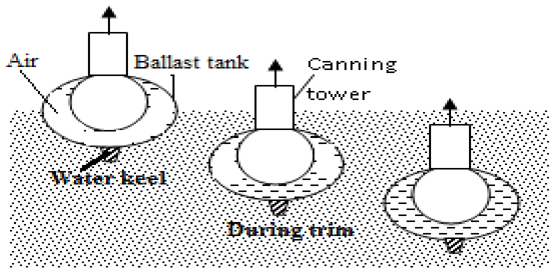
Lactometer: -It is used to test the purity of milk.
Battery hydrometer: -It is used to test Relative density of a car battery acid.

(ii) Cartesian Diver
A small inverted test tube with trapped air in a water container can be used to demonstrate the Cartesian diver.



Explanation:
Before the cork is pushed in there is a big volume of air in the test tube. So the average density of the tube and the air is less than that of water. So the test tube floats.
When the cork is pushed in, the pressure transmitted equally throughout the liquid, forces more water into the test tube reducing the air space.
So the average density of the tube and air increases until it sinks.

(iii) Submarines
The average density of submarines is varied by means of ballast tanks which can be filled with water and emptied.
For the submarines to float, the ballast tanks are filled with air. To sink the submarines, the tanks are filled with water causing average density to rise higher than that of water.



(iii) Ships
Why ships float.
Ships float on water, although they are made from iron and steel which are denser than water. This is because:
(i) The steel or iron ship is made hollow and contains air. So the average density of the ship is less than that of water.
(ii) The overall weight of the ship is less than the up thrust, and so it rises up until the weight is equal to the upthrust and it floats on the water.

The loading lines called plimsoul marks on the sides show the level to which it can be safely loaded under different conditions.
Weight of displaced water (W_w) = weight of the ship (W_s) + weight of the cargo (W_c).

$$\mathbf{W_w = W_s + W_c}$$

(iv) Balloons
These are airships used in meteorological measurements.
A balloon filled with hydrogen weighs less than the weight of air it displaces.
The up thrust being greater than its weight, a resultant up ward force on the balloon causes it to rise.
The balloon continues to rise up until the upthrust acting on it is equal to the weight of the balloon plus its content and then it floats.
The lifting power of the balloon is calculated from the formula:

$$U = W_{balloon} + W_{hydrogen} + W_{load}$$
$$U = m_b g + V_h \rho_h g + m_l g$$

Upthrust in air = Weight of displaced air
Upthrust in air = $\rho_a V_a g$

(v) Ice melting in water.
When a glass of water with some ice floating on top fills the glass to the brim, the water does not overflow as the ice melts but it remains at the same level. This is because the water just fills up the space of the glass.

Example 1:
A piece of cork of volume $100cm^3$ is floating on water.
If the density of the cork is $0.25gcm^{-3}$. Calculate the volume of cork immersed in water.

Solution

(a) Upthrust in water
$\rho_f = 1gcm^{-3} = 1000\ kgm^{-3}$: $\rho_b = 0.25gcm^{-3} = 0.25 \times 1000kgm^{-3}$
$V_b = 100cm^{-3}$ = 100/(100x100x100) kgm^{-3};

Up thrust = weight of displaced water
Upthrust $= V_f \rho_f g$
Upthrust $= \left(\frac{800}{100 \times 100 \times 100}\right) \times 1000 \times 10$
Upthrust = 8 N

Upthrust $= V_f \rho_f g$
$m_b = V_b \rho_b$

$$V_f \times 1000 = \left(\frac{100}{100 \times 100 \times 100}\right) \times (0.25 \times 1000) \times 10$$

$$1000V_f = 2.5$$
$$V_f = 0.000025\ m^3 \text{ or } 2.5 \times 10^{-5}\ m^3$$

EXERCISE:

1. A glass block weighs 25N in air. When wholly immersed in water, the block weighs 15N. Calculate the;
(i) up thrust on the block. [10N]
(j) density of the glasskgm^{-3}[2500kgm^{-3}]

2. A piece of iron weighs 555N in air. When completely immersed in water, it weighs 530N and weighs 535N when completely immersed in alcohol. Calculate the relative density of alcohol. [R.D=0.8]

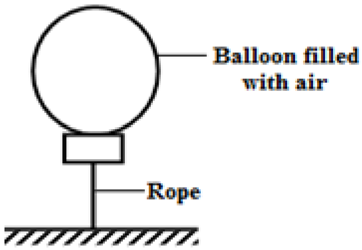
Example: 2
A balloon has a capacity $10m^3$and is filled with hydrogen. The balloon's fabric and the container have a mass of 1.25kg. Calculate the maximum mass the balloon can lift.{Density of hydrogen = 0.089kgm^{-3}: density of air=1.29kgm^{-3}}.

Solution:

Volume of balloon,$V_b = 10m^3$
Density of hydrogen, $\rho_h = 0.089kgm^{-3}$
Density of air, $\rho_a = 1.29kgm^{-3}$
Volume of air displaced,V_a =Volume of balloon,$V_b = 10m^3$
Volume of hydrogen, V_h =Volume of balloon,$V_b = 10m^3$
Mass of balloon and container,$= 1.25kg$
Let the mass of the load = x

$$\text{Upthrust} = \text{Weight of balloon} + \text{weight of } H_2 + \text{load}$$
$$U = m_b g + V_h \rho_h g + m_l g$$
$$V_a \rho_a g = m_b g + V_h \rho_h g + m_l g$$
$$10 \times 1.29 \times g = 1.25 \times g + 0.089 \times 10 \times g + x \times g$$
$$x = 10.76kg$$

Example: 3



A large balloon is filled with hot air of density 1.20kgm^{-3} to a volume of 200m^3. It has a total weight of 2200N. It is held to the ground by a vertical rope. Find the:
(i) up thrust on the balloon.
(ii) Tension in the rope.

Solution:

Volume of balloon,$V_b = 220m^3$
Density of air, $\rho_a = 1.20kgm^{-3}$

$$\text{Upthrust} = \begin{pmatrix}\text{Weight of}\\ \text{air displaced}\end{pmatrix}$$
$$U = V_a \rho_a g$$
$$U = 200 \times 1.20 \times 10$$
$$U = 2400\ N$$

$$\text{Tension} = \begin{pmatrix}\text{Resultant}\\ \text{Force}\end{pmatrix}$$
$$T = 2400 - 2200$$
$$T = 200\ N$$

Relationship between density of a floating body, density of a liquid and fraction submerged.

$$\begin{pmatrix}\text{Density of}\\ \text{floating object}\end{pmatrix} = \begin{pmatrix}\text{Fraction}\\ \text{submerged}\end{pmatrix} \times \begin{pmatrix}\text{Density of}\\ \text{liquid}\end{pmatrix}$$

EXERCISE:

1. A rubber balloon of mass 5g is inflated with hydrogen and held stationary by means of a string. If the volume of the inflated balloon is 0.005m^3, find the tension in the string. (Assume hydrogen is a light gas, and density of air = 1.25kg^{-3}):
[Ans: 1.25 X 10^{-2}N]

40. A block of metal (density 2700 kg/m^3) has volume 0.09 m^3. Calculate the up thrust force when it is completely immersed in brine (density 1 200 kg/m^3)
A. 600 N B. 1 080 N
C. 180 N D. 1200 N

41. An iron box of mass 90 g and density 0.9gcm^{-3} floats on brine (density 1200kg/m^3). What is the volume immersed in the brine?
A. 40 cm^3 B. 60 cm^3
C. 90 cm^3 D. 75 cm^3

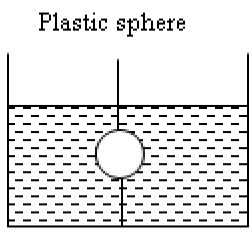
42. The envelope of a hot air balloon contains 1500 m^3 of hot air of density 0.8 kgm^{-3}. The mass of the balloon (not including the hot air) is 420 kg. the density of surrounding air is 1.3 kg/m^3. What is the lifting force?
A. 3 300 N B. 4 400 N
C. 5 500 N D. 6 600 N

43. What fraction of a wooden cube of one side 10cm will be below the water level if the cube is floating in water? (d_{water} = 1g/cm^3, d_{wood} = 0.6 g/cm^3)
A. $^3/_5$ B. $^2/_5$
C. $^1/_5$ D. $^1/_{10}$

44. An ice cube of volume 600 cm^3 floats in water. What is the volume of the part above the water level? (d_{ice} = 0.9 g/cm^3, d_w = 1 g/cm^3)
A. 60 cm^3 B. 80 cm^3
C. 520 cm^3 D. 540 cm^3

45. A cubical brass block floats in mercury. What fraction of the block lies above the mercury surface? (the densities of brass and mercury are 8 600 kg/m^3 and 13 600 kg/m^3 respectively)
A. $^{86}/_{136}$ B. $^{50}/_{86}$
C. $^{136}/_{86}$ D. $^{50}/_{136}$

46. A large, hollow plastic sphere is held below the surface of a fresh water pool by a cable attached to the bottom of the pool. The sphere has a volume of 0.400 m^3.



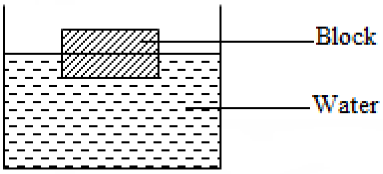
Calculate the buoyancy force exerted by the water on the sphere.
A. 4 000 N B. 800 N

C. 3 200 N D. 4 800 N

47. A lead sphere has a total mass of 45.2 kg. If it is put into water, what will be the upthrust force on it? (Density of lead is 11 300 kg/m^3)
A. 10 N B. 20 N
C. 30 N D. 40 N

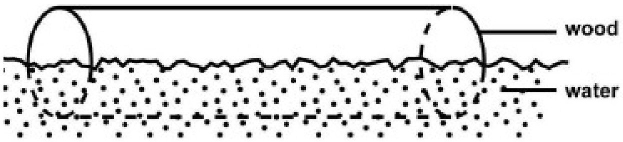
48. A block of wood of volume 80$cm^3$and density 0.5 gcm^{-3}floats in water. What is the volume immersed in water (density of water = 1gcm^{-3})
A. 50 cm^3 B. 40 cm^3
C. 30 cm^3 D. 20 cm^3

49. The Figure below shows a block of volume 40 cm^{-3} floating in water with only half of its volume submerged.



If the density of water is 1000kg m^{-3}, determine the mass of the wood.
A. 40 x 1000 kg. B. 20 x 1000 kg.
C. 40 x 10^{-6} x 500 kg. D. 20 x 10^{-6} x 500 kg.

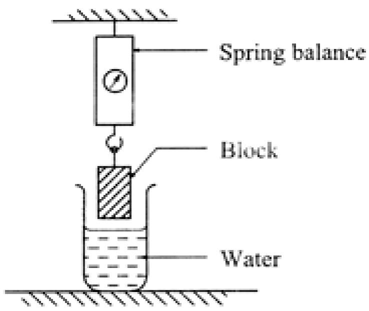
50. The figure below shows a block of wood of volume 40 cm^3 floating in water with only half of its volume submerged.



Ifthe density of water is 1000 kgm^{-3}, determine the mass of the wood underwater.
A. 40 x 1000 kg. B. 20 x 1000 kg.
C. 40 x 10-6 x 500 kg. D. 20 x 10-6 x 500 kg

51. A balloon is filled with hydrogen and released in the open air. It will rise
A. to a certain height and then float
B. to a certain height and then drop
C. to a certain height and then burst
D. indefinitely

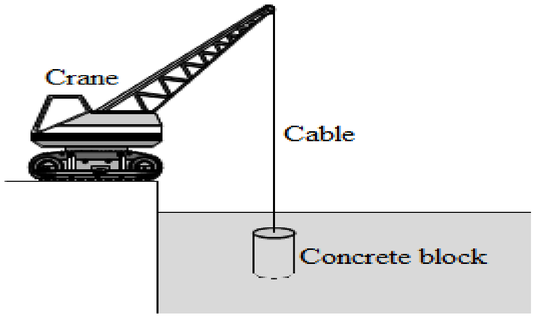
52. The figure below shows a spring balance supporting a block being lowered into a beaker containing water.



When the block is immersed in water, the reading of the spring balance
A. reduces B. increases
C. becomes zero. D. remains constant.

53. The spring balance in the figure above reads 5N on suspending the block. When the block is completely submerged in water, the spring balance reads 1N.
(i) State the forces acting on the block when fully immersed.
(ii) Determine the volume of the block.
(iii) Explain why the spring balance reading is likely to increase when the block is completely immersed in paraffin instead of water.

54. A concrete block is suspended in water by acable from a crane as shown below.



The block is now lowered at a constant speed. Which row in the table describes the changes, if any, to: the pressure acting on the top of the block; the buoyancy force on the block; and the tension in the cable, as the block is lowered in the water?

	Pressure acting on top of block	Buoyancy force	Tension in Cable
A	Increases	Staysthe same	Staysthe same
B	Increases	Increases	Decreases
C	Decreases	Decreases	Increases
D	Decreases	Stays the same	Stays the same
E	Staysthe same	Increases	Stays the same

55. A skydiver falls from the open door of an aircraft in steady level flight. It is observed that it takes three seconds for the skydiver to reach terminal velocity. Which statement about the motion of the object is correct? **ANS : D**

A	The horizontal component of the skydiver's velocity is constant.
B	The horizontal component of the skydiver's acceler is zero.
C	The vertical component of the skydiver's vel decreases for three seconds.
D	The vertical component of the skydiver's accelerati zero after three seconds.

SECTION B

56. (a) State **Archimede**'s Principle.
(b) Describe an experiment to verify Archimedes's Principle.
(c) A piece of iron weighs 355 N in air. When completely immersed in water, it weighs 305 N and weighs 315 when completely immersed in methylated spirit. Calculate the relative density of methylated spirit.
(d) State the application of Archimedes's principle.

57. (a) State the **law of flotation**.

(b) Describe an experiment to verify the law of flotation.
(c) A piece of wood of volume 40 cm^3 floats with only half of volume submerged. If the density of water is 1000 kg m^{-3}, calculate the density of wood.

58. A balloon has a capacity of 20 m^3 and is filled with hydrogen. The balloon's fabric and the container have a mass of 2.5 kg. Calculate the maximum mass load the balloon can lift. (Density of hydrogen = 0.089 kgm^{-3} and of air = 1.29 kgm^{-3}, gravity, g = 10 ms^{-2}).

59. A hydrometer consists of a spherical bulb and a cylindrical stem of cross-sectional area 0.4cm^2. The total volume of the bulb and stem is 13.2cm^3. When immersed in water, the hydrometer floats with 8.0cm of the stem above the water surface in alcohol it floats with 1.0 cm of the stem above the surface. Calculate the density of the alcohol.(0.78gcm-3)

60. (a) Define **terminal velocity**.
(b) Explain with a help of velocity-time graph, what happens to a USA soldier parachuted from a war plane flying at a high altitude in an area free of enemies in Iraq from the time he leaves the plane till he lands to the ground.

61. A glass block weighs 25N in air. When wholly immersed in water, the block weighs 15N. Calculate the;
(k) up thrust on the block [10N]
(ii) Density of the glass kgm^{-3} [2500kgm^{-3}]

62. A piece of iron weighs 555N in air. When completely immersed in water, it weighs 530N and weighs 535N when completely immersed in alcohol. Calculate the relative density of alcohol. [R.D=0.8]

63. A rubber balloon of mass 5g is inflated with hydrogen and held stationary by means of a string. If the volume of the inflated balloon is 0.005m^3, find the tension in the string. (Assume hydrogen is a light gas, and density of air = 1.25kg^{-3}):[Ans: 1.25 X 10^{-2}N]

64. When a metal is completely immersed in liquid A its apparent weight is 5N. When immersed in another liquid B the apparent weight is 16N if the density of B is times that of A. Calculate the mass of the metal. [= 5.2kg].

65. The mass of a piece of cork (0.25gcm^{-3}) is 20g.
(i) What fraction of the cork is immersed when it floats in water?
(ii)Find the volume of the cork submerged

66. A solid of volume 1 x10m^3 floats on water of density 1 x10 kgm^{-3} with $\frac{3}{5}$ of its volume submerged. Find the;
(i) mass of solid [=0.06kg]
(ii) density of solid [= 600kgm^{-3}]

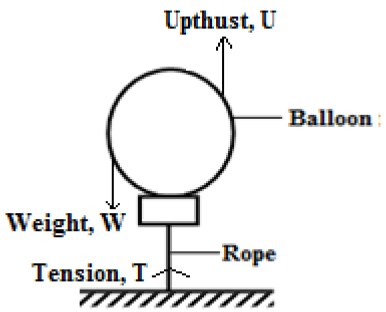
67. A piece of wood that measures 2cm by 3cm at the bottom and 8cm in height floats in water with $\frac{1}{4}$ of its volume submerged. Calculate the:
(i) volume of water displaced
(ii) mass of the wood

68. A piece of marble of weight 14N and relative density 2.8 is supported by a light string from a spring balance and lowered into a vessel of water standing on a weighing machine. The weighing machine reads 57.5N before the marble enters water. What will be the readings of both the spring balance and the weighing machine when the marble is completely immersed in water?

69. Sulphuric acid has a **specific gravity** of 1.8. This meant that a certain quantity of this acid is 1.8 times

70. heavier than the same quantity of water. Find the weight in kg of two litres of sulphuric acid. [3.6kg].

71. A balloon of mass 30kg and volume 50cm^3 is filled with hydrogen gas of density 0.09kgm^{-3} and centered to the ground. If the density of the surrounding air is 1.25kgm^{-3}



Find the
(i) Upthrust on the balloon. (625N)
(ii) Force needed to hold the balloon to the ground. (T = 280N)
(iii) Initial acceleration of the balloon when released.

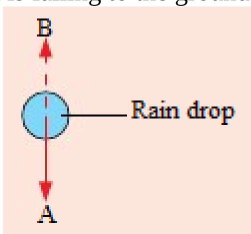
$$\begin{pmatrix}\text{Mass to}\\ \text{move}\end{pmatrix} = \begin{pmatrix}\text{Mass of}\\ \text{material}\end{pmatrix} + \begin{pmatrix}\text{Mass of}\\ \text{Hydrogen}\end{pmatrix} = 34.5\text{kg}$$

When released, T = 0

$$\mathbf{F = ma} \Leftrightarrow 280 = 34.5\text{a}$$
$$\text{a} = 8.116\ \text{ms}^{-2}$$

72. An iron block of mass 3.2×10^3kg and volume 0.6 m^3 is totally immersed in a liquid of density 1.56×10^3kg. Find the weight of the block in:
(i) Air (ii) Liquid

73. The figure below shows the forces acting on a raindrop which is falling to the ground.



(a) (i) A is the force which causes the raindrop to fall. What is this force called?
(ii) B is the total force opposing the motion of the drop. State one possible cause of this force.
(b) What happens to the drop when force A = force B?

LINEAR MOTION

A body is said to be in motion when it is moving.
The following terms are used to describe the motion of bodies.

1. **Distance and Displacement**

Distance: *Is the space between two points*.
Displacement: *Is the distance moved in a specified direction.*

The S.I unit of distance and displacement is **metre** or **m**
Distance is a scalar quantity while displacement is a vector quantity.

2. **Speed and Velocity**

Speed: *Is the rate of change of distance with time. Or It is distance moved in a unit time.*

$$\text{Speed} = \frac{\text{Distance}}{\text{Time taken}}$$

Velocity; *is the rate of change of displacement with time. Or It is speed in a specified direction.*

$$\text{Velocity} = \frac{\text{Displacement}}{\text{Time taken}}$$

The S.I unit of speed and velocity is **metre per second.** **(ms^{-1}).**

Differences between velocity and speed

Velocity	Speed
-Vector quantity	-scalar quantity
$-\frac{\text{Displacement}}{\text{Time taken}}$	$-\frac{\text{Distance}}{\text{Time taken}}$

Types of velocities

- **initial velocity u'**

Is the velocity with which a body starts motion in a given time interval.

Note;
(i) For a body starting from rest the initial velocity "u' must be zero ie. u = 0 ms^{-1}
(ii) For a stationary body starting motion means that the body is starting from rest u = 0 ms^{-1}
(iii) For a body traveling with a certain velocity, *x*, the initial velocity for such a body will be *x* so, u = *x* ms^{-1} e.g. a car traveling at 20 ms^{-1}, has u =20 ms^{-1}

- **Final velocity v'**

The velocity with which a body ends motion for a given time.

Note: If a body is brought to rest, then the final velocity is zero ie, v = 0 ms^{-1}.eg; A body traveling at 20m/s is uniformly brought to rest in 2s. Then; v = 0m/s.
The units of velocity must include m/s or km/hr or cm/s.

Average velocity:

$$\text{Average Velocity} = \frac{\text{Final velocity} + \text{Initial velocity}}{2}$$

$$\text{Average Velocity} = \frac{V + u}{2}$$

Uniform velocity
Is the constant rate of change of displacement.
OR Uniform velocity is when a body makes equal displacements in equal time intervals.

When a body moves with uniform velocity, initial velocity (u) must be equal to final velocity, v. i.e. V = u.
E.g. A car traveling with uniform velocity of 20ms^{-1} has u=20ms^{-1}. V=20ms^{-1}.
When a body moves with uniform velocity, its acceleration is zero. (i.e **a = 0**).

3. **Acceleration and Retardation**

Acceleration (a)
Is the rate of change of velocity with time.

$$\text{Acceleration} \quad = \quad \frac{\text{Change in velocity}}{\text{Time taken}}$$

$$\textbf{Acceleration}, \quad \mathbf{a} = \frac{\mathbf{V - u}}{\mathbf{t}}$$

Change in velocity = final velocity(V) -initial-velocity(U)
The S.I unit for change in velocity is **m/s^2** or **ms^{-2}**.

Uniform acceleration
Uniform acceleration is the constant rate of change in velocity with time.
OR: Uniform acceleration is when a body moves with equal change in velocity in equal time intervals.

When a body moves with uniform acceleration, the final velocity is not equal to initial velocity.

Retardation (or Deceleration): (-a)
Is the rate of change of decreasing velocity with time.

Example.
A car starts from rest and it accelerates to 10m/s. Calculate the change in velocity.
U = 0m/s ; V = 20m/s
$\text{Change in velocity} = v - u$
$\text{Change in velocity} = 20 - 0$
$= 20ms^{-1}$

Note: the velocity to which a body is accelerating becomes the final velocity for that given time interval.

Differences between velocity and acceleration

Velocity	Acceleration
i) S.I unit is **ms^{-1}** ii) Is the rate of change of displacement with time.	i) S.I unit is **ms^{-2}** ii) Is the rate of change of velocity with time.

Note: A rate refers to the change of one quanity with respect to another. The study of rates of change in mathematics is called **Calculus**. For example:

- Fertilizers spread at a rate of 500m^2 per kg.
- A car uses petrol at a rate of 10km per litre.

EQUATIONS OF MOTION

Equations of motions refers to the three expressions that describe the behaviour of a uniformly accelerated body.
They are also refered to as **SUVAT** equations, since they arise from definitions of kinematic quanitities, of displacement, **S**, initial velocity, **U**, final velocity, **V**, acceleration, **A**, and time, **T**.
These Equations are:

$$1^{st}: \quad \mathbf{v = u + at}$$

$$2^{nd}: \quad \mathbf{s = ut + \frac{1}{2}at^2}$$

$$3^{rd}: \quad \mathbf{v^2 = u^2 + 2as}$$

The units of **acceleration** must always be **ms^{-2}** and the units **ms^{-1}** or km / hr are for **velocity** and **speed**.

1st Equation of motion

From the definition of acceleration.

$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Time taken}}$$

, $a = \dfrac{V - u}{t}$

$at = v - u$

$\mathbf{v = u + at}$

This is called the first equation of motion.

Example: 1

A car started from rest it accelerates uniformly for 5s at a rate of $4ms^{-2}$. Calculate the final velocity.

Solution

Given	From;
u=0 m/s v=0 m/s a=$4ms^{-2}$ t=5s v=?	$v = u + at$ $v = 0 + (4)(5)$ $v = 20$ $\underline{\underline{v = 20ms^{-1}}}$

Example 2.

A body starting from rest is accelerated to 30m/s in two seconds. Calculate the acceleration of the body.

Solution

Given	From;
u=0m/s v=30m/s t=2s	$v = u + at$ $30 = 0 + a(2)$ $30 = 2a$ $15 = a$ $\underline{\underline{a = 15ms^{-2}}}$

Example 3.

A body starts from rest and accelerated uniformly at $2m/s^2$ for 3s. Calculate the final velocity.

Solution

Given	From;
u=0m/s a=$2m/s^2$ t=3s	$v = u + at$ $v = 0 + (2)(3)$ $v = 6$ $\underline{\underline{v = 6ms^{-1}}}$

Example 4.

A body traveling at 10m/s is accelerated uniformly for 3 seconds at $5m/s^2$. Calculate the velocity at the end of the third second.

Solution

Given	From;
u=10m/s a=$5m/s^2$ t=3s	$v = u + at$ $v = 10 + (5)(3)$ $v = 10 + 15$ $\underline{\underline{v = 25ms^{-1}}}$

Example: 5.

A body traveling at $20ms^{-1}$ is accelerated for 4s at $5ms^{-2}$. Calculate the average velocity.

Solution

Given	From;	Then from ;
u = 20m/s a = $5m/s^2$ t = 4s	v = u + at v = 20 + (5)(4) v = 20 + 20 $\underline{\underline{v = 40ms^{-1}}}$	$\begin{pmatrix}\text{Average}\\\text{Velocity}\end{pmatrix} = \frac{V + u}{2}$ $\begin{pmatrix}\text{Average}\\\text{Velocity}\end{pmatrix} = \frac{40 + 20}{2}$ $\text{Average Velocity} = \frac{60}{2}$ $\underline{\underline{\text{Average Velocity} = 30ms^{-1}}}$

Example: 5.

A car travels with a uniform velocity of $20ms^{-1}$ for 6s. Calculate its acceleration.

Solution

Given	From;
u=20 m/s v=20 m/s a=? T = 6s	$v = u + at$ $20 = 20 + a(6)$ $20 = 20 + 6a$ $6a = 0$ $\underline{\underline{a = 0ms^{-2}}}$
From the above example, it's noted that for a body moving with uniform velocity, its acceleration is zero because the change in velocity becomes zero as initial velocity is equal to final velocity.	

Example: 6.

A car traveling at 90km/hr is uniformly brought to rest in 40 seconds. Calculate the acceleration.

Solution

Given	From;
u=90km/hr $= \frac{90\times1000}{1\times60\times60} =$ $25m/s$ a=? t=40s v=0 m/s	$v = u + at$ $0 = 25 + (a)(40)$ $0 = 25 + 40a$ $-40a = 25$ $\underline{\underline{a = -0.625ms^{-2}}}$
***Note**: If the value obtained for acceleration is negative, it implies that the body is decelerating or retarding. This occurs when there's a decrease in velocity.*	

2nd Equation of motion

Displacement: "***S*** or ***x***" is length moved in specified direction

From the definition of Displacement.

$Displacement = (Average\ velocity) \times (Time)$

$s = \left(\frac{v+u}{2}\right) \times t \quad Where$: $v=u+at$

$$s = \left(\frac{u + at + u}{2}\right) \times t$$

$$s = \left(\frac{2u + at}{2}\right) \times t$$

$$s = \left(\frac{2ut + at^2}{2}\right)$$

$$\boldsymbol{s = ut + \frac{1}{2}at^2}$$

This is called the second equation of motion. This equation is mainly used when the question involves distance and time.

Example: 1
A body starts from rest and accelerates uniformly at $2ms^{-2}$ for 3s. Calculate the total distance travelled.

Solution

Given	From;
u=0 m/s a=$2ms^{-2}$ t=3s s=?	$s = ut + \frac{1}{2}at^2$ $s = (0)(3) + \frac{1}{2}(2)(3^2)$ $\underline{s = 9\,m}$

Calculations involving deceleration or Retardation
When calculating a problem involving deceleration; it should be remembered that the value of "a" should be negative.

Example 2:
A body moving at 40 ms^{-1} decelerates uniformly for 20s at $3ms^{-2}$. Calculate distance covered.

Solution

Given	From;
u=40 m/s a=$-3ms^{-2}$ t=20s s=?	$s = ut + \frac{1}{2}at^2$ $s = (40)(20) + \frac{1}{2}(-3)(20^2)$ $s = 800 - 600$ $\underline{s = 200\,m}$

Example 3:
A car traveling at 40 ms^{-1} is uniformly decelerated to $25ms^{-1}$ for 5s. Calculate the total distance covered.

Solution

Given	From;	Then, from:
u=40 m/s v=25 m/s a=? t=5s s=?	$v = u + at$ $25 = 40 + 5a$ $5a = 25 - 40$ $5a = -15$ $\underline{a = -3ms^{-2}}$	$s = ut + \frac{1}{2}at^2$ s $= (40)(5) + \frac{1}{2}(-3)(5^2)$ $s = 200 - 37.5$ $\underline{s = 162.5\,m}$

Third Equation of motion
From: $Displacement = (Average\ velocity) \times (Time)$.
Making't' the subject of the formula in the first equation of motion and substituting it in here, we get;

$$Displacement, s = \left(\frac{v + u}{2}\right) \times \left(\frac{v - u}{a}\right)$$

$$s = \frac{(v + u)(v - u)}{2a}$$

$$2as = v^2 - u^2$$

$$\boldsymbol{v^2 = u^2 + 2as}$$

This is called the third equation of motion

This equation is applied when time is not given and not required.

Example 1:
Calculate the final (maximum) velocity of a body traveling at 4m/s. When it accelerates at $2m/s^2$ and covers a distance of 5m.

Solution

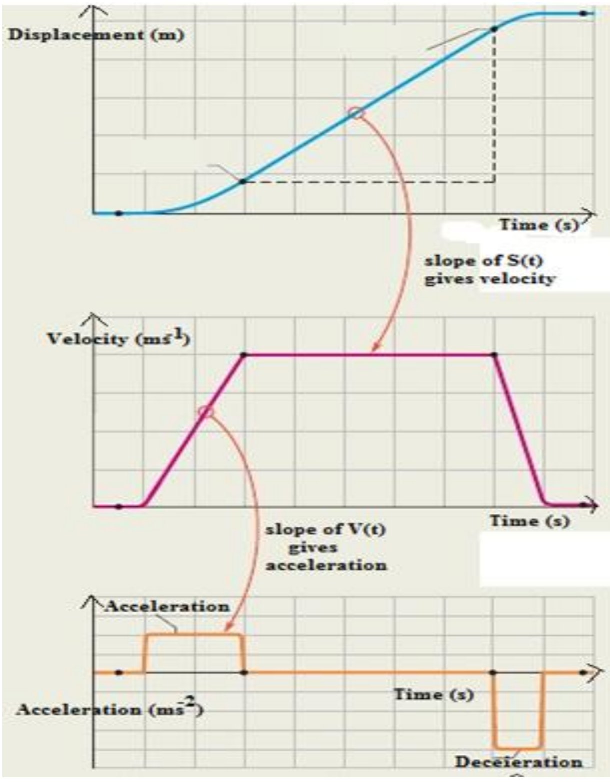
Given	From;
u=4 m/s v=? a=$2ms^{-2}$ s=5m	$v^2 = u^2 + 2as$ $v^2 = 4^2 + 2(2)(5)$ $v^2 = 16 + 20$ $v^2 = 36$ $\boldsymbol{v = 6ms^{-1}}$

Example 2:
A body traveling at 90km/hr is retarded to rest at $20m/s^2$. Calculate the distance covered.

Solution

Given	From;
u=90km/hr $=\frac{90\times1000}{1\times60\times60} = 25m/s$ a=$-20m/s^2$ v=0 m/s s=?	$v^2 = u^2 + 2as$ 0^2 $= (25)^2 + 2(-20)s$ $0^2 = 625 - 40s$ $40s = 625$ $\frac{40s}{40} = \frac{625}{40}$ $\underline{s = 15.625m}$

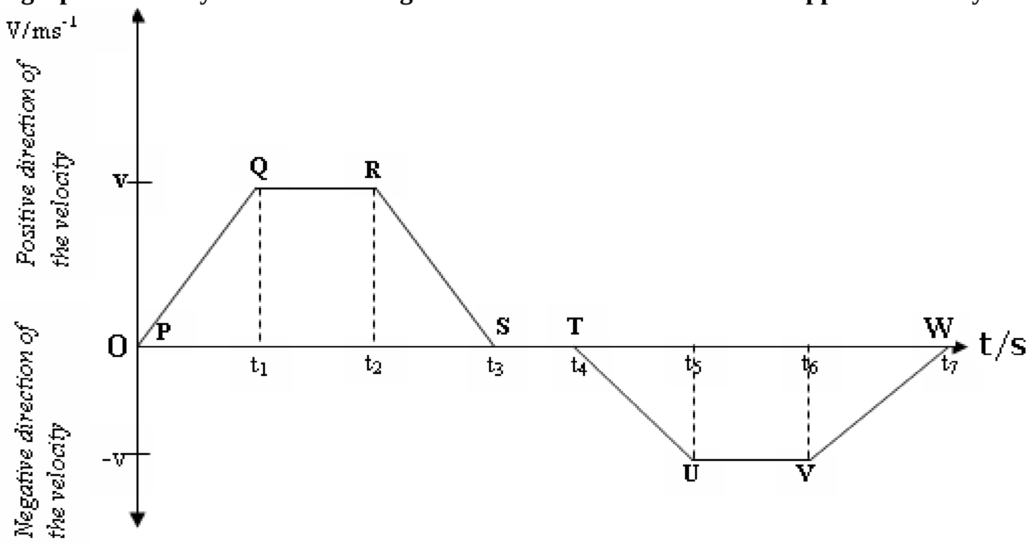
Graphical presentation of uniform velocity and uniform acceleration.



Uniform motion can be represented on a **2** type of graphs.

i) Velocity against time graph
ii) Distance against time.

A velocity-time graph for a body that travelled a given distance and returned and stoppedon the way.



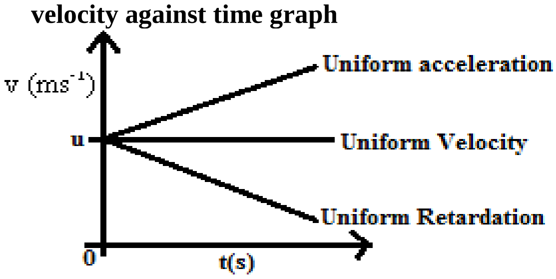
Notes:

1. When interpreting a graph, it is necessary to bear in mind that ***u***, ***v***, ***a***, and ***s*** are vectors. If, say, one direction is taken to be positive, then:
   (i) The velocity of a body which is moving in the opposite direction is negative.
   (ii) Points below the starting point have negative values of ***s.***
   (iii) **Downward** directed accelerations are negative.
   (iv) The magnitude and the direction of the slope of the graph give the magnitude and direction of the acceleration.

2. These facts will help you to understand the interpretation of the above velocity-time graph where there are negative values of velocity.

Stage	State of the body	Interpretation
P – Q	The body starts from rest and moves with a uniform acceleration during this period.	- The velocity is positive and increasing. - The slope is positive and constant. - The acceleration is positive and constant.
Q – R	The body is moving with a constant velocity during this period.	- The velocity is positive and constant. - The slope is zero. - The acceleration is zero.
R – S	At t_2, the body brakes and is uniformly decelerated to rest at t_3.	- The velocity is positive and decreasing. - The slope is negative and constant. - The acceleration is negative and constant. - The negative acceleration means that it acts in the opposite direction the direction of velocity.
S – T	The body is stationary at this period	- The velocity is zero (the body is stationary) - The slope is zero - The acceleration is zero
T – U	At time $t_{4,}$ the body returns and moves with a constant acceleration in the opposite direction.	- The velocity is negative and increasing. - The slope is negative and constant. - The acceleration is negative and constant.
U – V	The body is moving with a constant velocity in the opposite direction during this period.	- The velocity is negative and constant. - The slope is zero. - The acceleration is zero.
V – W	At time t_6, the body brakes and decelerated uniformly until it comes to rest at time t_7.	- The velocity is negative and decreasing. - The slope is positive and constant. - The acceleration is positive and constant.

i) velocity against time graph



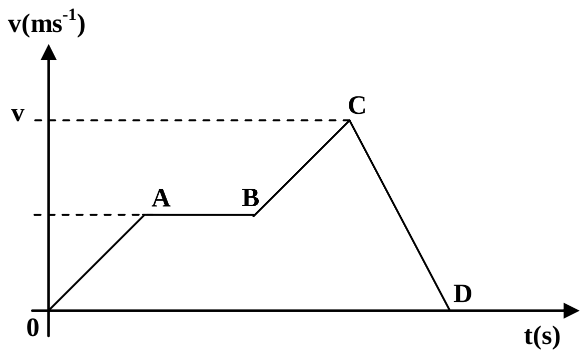
Note: When a body maintains the same speed, it implies that it moves with uniform velocity.

Worked Examples

A car starts from rest and accelerates uniformly for time t_1 seconds to attain a maximum velocity v ms^{-1}. It maintained this velocity for t_2 seconds, then the brakes were applied and the car uniformly retarded to a rest for t_3 seconds.

(i) Represent the above motion in a velocity-time graph.

(ii) On your graph show by shading the total distance travelled.



OA- uniform acceleration
AB- uniform velocity
BC- uniform acceleration
CD- uniform deceleration or uniform retardation

- The slope of a velocity time graph gives the acceleration of the body. ie**:**

$$\textbf{slope}, \mathbf{s} = \frac{\textbf{Change in v}}{\textbf{Change in t}} = \textbf{acceleration}$$

- The Area under any stage or section of velocity time graph gives the distance covered during that time.

Drawing a velocity against time graph

This involves the following steps:

✓ Divide the motion into stages basing on the timing.
✓ Obtain the initial velocity (u) and final velocity (v) for each stage.
✓ The final velocity for one stage becomes the initial for the next stage.

Example 1:

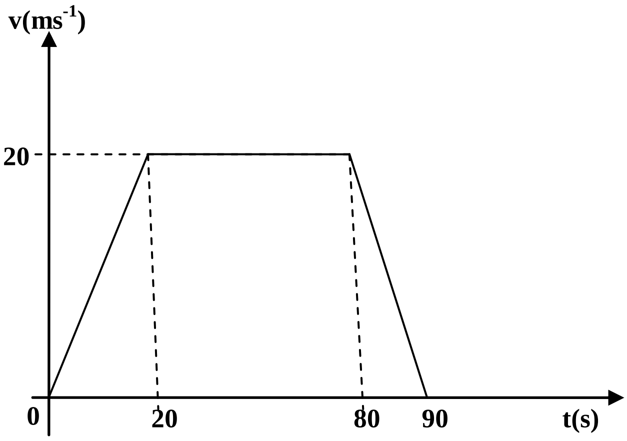
A cyclist starts from rest and accelerate uniformly at $1m/s^2$ for 20s. Then he maintains the maximum speed so reached for 1 minute and finally decelerates to rest uniformly for 10s.

i) Draw a velocity against time graph for the body.
ii) Calculate the total distance travelled.

Solution

Stage1	**Stage 2**	**Stage 3**	Then from;
u=0 ms^{-1} a=1ms^{-2} t=20s v=?	u= $20ms^{-1}$ a= 0 ms^{-2} t =1min = 60s	u= $20ms^{-1}$ v= $0\ ms^{-1}$ t = 10s	$v = u + at$ v $= 0 + (1)(20)$ $v = 20ms^{-1}$

(i) A velocity against time graph for the motion.



ii) Total distance travelled

Stage 1:	**Stage 2:**
$\text{Distance} = \frac{1}{2}\text{bh}$ $\text{Distance} = \frac{1}{2} \times 20 \times 20$ $\text{Distance} = 200\text{m}$	$\text{Distance} = \text{lw}$ $\text{Distance} = 60 \times 20$ $\text{Distance} = 1200\text{m}$
Stage 3: $\text{Distance} = \frac{1}{2}\text{bh}$ $\text{Distance} = \frac{1}{2} \times 10 \times 20$ $\text{Distance} = 100\text{m}$	**Then Total Distance is;** =Stage1+ Stage2 + Stage3 =200m + 1200m + 100m **= 1500m**

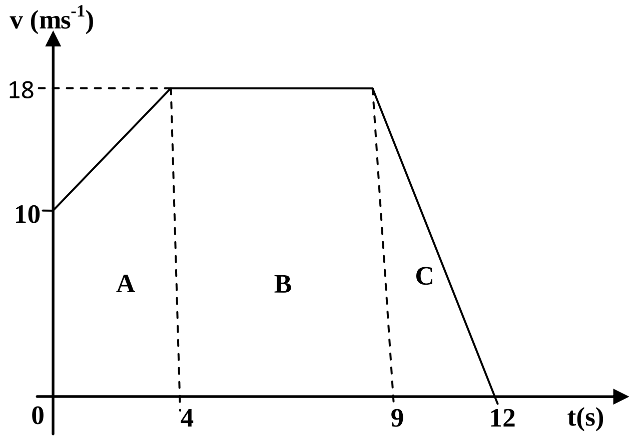
Example 2:

A car traveling at $10ms^{-1}$ is uniformly accelerated for 4s at $2ms^{-2}$. It then moves with a constant speed for 5s after which it is uniformly brought to rest in another 3s.

i) Draw a velocity against time graph.
ii) Calculate the total distance travelled.

Solution

Stage A:	**Stage B:**
u=10 ms^{-1} a=2 ms^{-2} t=4s	$u = 18ms^{-1}$ a = 0 ms^{-2} t = 5s v= ?
Stage C: $u = 18\ ms^{-1}$ $v = 0\ ms^{-1}$ t = 3s	Then from; $v = u + at$ $v = 10 + (2)(4)$ $v = 18ms^{-1}$



i) Total distance travelled

Stage A: $\text{Distance} = \frac{1}{2}h(a+b)$ $\text{Distance} = \frac{1}{2} \times 4 \times (10+18)$ $\text{Distance} = 56\text{ m}$	**Stage B:** $\text{Distance} = lw$ $\text{Distance} = 5 \times 18$ $\text{Distance} = 90\text{ m}$
Stage C: $\text{Distance} = \frac{1}{2}bh.$ $\text{Distance} = \frac{1}{2} \times 3 \times 18$ $\text{Distance} = 27\text{ m}$	**Then Total Distance is;** =Area (A+B+C) =56 m + 90 m + 27 m **= 173 m**

Note: Distance covered during stage A can also be obtained by dividing the area A into a triangle and arectangle and then finding the sum of the two areas.

ie; $A_1 = \frac{1}{2}bh = \frac{1}{2} \times 4 \times 8 = 16\text{m}$

$A_2 = lw = 4 \times 10 = 40\text{m}$

Thus: Area, A = Area A_1 + Area A_2

= 16 m + 40 m

$= \mathbf{56m}$

Example 3:

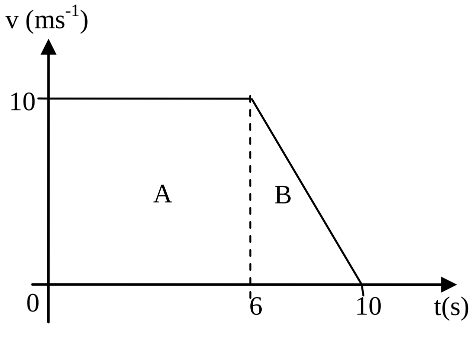
A body moving with uniform velocity:

A car travels at a velocity of 20m/s for 6s. It is then uniformly brought to rest in 4s.

- **i)** Draw a velocity against time graph.
- **ii)** Calculate the retardation
- **iii)** Find the total distance traveled
- **iv)** Calculate the average speed of the body

Solution

Stage A: $u = 20\text{ ms}^{-1}$ $a = 0\text{ ms}^{-2}$ $v = 20\text{ ms}^{-1}$; $t = 6\text{s}$	**Stage B:** $u = 20\text{ms}^{-1}$ a = ? $t = 4\text{s}$ $v = 0\text{ms}^{-1}$
Then from; $v = u + at$ $0 = 20 + (a)(4)$ $a = -5\text{ms}^{-2}$	



ii) The retardation

Retardation or deceleration occurs in region B.

$u=20\text{ ms}^{-1}$ $v=0\text{ ms}^{-1}$ t = (10 - 6) t=4s	Then from; $v = u + at$ $0 = 20 + (a)(4)$ $-4a = 20$ $a = -5ms^{-2}$ Thus the retardation is $\mathbf{5ms^{-2}}$

iii) Total distance travelled

Stage A: $\text{Distance} = l \times w$ $\text{Distance} = 6 \times 10$ $\text{Distance} = 60\text{ m}$	**Stage B:** $\text{Distance} = \frac{1}{2}bh$ $\text{Distance} = \frac{1}{2} \times 4 \times 10$ $\text{Distance} = 20\text{ m}$
Then Total Distance is; =Area (A+B) =60 m + 20 m **= 80 m**	

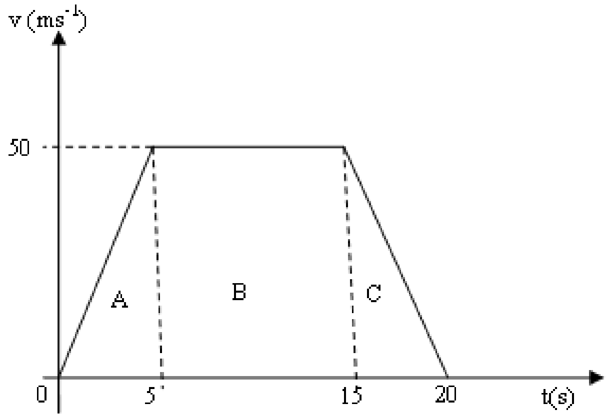
iv)

$$\text{Average speed} = \frac{\text{Total Distance travelled}}{\text{Total Time Taken}} = \frac{80\text{ m}}{10\text{ s}}$$

$\text{Average speed} = \mathbf{8ms^{-1}}$

EXERCISE

Qn1. The graph below shows motion of abody of mass 2kg accelerating from rest.



(a) Describe the motion of the body

(b) Use the graph to calculate the:

- (i) total distance covered.
- (ii) Distance covered at uniform velocity.
- (iii) Acceleration.
- (iv) Retardation.
- (v) average retarding force

Solution

For A	**For B**	**For C**
$u=0\text{ms}^{-1}$; $v=50\text{ms}^{-1}$ Then from; $v = u + at$ $50 = 0 + (a)(5)$ $50 = 5a$ $a = 10\ ms^{-2}$	$u=50\text{ms}^{-1}$; $v=50\text{ms}^{-1}$ Then from; $v = u + at$ $50 = 50 + (a)(5)$ $50 = 50 + 5a$ $a = 0\ ms^{-2}$	$u=50\text{ms}^{1}$; $v=0\text{ms}^{-1}$ Then from; $v = u + at$ 0 $= 50 + (a)(5)$ $-5a = 50$ $a = -10\text{ ms}^{-2}$

Description of the motion

- The body *accelerates uniformly at* 10 ms^{-2} from *rest* to 50 ms^{-1} for the *first* 5s.
- It then moves with a *uniform velocity* of 50 ms^{-1} for the *next* 10s. (Or it maintains it for next 10s).
- It finally *decelerates or retards uniformly* at $10\ ms^{-2}$ from 50 ms^{-1} to *rest* in the last 5s.

a) i) Total distance= Area A + Area B + AreaC

For A	For B	For C
$A = \frac{1}{2}bh$ $A = \frac{1}{2} \times 5 \times 50A$ $= 125$ m	$A = lw$ $A = 10 \times 50A$ $= 500$ m	$A = \frac{1}{2}bh$ $A = \frac{1}{2} \times 5 \times 50A$ $= 125$ m

Total distance = Area A + Area B + Area C
= 125m + 500m + 125m
= 750 m

ii) Distance covered when moving with uniform
Area B = *lw*
$= 10 \times 50$
= 500 m

iii) Acceleration
For A
u = 0 ms^{-1}; v = 50 ms^{-1}; t = 5s

$$v = u + at$$
$$50 = 0 + (a)(5)$$
$$5a = 50$$
$$a = 10 \text{ ms}^{-2}$$

iv) Retardation or Deceleration
For C
u = 50 ms^{-1}; v = 0 ms^{-1}; t = 5s

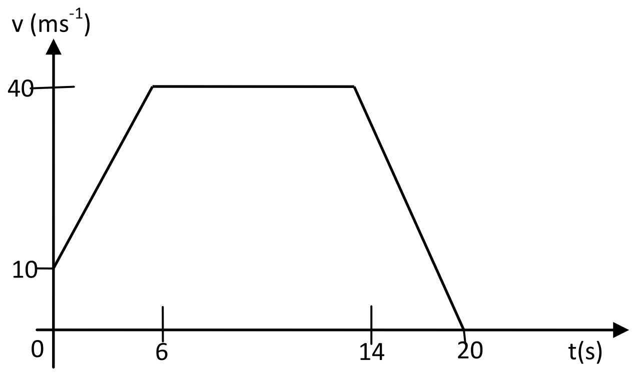
$$v = u + at$$
$$0 = 50 + (a)(5)$$
$$-5a = 50$$
$$a = -10\ ms^{-2}$$

Thus the retardation is **10 ms^{-2}**

i) **Average retarding force**
Mass, m = 2kg, Retardation = 10 ms^{-2}

Then from;
Force = mass × acceleration
Average retarding force = mass × retardation
= 2 × 10
= 20 N

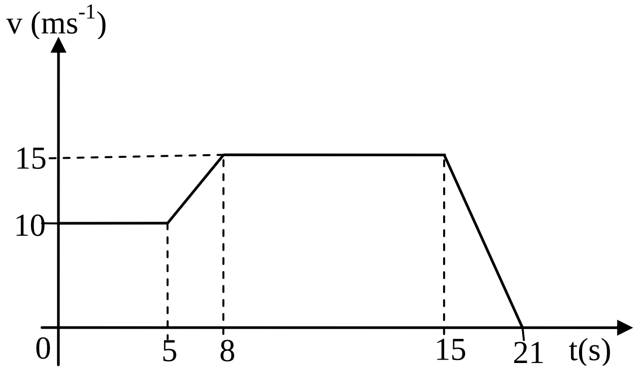
Qn2. The graph below shows motion of a body of mass 3kg. Use it to answer the questions that follow.



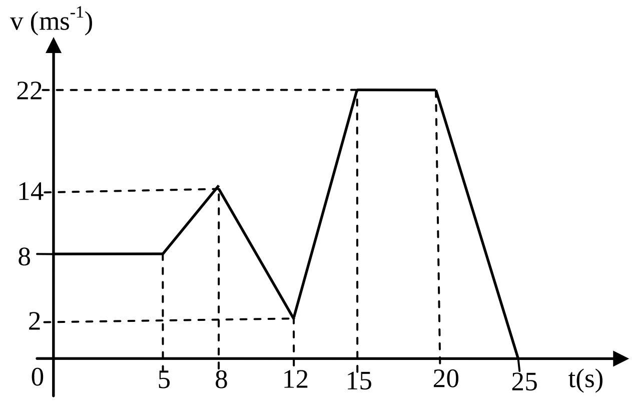
a) Describe the motion of the body
b) Use the graph to calculate the:
  (i) Distance covered during acceleration. (150 m)
  (ii) Distance covered when moving at constant velocity. (320 m)
  (iii) total distance covered. (590 m)
  (iv) acceleration. ($a = 5\ ms^{-2}$)
  (v) retardation. ($a = -6.67\ ms^{-2}$)
  (vi) average accelerating force. ($F = 15\ N$)

Qn 3. The graphs below show motion of bodies. Use them to answer the following questions.
a) Describe the motion of the body
b) Use the graph to calculate the:
  (i) Total distance covered. (ii) Average velocity
  (iii) Acceleration. (iv) Retardation.

(A)



(B)

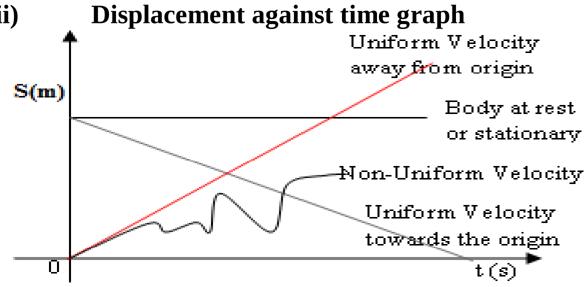


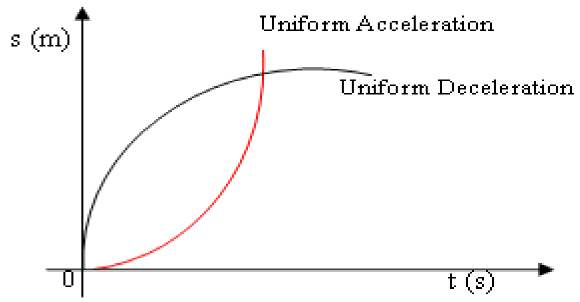
Qn4. A body accelerates uniformly from rest at 3ms^{-2} for 4 seconds. Its velocity then remains constant at the maximum value reached for 7 seconds before retarding uniformly to rest in the last 5 seconds. Calculate the:
(i) uniform velocity ($v = 12\ ms^{-1}$)
(ii) total distance travelled ($= 138\ m$)
(iii) retardation ($a = -2.4\ ms^{-2}$)
(iv) average velocity for the journey. ($v = 8.63\ ms^{-1}$)

Qn5. A body moves from rest at a uniform acceleration of 2ms^{-2}.
a) Sketch a velocity time graph for the motion of the body.
b) Find:
  i) its velocity after 5 seconds. ($v = 10 ms^{-1}$)
  ii) how far it has gone in this time. ($s = 25\ m$)
  iii) how long it will take the body to be 100 m from the starting point. ($t = 10\ s$)

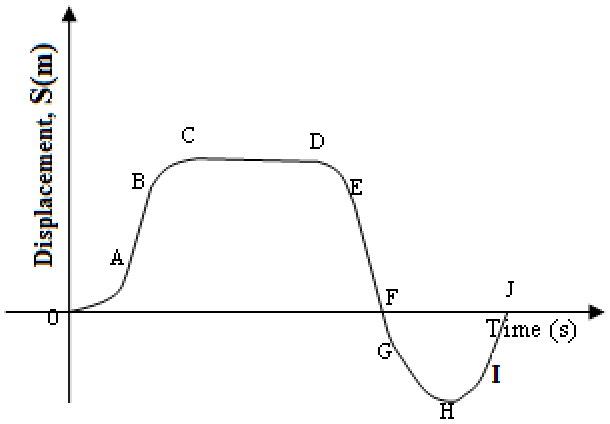
Non-uniform acceleration is when the rate of change of velocity with time is not constant.

ii) Displacement against time graph



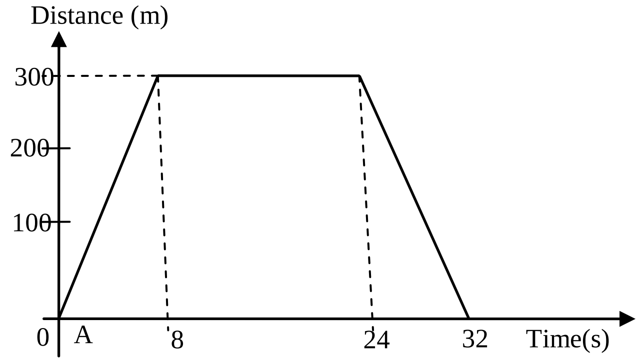


Describing the motion on a displacement time graph



Along:
OA- accelerating
AB- moving with uniform velocity away from the origin
BC- Decelerating
CD- Stationary
DE- Accelerating and moving toward the origin
EF- Moving with uniform velocity
FG- Moving with uniform velocity in opposite direction to the original direction.
GH- Decelerating
At "H"- Momentarily stationary
HI- Accelerating and moving back towards the origin.

Example 1:
The graph below shows the variation of distance with time for a body.



a) Describe the motion of the body
b) Calculate the:
i) acceleration of the body
ii) maximum velocity attained by the body

Solution

For A s = 300 m; t = 8s $u = \frac{\text{distance}}{\text{time}} = \frac{300}{8}$ u =37.5ms^{-1}	Then from; $s = ut + \frac{1}{2}at^2$ $300 = 37.5(8) + \frac{1}{2}(a)(8^2)$ $32a = 0 \Rightarrow a = 0\ ms^{-2}$

Description of the motion

- The body starts from A and moves 300m with a uniform velocity of 37.5 ms^{-1} for the first 8seconds.
- It then rests for the next 16 seconds.
- It finally returns to A with the uniform velocity of 37.5 in the last 8 seconds.

Practice Question:
Qn: 1; [UNEB 1997 Paper II Qn.2]
Two vehicles A and B accelerate uniformly from rest. Vehicle A attains a maximum velocity of $30ms^{-1}$ in 10s while B attains a maximum velocity of $40ms^{-1}$ in the same time. Both vehicles maintain these velocities for 6s before they are decelerated to rest in 6s and 4s respectively.

(i) Sketch on the same axes, velocity time graphs for the motion of the vehicles.
(ii) Calculate the velocity of each vehicle 18s after the start. ($v_A = 20ms^{-1}\ and\ v_B = 20ms^{-1}$)
(iii) How far will the two vehicles be from one another during the moment in (ii) above? ($S_A = 380m\ and\ S_B = 500m: S_{AB} = 120m$)

Qn 2. A car is being driven along a road at a steady speed of 25ms^{-1} when the driver suddenly notices that there is a fallen tree blocking the road 65 m ahead, he immediately applies the brakes giving the car a constant retardation of 5ms^{-2}. How far infront of the tree does the car come to rest? (**Ans. 2.5 m**)

Qn: 3 Starting from rest on a level road a girl can reach a speed of 5 m/s in 10 s on her bicycle. Find
(a) the acceleration,
(b) the average speed during the 10 s,
(c) the distance she travels in 10 s.
(d) Eventually, even though she is still pedaling as fast as she can, she stops accelerating and her speed reaches a maximum value. Explain in terms of the forces acting why this happens.

MOTION UNDER GRAVITY (FALLING BODIES)
Motion under gravity is the motion described by a body falling freely, where the only force acting on it is the gravitation force.
The acceleration of such a body is called *acceleration due to gravity.*

Acceleration due to gravity, **g**.
Acceleration due to gravity is the rate of change of velocity of a body falling freely under the force of gravity.

Note: Acceleration due to gravity varies from place to place because:
- The earth is not a perfect sphere
- The earth is always rotating

All bodies thrown upwards or falling freely in the earth's surface, have a constant acceleration called Acceleration due to gravity, $i.e$: $\boldsymbol{a = g = 10\ ms^{-2}}$.

Since the gravitational force acts vertically down wards, ie accelerates all objects down wards towards the earth's surface. Thus for downward motion (falling objects), $\boldsymbol{a = +g = +10\ ms^{-2}}$***. And for upward motion (objects thrown upwards),*** $\boldsymbol{a = -g = -10\ ms^{-2}}$.

In a vacuum, all bodies fall at the same rate. However, in atmosphere different bodies fall at different rate because the air resistance is greater to light objects.

Simple Projectile motion

A projectile is a particle which has both vertical and horizontal motions when thrown in air (or when given an initial velocity).

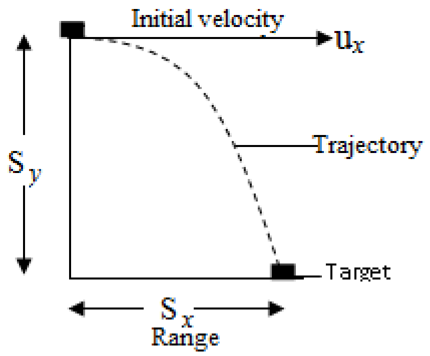
For example: A stone thrown vertically upwards, a ball kicked either vertically or horizontally.

The path taken by a projectile is called a **Trajectory** and the horizontal distance travelled by a projectile is called the **Range.**

Types of Projections

(i) Horizontal projection

Is a type of projection, where the horizontal velocity is constant (the same) while the acceleration is zero.

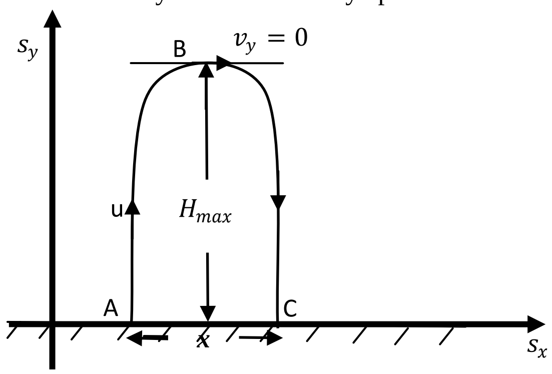


$$s_x = ut$$
$$v_x = u_x = u$$

(ii) Vertical Projection

Is a type of projection, where the vertical acceleration is constant and is equal to acceleration due to gravity, $g = 10\,ms^{-2}$
 while the acceleration is zero.

Consider a body thrown vertically upwards from A.



In projectiles, the horizontal and vertical motions are handled separately but simultaneously. The horizontal velocity of the body in motion remains the same throughout since there is no acceleration due to gravity in the horizontal.

First equation of motion

$$\begin{pmatrix} v_x \\ v_y \end{pmatrix} = \begin{pmatrix} u \\ u \end{pmatrix} + \begin{pmatrix} 0 \\ g \end{pmatrix} t \qquad \Rightarrow \begin{cases} v_x = u \\ v_y = u + gt \end{cases}$$

Second equation of motion

$$\begin{pmatrix} s_x \\ s_y \end{pmatrix} = \begin{pmatrix} u \\ u \end{pmatrix} t + \frac{1}{2}\begin{pmatrix} 0 \\ g \end{pmatrix} t^2 \qquad \Rightarrow \begin{cases} s_x = ut \\ s_y = ut + \frac{1}{2}gt^2 \end{cases}$$

Third equation of motion

$$\begin{pmatrix} v_x^2 \\ v_y^2 \end{pmatrix} = \begin{pmatrix} u^2 \\ u^2 \end{pmatrix} + 2\begin{pmatrix} 0 \\ g \end{pmatrix}\begin{pmatrix} s_x \\ s_y \end{pmatrix} \quad \Rightarrow \begin{cases} v_x^2 = u^2 \\ v_y^2 = u^2 + 2gs_y \end{cases}$$

Where $\boldsymbol{g = +10\,ms^{-2}}$*.for downward motion (freely falling objects or objects dropped from a height), If a body is dropped from a height, then* $\boldsymbol{u = 0\,ms^{-1}}$*hence.*

$$\boldsymbol{S = \frac{1}{2}gt^2 \ \ and \ \ v = gt \ or \ v = \sqrt{2gs}}\,.$$

.

Alternatively the principle of conservation of energy may be used for a freely falling body.

ie $:\frac{1}{2}mv^2 = mgh \Rightarrow \boldsymbol{v = \sqrt{(2gh)}}$.

$\boldsymbol{g = -10\,ms^{-2}}$*.for upward motion (objects thrown upwards),*

Maximum Height,$\boldsymbol{s_y = H_{max}}$: Is the highest vertical distance attained by a projectile.

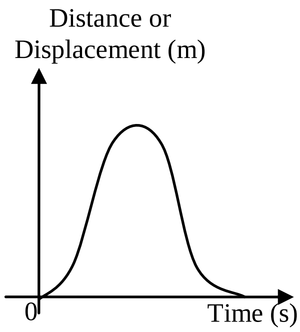
At H_{max} ,$v_y = 0$:

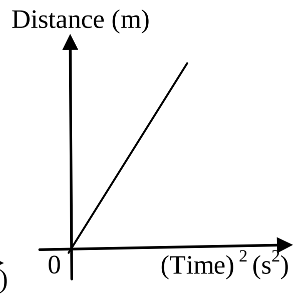
Time of Flight, T: Is the total time taken for a projectile to move from origin until it lands. This time is twice the time taken to reach the maximum height.

If **t** is the time taken to reach the maximum height, then **T= 2t.**

It is the same for both vertical and horizontal projections.

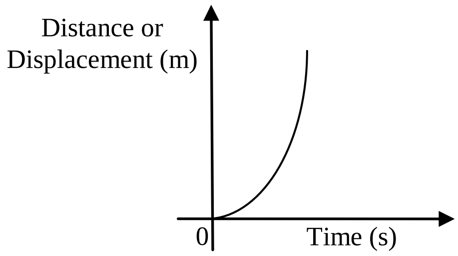
Distance - Time or Displacement –Time Graphs for a body thrown vertically upward.





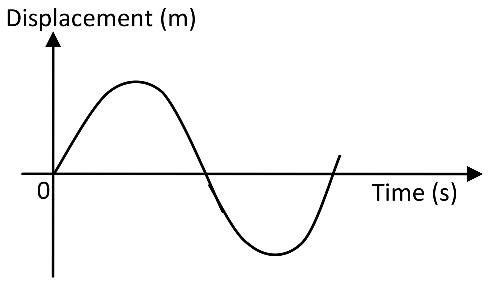
$$\mathbf{S = ut - \frac{1}{2}gt^2}$$

Distance- Time or Displacement –Time Graph for a body falling freely from rest.

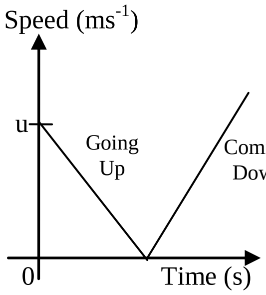


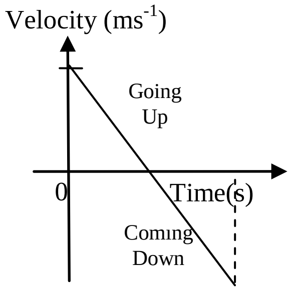
$$\mathbf{S = ut + \frac{1}{2}gt^2}$$

Displacement –Time Graph for a body thrown vertically upwards from appoint above the ground.



Speed- Time and Velocity –Time Graphs For a body thrown vertically upwards.

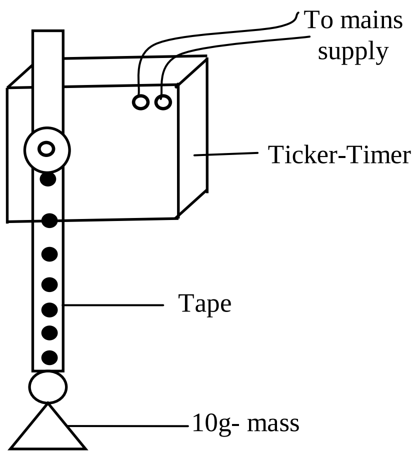




The speed of the object decreases as it goes higher. At maximum height reached the speed is zero because the object is momentarily at rest and when the object starts to fall the speed increases.

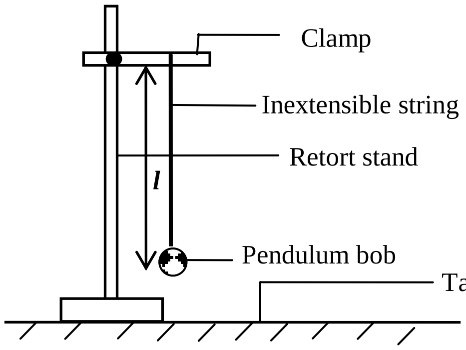
The velocity decreases upwards and it is zero at the maximum height. However the velocity increases downwards and negative because of the change in direction.

Experiment to measure acceleration due to gravity.



- A tape is passed through a ticker-timer and attached to a 10g- mass.
- The ticker-timer makes dots on the tape at an interval determined by the frequency of the mains supply. i.e $T = \frac{1}{f}$. This is the time taken to make **one space** (2 dots).
- The distance **S** between the first dot to the last dot made just before the mass hits the ground is measured using a metre-rule.
- The time, **t** taken to make n- spaces in distance S is calculated from: $t = nT$.
- The acceleration due to gravity, g is then calculated from $\mathbf{S = \frac{1}{2}gt^2}$

Experiment to measure acceleration due to gravity

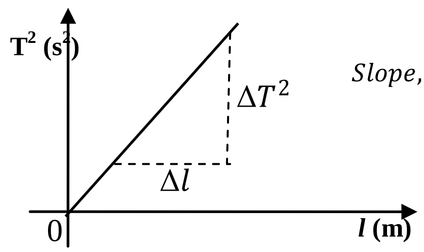


- A pendulum bob is suspended from a clamp using an inextensible string as shown in the diagram above.
- The length of the string of the pendulum bob '*l*' is adjusted to a known length, *l*. eg. *l = 0.3m*.
- The bob is the slightly displaced through a small angle and released.
- The stop clock is started and the time taken to make 20 oscillations (20T) is measured and recorded.
- The period time T for a single oscillation is calculated and recorded.
- The experiment is repeated for other increasing values of *l*, and the corresponding values of 20T, T and T^2 calculated and tabulated.

$l(m)$	20T(s)	T(s)	$T^2(s^2)$

- A graph of T^2 against *l* is plotted. It is a straight line graph through the origin and its slope, S is calculated.

<u>A graph of T^2 Against ***l***</u>



$$Slope, S = \frac{\Delta T^2}{\Delta l}$$

The acceleration due to gravity,g. is then calculated from;

$$\boldsymbol{g = \frac{4\pi^2}{S}}$$

NOTE: *Experiments have shown that the periodic time T does not depend on the mass of the bob, but it depends on the length of pendulum l bob and acceleration due to gravity g at that point. i.e***:**

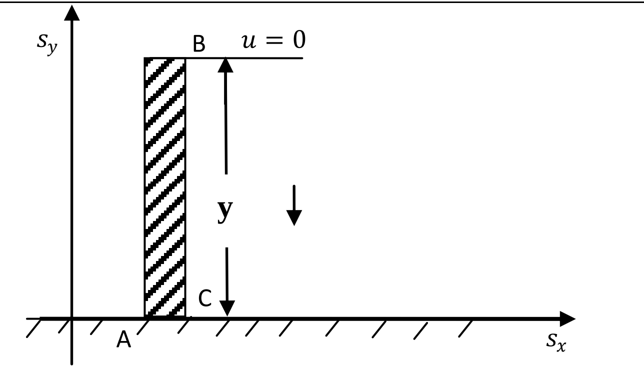
$$\boldsymbol{T = 2\pi\sqrt{\frac{l}{g}}}$$

Example 1:

A stone falls from rest from the top of a high tower. Calculate the : (i) velocity after 2s.

(ii) height of the tower.

<u>**Solution**</u>

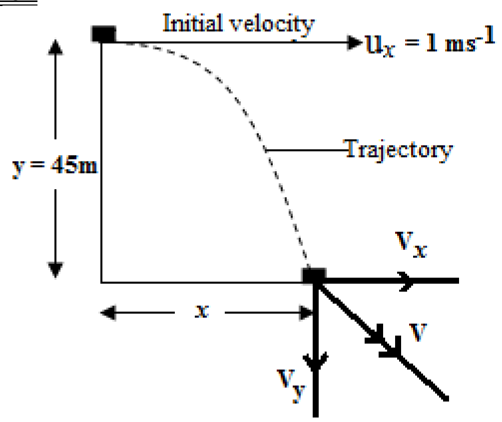


Vertical motion	Then from:
$u_y = 0 \text{ ms}^{-1}$ $a_y = g = 10 \text{ ms}^{-2}$ $t = 2s$ $s = ?$	$V_y = u_y + gt$ $V_y = 0 + (10 \times 2)$ $V_y = 20$ $V_y = 20 \, ms^{-1}$
Alternatively We can use the principle of conservation of energy $\text{P.E}_{\text{Bottom}} = \text{K.E}_{\text{Top}}$ $mgh = \frac{1}{2}mv^2$	$s = u_y t + \frac{1}{2}gt^2$ $y = 0(2) + \frac{1}{2}(10)(2^2)$ $y = 20 \text{ m}$

Example 2:
An object is dropped from a helicopter at a height of 45m above the ground.
a) If the helicopter is at rest, how long does the object take to reach the ground and what is its velocity on arrival?
Solution

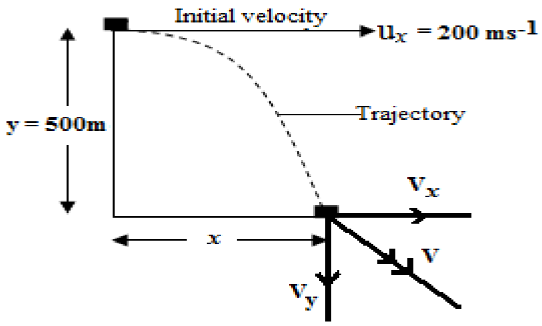
Vertical motion	Then from:
$u_y = 0 \text{ ms}^{-1}$ $a_y = g = 10 \text{ ms}^{-2}$ $t = ?$ $s = 45 \text{ m}$ $s = ut + \frac{1}{2}gt^2$ $45 = 0(t) + \frac{1}{2}(10)(t^2)$ $45 = 5t^2$ $t = 3 \text{ s}$	$v = u + gt$ $v = 0 + (10 \times 3)$ $v = 30$ $v = 30 \text{ ms}^{-1}$

b) If the helicopter had a velocity of 1ms^{-1} when the object was released, Find the final velocity of the object?
Solution



Horizontal motion	Vertical motion
$u_x = 1 \text{ ms}^{-1}$ $a_x = 0 \text{ ms}^{-2}$ $t = 3s$	$u_y = 0 \text{ ms}^{-1}$ $a_y = g = 10 \text{ ms}^{-2}$ $t = ?$ $s = 45 \text{ m}$
$s = ut + \frac{1}{2}gt^2$ $x = 1(2) + \frac{1}{2}(0)(3^2)$ $x = 2 \text{ m}$ $V_x = u_x + a_x t$ $V_x = 1 + (0 \times 2)$ $V_x = 1$ $V_x = 1 \, ms^{-1}$ **Or, use 3rd equation** $v_x^2 = u_x^2 + 2gx$ $v_x^2 = 1^2 + 2(0)(2)$ $v_x^2 = 1^2$ $V_x = 1 \, ms^{-1}$	$V_y = u_y + a_y t$ $V_y = 0 + (10 \times 3)$ $V_y = 30$ $V_y = 30 \, ms^{-1}$ **Or, use 3rd equation** $v_y^2 = u_y^2 + 2gy$ $v_y^2 = 0^2 + 2(10)(45)$ $v_y^2 = 900$ $V_y = 30 \, ms^{-1}$ Velocity with which the body hits the ground $V = \sqrt{V_x^2 + V_y^2}$ $V = \sqrt{1^2 + 30^2}$ $V = \sqrt{901}$ $V = 30.02 \, ms^{-1}$

Example 3:
An object is released from an aircraft traveling horizontally with a constant velocity of 200ms^{-1} at a height of 500m.



a) Ignoring air resistance, how long it takes the object to reach the ground?
b) Find the horizontal distance covered by the object between leaving the aircraft and reaching the ground.

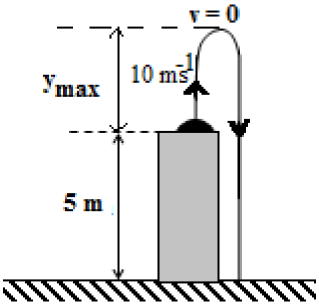
Solution

Horizontal motion	Vertical motion
$u_x = 200 \text{ ms}^{-1}$ $a_x = 0 \text{ ms}^{-2}$ $t =$	$u_y = 0 \text{ ms}^{-1}$ $a_y = -g = -10 \text{ ms}^{-2}$ $t = ?$ $s = 500 \text{ m}$
Horizontal distance, x $s = ut + \frac{1}{2}gt^2$ $\mathbf{x = ut}$ $x = 200(10)$ $x = 2000 \text{ m}$ $V_x = u_x + a_x t$ $V_x = 200 + (0 \times 10)$ $V_x = 200$ $V_x = 200 \, ms^{-1}$ **Or, use 3rd equation** $v_x^2 = u_x^2 + 2gx$	Then from: $s = ut + \frac{1}{2}gt^2$ $\mathbf{y = \frac{1}{2}gt^2}$ $500 = \frac{1}{2}(10)(t^2)$ $500 = 5t^2$ $100 = t^2$ $t = 10 \text{ s}$ $V_y = u_y + a_y t$ $V_y = 0 + (10 \times 10)$ $V_y = 100$ $V_y = 100 \, ms^{-1}$

v_x^2 $= 200^2 + 2(0)(2000)$ $v_x^2 = 200^2$ $V_x = 200\ ms^{-1}$	**<u>Or, use 3rd equation</u>** $v_y^2 = u_y^2 + 2gy$ $v_y^2 = 0^2 + 2(10)(500)$ $v_y^2 = 10000$ $V_y = 100\ ms^{-1}$
Velocity with which the body hits the ground $V = \sqrt{V_x^2 + V_y^2}$ $V = \sqrt{200^2 + 100^2}$ $V = \sqrt{40000 + 10000}$ $V = \sqrt{50000}$ $\underline{V = 223.61\ ms^{-1}}$	

Example 4:
A ball is thrown vertically upwards with a velocity of 10ms-1 from a point 50m above the ground. With the aid of a velocity- time graph. Describe the motion of the ball.

Solution.



<u>Horizontal motion</u>	<u>Vertical motion</u>
$u_x = 0$ $a_x = 0\ \text{ms}^{-2}$ $t =$	$u_y = 10\ \text{ms}^{-1}$ $a_y = g = 10\ \text{ms}^{-2}$ $t = ?$ $s = -5\ \text{m}$

Then considering : <u>Vertical motion</u>

$s = ut + \frac{1}{2}gt^2$

$\mathbf{y = ut + \frac{1}{2}gt^2}$

Note: *since the ground is 5m below the point of projection, then,* ***S = y = -5m.***

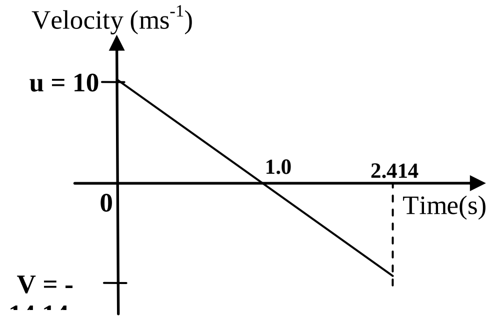
$-5 = 10t + \frac{1}{2}(-10)(t^2)$

$-5 = 10t - 5t^2$

$5t^2 - 10t - 5 = 0$

$\underline{t = 2.414\ s}$

Time to reach maximum height. **At y_{max} , $v = 0$** $V_y = u_y + a_y t$ $0 = 10 + (-10t)$ $10t = 10$ $t = 1\ s$ *The maximum height,* y_{max} **.** **At y_{max} , $v = 0$** **<u>Using the 3rd equation</u>** $v_y^2 = u_y^2 + 2gy$ $0 = u_y^2 + 2(-g)y_{max}$ $0 = 10^2 + 2(-10)y_{max}$ $20y_{max} = 100$ $y_{max} = 5\ m$ <u>Thus the total Height is given by:</u> $s = 5 + y_{max}$ $s = 5 + 5$ $s = 10\ m$	*Time taken to move from maximum height to the ground is:* $s = ut + \frac{1}{2}gt^2$ $10 = 0 \times t + \frac{1}{2} \times 10 \times t^2$ $5t^2 = 10$ $t^2 = 2$ $t = 1.414\ s$ *Velocity with which the body hits the ground.* $V_y = u_y + a_y t$ $V_y = 0 + (10 \times 1.414)$ $V_y = 14.14$ $V_y = 14.14\ ms^{-1}$
<u>Velocity –time time graph for the motion.</u>	



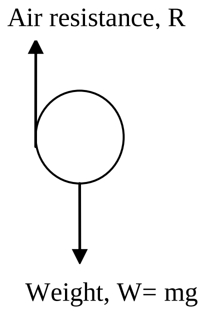
- ❖ When the ball is thrown vertically upwards with a velocity of 10 ms^{-1}, it decelerates uniformly at 10ms^{-2} till its velocity is zero after 1s (At maximum height).
- ❖ From the maximum height, the ball begins to fall downwards with uniform acceleration of 10ms^{-2} but the direction is now opposite and hence th velocity is negative.
- ❖ This continues until it hits the ground with a velocity of 14.14ms^{-1} after 2.414 s.

Trial Questions:
1. An object is dropped from a helicopter. If the object hits the ground after 7s, calculate the height from which the object was dropped.

2. A ball is projected horizontally from a height of 20m with a speed of 5ms^{-1}. Find the:
   (i) Horizontal distance covered. (**Ans: 10 m**)
   (ii) speed with which it hits the ground.
   (**Ans: 20.616 ms^{-1}**)

Note: For a body thrown vertically up ward, the time taken to reach the maximum vertical height is equal to the time taken for the body to fall from maximum height.

Note; If a body is not falling freely but there is air resistance R then the acceleration of the body can be calculated from:-
ma = mg – R , where m is the mass of the body.

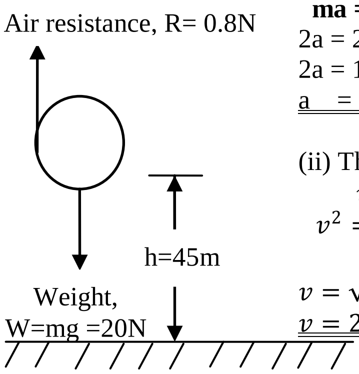


Resultant force, F
F = mg – R ……………. (i)
Then from:
F = ma ………………….(ii)

From equations (i) and (ii)
ma = mg – R

Example 4:
An object of 2kg is dropped from a helicopter at a height 45m above the ground. If the air resistance is 0.8N, calculate the:
i) acceleration of the body
ii) velocity with which the body hits the ground

<u>Solution</u>
For vertical motion
m = 2kg, u= 0 ms^{-1}: g =10 ms^{-2}
R = 0.8 N, s = 45m, a = ?, v = ?



(i) Then from**:**
ma = mg – R
2a = 2 (10) -0.8
2a = 19.2
<u>a = 9.6 ms^{-2}</u>

(ii) Then from**:**
$$v^2 = u^2 + 2as$$
$$v^2 = 0^2 + 2(9.6)(45)$$
$$v^2 = 864$$
$$v = \sqrt{864}$$
$$\underline{v = 29.39\ ms^{-1}}$$

Exercise
Qn: 1. The table below shows the variation of velocity with time for a body thrown vertically upwards from the surface of a planet.

Velocity (ms^{-1})	8	6	4	2	0	-2
Time (s)	0	1	2	3	4	5

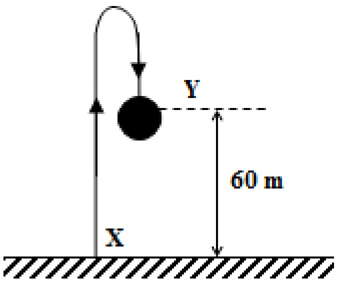
(a) What does the negative velocity mean?
(b) Plot a graph of velocity against time.
(c) Use the graph in (b) above to find the
 i) Acceleration due to gravity on the planet. ($2ms^{-2}$)
 ii) Total distance travelled. (17m)
(d) If the body weighs34n on earth, what is its weight on the planet? (= 6.8N)

2. An aeroplane travelling at 200ms^{-1} at a height of 180m is about to drop an aid package of medical supplies onto an IDP camp in northern Uganda.
(a) At what horizontal distance before the target should the package be released? [*x* = 1200m]
(b) Find the time taken by the package to hit the target. [t = 6s]

3. A bomb is released from a jet fighter plane moving with velocity of 400 ms^{-1} to hit a rebel camp in northern Uganda. If the bomb took 10 seconds to hit the target, calculate:
(i) The altitude at which the bomb was released.
(ii) The horizontal distance from the vertical point of the plane to the target.
(iii) The velocity with which the bomb hits the target. (Take g = 10 ms^{-2})

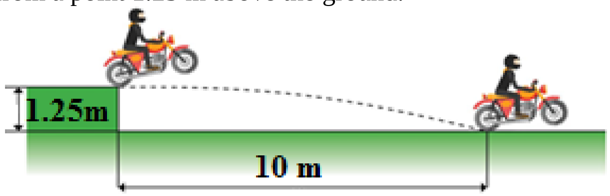
4. A ball is hit horizontally off a cliff with a velocity of 30 ms^{-1}. If it takes 5 seconds to reach the ground, calculate:
(i) The height of the cliff.
(ii) The horizontal distance from the foot of the cliff to the point where the ball lands.
(iii) The velocity with which the ball hits the ground.

5. A body is projected upwards from point X at 40ms^{-1} and it takes the path shown above.



Find the velocity of the body at a point Y, 60m above the point of projection.

6. A motorcycle stunt-rider moving horizontally, takes off from a point 1.25 m above the ground.



(a) She lands 10m away from the take-off point, as shown. What was the speed at take-off?

A	5 m s^{-1}
B	10 m s^{-1}
C	15 m s^{-1}
D	20 m s^{-1}

(b) What was the speed with which the rider hits the ground?

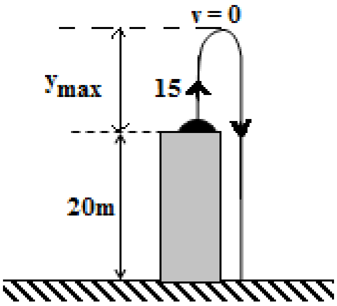
7. A ball is thrown vertically upwards with a velocity of 30 ms^{-1} and caught by the thrower on its return. Neglecting air resistance,
(i) Sketch a velocity time graph for the motion of the ball.
(ii) Find the maximum height reached and the time taken to reach this height.

8. A stone is fired vertically upwards from a catapult and lands 5.0s later. Find:
(i) The initial velocity of the stone. (**Ans: 25 ms^{-1}**)
(ii) How long the stone was at a height above 20m. (**Ans: 3 s**)

9. A stone is thrown vertically upwards at 10ms^{-1} from a bridge which is 15m above a river. Calculate the:
(i) Speed of the stone as it hits the river. (**Ans: 20 ms^{-1}**)
(ii) Speed it would hit the river with, if it was thrown down wards at 10ms^{-1}. (**Ans: 20 ms^{-1}**)

10. A sand bag is released from a balloon which is ascending with a steady vertical velocity of 8ms-1. If the sand bag hits the ground 15s later, what was the height of the balloon above the ground when the sand bag was released. (**Ans: 1005 m**)

11. A man at the edge of a cliff and throws a stone vertically upwards at $15ms^{-1}$.



After how long will the stone hit the ground which is 20m below the point of projection.

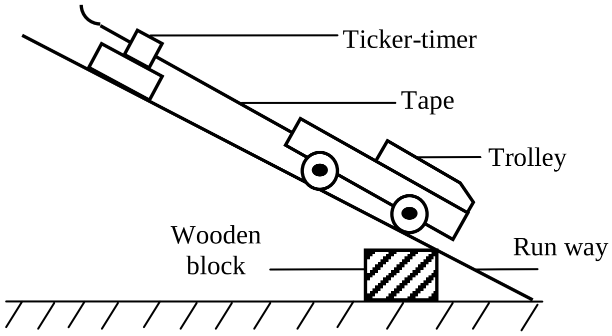
12. A block of plastic and a block of lead, each 0.2 kg are released simultaneously to fall down a well with water at the bottom. The lead block took 4.0 s to reach the water surface.
(i) State and explain any difference in the time of arrival of the two blocks at the surface of water.
(ii) Calculate the speed with which the lead block strikes the water surface.
(iii) Find the distance of the water surface from the top of the well.

THE TICKER - TAPE TIMER

(a) Determining the velocity and acceleration of a body using a ticker tape timer:

(i) Compensation for friction

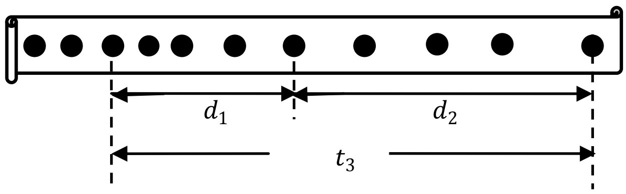
Before each experiment with a trolley, it is necessary to compensate for friction.
This can be done by tilting the runway with suitable packing pieces until it moves with uniform velocity after having been given a slight push. In this situation, the dots printed on the paper tape are equally spaced.



- A paper tape is driven through aticker timer connected to a mains supply of known frequency, f e.g 50Hz by a trolley running freely on an inclined plane.

Measuring the distances, d and time, t.

- After the trolley has reached the end of the run way, the tape is removed and distance, $\mathbf{d_1}$ between$\mathbf{n_1}$**-dotspaces (**eg 10dot spaces**)** is measured and recorded. The first mark made is the zero time.



- The time 't' between n- spaces, is calculated from: $\mathrm{t = number\ of\ spaces, n \times Periodic\ time, T}$

$$\mathrm{t_1 = n_1T, where. T = \frac{1}{f}}$$

- The angle of inclination of the run way to the horizontal is increased steadily such that the trolley moves faster than before. the tape is removed and the new distance, $\mathbf{d_2}$ between $\mathbf{n_2}$**-dot spaces (**eg 10 new dot spaces**)** is measured and recorded.
  The time 't_2' between n_2- spaces, is calculated from:

$$\mathrm{t_2 = n_2T, where. T = \frac{1}{f}}$$

Determining the speed or Velocity, V.

- The speed or velocity at different times is the calculated as follows:.

$$v_1 = \frac{d_1}{t_1} \text{ and} v_2 = \frac{d_2}{t_2}$$

Determining the acceleration, a.

- The acceleration of the trolley is then calculated from:
  $acceleration,\ \boldsymbol{a} = \frac{\boldsymbol{v_2 - v_1}}{\boldsymbol{t_3}}$:

Where $t_3 = n_3T$, is the interval for the velocity change to occur.

OR

- ❖ The procedures are repeated, various velocities determined and a graph of velocity against time plotted. The slope of the graph gives the acceleration of the body.

Using the ticker tape timer to determine Acceleration After it has printed dots on a tape.

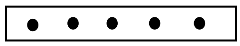
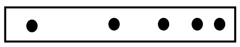
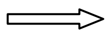
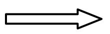
Frequency: These are vibrations per second or number of dots per second. The S I unit is **hertz**. (**Hz**).

NB: Frequency is also number of dots printed per second. Example: A frequency of 60Hz mean 60 dots per second.

Period: This is the time taken for a dot to be printed on a tape. The SI unit of period is seconds.

Period, $T = \frac{1}{\text{frequency}, f} \Leftrightarrow T = \frac{1}{f}$

Ticker tapes showing dots for bodies in motion

State of motion	Sample tape	Direction of Motion
Uniform velocity		
Uniform acceleration		
Uniform deceleration		

Example:

Calculate the period for a frequency of 60 Hz

Frequency, f = 60Hz

Period time, $T = \frac{1}{f} = \frac{1}{60} = 0.0167$ s

Calculating time taken from a tape

Time taken, t = number of spaces(n)×Periodic time(T)

Time taken, t= nT

Example: 1

Below is a tape printed by ticker- tape timer vibrating at 100Hz. Find the time taken to print these dots.

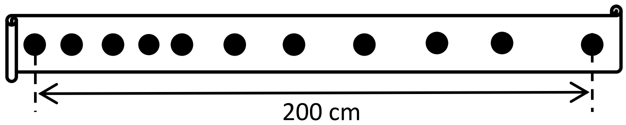
Frequency, f = 100Hz Period time, $T = \frac{1}{f}$ $T = \frac{1}{100}$ T= 0.01	$\left(\begin{matrix}\text{Time}\\\text{taken}\end{matrix}\right) = \left(\begin{matrix}\text{number of}\\\text{spaces}\end{matrix}\right) \times \left(\begin{matrix}\text{Periodic}\\\text{time}\end{matrix}\right)$ Time taken,t=nT Time taken,t=10(0.01) Time taken,t=0.1s

Calculating the average speed

$$\textbf{Average speed} = \frac{\textbf{Distance, (d)}}{\textbf{Time taken, (t)}} = \frac{d}{t}$$

Example: 2

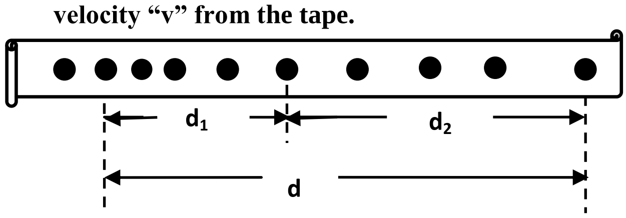
Below is a tape printed by a ticker –tape timer vibrating at 50Hz. Calculate the average speed.



Solution

Frequency, f = 50Hz Period time, $T = \frac{1}{f}$ $T = \frac{1}{50}$ T= 0.02	$\left(\begin{matrix}\text{Time}\\\text{taken}\end{matrix}\right) = \left(\begin{matrix}\text{number of}\\\text{spaces}\end{matrix}\right) \times \left(\begin{matrix}\text{Periodic}\\\text{time}\end{matrix}\right)$ Time taken,t=nT Time taken,t=10(0.02) Time taken,t=0.2s Distance=200cm= $\frac{200}{100} = 2$m Average speed= $\frac{\text{Distance, (d)}}{\text{Time taken, (t)}}$ Average speed= $\frac{d}{t}$ Average speed= $\frac{2}{0.2}$ Average speed=10ms^{-1}

(b) Calculating the initial velocity "u" and final velocity "v" from the tape.



Initial velocity, u = Average speed for initial distance =initial distance "d_1" divided by time taken "t_1"

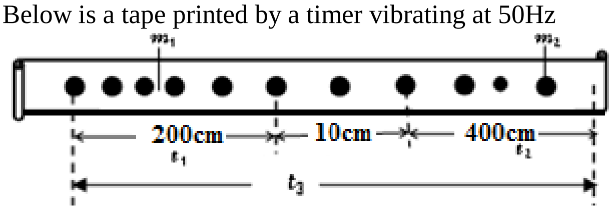
Initial speed, $u = \frac{d_1}{t_1}$; where, Time taken, $t_1 = n_1T$

Final velocity (v) = Average speed for final distance = final distance "d_1" divided by time taken "t_2"
i.e.

Final speed, $v = \frac{d_2}{t_2}$; where, Time taken, $t_2 = n_2T$

Example:3

Below is a tape printed by a timer vibrating at 50Hz



Calculate the;

i) Initial velocity ii) Final velocity iii) Acceleration

For the above, the following steps should be involved.

- ✓ identifying the frequency
- ✓ finding the periodic time from T= 1/f
- ✓ finding the time taken to cover given distances
- ✓ calculating the required velocities
- ✓ finding the time taken to cover distance between mid points of the distances
- ✓ calculating the required acceleration

Solution

Frequency, f = 50Hz

Period time, $T = \frac{1}{f}$

$T = \frac{1}{50}$

<u>T= 0.02s</u>

When, d_1=200cm ,

$= \frac{200}{100}$

$= 2m$

(i)

$\begin{pmatrix}\text{Time}\\ \text{taken}\end{pmatrix} = \begin{pmatrix}\text{number of}\\ \text{spaces}\end{pmatrix} \times \begin{pmatrix}\text{Periodic}\\ \text{time}\end{pmatrix}$

Time taken, $t_1 = n_1 T$

Time taken, t_1=5(0.02)

<u>Time taken, t_1=0.1s</u>

Initial speed, $u = \frac{d_1}{t_1} = \frac{200}{0.1} = 2000cms^{-1}$

Or

Initial speed, $u = \frac{d_1}{t_1} = \frac{\left(\frac{200}{100}\right)}{0.1} = 20ms^{-1}$

(ii)

When, d_2=400cm, $= \frac{400}{100} = 4m$

Time taken, $t_2 = n_2 T$

Time taken, t_2 = 3(0.02)

<u>Time taken, t_2 = 0.06s</u>

Final speed, $v = \frac{d_2}{t_2} = \frac{400}{0.06} = 6666.67cms^{-1}$

Or

Final speed, $v = \frac{d_2}{t_2} = \frac{\left(\frac{400}{100}\right)}{0.06} = 66.67ms^{-1}$

(iii)

$\begin{pmatrix}\text{Time taken}\\ \text{for change}\end{pmatrix} = \begin{pmatrix}\text{number of}\\ \text{spaces}\\ \text{between mid}\\ \text{points of}\\ d_1 \text{ and } d_2\end{pmatrix} \times \begin{pmatrix}\text{Periodic}\\ \text{time}\end{pmatrix}$

Time taken, $t_3 = n_3 T$

Time taken, t_3= 6(0.02)

<u>Time taken, t_3= 0.12s</u>

Acceleration;

Acceleration calculated applying v = u + at

$$\textbf{Acceleration, a} = \frac{\textbf{change in velocity}}{\textbf{Time for the change}}$$

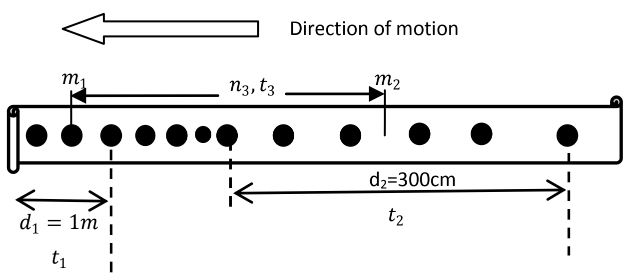
$$\text{Acceleration, a} = \frac{v - u}{t_3}$$

$$\text{Acceleration, a} = \frac{66.67 - 20}{0.12} = \frac{46.67}{0.12}$$

<u>Acceleration, a = 388.92ms^{-2}</u>

Example II:

Below is a tape printed by a ticker timer vibrating at 20Hz. Calculate the acceleration.



Solution

Frequency,

f = 20Hz

Period time, $T = \frac{1}{f}$

$T = \frac{1}{20}$

<u>T= 0.05 s</u>

When, d_1= 1m

Time taken, $t_1 = n_1 T$

Time taken, t_1=2(0.05)

<u>Time taken, t_1=0.1s</u>

Initial speed, $u = \frac{d_1}{t_1} = \frac{1}{0.05}$

$= 10ms^{-1}$

When, d_2=300cm,

$= \frac{300}{100} = 3m$

Time taken, $t_2 = n_2 T$

Time taken, t_2=5(0.05)

<u>Time taken, t_2=0.25s</u>

Final speed, $v = \frac{d_2}{t_2} = \frac{3}{0.25}$

$= 12ms^{-1}$

Time taken, $t_3 = n_3 T$

Time taken, t_3=7.5(0.05)

<u>Time taken, t_3=0.375s</u>

Acceleration;

Acceleration calculated

Applying: v = u + at

$$\textbf{a} = \frac{\textbf{change in velocity}}{\textbf{Time for the change}}$$

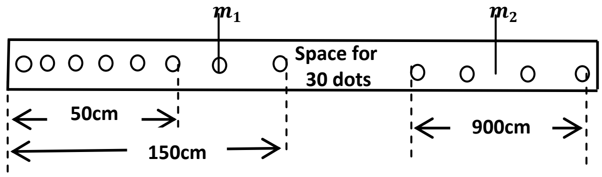
$$\text{Acceleration, a} = \frac{v - u}{t_3}$$

$$\text{Acceleration, a} = \frac{12 - 10}{0.375}$$

<u>Acceleration, a = 5.33ms^{-2}</u>

Example III

The timer is vibrating at 20Hz. Calculate the acceleration



Solution

Frequency, f = 20Hz

Period time, $T = \frac{1}{f}$

$T = \frac{1}{20} = 0.05s$

$d_1 = (150 - 50)cm$

$d_1 = 100cm$

$d_1 = \frac{100}{100} = 1m$

$t_1 = n_1 T$

$t_1 = 2(0.05) = 0.1s$

$u = \frac{d_1}{t_1} = \frac{1}{0.1}$

$= 10ms^{-1}$

$d_2 = 900cm$

$d_2 = \frac{900}{100} = 9m$

$t_2 = n_2 T$

$t_2 = 3(0.05)$

<u>$t_2 = 0.15s$</u>

$v = \frac{d_2}{t_2} = \frac{9}{0.15} = 60ms^{-1}$

Time taken, $t_3 = n_3 T$

Time taken, t_3=31.5(0.05)

<u>Time taken, t_3=1.575s</u>

Acceleration;

Acceleration calculated applying v = u + at

$$\textbf{a} = \frac{\textbf{change in velocity}}{\textbf{Time for the change}}$$

$$\text{Acceleration, a} = \frac{v - u}{t_3}$$

$$\text{Acceleration, a} = \frac{60 - 10}{1.575}$$

<u>Acceleration, a =31.75ms^{-2}</u>

NOTE: If there are n-dots, then there are (n-1) spaces.

i.e: $\boldsymbol{n_s = (n_d - 1)}$. Where $\mathbf{n_s}$ is the number of spaces and $\mathbf{n_d}$ is the number of dots.

Example:
A ticker timer is vibrating at 10Hz. Calculate the time taken if the timer prints 21 dots.

Solution

Number of dots, n_d=21 dots Number of spaces, $\boldsymbol{n_s = (n_d - 1)}$. Number of spaces, $\boldsymbol{n_s = (21 - 1)}$. Number of spaces, $\boldsymbol{n_s = 20}$ spaces Frequency, f = 10Hz Period time, $T=\frac{1}{f}=\frac{1}{10}$=0.1s $\begin{pmatrix}\text{Time}\\ \text{taken}\end{pmatrix}=\begin{pmatrix}\text{Number of}\\ \text{spaces}\end{pmatrix}\times\begin{pmatrix}\text{Period}\\ \text{time}\end{pmatrix}$	$t = nT$ $t = 20(0.1)$ $t = 2s$

Example:
A ticker timer prints 11 dots at 20Hz in a space of 2m. Calculate the average speed.
Solution

Number of dots, n_d=11 dots Number of spaces, $\boldsymbol{n_s = (n_d - 1)}$. Number of spaces, $\boldsymbol{n_s = (11 - 1)}$. Number of spaces, $\boldsymbol{n_s = 10}$ spaces Frequency, f = 20Hz Period time, $T=\frac{1}{f}=\frac{1}{20}$=0.05s $\begin{pmatrix}\text{Time}\\ \text{taken}\end{pmatrix}=\begin{pmatrix}\text{Number of}\\ \text{spaces}\end{pmatrix}\times\begin{pmatrix}\text{Period}\\ \text{time}\end{pmatrix}$	$t = n_sT$ $t = 10(0.05)$ $t = 0.5s$ Average speed, $v = \frac{\text{Distance}}{\text{Time taken}}$ $v = \frac{2}{0.5}$ $v = 4ms^{-1}$

Note:
In experiments with ticker timer being pushed by a trolley, the first dots are ignored because they are overcrowded for accurate measurements.

(c) Calculating Acceleration from given number of dots.
If the distance is measured from $\mathbf{m^{th}}$ dot to $\mathbf{n^{th}}$ dot then the number of spaces can be calculated directly by subtracting m from n.
Number of spaces, $\boldsymbol{n_s = (n^{th}dot - m^{th}dot)}$.
Time taken, **t**=Number of spaces, $\boldsymbol{n_s}$×Period time, **T**
Period time, **T** = $\frac{1}{\text{frequency, } \mathbf{f}}$

Example:
The distance between 15^{th} dot and 18^{th} dot is 10cm. if the ticker timer is vibrating at 20Hz. Calculate the;
i) time taken

Number of spaces, $n_s = (n^{th}dot - m^{th}dot)$
Number of spaces, $n_s = (18 - 15)$
Number of spaces, $n_s = 3$ spaces

Frequency, f = 20Hz

Period time, $T=\frac{1}{f}=\frac{1}{20}$ = 0.05s

Time taken, **t** = Number of spaces, $\boldsymbol{n_s}$×Period time, **T**
Time taken, **t** = 3(0.05)
t = 0.15s

ii) average speed
Distance covered = 10cm = 0.1m

$$\text{Average speed, } v = \frac{\text{Distance}}{\text{Time taken}} \Leftrightarrow v = \frac{0.1}{0.15}$$

$$v = 0.67ms^{-1}$$

Example:
A trolley is pulled from rest with a constant force down an inclined plane. The trolley pulls a tape through a ticker timer vibrating at 50Hz. The following measurements were made from the tap.
Distance between 16^{th} dot and 20^{th} dot= $\mathbf{d_1}$=20cm
Distance between 20^{th} dot and 30^{th} dot = 34cm
Distance Q between 30^{th} dots and 40^{th} dot = 48cm
Distance between 40^{th} dot and 50^{th} dot = $\mathbf{d_2}$=62cm
Calculate the acceleration of the trolley.

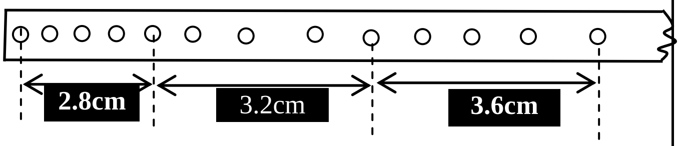
Solution

$\begin{pmatrix}\text{Number of}\\ \text{spaces}, n_s\end{pmatrix}$ $= (n^{th}\text{dot} - m^{th}\text{dot})$ $= (20 - 16)$ $= 4$ spaces Number of spaces, n_s = 4 spaces Frequency, f = 50Hz Period time, $T=\frac{1}{f}=\frac{1}{50}$ T = 0.02s $d_1 = 20cm = \frac{20}{100}$ $d_1 = 0.2m$ $t_1 = n_1T = 4(0.02)$ $t_1 = 0.08s$ $u = \frac{d_1}{t_1} = \frac{0.2}{0.08}$ $u = 2.5ms^{-1}$ $d_2 = 62cm$ $d_2 = \frac{62}{100} = 0.62m$	$t_2 = n_2T$ $t_2 = 10(0.02)$ $t_2 = 0.2s$ $v = \frac{d_2}{t_2} = \frac{0.62}{0.2}$ $v = 3.1ms^{-1}$ For $\mathbf{d_1}$ last dot is 20^{th} For $\mathbf{d_2}$ last dot is 50^{th} $\begin{pmatrix}\text{Time taken}\\ \text{for change; } t_3\end{pmatrix}$ $= (50^{th} - 20^{th}) \times 0.02$ $\begin{pmatrix}\text{Time taken}\\ \text{for change; } t_3\end{pmatrix}$ = 30×0.02 t_3 = 0.6s **Acceleration;** Acceleration calculated applying v = u + at $\mathbf{a} = \frac{\textbf{change in velocity}}{\textbf{Time for the change}}$ *Acceleration, a* = $\boldsymbol{\frac{v - u}{t_3}}$ *Acceleration, a* = $\boldsymbol{\frac{3.1 - 2.5}{0.6}}$ *Acceleration, a* =$1.0ms^{-2}$

EXERCISE

1. A paper tape dragged through a ticker timer by a trolley has the first ten dots covering a distance of 4cm and the next ten dots covering a distance of 7cm. If the frequency of the ticker timer is 50Hz, calculate the acceleration of the trolley.
(Ans:=$\mathbf{75cms^{-2}}$ or $\mathbf{0.75ms^{-2}}$)

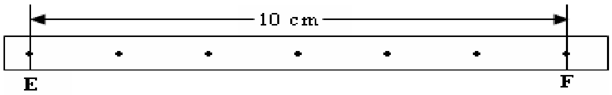
2. The ticker timer below was pulled by a decelerating trolley. The tape consists of 3 five dot spaces and the frequency of the timer is 50Hz.



A ticker timer is connected to the mains supply of frequency 40Hz. Find the time it takes to print three consecutive dots.

A. 0.08 s   B. 0.25 s   C. 0.050 s   D. 0.75 s

3. The ticker tape shown in the figure was pulled through a ticker timer, which makes 50 dots per second.



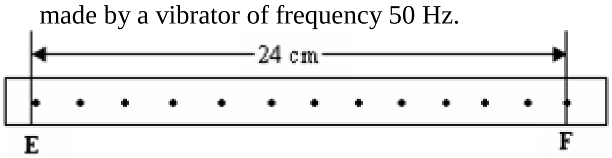
The speed at which the tape was pulled is

A. 10cm s-1   B. 25cm s-1
C. 50cm s-1   D. 100cm s-1

4. A tape is pulled through a ticker-timer, which has a frequency of 50Hz. If the distance between successive dots is 2cm, calculate the speed of the body

A. $0.01cms^{-1}$ B. $50.33cms^{-1}$
C. $83.330cms^{-1}$ D. $100.00cms^{-1}$

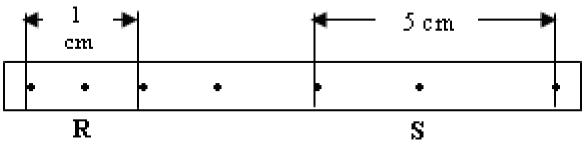
5. The equally spaced dots on the ticker tape above are made by a vibrator of frequency 50 Hz.



The speed of the tape in m/s is

A. 0.1   B. 0.01
C. 0.001   D. 1

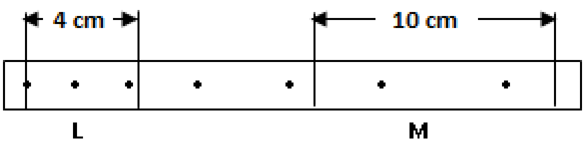
6. The tape shown in the diagram below was made by a trolley moving with a constant acceleration. If the frequency of the ticker-timer is 50 Hz,



find the acceleration in m/s^2

A. $75\ ms^{-2}$ B. $2\ ms^{-2}$
C. $5\ ms^{-2}$ D. $12.5\ ms^{-2}$

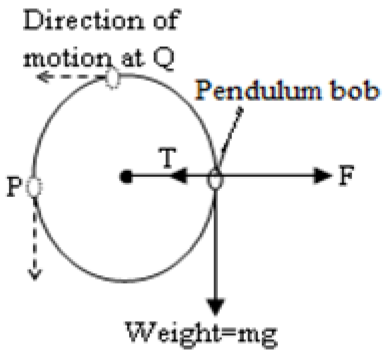
7. Calculate the acceleration, in ms^{-2}, for the motion shown in the diagram below. (Take frequency = 100Hz)



1: 11. CIRCULAR MOTION

Circular motion is motion in which a body moves in a circle about a fixed point.

For a body moving in a circle;
- ✓ Its direction and velocity are constantly changing.
- ✓ It has an acceleration called centripetal acceleration.
- ✓ It has a force called Centripetal force acting towards the centre of the circular path.



T=Tension in the string which produces the **centripetal force.**

Note: When the object is released, it moves such that the direction of motion at any point is along a tangent to the circular path.

Forces acting on the body

(i) **Tension:** Force acting towards the centre of the circular path. It provides the centripetal force.

(ii) **Centripetal force**: Force acting towards the centre of the circular path. Mathematically the centripetal force F is expressed as: $\boldsymbol{F} = \frac{\boldsymbol{mv^2}}{\boldsymbol{r}}$, where m = mass, v = speed and r = radius of circle or orbit.

Centripetal acceleration, $\boldsymbol{a} = \frac{\boldsymbol{v^2}}{\boldsymbol{r}}$

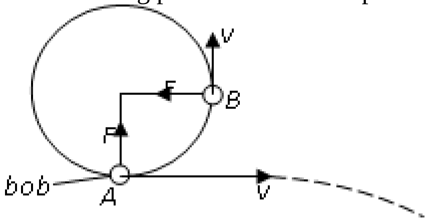
(iii) **Centrifugal force**: Apparent Force acting away from the centre of the circular path.

(iv) **Weight:** Force acting vertically down wards towards the centre of the earth.

Examples of bodies moving in circular paths

(i) A bob attached to a string and whirled in a circle

The tension in the string provide s the centripetal force



If the string breaks at appoint A or B the bob will slide off in a straight line making a tangent to its original circular path at point A or B.

It would move like a projectile into the directions shown and eventually falls down to the ground.

This is because, when the string breaks, the horizontal component of the tension in the string which was providing the centripetal force required to keep the ball moving around a circle no longer exists.

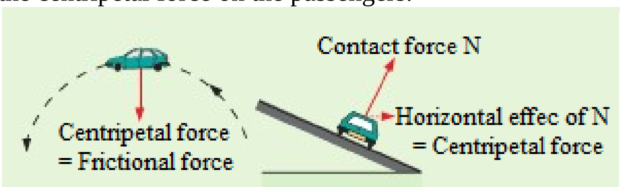
This horizontal force on the ball just before the string breaks provides the acceleration of the ball in a horizontal direction in accordance with Newton's 2nd law of motion. It then gradually curves down downwards until it hits the ground due to the force of gravity on it.

(ii) Motion of satellite and planets in orbits.

The centripetal force which keeps the planets and other satellites in orbits is provided by the gravitational attraction of the body around which they are moving.

(iii) A car moving around a bend.

The friction at the tryes provides the centripetal force to move the car around the bend. Passengers in the car feel pressed against the side of the car. The car exerts a reaction on the passengers. It is this reaction that provides the centripetal force on the passengers.



Safe cornering that does not rely entirely on friction is achieved by 'banking' the road as in the second Figure . Some of the centripetal force is then supplied by the part of the contact force N, from the road surface on the car, that acts horizontally.

A bend in a railway track is banked, so that the outer rail is not strained by having to supply the centripetal force by pushing inwards on the wheel flanges**.**

(iv) A bucket of water can be whirled in a vertical plane without the water coming out at the highest point.

This is because at the highest speed of rotation, the weight of the water is less than the centripetal force and so the water stays in the bucket.

At a lower speed the weight of the water is greater than the centripetal force and hence the water leaves the bucket.

Applications of centripetal force

(i) It enables vehicles to go round bends and roundabouts.

Very sharp bends are banked (raised at one side) to prevent side slip at the wheels and to increase on the centripetal force. A cyclist leans when going round a bend in order to counter balance the movement produced by the centripetal force with the normal reaction at the ground.

(ii) Centrifuges

It is used in centrifuges which are instrument used for separating particles in suspension from a less dense liquid. The liquid is first rotated. The centripetal force on the solid particles urges them towards the center of the centrifuge where they collect.

This same method is used in separating cream from denser milk, blood from plasma, in drying machines, etc.

(iii) It is employed in the motion of satellite and space crafts around the earth.

The satellites are used in telecommunication and radio transmission. They move in orbits called **parking orbits** where they have the same period as that of the rotation of the earth i.e. 24 hours, hence they are always above the same place on the earth. The gravitational attraction of the earth provides the necessary centripetal force to make the satellites follow a circular path.

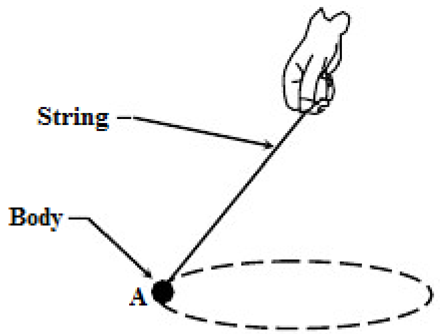
(iv) Rotation of wheels e.g. Car wheels Gear wheels, the balance wheels of the clocks etc.
(v) Merry go round at amusement parks.

EXERCISE:

1. A ball of mass 200g is whirled at the end of a string in a horizontal circular path at a speed of $5ms^{-1}$. If the string is 2m long, find:
(i) the centripetal force the string exerts on the ball.
(ii) the value of the centripetal acceleration.

2. (a) Define the term **acceleration**.

(b) A body attached to a string is swung in a vertical circular path in air as shown in the figure below.



(i) Copy the above diagram and on it indicate and name all the forces acting on the body if the body is moving in an anti-clockwise direction.
(ii) Explain what happens if the string breaks when the ball is in position A.

(c) Explain why the weight of an object on the earth's surface may vary from one place to another.

(d) (i) what is meant by centripetal force.
(ii) state the factors affecting the centripetal force.

See UNEB

1999 Paper II Qn.1	

1: 12. NEWTON'S LAWS OF MOTION

These are three laws that summarize the behavior of particles in motion.

1:12:1. Newton's First Law of motion

Newton's first law of motion states that a body continues in its state of rest or uniform motion in a straight line unless acted upon by an external force.

Common experiences have shown that objects at rest do not begin to move on their own
accord or objects on motion do not come to rest instantly on their own. As a result of this, the following are sited as examples of Newton's first law of motion.

(a) **A body at rest**

If a pile of coins is placed on a table, the one at the bottom can be removed without disturbing the ones on the top.

Explanation: The force applied only acts on that particular coin at the bottom. Since the rest are not acted upon by the force, they remain undisturbed.

(b) **A body in motion**

(i) A person riding a bicycle along a level road does not come to a restimmediately when he stops pedaling. The bicycle continues to moveforward for some time, but eventually comes to a rest.

Explanation

The bicycle continues to move because of inertia and comes to a rest after time as a result of the retarding action of the external forces such as air resistance andfrictional force between the tyre and the road surface. These external forces oppose the motion and eventually come to a rest.

(ii) Collision of two vehicles or when a sharp brake is applied to a car moving at a high velocity.

In the above incidences, passengers who do not fasten their safety belts are often injured when they jack forward and hit the wind screen.

Explanation

An external force acts on the vehicle but not on the passenger who simply continue their motion in a straight line in accordance with Newton's first law of motion.

(iii) A bullet fired at an angle from a gun.

When a bullet is fired from a gun held at angle to the ground, the bullet travels and eventually falls to the ground.

Explanation

The motion of the bullet is opposed by air resistance and the gravitational force, hence, sooner or later it returns to the ground.

Note: As per Newton's first law of motion, it is supposed that, if the external forces such as friction between solid surfaces in contact, air resistance and gravitational force in the above examples were not there, the bodies would continue to move for ever.

Example: A rolling ball would keep rolling; a desk would remain in class room.

Inertia

Definition: *Inertia is the tendency of a body to remain at rest or to keep moving with a uniform velocity in a straight line.*

Inertia is the reluctance of a body to move, when at rest or to stop when moving.

For this reason, Newton's first law is sometimes called **"the law of inertia".**

A body of large mass requires a large force to change its speed or its direction i.e. the body has a large inertia. Thus, the mass of a body is a measure of its inertia.

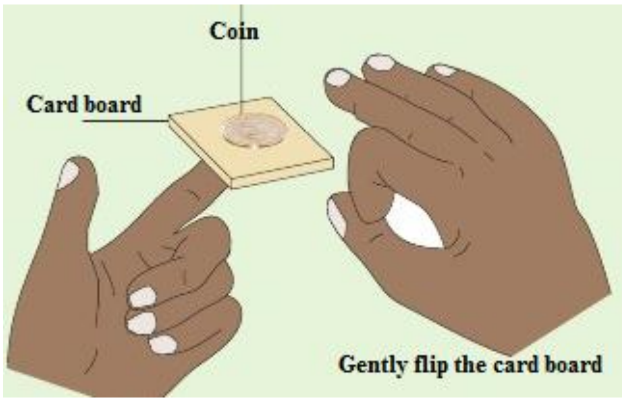
Thus, when a force acts on a body, the body;

- ✓ Starts or stops moving.
- ✓ Increases or reduces speed depending on the direction of the force.
- ✓ Changes direction of motion.

Examples:

- ✓ A passenger jerks forwards when a bus is suddenly stopped or jerksbackwards when a bus is suddenly started.
- ✓ Books placed on the cloth remain on table when the cloth is pulled faster.

Demonstration of Newton's 1st law of motion



If the card is flicked sharply the coin stays where it is while the card flies off.

1:12:2. Newton's second law of motion

Newton's second law states that the rate of change in momentum is directly proportional to the force acting on the body and takes place in the direction of the force.

$$F \,\alpha \frac{mv - mu}{t} \Leftrightarrow F \,\alpha\, m\left(\frac{v-u}{t}\right) \Leftrightarrow F \,\alpha\, ma \Leftrightarrow F = k\, ma$$

When we consider a force of 1N, mass of 1kg and acceleration of 1ms^{-2}, then, **k=1**.Therefore;

$$\mathbf{F = ma}$$

A newton; Is the force which acts on a mass of 1kg to produce an acceleration of 1ms^{-2}.

IMPULSE:

From Newtons second law of motion, **Ft = mv - mu**

The product **Ft** is called i**mpulse**, **p**, and is equal to the change in momentum.

Thus, **Impulse of a force on a body refers to the change in momentum of the body.**

As the gun and the bullet were initially at rest, their initial momenta were both zero, hence the final momentum in each case is the change in momentum. Since their impulses were equal and opposite, their momenta will be equal and opposite.

The bullet leaves the gun barrel with a **muzzle velocity** and the gun kicks or reacts in the opposite direction with a velocity called **recoil velocity**.

Thus; Mass of bullet x Muzzle velocity = Mass of gun x recoil velocity

Since the two velocities (muzzle and recoil velocities) and the two momenta are vector quantities and are acting in opposite directions, their sum is zero.

The above observation illustrates an important principle called the principle of conservation of momentum.

Examples of Newton's second law of motion.

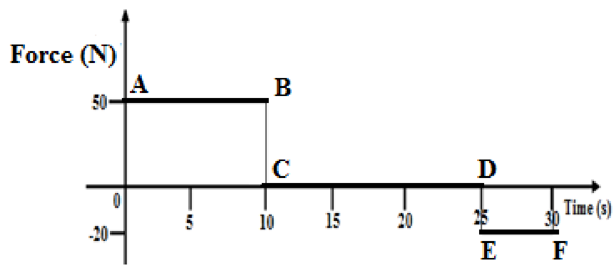
(i) Catching the ball by a field player

(ii) Bending of the knees when landing.

When catching a ball moving at a high speed, one pulls the hands backward. This is done to increase the time for the momentum to reduce to zero, hence reducing the force exerted by the ball onto the player's hands.

For the same reason, one bends the knees while landing during long or high jump.

$$F = m\left(\frac{v-u}{t}\right)$$



Acceleration: For a body to accelerate, it must be acted upon by a force in the same direction as that of the motion of the body. (Newton's 2nd law of motion). Thus for the first 10s, (along **AB**), a force of **+50N** means a force of 50N is acting on the body in the same direction in which the body is moving. From, **F = ma**, F has a positive value when a is positive since m is a scalar which is always positive. Hence the body is accelerating.

Deceleration: For a body to decelerate (have a negative acceleration), it must be acted upon by a force in the opposite direction to that of its motion. Thus for the last 5s, (i.e between 25s and 30s), (along **EF**) a force of **-20N** means a force of 20N is acting on the body in the opposite direction to that in which the body is moving. From, **F = ma**, F has a negative value when a is negative since m is a scalar which is always positive. Hence the body is decelerating.

Constant Velocity: For a body to move with a constant velocity, Its acceleration must be zero. From, **F = ma**, a is zero when F is zero since m can never be zero.

Hence the body moves with a constant velocity when the net force acting on it is zero. This can also be deduced from Newtons's 1st law of motion according to which, no force is required to keep the body moving with constant velocity. Thus for the between 10s and 25s,(along **CD**), **F = 0,** hence the body is moving with a constant velocity.

Question :UNEB 2011 PP2 No. 2(e).

A bullet of mass 0.006kg travelling at 120 ms-1 penetrates deeply into a fixed target and is brought to rest in 0.01s. Calculate the:

(i) Distance of penetration of the bullet.

Using the 1st equation of motion,

$$\mathbf{v = u + at}$$
$$0 = 120 + 0.01a$$
$$a = -12000\text{ms}^{-2}$$

(The negative sign of acceleration means retardation).

Then using the 2nd equation of motion,

$$\mathbf{s = ut + \frac{1}{2}at^2}$$
$$s = 120 \times 0.01 + \frac{1}{2} \times (-12000) \times (0.01)^2$$
$$s = 1.2 - 0.6$$
$$s = 0.6\text{ m}$$

(ii) Average retarding force on the bullet.

Then using Newton's 2ndlaw of motion,

$$\mathbf{F = ma}$$
$$F = 0.006 \times (-12000)$$
$$F = -72\text{ N}$$

(The negative sign of force means retarding force).

Hence the average retarding force on the bullet is 72 N.

Example 2

A car of mass 1 tonne travelling at 36kmh^{-1} is brought to rest over a distance of 20m. Find the :

(a) Average retardation. $[a = -2.5\text{ ms}^{-2}]$

(b) Average retarding force. [F = 250 N]

Example 3

A bullet of mass 20g is fired with a velocity of 16ms-1 and it penetrates a sand bag and finally brought to rest in0.05s. Find the :

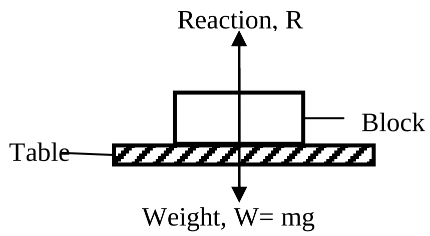
(a) Depth of penetration. $[s = 0.4\text{ m}]$

(b) Average retarding force. [F = 6.4 N]

1:12:3. Newton's third law of motion

It states that for every action, there is an equal and opposite reaction.

When a body, A exerts a force on body B, body B also exerts an equal force in the opposite direction.



The block exerts a weight, **W= mg** on the table and the table also exerts an equal reaction R on the block. R= mg, so that the net force on the block is zero and therefore there is no vertical motion.

Applications of Newton's third law of motion

(a) A man jumping from a boat

A man jumping from a boat exerts action force on the boat and the boat exerts a reaction force. As he jumps to the river bank, the boat moves backwards.

(b) Propulsion of a bullet from a gun

When a bullet is fired from a gun, the energy of the explosion of the charge in the cartridge acts on both the bullet and the gun, thus producing equal and opposite forces acting on them. These equal forces act for the same time i.e the time taken by the bullet to travel up the barrel of the gum. The time effect of a force is called impulse; thus the bullet and the gun are given equal and opposite impulses. In each case, the impulse is equal to the change in momentum.

(c) Rockets , jets and Ballons propulsion.

Rockets and jet engines are designed to burn fuel in oxygen to produce large amounts of exhaust gases.

These gases are passed backwards through the exhaust pipes at high velocity (large momentum).

This in turn gives the Rocket or jet a high forward momentum which is equal but opposite to that of the exhaust gases.

$$\boldsymbol{m_g v_g = -m_R v_R}$$

Where$m_g v_g$ is the momentum of the exhaust gases, and $m_R v_R$ is momentum of the Rocket.

(d) Motion in the lift

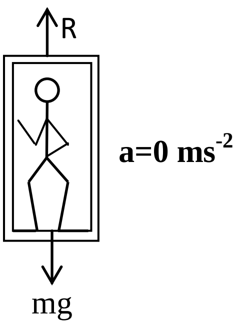
Imagine you're on a rocket or lift standing on a scale. You're still near enough to the Earth so that your actual weight is unchanged. The scale, recall, measures normal force, not weight. Your apparent weight depends on the acceleration of the rocket or lift.

Example:

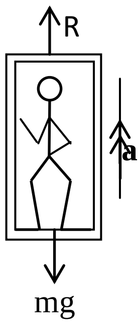
The valve of a cylinder containing 12g of compressed gas is opened and the cylinder empties in 1minute and 30 seconds. If the gas issues from the exist nozzle with an average velocity of 25 ms-1, find the force exerted on the cylinder. [F = 3.3 N]

Consider a person of mass m standing in a lift, when the;

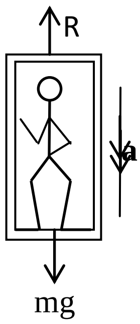
i) Lift is stationary or moving with uniform velocity

	The person exerts a weight, mg on the lift and at the same time, the lift exerts a reaction, R, on the person. **R= mg**.

ii) Lift is moving upwards with acceleration, a.

	In this case, three forces act on the lift. i.e, the resultant accelerating force (**ma**), the weight, **(mg)** and the normal reaction or Apparent weight (**R**). **Accelerating force = Net force** ma = R – mg R = mg + ma **R = m (g+a)**
Thus, the reaction on the person (apparent weight, R) is greater than the actual weight of the person, mg. This is why one feels **heavier** when the lift is just beginning its upward journey.	

iii) Lift is moving down wards with acceleration, a.

	In this case, the resultant accelerating force (**ma**), and the weight, **(mg)** act down wards. The normal reaction or Apparent weight (**R**) act upwards. **Accelerating force = Net force** ma = mg - R R = mg - ma **R = m (g - a)**
Thus, the reaction on the person (apparent weight, R) is less than the actual weight of the person, mg. This is why one feels **lighter** when the lift is just beginning its downward journey.	

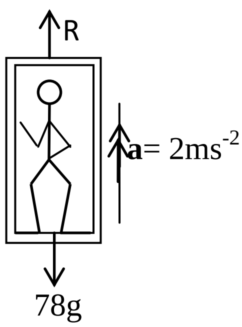
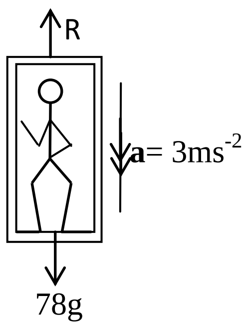
Example:1

A person of mass 78kg is standing inside an electric lift. What is the apparent weight of the person if the;

a) Lift is moving upwards with an acceleration of $2ms^{-2}$?

b) Lift is descending with an acceleration of $2ms^{-2}$?

Solution

(a)	(b)
	
m = 78kg, a = $2ms^{-2}$ R=? R = mg + ma **R = m (g+a)** R = 78 (10+2) R = 936N	m = 78kg, a = $3ms^{-2}$ R=? R = mg - ma R = 78(10 - 3) R = 546N

1: 12.4: COLLISIONS AND MOMENTUM

Linear Momentum:
Momentum is the product of mass and its velocity.

$$\begin{pmatrix}\textbf{Linear Momentum}\\ \textbf{of a body}\end{pmatrix} = \begin{pmatrix}\textbf{Mass of}\\ \textbf{the body}\end{pmatrix} \times \textbf{Velocity}$$

Impulse:
Impulse is the change in the momentum of a body.

$$\textbf{Impulse} = \textbf{mv} - \textbf{mu}$$

Impulse can also be defined as the product of force and time of impact.
From Newton's second law of motion,

$$F = \frac{mv - mu}{t} \Leftrightarrow Ft = mv - mu$$

$$\textbf{Impulse} = \textbf{Ft} = \textbf{mv} - \textbf{mu}$$

The S.I unit of momentum and impulse is **Kgms^{-1}**
Note: Momentum and impulse are vector quantities.

Principle of conservation of momentum
It states that when two or more bodies collide, the total momentum remains constant provided no external force is acting.

It states that when two or more bodies collide, the total momentum before collision is equal to the total momentum after collision.

Suppose a body of mass m_1 moving with velocity u_1 collides with another body of mass m_2 moving with velocity u_2. After collision, the bodies move with velocities v_1 and v_2 respectively, then;

$$\boldsymbol{m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2}$$

Types of collisions

✓ **Elastic collision**
Elastic collision is the type of collision whereby the colliding bodies separate immediately after the impact with each other and move with different velocities.

In short, for elastic collision,

$$\begin{pmatrix}\textbf{\textit{Total momentum}}\\ \textbf{\textit{before collision}}\end{pmatrix} = \begin{pmatrix}\textbf{\textit{Total momentum}}\\ \textbf{\textit{after collision}}\end{pmatrix}$$

$$\mathbf{m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2}$$

✓ **Inelastic collision**
Inelastic collision is when the colliding bodies stay together and move with the same velocity after collision.
In short, for inelastic collision,

$$\begin{pmatrix}\textbf{\textit{Total momentum}}\\ \textbf{\textit{before collision}}\end{pmatrix} = \begin{pmatrix}\textbf{\textit{Total momentum}}\\ \textbf{\textit{after collision}}\end{pmatrix}$$

$$\mathbf{m_1u_1 + m_2u_2 = (m_1 + m_2)V}$$

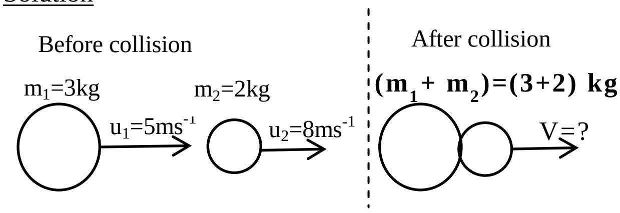
Comparisons between Elastic collision and Inelastic collision

Elastic collision	Inelastic collision
(i) Bodies separate after collision	Bodies stick together after collision.
(ii) Bodies move with different velocities after collision	Bodies move with same velocity after collision
(iii) Kinetic energy of the bodies is conserved	Kinetic energy of the bodies is not conserved
Momentum is conserved. Total momentum before collision = Total momentum after collision $\mathbf{m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2}$	*Momentum is conserved. Total momentum before collision = Total momentum after collision* $\mathbf{m_1u_1 + m_2u_2 = (m_1 + m_2)}\boldsymbol{V}$

NOTE; For any stationary body or body at rest, the initial velocity is zero so the initial momentum of such a body before collision is zero.

Example:1
A body of mass 3kg traveling at 5ms^{-1} collides with a 2kg body moving at 8ms^{-1} in the same direction. If after collision the two bodies moved together, Calculate the velocity with which the two bodies move after collision.

Solution

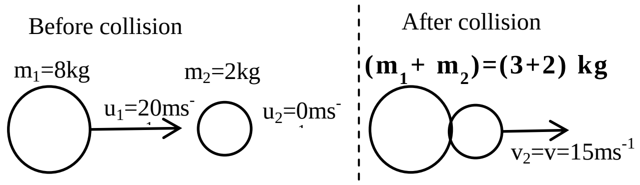


$$\begin{pmatrix}\text{Total}\\ \text{momentum}\\ \text{before collision}\end{pmatrix} = \begin{pmatrix}\text{Total}\\ \text{momentum}\\ \text{after collision}\end{pmatrix}$$

m_1= 3kg, m_2= 2kg u_1=5ms^{-1}, u_2=8ms^{-1} v_1=V=?, v_2=V=?	$m_1u_1+m_2u_2 = (m_1+m_2)V$ $3(5)+2(8)= (3+2)V$ $15+16= 5V$ $31= 5V$ $\frac{31}{5} = \frac{5V}{5}$ $6.2 = V$ $V = \underline{6.2\ ms^{-1}}$

Example: 2
A body of mass 8kg traveling at 20 ms^{-1} collides with a stationary body and they both move with velocity of 15ms^{-1}. Calculate the mass of the stationary body.

Solution

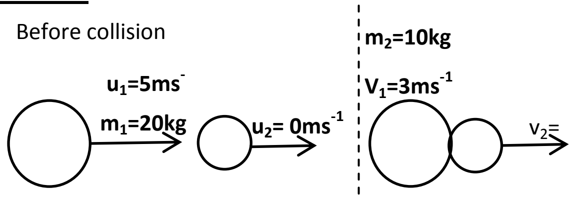


m_1= 8kg, m_2= 2kg u_1=20ms^{-1}, u_2=8ms^{-1} v_1=V=1 ms^{-1}, v_2=V=15 ms^{-1} (Total momentum before collision) = (Total momentum after collision)	$m_1u_1+m_2u_2=(m_1+m_2)V$ $8(20)+m_2(0)=(8+m_2)(15)$ $160+0=8(15)+15m_2$ $40=15m_2$ $2.67=m_2$ $m_2=2.67$kg

Example: 3

A body of mass 20kg traveling at 5ms^{-1} collides with another stationary body of mass 10kg and they move separately in the same direction. If the velocity of the 20kg mass after collision was 3ms^{-1}. Calculate the velocity with which the 10kg mass moves.

Solution



m_1= 20kg, m_2= 10kg u_1=5ms^{-1}, u_2=0ms^{-1} v_1=3ms^{-1}v_2=? (Total momentum before collision) = (Total momentum before collision)	$m_1u_1+m_2u_2=m_1v_1+m_2v_2$ $20(5)+10(0)=20(3)+10(v_2)$ $100+0=60+10v_2$ $100-60=10v_2$ $\frac{40}{10}=\frac{10v_2}{10}$ $4=v_2$ $\mathbf{v_2=4ms^{-1}}$

Exercise:

1. A particle of mass 200g moving at 30ms^{-1} hits a stationary particle of mass100g so that they stick and move together after impact. Calculate the velocity with which they move after collision.**(Ans:V= 20ms^{-1})**

2. A military tanker of mass 4tonnes moving at 12ms^{-1} collides head on with another of mass 3tonnes moving at 2oms^{-1}. After collision, they stick together and move as one body. Ignoring the effect of friction, find their common velocity.

(Ans: V=1.7ms^{-1}in the direction of the 2nd tank**)**

3. A body of mass 10kg moving at 20ms^{-1} hits another body of mass 5kg moving in the same direction at 10ms^{-1}. After collision, the second body moves separately forward with a velocity of 30ms^{-1}. Calculate the velocity of the first body after collision. **.(Ans:v_1=10ms^{-1})**

4. A car X of mass 1000kg travelling at a speed of 20 ms-I in the direction due east collides head-on with another car Y of mass1500kg, travelling at 15ms-1 in the direction due west. If the two cars stick together, find their common velocity after collision.

5. A body Q of mass 50g collides with a stationary body "P" of mass 4g. If a body "Q" moves backward with a velocity of 10ms^{-1} and a body "P", moves forward with a velocity of 6ms^{-1}. Calculate the initial velocity of a body Q. .[u_Q= -9.52ms^{-1}]

6. A moving ball "P" of mass 100g collides with a stationary ball Q of mass 200g. After collision, P moves backward with a velocity of 2ms^{-1} while Q moves forward with a velocity of 5ms^{-1}. Calculate the initial velocity of P. [u_P= -8ms^{-1}]

7. A body of mass 600g traveling at 10ms^{-1} is accelerated uniformly at 2 ms^{-2} for four seconds. Calculate the;
   (i) Change in momentum. [4.8kgms^{-1}]
   (ii) force acing on a body [1.2N]

8. A van of mass 1.5 tonnes travelling at 20ms^{-1}, hits a wall and is brought to rest as a result in 0.5seconds. Calculate the;
   (i) Impulse. [30000 kgms^{-1}]
   (ii) Average force exerted on the wall. [60N]

9. A man of mass 60kg jumps from a high wall and lands on a hard floor at a velocity of 6ms.Calculate the force exerted on the man's legs if;

(i) He bends his knees on landing so that it takes 1.2s for his motion to be stopped. [F =-300 N]

(ii) He does not bend his knees and it takes 0.06s to stop his motion. [F =-6000 N]

EXPLOSIONS

Momentum is conserved in explosions such as exploding fire works, when a riffle is fired etc. During the firing, the bullet receives an equal but opposite amount of momentum to that of the rifle.

Total momentum before collision = Total momentum after collision

$$m_gu_g + m_bu_b = m_gv_g + m_bv_b$$
$$m_g(0) + m_b(0) = m_g(-v_g) + m_bv_b$$
$$0 = m_g(-v_g) + m_bv_b$$
$$\mathbf{m_gv_g = m_bv_b}$$

Where; m_g is mass of the rifle (or gun), V_g is velocity of the rifle which is also called recoil velocity. m_b is mass of the bullet, V_b is velocity of the bullet.

For any explosion of bodies, the amount of momentum for one body is equal but opposite to that of another body. The **negative sign** indicates that the momenta are in opposite directions.

Example:1

A bullet of mass 8g is fired from a gun of mass 500g. If the missile velocity of the bullet is 500ms^{-1}. Calculate the recoil velocity of the gun.

Solution

m_b= 8g = $\frac{8}{1000}$ = 0.008kg, m_g= 500g = $\frac{500}{1000}$ = 0.5kg v_b= 500ms^{-1}, v_g = ?	From, $m_gv_g=-m_bv_b$ $0.5V_g$ = - 0.008(500) $0.5V_g$ = - 4 $\mathbf{V_g= -8ms^{-1}}$

The negative sign indicates that the recoil velocity, V_g is in opposite direction to that of the bullet.

Example: 2
A bullet of mass 200g is fired from a gun of mass 4kg. If the muzzle velocity of the bullet is $400ms^{-1}$, calculate the recoil velocity.

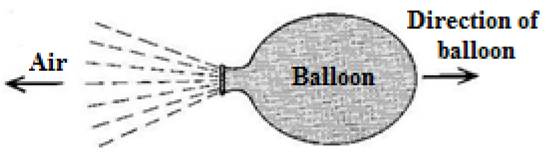
Solution

$m_b = 200g = \frac{200}{1000} = 0.2kg$, $m_g = 4kg$ $v_b = 400ms^{-1}$, $v_g = ?$	From, $m_g v_g = -m_b v_b$ $4V_g = -0.2(400)$ $4V_g = -80$ $\frac{4V_g}{4} = \frac{-80}{4}$ $\mathbf{V_g = -20ms^{-1}}$

Example: 3
A bullet of mass 12.0g travelling at $150ms^{-1}$ penetrates deeply into a fixed soft wood and is brought to rest in 0.015s. Calculate
(i) How deep the bullet penetrates the wood **[1.125m]**
(ii) the average retarding force exerted by the wood on the bullet. **[120N]**

Applications of momentum

(i) An air filled balloon when released with its mouth open moves in an opposite direction as that of escaping air. This is because, the balloon exerts a force inside it making it escape.



By Newton's 3rd law of motion, the escaping air exerts an equal force on the balloon in the opposite direction. In other words, the balloon acquires an equal but opposite momentum to that of the escaping air. This makes the balloon to move in the opposite direction to that of the escaping air.

(ii) A rocket and a jet acquires an equal and opposite momentum as the exhaust gases. This makes it move upwards as the gases move backwards.

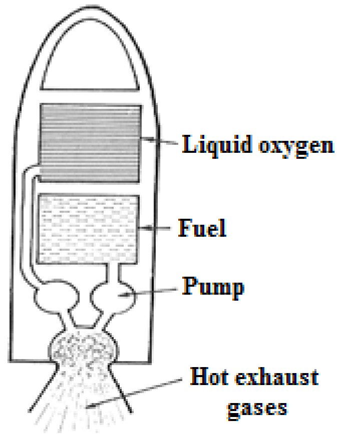
(iii) A gun is held tightly when bullets are fired. The gun acquires an equal and opposite momentum as that of the bullets.

ROCKET AND JET ENGINES

These work on the principle that in any explosion one body moves with a momentum which is equal and opposite to that of another body in the explosion.
For the rocket and the jet engine, the **high velocity hot gas** is produced by the burning of fuel in the engine.

Note: Rockets use liquid oxygen while jets use oxygen from air. *A jet engine doesn't go outside the atmosphere because it uses atmospheric oxygen to burn its fuel while, a rocket engine goes out of atmosphere the since it burns fuel when it is in space because it can be loaded with liquid oxygen cylinders.*

(a) How a rocket engine work:



<u>Principle:</u> the jet and rocket engines work on the principle that momentum is conserved in explosion.

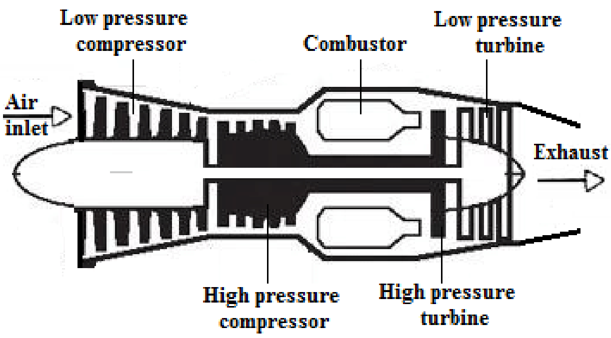
<u>High velocity</u>: the engine burns the fuel and the hot exhaust gases are released out at a very high velocity.

<u>Large momentum</u>: the large velocity of the hot gas results in the gas to leave the exhaust pipe with a large momentum.

<u>Engine:</u> the engine itself acquires an equal but opposite momentum to that of the hot gas.

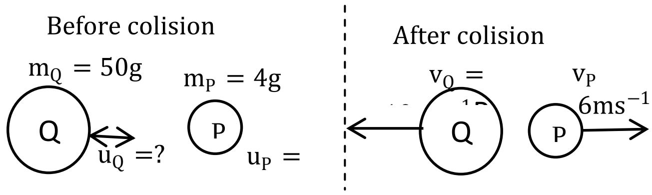
Note: when the two bodies collide and they move separately after collision but in opposite directions then.
$m_1u_1 + m_2u_2 = m_1v_1 + m_2(-v_2)$
$m_1u_1 + m_2u_2 = m_1v_1 - m_2v_2$

(b) A jet Engine
Jet engines use oxygen from air.



Example:
A body Q of mass 50g collides with a stationary body "P" of mass 4g. If a body "Q" moves backward with a velocity of $10ms^{-1}$ and a body "P", moves forward with a velocity of $6ms^{-1}$. Calculate the initial velocity of a body Q.

<u>Solution</u>
$m_Q = 50g, = \frac{50}{1000} = 0.05kg$ $m_P = 4g = \frac{4}{1000} = 0.004kg$
$u_Q = ?$, $u_P = 0ms^{-1}$
$v_Q = 10 ms^{-1}$, ← $v_P = 6ms^{-1}$ →



Total momentum before collision = Total momentum after collision

$$m_Q u_Q + m_P u_P = m_Q v_Q + m_p v_P$$

$$0.05u_Q + 0.004(0) = 0.05(-10) + 0.004(6)$$
$$0.05u_Q = -0.5+0.024$$
$$0.05u_Q = -0.476$$
$$\frac{0.05u_Q}{0.05} = \frac{-0.476}{0.05}$$
$$\mathbf{u_Q = -9.52ms^{-1}}$$

Thus, the initial velocity of Q is $9.52ms^{-1}$ to the left

Example: 2

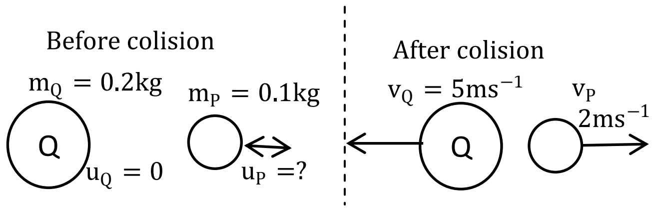
A moving ball "P" of mass 100g collides with a stationary ball Q of mass 200g. After collision, P moves backward with a velocity of $2ms^{-1}$ while Q moves forward with a velocity of $5ms^{-1}$. Calculate the initial velocity of P.

Solution

$m_Q = 200g, = \frac{200}{1000} = 0.2kg$ $m_P = 100g = \frac{100}{1000} = 0.1kg$

$u_Q = 0$, $u_P = ?$

$v_Q = 5\ ms^{-1}$, $v_P = 2ms^{-1}$



Total momentum before collision = Total momentum after collision

$$m_Q u_Q + m_P u_P = m_Q v_Q + m_p v_P$$

$$0.2(0) + 0.1u_P = 0.2(5) + 0.1(-2)$$
$$0.1u_P = 1 + -0.2$$
$$0.1u_Q = -0.8$$
$$\frac{0.1u_Q}{0.1} = \frac{-0.8}{0.1}$$
$$\mathbf{u_P = -8ms^{-1}}$$

Thus, the initial velocity of Q is $8ms^{-1}$ towards Q.

Example: 3.

A body of mass 10kg moves with a velocity of $20ms^{-1}$.Calculate its momentum.

Solution

m=10kg; $v=20ms^{-1}$

Linear Momentum = Mass × Velocity
= 10 × 20
= $200kgm^{-1}$

Initial Momentum = Mass × Initial Velocity = mu

Final Momentum = Mass × Final Velocity = mv

Example:2

A 20kg mass traveling at 5mls is accelerated to 8mls. Calculate the change in momentum of the body.

Solution

M =10kg, u =$5ms^{-1}$, v = $8ms^{-1}$	
Initial Momentum = mu = 20×5 = $100kgms^{-1}$	Final Momentum = mv = 20×8 = $160kgms^{-1}$
Change in Momentum = mv - mu = 160 - 100 = $60kgms^{-1}$	

Note: The change in momentum is called Impulse.

Example:3

A one tonne car traveling at $20ms^{-1}$ is accelerated at $2ms^{-2}$ for five second. Calculate the;

(i) change in momentum

(ii) rate of change in momentum

(iii) Accelerating force acting on the body.

Solution

m=1tonne =1000kg $u=20ms^{-1}$ v= ? $a=2ms^{-2}$ t= 5s (i) change in momentum. Change in Momentum = mv - mu $= m(v-u)$ But ; $v = u + at$ $v = 20 + 2(5)$ $v = 30ms^{-1}$ Change in Momentum = mv - mu $= m(v-u)$ $= 1000(30-20)$ $= 1000(10)$ $= 10{,}000kgms^{-1}$	(ii) Rate of change in momentum Rate of change in momentum $= \frac{\text{Change in mometum}}{\text{Time taken}}$ $= \frac{m(v-u)}{t}$ $= \frac{1000(30-20)}{5}$ $= \frac{10000}{5}$ =2000 N

NOTE: The S.I unit for the rate of change in momentum is a **newton**.

(iv) Accelerating force acting on the body.

Accelerating force, F = Rate of change in momentum

$$= \frac{m(v-u)}{t}$$

$$= \frac{1000(30-20)}{5}$$

F = 2000N

From above, the force applied is equal to the rate of change in momentum. This leads to Newton's second law of motion.

Exercise

1. A body of mass 600g traveling at 10mls is accelerated uniformly at 2 ms^{-2} for four seconds. Calculate the;
   (i) change in momentum
   (ii) force acing on a body

Solution

(i) mass, m = 600g $=\frac{600}{1000}$ $= 0.6$kg u=10ms^{-1} v=? a=2 ms^{-2}, t = 4s From; $v = u + at$ $v = 10 + 2(4)$ $v = 18ms^{-1}$ Change in Momentum = mv - mu $= m(v - u)$ $= 0.6(18 - 10)$ $= 0.6(8)$ $= 4.8kgms^{-1}$	(ii) Rate of change in momentum $=\frac{m(v-u)}{t}$ $=\frac{0.6(18-10)}{4}$ =1.2 N (iii) Force acting on the body But ; $v = u + at$ But ; $18 = 10 + 4t$ But ; $a = 2\text{ms}^{-1}$ **F = ma** =0.6(2) F =1.2N Thus, Force acting on the body is equal to the rate of change in momentum.

Example:4

A van of mass 1.5 tonnes travelling at 20ms^{-1}, hits a wall and is brought to rest as a result in 0.5seconds. Calculate the;

(i) Impulse
(ii) Average force exerted on the wall.

Solution

m=1.5tonnes =1.5x1000 = 1500 u=20ms^{-1} v=0ms^{-1} t=0.5s	(i)Impulse: Impulse=Change in Momentum = mv - mu $= m(v - u)$ $= 1500(0 - 20)$ $= 1500(-20)$ $= -30{,}000kgms^{-1}$
The Negative sign means that the direction of the impulse is opposite to that in which the van was moving.	
. (ii)Average force exerted on the wall: From;Impuse $=$ Force $\times$ Time $=$ Ft $-30000 = \text{F} \times 0.5$ $\text{F} = -60{,}000\text{N}$	

Example:5

A man of mass 60kg jumps from a high wall and lands on a hard floor at a velocity of 6ms.Calculate the force exerted on the man's legs if;

(i) He bends his knees on landing so that it takes 1.2s for his motion to be stopped.
(ii) He does not bend his knees and it takes 0.06s to stop his motion.

Solution

(i) m=60kg u=6ms^{-1} v=0ms^{-1} t=1.2s Force acting on the body But ; $v = u + at$ But ; $0 = 6 + 1.2a$ But ; $a = -5\text{ms}^{-1}$ **F = ma** =60(-5) F =-300N	(ii) m= 60kg u=6ms^{-1} v=0ms^{-1} t=0.06s Force acting on the body But ; $v = u + at$ But ; $0 = 6 + 0.06a$ But ; $a = -100\text{ms}^{-1}$ **F = ma** = 60(-100) F =-6000N
Note: ❖ The negative signs means the force acts to oppose that exerted by the man. ❖ Landing in (ii) exerts a larger force on the knees, which can cause injury compared to that in (ii).	

EXERCISE :

1. An athlete of 80 kg moving at 5ms^{-1}, slides trough a distance of 10m before stopping in 4 seconds. Find the work done by friction on the athlete.

2. A car of mass 1500kg starts from rest and attains a velocity of 100ms^{-1}in 20 seconds. Find the power developed by the engine.
A. 750kW B. 3,000kW
C. 30, 000kW D. 750, 000kW

3. A ball of 3kg moves at 10ms^{-1} towards a volley ball player. If the player hits the ball and the ball moves back with a velocity of 5ms^{-1}. Find the change in momentum.
A. $\frac{5\times3}{10}$ B. $\frac{10\times3}{5}$
C. $3(10-5)$ D. $3(10+5)$

7. A rubber bullet of mass 100g is fired from a gun of mass 5 kg at a speed of 200 ms^{-1}. Find the recoil velocity of the rifle.
A. $\frac{5\times200}{100\times1000}$ B. $\frac{5\times1000}{100\times200}$
C. $\frac{100\times200}{5\times1000}$ D. $\frac{200\times1000}{5\times100}$

8. A body moves with uniform acceleration if
A. its momentum remains constant
B. it covers equal distances in equal times
C. the velocity changes by equal amount in equal times.
D. the net force on the body is zero

9. A cyclist traveling at a constant acceleration of 2ms^{-2} passes through two points A and B in a straight line. If the speed at A is 10ms^{-1} and the points are 75m apart, find the speed at B.
A. 15.8ms^{-1} B. 17.3ms^{-1}
C. 20.0ms^{-1} D. 400.0ms^{-1}

3. A body moves with a uniform acceleration of Pms^{-2}. If its initial velocity is *x*ms^{-1} and it travels for *t* s to attain a final velocity of *y*ms^{-1}, find the value of *p* in terms of *x, y* and *t*.
A. $x + yt$ B. $\frac{y-x}{t}$
C. $\frac{y+x}{t}$ D. $y + xt$

10. .A body is said to be moving with a constant velocity if;
(i) Its momentum remains constant

(ii) It covers equal distances in equal times
(iii)The velocity changes by equal amount in equal times.
(iv)The net force on the zero

A. All B. (i), (ii) and (iv)
C. (i) and (ii) only D. (ii) only

11. A car of mass of mass 1200 kg moving with a constant velocity of 60 ms^{-1} is retarded uniformly to rest in 12 sec .Calculate the retarding force.

A. (1200 x 12) N B (1200 x 5) N
C. (1200 x 10) N D. (1200 x 60) N

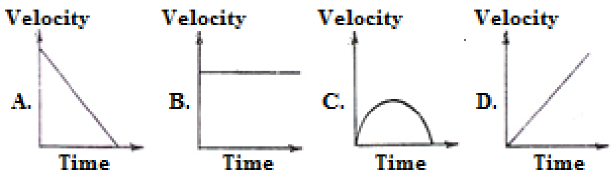
12. The gradient of a velocity-time graph represents the

A. Speed of the body
B. Velocity of the body
C. Acceleration of the body
D. The distance covered by the body

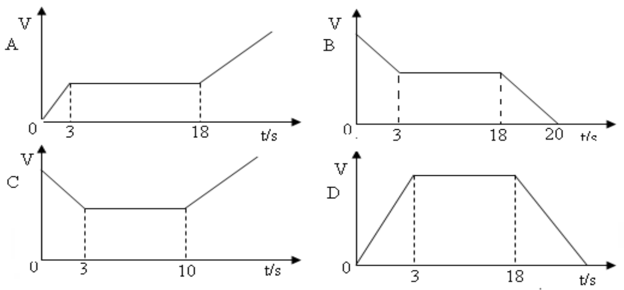
13. A body is said to be moving with uniform velocity when the rate of change of

A. acceleration with time is constant
B. velocity with time is constant
C. distance with time is constant
D. displacement with time is constant.

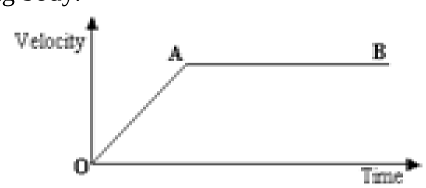
8. Which one of the above sketches represents uniformly accelerated motion?



9. A lift accelerates uniformly from rest for 3s. It then moves at uniform velocity for 15s thendecelerates uniformly for 2s before coming t rest. Which of the following velocity-time graph represents the motion of the lift.



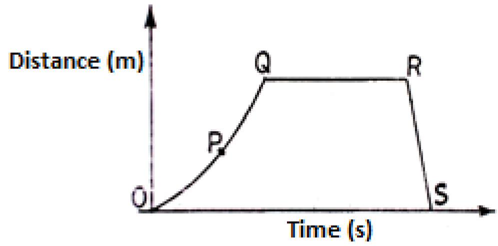
10. The Figure below shows a velocity-time graph for a moving body.



Which one of the following statements is true about the motion of the body?

A. Velocity of the body is constant between O and B.
B. Velocity of the body is constant between A and B.
C. The body is accelerating between A and B.
D. The body is not accelerating between O and A

11. The graph in figure 1 describes the motion of particle. Between which points is the particle at rest?

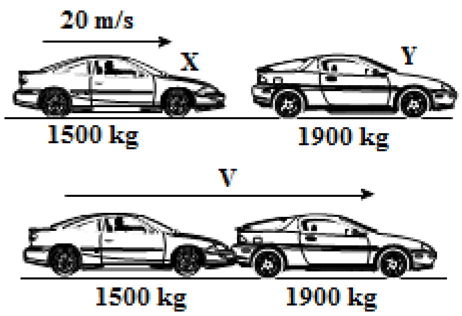


A. O and P. B. P and Q.
C. Q and R. D. R and S.

12. A car starts from rest and accelerates uniformly at the rate of $2ms^{-2}$ from 1/4 of a minute. Find the velocity of the car after this time.

A. $0.5ms^{-1}$ B. $12ms^{-1}$C. $15ms^{-1}$ D. $30ms^{-1}$

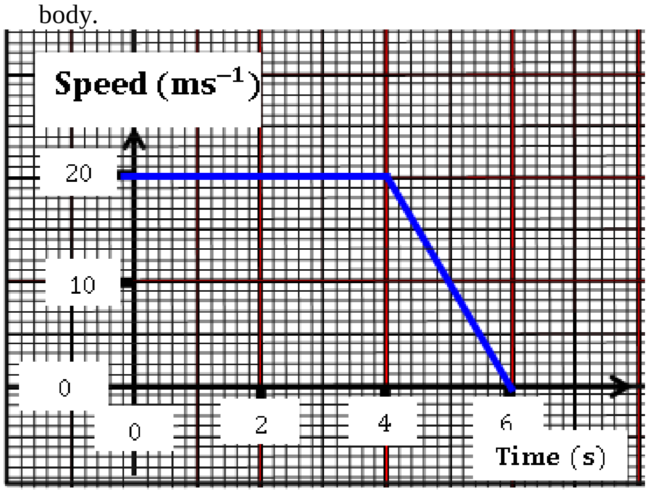
13. Car X of mass 1500 kg travels at 20 m/s along a straight, horizontal road. It collides with a stationary car Y of mass 1900 kg. The two cars lock together after the collision.



The speed of the cars after the collision is;

A. 8À m/s B. 9¼ m/s
C. 11 m/s D. 16 m/s E. 20 m/s

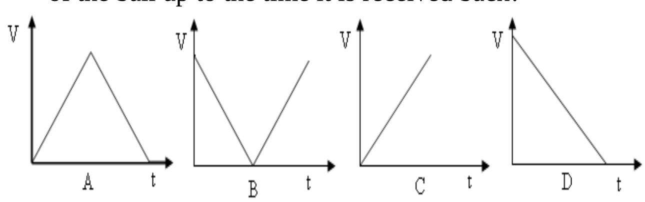
14. The in the figure shows a speed-time graph for a body.



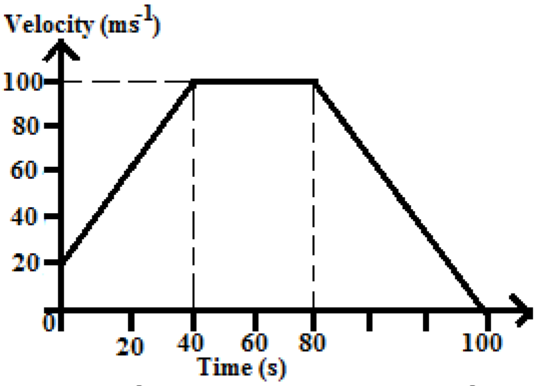
Calculate the distance traveled during retardation

A. 20m B. 40m C. 80m D. 100m

15. A boy throws a ball in the air and it goes up and falls back to his hand. Which one of the following sketches of velocity-time graph represents the motion of the ball up to the time it is received back?

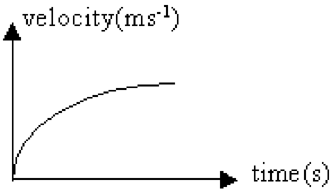


16. The velocity-time graph for a car is as shown in fig. Find the total distance the car travels.



A. 2.08×10^3m B. 3.0×10^3m
C. 4.0x103m D. 7.0×10^3m

17. Which of the following best describes the motion represented by the velocity-time graph shown in the diagram?



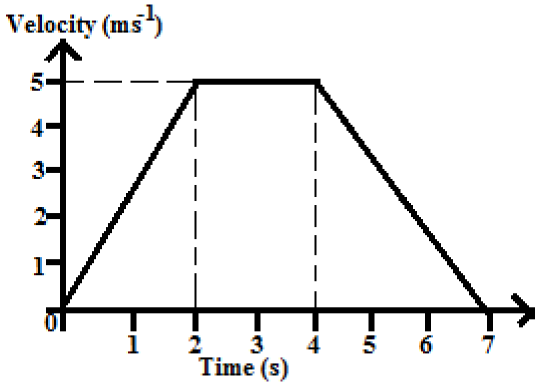
A. Decelerated
B. Uniformly accelerated motion
C. Non-uniformly accelerated motion
D. Uniform velocity motion

18. A car is uniformly accelerated from rest and after 10s acquires a speed of 20ms^{-1}. How far does it move during the eleventh second?
A. 20m B. 21m C. 100m D. 121m

18. Which one of the following is not true about a body moving with a constant velocity?
A. its acceleration is zero
B. Its momentum is constant
C. Its kinetic energy is constant
D. There is a resultant force on it

19. A car travelling at 20ms^{-1} is brought to rest in 10s. Find the distance it travels
A. 100m. B. 200m C. 300m D. 400m

20. Use the velocity-time graph in the figure to find the distance over which there is deceleration.



21. When a car is suddenly brought to rest, a passenger jerks forward because of
A. inertia B. friction
C. gravity D. momentum

22. A boxer while training noticed that a punch bag is difficult to set in motion and difficult to stop. What property accounts for this observation?
A. Size. B. Inertia.
C. Friction. D. Weight of the bag.

22. Eggs packed in a soft, shock-absorbing box are placed in a car. When the car suddenly starts or stops moving, the eggs do not crack because.
A. no force acts on them
B. the force acts on them for only a short time
C. the force is small and acts for a longer time
D. the force causes fast change of momentum.

23. A body of mass 20 kg moves with a uniform velocity of 4 m/s from rest. Find its momentum.
A. 5 kg m/s B. 80 kg m/s
C. 160 kg m/s D. 320 kg m/s

24. An object of mass 2 kg moving at 5 ms^{-1}, collides with another object of mass 3 kg which is at rest. Find the velocity of the two bodies if they stick together after collision
A. 1.0 ms^{-1} B. 2.0 ms^{-1}
C. 2.5 ms^{-1} D. 5.0 ms^{-1}

25. A bullet of mass 0.1 kg is fired from a rifle of mass 5 kg. The rifle recoils at a velocity of16 ms^{-1}. Calculate the velocity with which the bullet is fired.
A. 66 ms^{-1} B. 110 ms^{-1}
C. 210 ms^{-1} D. 800 ms^{-1}

26. A body of mass 20 kg moves with a uniform velocity of 4 m/s from rest. Find its momentum.
A. 5kgm/s B.80
C.160 D. 320

27. When a person steps forward from rest, one foot pushes backwards on the ground. The ground will as a result push that foot
A. backwards with an equal force
B. forwards with an equal force
C. backwards with a smaller force
D. forwards with a smaller force

28. If the forces acting on a moving body cancel each other out (i.e. are in equilibrium) the body will
A. Move in straight line to the steady speed
B. Slow down to a steady slower speed
C. Speed up a steady faster speed
D. Be brought to a state of rest.

29. A rider on a horse back falls forward when the horse suddenly stops. This is due to
A. Inertia of the horse
B. inertia of the rider
C. large weight of the horse.
D. losing of the balance.

30. A mass is projected vertically upwards with a velocity of 10ms^{-1}. What is the maximum height reached by the mass?
A: 1.0m B: 5.0m C: 10.0m D: 100.0m

31. A body of mass 20 kg, moving with uniform acceleration, has an initial momentum of 200kg m/s and after 10s, the momentum is 300 kg ms^{-1}. What is the acceleration of the body?

A. 0.5 m/s^2 B. 5 m/s^2
C. 25 m/s^2 D. 50 m/s^2

Paper II Questions

32. (a) State Newton's laws of motion.
(b) Define:
(i) Inertia of a body (ii) Momentum

(c) Explain why a passenger standing on the floor of a lorry jerks backwards when the lorry starts moving forwards.

(d) A 7-tonne truck initially moving at a velocity of 50m/s accelerates to 80m/s in 3 seconds. Calculate the force on the truck that caused the velocity change.

33. (a) (i) What is meant by linear momentum?
(ii) State the law of conservation of linear momentum.

(b) A bullet of mass 20g is fired into a block of wood of mass 400g lying on a smooth horizontal surface. If the bullet and the wood move together with the speed of 20ms^{-1}, calculate the;
(i) speed with which the bullet hits the wood,
(ii) kinetic energy lost.

(c) State the energy changes involved in (b) above.

34. (a) State the law of conservation of linear momentum.
(b) A water jet directed to a spot on the ground digs a hole in the ground after sometime. Explain.

(c) A moving ball P of mass 100g collides with a stationary ball Q of mass 200g. After collision, P moves backwards with a velocity of 2ms^{-1} while Q moves forwards
with a velocity of 5ms^{-1}. Calculate the;
(i) Initial velocity of P.
(ii) Force exerted by P on Q if the collision took 0.03s.

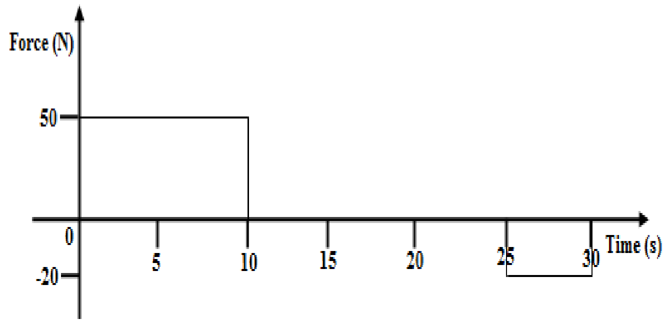
(d) Explain the principal of operation of a rocket engine

35. A sphere of mass 3 kg moving with velocity 4m/s collides head on with a stationary sphere of mass 2kg & imparts to it a velocity of 4.5 m/s. Calculate the velocity of the 3kg sphere after the collision.

36. A railway track of mass 4x104 kg moving at a velocity of 3m/s collides with another truck of mass 2 x104 kg which is at rest. The couplings join & the trucks move off together.
(a) State the type of collision.
(b) Calculate the common velocity after collision.

37. A body accelerates uniformly from rest at 3ms^{-2} for 4 seconds. Its velocity then remains constant at the maximum value reached for 7 seconds before retarding uniformly to rest in the last 5 seconds. Calculate the:
i) uniform velocity ($v = 12\ ms^{-1}$)
ii) total distance travelled ($= 138\ m$)
iii) retardation ($a = -2.4\ ms^{-2}$)
iv) average velocity for the journey.($v = 8.63\ ms^{-1}$)

38. A body of mass 5kg is at rest when a force is applied to it. The force varies with time as shown below.



(i) Using the graph, calculate the velocity of the body between 0 and 30 seconds.
(ii) Sketch the velocity – time graph for the first 30 seconds of its motion.
(iii) How far does it travel in the first 10 seconds?
(**Note: Also Check UNEB 2007 PP1 No.45)**

39. A body moves from rest at a uniform acceleration of 2ms^{-2}.
c) Sketch a velocity time graph for the motion of the body.
d) Find:
i) its velocity after 5 seconds. ($v = 10ms^{-1}$)
ii) how far it has gone in this time. ($s = 25\ m$)
iii) how long it will take the body to be 100 m from the starting point. ($t = 10\ s$)

40. [UNEB 1997 Paper II Qn.2]
Two vehicles A and B accelerate uniformly from rest. Vehicle A attains a maximum velocity of $30ms^{-1}$ in 10s while B attains a maximum velocity of $40ms^{-1}$ in the same time. Both vehicles maintain these velocities for 6s before they are decelerated to rest in 6s and 4s respectively.
(i) Sketch on the same axes, velocity time graphs for the motion of the vehicles.
(ii) Calculate the velocity of each vehicle 18s after the start
($v_A = 20ms^{-1}\ and\ v_B = 20ms^{-1}$)

(iii) How far will the two vehicles be from one another during the moment in (ii) above?
($S_A = 380m\ and\ S_B = 500m{:}\ S_{AB} = 120m$)

41. A motorist P started from rest and accelerated uniformly to a velocity of 20ms^{-1}in 6s while motorist Q accelerates uniformly from 10ms^{-1} to 40ms^{-1}in the same time. Motorist P then comes to rest in the next 18s. Motorist Q first moves at constant speed for 100s, before it is uniformly brought to rest in 16s.
(i) Sketch on the same axes, velocity time graphs for the motion of the vehicles.
(ii) Calculate the total distance travelled by A, his acceleration and retardation.
($D_P = 240m,\ a_P = \frac{10}{3}\ ms^{-2}\ and\ -a_P = \frac{10}{9}\ ms^{-2}$)

(iii) Calculate the total distance travelled by A, his acceleration and retardation.

$(D_Q = 4470m,\ a_Q = 5\ ms^{-2}\ and\ -a_Q = 2.5\ ms^{-2})$

(iv) Calculate the average speed for each of the motorists, P and Q.

$(Av.S_P = 10ms^{-1},\ and\ Av.S_Q = 36.64\ ms^{-1})$

COMMON PHYSICS MISCONCEPTIONS.

1. If an object is moving, there must be some force making it move. Wrong! It could be moving without accelerating i.e with uniform velocity.

2. If **v = 0,** then acceleration, **a** and $\mathbf{F_{net}}$ must be zero. Wrong! Think of a projectile shot straight up at its peak.

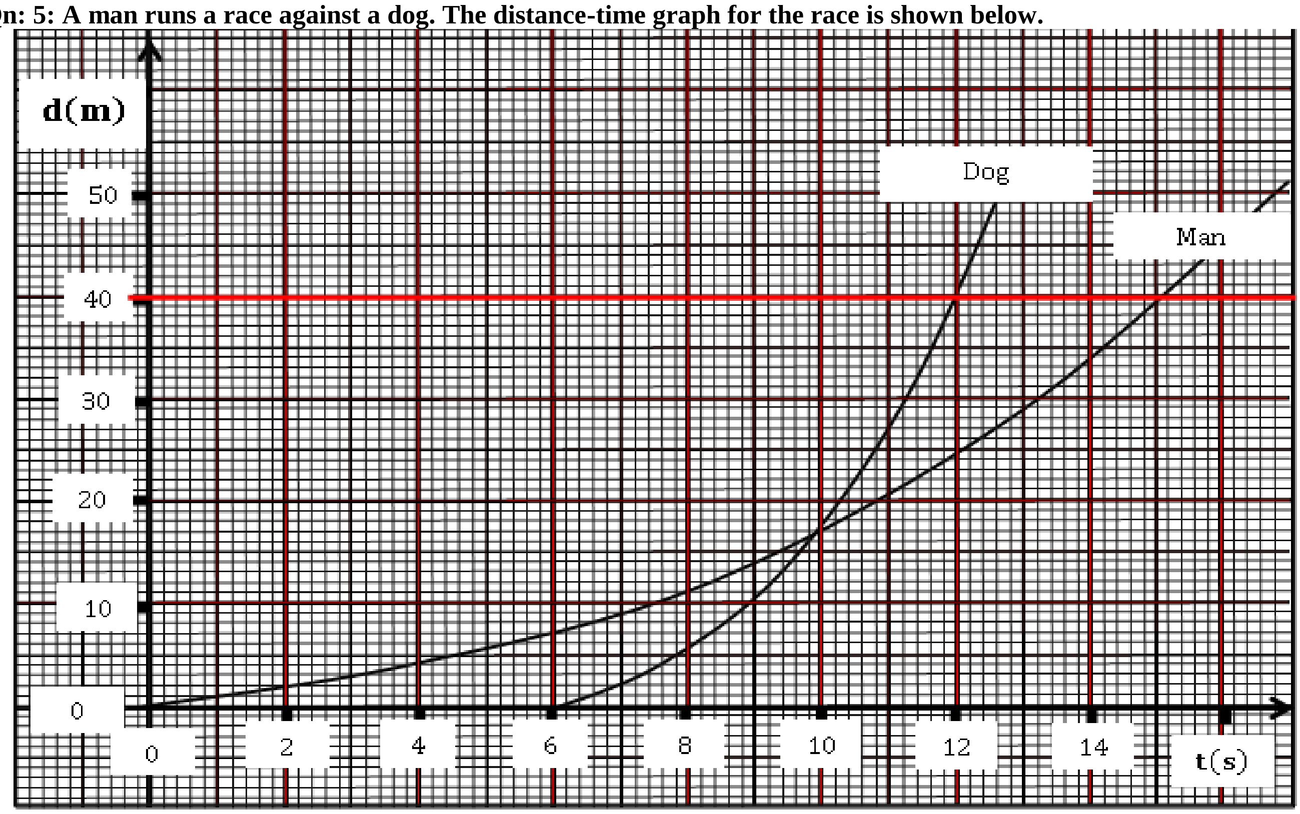
3. An object must move in the direction of the net force. Wrong! It must accelerate that way but not necessarily move that way.

4. Heavy objects must fall faster than light ones. Wrong! The rate is the same in a vacuum.

5. When a big object collides with a little one, the big one hits the little one harder than the little one hits the big one. Wrong! The 3rd Law says they hit each other with the same force.

6. If an object accelerates, its speed must change. Wrong! In circular motion, it could be turning at constant speed.

Qn: 5: A man runs a race against a dog. The distance-time graph for the race is shown below.



Which of the following statements is true

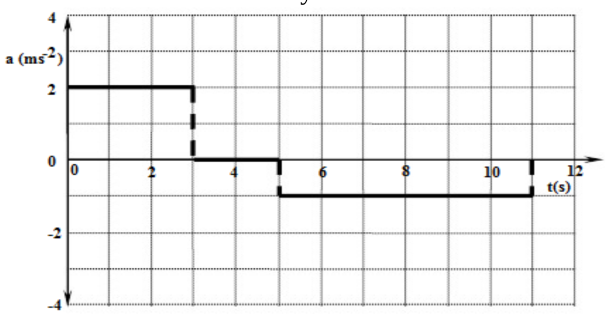
A. the dog's time for the race was 6s.

B. the dog overtook the man 9.8s after he had started running

C. the man's speed did not change after 6s.

D. the dog ran a shorter distance than the man

6.(a) The Figure show a graph of acceleration against time for the motion of a trolley which started from rest.



(i) Use the information to draw a sketch graph of velocity against time for the motion. (3 marks)

(ii) Find the total distance travelled by the trolley. (2 marks)

(iii) Describe the motion of the trolley (5 marks)

(b) A stone is thrown horizontally with a velocity of $15.0ms^{-1}$ from the top of a building 20m high. How far horizontally from the bottom of the building will the stone fall? (4 marks)

7. An aircraft of mass 5000kg moves with an initial velocity of $10ms^{-1}$, on a runway. It then accelerates at $4ms^{-2}$ for 25 seconds before it takes off. Its change in momentum before takeoff is:

A: 2.5×10^5 B: 3.0×10^5

C: 5.0×10^5 D: 5.5×10^5

2 THERMOMAL PROPERTIES OF MATTER

Heat is a form of energy, which results from the random movement of molecules of a body. It is a measure of how much kinetic and potential energy the molecules of a body have.
Once heat has been transferred to a body, it becomes internal molecular energy.

Temperature is the number on a given scale which expresses the degree of hotness or coldness of a body.
The S.I unit of temperature is a **kelvin** (**K**).

(a) THERMOMETERY

A thermometer is an instrument which is used for measuring temperature on the basis of certain physical properties which change with changes in temperature.
These properties are called thermometric properties

Thermometric properties
A thermometric property is a property of a substance which continuously change with temperature and may be used for temperature measurements, these include:
-Increase in length.
-Change in potential difference
-Change in volume
-Change in pressure.

Thermometer scales.
There are 3 thermometer scales commonly used
(i) Celsius / centigrade scale (^{0}C)
(ii) Fahrenheit scale (^{0}F)
(iii) Kelvin scale/ absolute (k)

Relation between Celsius and Fahrenheit

$$F = \frac{9}{5}(C + 32)$$

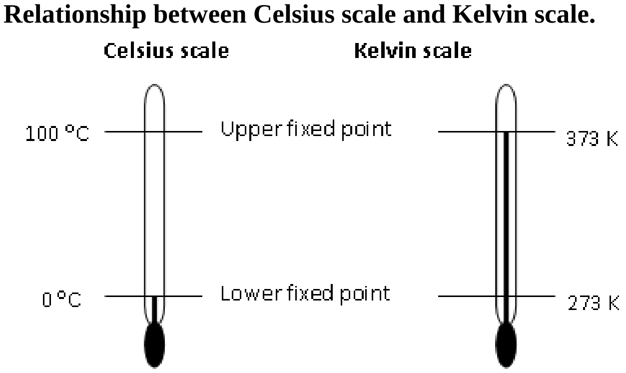
And if Celsius scale reads 1000c then

$$F = \frac{9}{5}(100 + 32) = 212^0F$$

Converting from Fahrenheit to Celsius.

$$C = \frac{5}{9}(F - 32)$$

Relationship between Celsius scale and Kelvin scale.



The temperature value, **θ**, on Celsius scale is related to the temperature value, **T**on Kelvin scale by the formula:

$$\mathbf{T = \theta + 273.} \quad \text{or} \quad \mathbf{\theta = T - 273.}$$

Convert 0^0C to Kelvin scale	Convert 100^0C to Kelvin scale (Absolute scale)
$T = 273 + \theta$ $T = 273 + 0$ T = 273K	$T = 273 + \theta$ $T = 273 + 100$ T = 373K

EXERCISE:

1. Convert the following temperature readings to Celsius scale.
(a) 1010 K (b) 233 K (c) 373 K

2. Convert the following temperature readings to Kelvin scale.
(a) 240 ℃ (b) 30℃ (c) 120℃

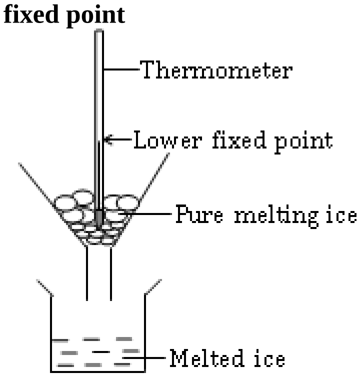
The Lower and Upper fixed points of a thermometer
To obtain a standard scale on a thermometer. Two fixed points must be marked out on it. The upper and lower fixed points.
The expansion of liquids when the temperature rises is applied in thermometers. A thermometer has two reference temperatures called fixed point. These are lower fixed point and upper fixed point.

The upper fixed point is the temperature at which pure water boils under normal atmospheric pressure.

The lower fixed point is the temperature at which pure water freezes under normal atmospheric pressure.

(a) Lower fixed points:
This is the temperature of pure melting ice at standard atmospheric pressure; 76cmHg or 760 mmHg.
-On Fahrenheit scale = 32^0F
-On Celsius scale = 0^0C
-On Kelvin scale = 237K

Marking upper and lower fixed points
a) lower fixed point

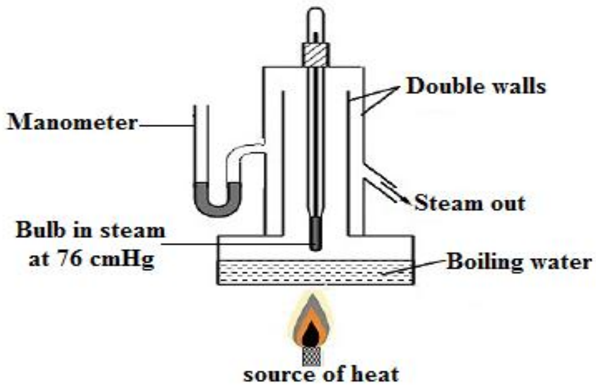


- ✓ A thermometer to be marked is placed in pure ice melting such that the bulb is packed round with ice.
- ✓ Adjust the thermometer so that the mercury thread is clearly seen.

- ✓ Marking lower fixed point. The thermometer is left in ice until level of mercury remains stationery. This level is marked and it's the lower fixed point.\

b) Upper fixed point

A hypsometer is a two walled vessel made out of a round bottom flask.



- ✓ Placing thermometer in steam. A thermometer to be marked is placed in steam in a hypsometer.
  The thermometer should be in steam not boiling water because boiling water temperature is affected by dissolved impurities.

- ✓ Double walls. The double walls help to keep the steam at exactly 100°c so that steam does cool and condense.
- ✓ A manometer. The manometer is attached to the hypsometer to ensure that the pressure within it is 76cm Hg.

- ✓ Marking upper fixed point. The thermometer is left in steam until the level of mercury remains stationery. This marked and it's the upper fixed point.

<u>Properties of a liquid that make it suitable for thermometer</u> (Qualities of a good thermometric liquid).

- ❖ It should be opaque so as to be readily seen.
- ❖ It's expansion should be regular, i.e. expansion per degree should be the same at different point on the temperature scale.
- ❖ It should have high boiling point and low melting point so that both high and low temperature can be measured.
- ❖ It should be able to expand so much for a small temperature change.
- ❖ It should be a good conductor so that it responds rapidly to the temperature change.
- ❖ It must not stick to the inside of the tube.
- ❖ Must not be very expensive.
- ❖ Must not be poisonous.

<u>Reasons why water is never used in thermometer</u>

- ❖ It has a small range of expansion because its freezing point is 0oc and boiling point is 100°c.
- ❖ The meniscus in the glass is different to read since water is colourless and wets the glass.
- ❖ It does not expand uniformly.
- ❖ It is not opaque.

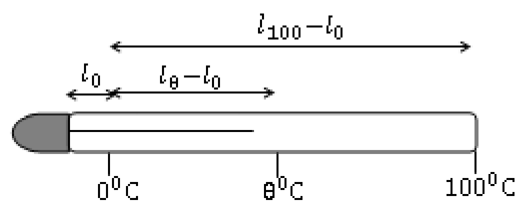
<u>Advantages of mercury over alcohol when used as thermometric liquid</u>.

Mercury	Alcohol
-It is opaque	-It is transparent
-Good conduct of heat	-Poor conduct of heat as compared to mercury
-Expand regularly	-Does not expand regularly as mercury
-Has a high boiling point (357^{0}C)	-Has low boiling point 78^{0}C
-Mercury does not stick on glass.	-Sticks on glass
-It is opaque so it can be easily seen.	-It is colourless

<u>Advantages of Alcohol over mercury when used as thermometric liquid</u>.

Alcohol	Mercury
-Has a low freezing point (It can measure very low temperatures)	Has a high freezing point of -39^{0}c hence unsuitable to measure very low temperatures.
-Has a high linear expansivity (expands so much for small temperature change)	Has a low linear expansivity (expands little for the same temperature range)

Reading temperature on an un calibrated thermometer



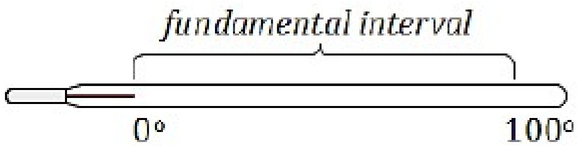
If l_{ice} is the length of the mercury thread above the bulb at melting ice, l_{steam} is the length of the mercury thread of steam at 760 mmHg and l_{object} is the length of mercury thread for the object being measured.
Then the required temperature θ°c is given by:

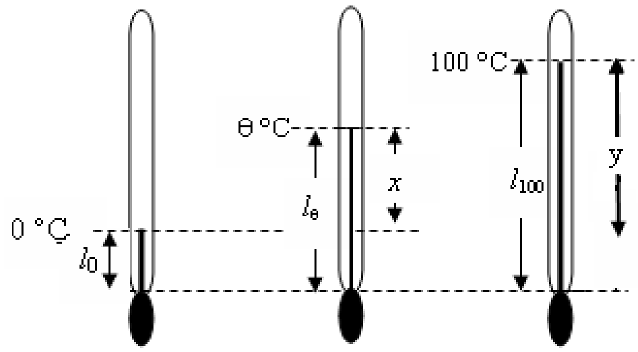
$$\theta = \left(\frac{l_{object} - l_{ice}}{l_{steam} - l_{ice}}\right) \times 100^0\text{C}$$

In other words l_{steam} is also the length of mercury thread at 100°c, l_{ice} is the length of mercury thread at 0°c and $l_{object}$is the length of mercury thread at the un known temperature, θ.

$$\theta = \left(\frac{l_\theta - l_0}{l_{100} - l_0}\right) \times 100^0\text{C}$$

Note: $(l_{100} - l_0)$ is the temperature range of the thermometer. In short the difference between the upper fixed point and the lower fixed point gives the temperature range of the mercury thread.
The interval between the upper fixed point and the lower fixed point is called the <u>fundamental interval</u>. This is divided into a hundred equal parts and each is called a <u>degree</u>.





Example 1:
In an un calibrated mercury thermometer, the length of the mercury thread above the bulb is 18mm at a temperature of melting ice and 138mm at a temperature of steam at 760mm Hg. When placed in a hot liquid the length of the mercury thread is 118mm. calculate the temperature of the liquid.

Solution

$l_0 = 18$ mm ; $l_\theta = 118$ mm ; $l_{100} = 138$ mm; θ =?	
$\theta = \left(\frac{l_\theta - l_0}{l_{100} - l_0}\right) \times 100^0\text{C}$ $\theta = \left(\frac{118-18}{138-18}\right) \times 100^0\text{C}$	$\theta = \left(\frac{100}{120}\right) \times 100^0\text{C}$ $\theta = 83^0\text{C}$

Example: 2
The top of a mercury thread of a given thermometer is 3cm from the ice point, if the fundamental interval is 5cm, determine the unknown temperature θ.

Solution

$l_\theta - l_0 = x = 3$cm ; $l_{100} - l_0 = y = 5$cm; θ =?	
$\theta = \left(\frac{l_\theta - l_0}{l_{100} - l_0}\right) \times 100^0\text{C}$	$\theta = \left(\frac{3}{5}\right) \times 100^0\text{C}$ $\theta = 60^0\text{C}$

Example: 3
The length of a mercury thread at a low fixed point and upper fixed point are 2cm and 8cm respectively for a certain liquid X. Given that the length of mercury thread at un known temperature θ is 6cm determine the value of θ.

Solution:

$l_0 = 2$cm ; $l_\theta = 6$cm ; $l_{100} = 8$cm; θ =?	
$\theta = \left(\frac{l_\theta - l_0}{l_{100} - l_0}\right) \times 100^0\text{C}$ $\theta = \left(\frac{6-2}{8-2}\right) \times 100^0\text{C}$	$\theta = \left(\frac{4}{6}\right) \times 100^0\text{C}$ $\theta = 66.7^0\text{C}$

Example: 4
Find the temperature in ^{o}C if the length of mercury thread is 7cm from the point and fundamental interval is 20cm.

Solution
$l_\theta - l_0 = 7\text{cm}; l_{100} - l_0 = 20\text{cm}; \theta = ?$

$$\theta = \left(\frac{l_\theta - l_0}{l_{100} - l_0}\right) \times 100^0\text{C}$$

$$\theta = \left(\frac{7}{20}\right) \times 100^0\text{C}$$

$$\theta = 35^0\text{C}$$

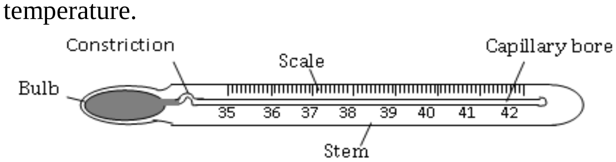
Example: 4
Find the unknown temperature θ given the following lengths of mercury.
-Length of steam = 25cm
-Length of ice point = 1cm
-Length of known temperature θ= 19cm

Solution

$l_0 = 1$cm ; $l_\theta = 19$cm ; $l_{100} = 25$cm; θ =?	
$\theta = \left(\frac{l_\theta - l_0}{l_{100} - l_0}\right) \times 100^0\text{C}$ $\theta = \left(\frac{19-1}{25-1}\right) \times 100^0\text{C}$	$\theta = \left(\frac{18}{24}\right) \times 100^0\text{C}$ $\theta = 75^0\text{C}$

THE CLINICAL THERMOMETER:

This thermometer is used to measure the human body temperature.



- ✓ The thermometer has a very fine bore (narrow capillary tube) which makes it sensitive.
- ✓ Expansion of mercury makes it shoot along the tube.
- ✓ The glass from which the tube is made is very thin which enables heat to reach the mercury quickly to read body's temperature.
- ✓ The bulb is the fluid reservoir. Thus it should be large enough to hold all the fluid. It is thin walled for quick response to heat.
- ✓ The glass stem is thick to act as a magnifying glass for the temperature readings.
- ✓ When thermometer bulb is placed into the mouth or armpit, the mercury expands and it is forced past the constriction along the tube.
- ✓ When removed, the bulb cools and the mercury in it contracts quickly.
- ✓ The mercury column breaks at the constriction leaving mercury in the tube. The constriction prevents flow back of mercury to the bulb when the thermometer is temporary removed from the patients mouth or armpits.
- ✓ The thermometer is reset by shaking the mercury back in the bulb.

Properties/qualities of a thermometer.

Quick action

This refers to the ability of a thermometer to measure temperature in the shortest time possible. This is attained by using;

-A thin walled bulb and using a liquid which is a good conductor of heat e.g. mercury.

Sensitivity

This is the ability of a thermometer to detect very small changes in temperature. It is attained by:

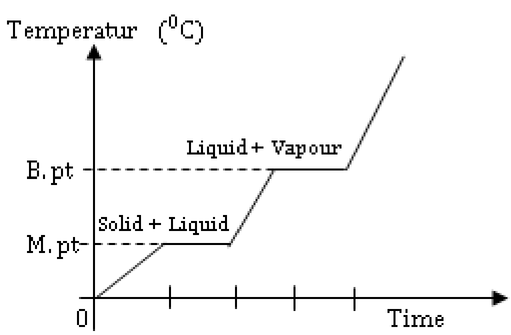
-Using a thermometer with a big bulb

-Using a liquid which has a high linear expansivity.

-Using a narrow bore or reducing the diameter of the bore hole.

Effect of heat on matter:

- ✓ When a solid is heated, the cohesive forces between its molecules are weakened and the molecules begin to vibrate vigorously causing the solid to (expand or) change into a liquid state.
- ✓ The temperature at which a solid changes into liquid is called the melting point. At melting point the temperature remains constant until the solid has melted.
- ✓ When the entire solid has melted and more heat is applied, the temperature rises. The heat gained weakens the cohesive forces between the liquid molecules considerably causing the molecules to move faster until the liquid changes into gaseous state.
- ✓ The temperature at which a liquid changes into gaseous state is called the boiling point. At boiling point temperature of the liquid remains constant since heat supplied weakens the cohesive forces of attraction in liquid molecules.
- ✓ If the heated substance is water its temperature rises with time as shown below.



(b) HEAT TRANSFER

Heat flows from a region of high temperature to a region of low temperature. There are three ways by which heat can be transferred, namely;

(i) Conduction
(ii) Radiation
(iii) Convection

(i) **CONDUCTION**

Conduction is the flow of heat through matter from a region of higher temperature to one of lower temperature without movement of matter as a whole.

Conduction in solids

Heat transfer in solids can occur as a result of;;

(i) Excess energy of vibrations being passed from one atom to another.

(ii) There excess Kinetic energy given to the free electrons near the source of heat being carried by these electrons as they move to colder region.

Note:

For heat to be transferred by conduction there should be a material medium. Metal are good conductors of heat because metals are made up of atom having free electrons that are loosely held.

Examples of metals which are good conductors are;

1. Aluminium
2. iron
3. Copper

New utensils or kettles, saucepans boilers, radiators are made of metals because metals are good conductors of heat as their atoms have free electrons that are loosely held. Non-metals, according to Kinetic theory do not have free electrons that are loosely held so that heat does not pass through them easily. This is why non-metals are called bad conductors or insulators e.g plastics, cork, wood.

Rate of heat transfer

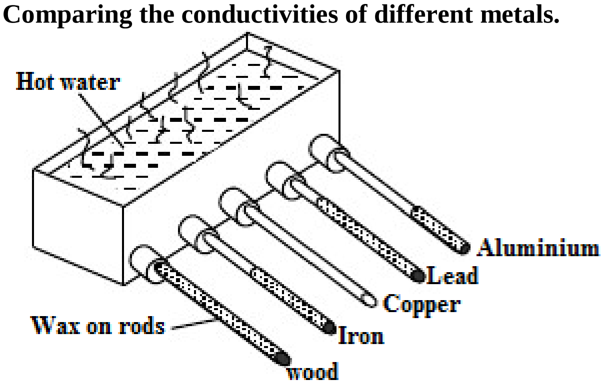
The rate of heat transfer along a metal bar depends on the following factors;

(i) The temperature difference between the ends.

(ii) The length and area of cross in short time when the cross section of the metal bar. Much heat is passed across in a short time when the cross sectional area of the bar is large and when the bar is short.

(iii) Material from which the solid is made of.

Comparing the conductivities of different metals.



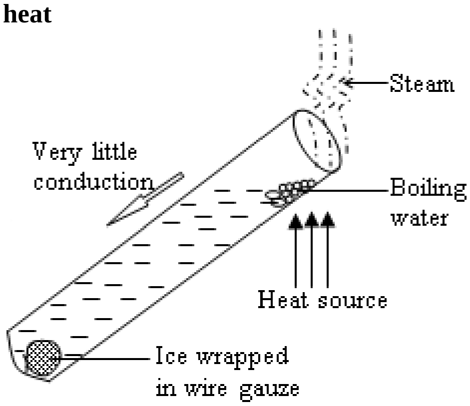
- ✓ The rate of conduction is compared by dipping the ends of four rods coated with wax in hot water.
- ✓ The rods are identical but made of different materials.
- ✓ After a short while, the wax begins to melt along the rods. It melts fastest along the copper rod and slowest along wood.
- ✓ This shows that **copper** is the best conductor and **wood** is the poorest of them. The order is **CAILSW**.

Bad and good conductors and their applications.
(i) Good conductors like aluminium are used in cooking utensils because they allow heat to pass through them easily. Copper is one of the best conductor but aluminium is usually used in making cooking utensils because it is much cheaper.

(ii) Bad conductor also called insulators are used in making of handles of cooking utensils because they do not allow heat to pass through easily.
A metal always feels cold when touched on a cold day because it loses heat from the body and transfer it to the surrounding very fast.

Explain why metals feel colder when touched than bad conductors
This is because metals carry heat away from the hands due to high degree of conduction while bad conductors do not conduct heat.
This also explains why a cemented floor feels colder than a carpeted floor.
N.B
Liquids conduct heat very slowly. This is because their molecules are apart.

Experiment to show that water is a poor conductor of heat



Procedure
-Water is put in a test tube slanted as shown in the diagram above.
-The upper part of the tube is heated and convection currents are seen at the top of the tube, water begins to boil.
-Ice at the bottom does not melt. This shows that water is poor conductor of heat.

(ii) CONVECTION
Convection is the flow of heat through fluid from a region of higher temperature to one of lower temperature by the movement of the fluid itself.
It is the heat transfer which involves bulk movement of molecules of the medium.

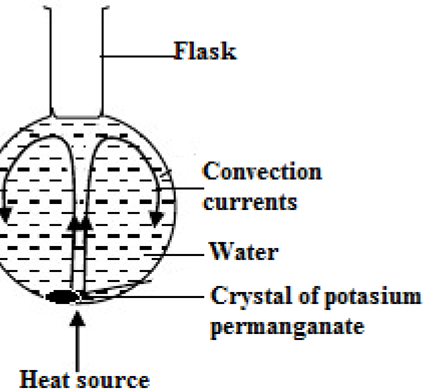
Convection cannot occur in vacuum because it requires a material medium. It occurs in fluids (liquid and gases) because they flow easily.

When a liquid is heated it expands and becomes less dense than the surrounding cold liquid.

Convection current.
Convection current is the cyclic motion of rising hot fluid and falling itself. The hot fluid rises because when heated it becomes less dense.

Explanation of convection current
-When the fluid is heated it expands and becomes less dense.
-The heated fluid is forced upward by the surrounding cooler fluid which moves under it.
-As the warm fluid rises, it gives heat to the surrounding cooler fluid.

Experiment to demonstrate convection current.

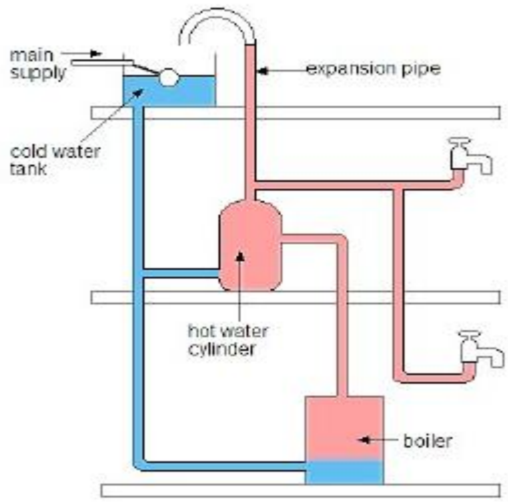


- ✓ When the flask is heated from the bottom as shown, the coloured solution of water rises upwards from the crystals and on reaching the top; it spreads as shown in the diagram.
- ✓ The solution rises because on heating, it expands and becomes less dense, so it is forced upwards by nearby cooler (denser) water.

Difference between convection and conduction

Conduction	***Convection***
-Involves no movement of matter itself.	-Involves movement of matter as a whole.

Application of convection current to hot water domestic supply system.



How it works
- ✓ Cold water is supplied to the boiler along the cold water supply pipe.
- ✓ In the boiler the cold water warms up, expands and becomes less dense, so it rises up.
- ✓ As more cold water is supplied to the boiler, hot water is displaced upwards and supplied to the hot water taps along hot water pipes A and D.
- ✓ The ventilation pipe, D is used to release steam.

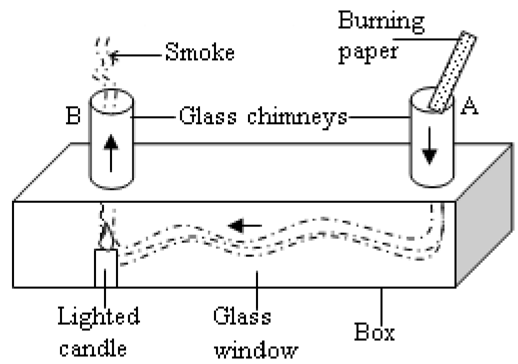
The expansion pipe A allows pipe D allows escape of:
(i) Dissolved air which comes out of the water when it is heated.
(ii) Steam, if the water is boiled.

If the expansion pipe is not there;
(i) The dissolved air which comes out when water is heated causes air lock in the pipe.
(ii) The steam if the water is boiled causes explosion.

a) Boiler
When working convection current of less dense hot water from boiler raises up through pipe A to the hot water tank. At the same time the more

b) Circulation
A circulation is set up in the hot water involving filling hot water from top down wards.
- ✓ When a volume of hot water flows to the hot water tank through pipe A, an equal volume of cold water flows to the boiler through pipe B.
- ✓ At the same time an equal volume flows through pipe C to the hot water tank.
- ✓ Pipe A leaves the boiler at the top and enters the hot water tank at the top because it carries more dense hot water.
- ✓ Pipe B is connected to the bottom of the hot water tank and to the bottom of the because it carries more dense cold water.

Convection in gases
Experiment to demonstrate convection in gases



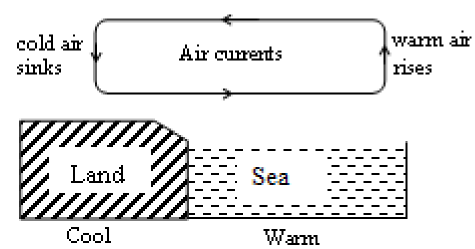
- ✓ The hot air above the candle rises up and gets out through B.
- ✓ A lighted piece of paper will produce smoke at point A.
- ✓ Cold air enters at point A and sweeps all the smoke to go and replace the hot air.
- ✓ The movements of smoke from A across the box and out through B shows convection of gases.

Explanation of how smoke moves:
Smoke moves by convection because;
- ✓ The air above the candle warms up, becoming less dense and then rises up through C.
- ✓ The dense cold air from the paper (smoke) enters X through chimney A to replace the risen air (smoke) causing convection currents.

Application of convection in gases:
-Chimneys in kitchens and factories
-Ventilation pipes in VIP latrines
-Ventilators in houses
-Land and sea breezes

Land and sea breezes

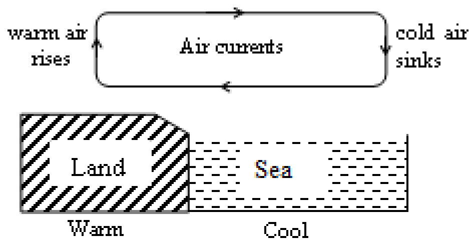
(i) Land breeze;



a) Cooling of land
At night land cools faster than sea because land is a better emitter of heat and has lower specific heat capacity than sea water.

b) Movement of air
The air above the sea is heated more than air above land, so the warmer air above sea rises and the cooler air from land occupy the space left. This results in a land breeze blowing towards the sea.

(ii) Sea breeze:



a) Heating land.

During day land is heated by the sun more than the sea because land is a better absorber of heat and has lower specific heat capacity than the sea.

b) Movement air

The much more heating of land causes the air above it to expand and rise as it becomes less dense. The space left is occupied by more dense air from the relatively cooler sea. So a cool sea breeze blows from the sea towards the land.

Ventilation:

- ✓ Air inside a room, air gets heated up on hot days.
- ✓ Roofs are usually provided with small openings called ventilators above the building so that the warm air which is less dense rises up and flow out through them.
- ✓ At the same time cool fresh air enters the building through the doors and windows. In this way circulation of air convection is set up.

(iii) RADIATION

Radiation is the flow of heat from one place to another by means of electromagnetic waves.

Heat energy is transfer from the sun to the earth by means of radiation. Radiation is the means by which heat can travel through the vacuum.

The energy from the hot body is called radiant energy.

Radiation is emitted by the bodies above absolute zero.

Radiant heat is mainly comprised of infrared which makes the skin feel warm. It travels as fast as light and it is the fastest means of heat transfer. It can travel through a vacuum.

Factors affecting the rate of radiation of heat energy

Factor	Explanation
✓ Temperature of the body	A hotter body radiates heat faster.
✓ Surface area of the body	Large surface area allows much heat energy to be radiated per second.
✓ Nature of the body	Dull surfaces radiate heat energy faster than highly polished surface.

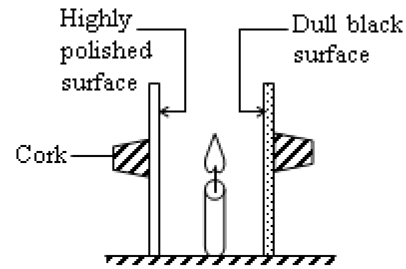
Good and bad absorbers

Shiny surface are bad absorbers of radiation while dull black surface are good absorbers. This implies that shiny surface reflects most of the heat radiations instead of absorbing. The dull black surface absorb most of the heat radiations and reflect very few.

Experiment to show absorbing of radiation in surface

Some surfaces absorb heat radiation better than others as illustrated below;

Method I



-Stick two pieces of cork using molten wax onto two vertical metal plates.

- The heat source is placed midway between the vertical plates so that the same amount of radiations are received by the two surfaces.

Observation:

-It will be observed that after a few minutes the wax on the dull black plate melts and the cork falls off before that on the shiny polished plate.

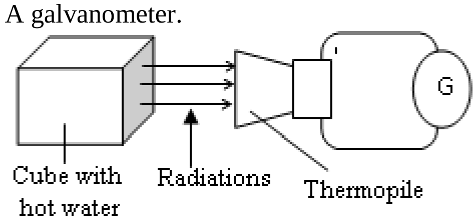
Conclusion:

-This indicates that dull black surfaces are better absorbers.

Method II:

Requirements: - A Leslie cube

-Thermopile (instrument that converts heat to electrical energy). A galvanometer.



-One side of the cube is dull black, the other is dull white and the last one is made shiny polished.

-The cube is filled with hot water and radiation from each surface is detected by a thermopile.

-When the radiant heat falling on the thermopile is much, it registers a large deflection of the point.

With different surfaces of the tube made to face the thermopile one at a time.

Observation:

-The greatest deflection of the pointer is obtained when dull dark surface faces the thermopile.

-The least deflection is obtained when a highly polished shiny surface faces the thermopile.

Conclusion:

-The dull and black surface is a good radiator or emitter of heat radiation while a polished shiny surface is a poor emitter of heat radiation.

Application of absorbers.

(i) Building in hot countries are painted white and roof surfaces are shinny because white and shinny surface are bad absorbers of heat radiation.

(ii) Reflection on electric devices are made up of polished metals because they have good reflecting properties.

Good and Bad emitter.
If the backs of the hands are held on either sides of the sheet, one first feels much heat from the black surface.
This shows that a black surface is a better emitter of heat than a shiny one.
-In short, black surface are good absorbers as well as good emitters of heat radiations.
-Shinny surfaces or polished surfaces are bad absorbers as well as bad emitters of radiations.

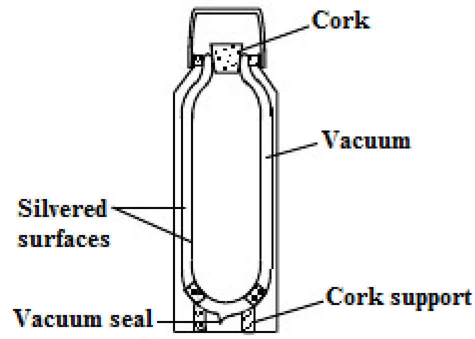
Applications
(i) Cooling fins on the heat exchanger of refrigerator are painted black so that they emit heat more quickly.
(ii) Tea pots and kettles are polished so that they keep heat longer as polished surface are poor emitters of heat radiation.

Laws of radiation:
- Heat radiation travels in a straight line.
- Good absorbers of heat radiation are also good emitters.
- Temperature of the body remains constant when the rate at which it absorbs heat radiation is equal to the rate at which it radiates heat energy.
- Bodies only radiate heat when their temperatures are higher than those of the surroundings and absorb heat from the surroundings if their temperatures are low.

Application of radiation:
Black and dull surfaces
(i) Car radiators are painted black to easily emit heat
(ii) Cooling fins of a refrigerator are black to easily emit heat.
(iii) Solar plates or panels are black to easily emit heat.

Polished and white surfaces
(i) White washed buildings keep cool in summer.
(ii) Roots and petro tanks are aluminium painted to reflect radiant heat.
(iii) White coloured clothes are won in summer to keep us cool.
(iv) Silver tea pots, kettles and saucepan retain heat for a long time.
Thermos/vacuum flasks

VACUUM FLASK
It is a flask with two silvered walls enclosing a vacuum. It is used for keeping contents at a fairly constant temperature.



The main features of a vacuum flask may be summarized as follows;

PART	FUNCTION
Vacuum	Minimises Heat loss or gain by Convection and Conduction
Cork	Minimises Heat loss or gain by Convection and Conduction
Silvered surfaces	Minimises heat loss or gain by Radiation.

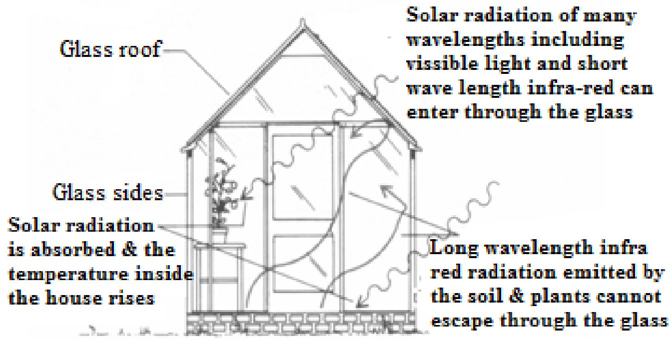
- A thermos flask also called vacuum flask keeps hot liquids hot and cold liquids cold.
- This is because heat losses are minimized. There are three ways by which heat can be lost namely: Conduction, convection and radiation.

Heat losses through the above ways are minimized by the vacuum flask as follows:
- Conduction and convection are minimized by the vacuum since for heat to be transferred by these ways, a material medium is required.
- Convection from the hot liquid upward to the outside is reduced by the cork which also reduces heat loses by conduction because it is a poor conductor of heat.
- Radiation is also minimized by the two silvered surfaces since they are bad emitters.

However when a hot liquid is kept in the vacuum flask for a long time, it cools because at a small rate, heat is lost by conduction, convection and radiation.

Choice of a dress
The choice of a dress one puts on depends on conditions of the environment. On hot days, a white dress is preferable because it reflects most of the heat radiations falling on it.
On cold days a dull black woolen dress is preferred because it absorbs most of the heat incident on it and can retain for a longer time.

THE GREEN HOUSE EFFECT.
Greenhouses are used to help certain plants grow better by providing a warmer air temperature.
In summer green houses do not need internal sources of heat because they are able to trap enough solar radiation to keep them very warm inside.



Sunshine contains radiation of many different kinds. Some of that radiation is the light which we can see , but much of it is invisible infrared radiation .

❖ The sun is very hot and sends this radiation in a form which can easily pass through the glass of a green house. This is short wavelength infrared radiation.

❖ Once inside the green house this infrared radiation is absorbed by the plants and the soil making them warmer.

❖ The warm soil and the plants now also emit infrared radiation but since the soil is cooler compared with the sun, this radiation has a much longer wavelength and cannot pass through the green house glass.

❖ In this way solar radiation becomes trapped inside the green house and causes its temperature to rise.

Global Warming (Green House Effect)

The Earth's atmosphere behaves like a green house. Radiation from the sun easily passes through the atmosphere and is absorbed by the earth. The Earth warms up and re-radiates energy but of longer wavelength.

So the atmosphere, consisting of water vapour, carbon dioxide and other gases, absorbs this energy and re-radiates it back to the Earth.

Thus the Earth gets warmer than it would be. Today global warming has become a serious issue.

TRANSFER OF HEAT ENERGY OBJECTIVES

1. Object A is 2 kg. It has a temperature of 40 C and has an internal energy of 500000 J. Object B is 2 kg. It has a temperature of 50 C and has an internal energy of 400000 J. Which of the following statements is correct?
A. Heat flow from object A to object B.
B. Heat flow from object B to object A.
C. No heat flow between object A and object B.
D. There is not enough information to determine the direction of heat flow.

2. Two kg of ice at 0 ^oC is floating on 5 kg of water at 0 ^oC. Which of the following statements is true?
A. Heat flow from ice to water
B. Heat flow from water to ice
C. No heat flow between ice and water
D. There is not enough information to determine the direction of heat flow.

3. Conduction is a transfer of thermal energy via
A. Vibration of the particles
B. Differences in densities.
C. Movement of particles from one place to another.
D. Radiation of wave

4. Convection is transfer of thermal energy due to
A. Vibration of the particles
B. Expansion of fluid.
C. Movement of particles from one place to another.
D. Radiation of wave

5. What is radiation?
A. Transfer of thermal energy by wave which does not require a material medium.
B. Transfer of thermal energy by vibration of nucleus.
C. Transfer of thermal energy by the movement of free electrons.
D. Transfer of thermal energy by movements of molecules due to a difference in densities.

6. Give a reason why Aluminium is a better conductor than wood?
A. Aluminium has a higher density than wood.
B. Aluminium has a higher specific heat capacity than wood.
C. Aluminium has more free electrons than wood.
D. Aluminium has a higher mass than wood

7. Conduction happens in
A. Solid only. C. Liquid only
B. Solid and liquid only D. Solid, Liquid and gas.

8. Convection happens in
A. Liquid only. C. Gas only
B. Liquid and gas only D. Solid, liquid and gas

9. Which of the following statements about radiation is true?
1. Radiation can pass through solids
2. Radiation can pass through liquids
3. Radiation can pass through gases
A. 3 only C. 2 and 3 only
B. 1 and 3 only. D. 1, 2 and 3

10. Which of the following heat transfer processes can take place in vacuum?
1. Conduction 2. Convection 3. Radiation
A. 1 only. B. 3 only
B. 1 and 2 only D.1, 2 and 3

11. Which of the following heat transfer processes is/are caused by the movement of particles?
1. Conduction 2. Convection 3. Radiation
A. 1 only C. 3 only
B. 1 and 2 only. D. 1, 2 and 3

12. Which of the following about conduction is/are true?

1. Conduction can transfer thermal energy faster in denser medium.
2. Conduction cannot happen together with convection.
3. Conduction can transfer thermal energy faster through good electrical conductors.

A. 1 and 2 only C. 1 and 3 only
B. 2 and 3 only D. 1, 2 and 3

13. The white porcelain lid of a cup of hot drink is to
1. reduce loss of thermal energy by evaporation.
2. reduce loss of thermal energy by radiation.
3. reduce loss of thermal energy by convection.

A. 1 and 2 only C. 1 and 3 only
B. 2 and 3 only D. 1, 2 and 3

14. The wooden handle of a pot

A. Prevents the transfer of thermal energy by conduction to the hand.
B. Reduces the transfer of thermal energy by conduction to the hand.
C. Prevents the transfer of thermal energy by radiation to the hand.
D. Reduces the transfer of thermal energy by radiation to the hand.

15. During a barbecue, why do we always cook food on top of the charcoal?

A. To increase the rate of heat transfer by conduction.
B. To increase the rate of heat transfer by convection.
C. To increase the rate of heat transfer by radiation.
D. To increase the rate of heat transfer by evaporation.

16. Which of the following about the vacuum flask are correct?
1. The silvered surface reduces loss of thermal energy by radiation.
2. The vacuum in the flask reduces loss of thermal energy by radiation.
3. The stopper reduces loss of thermal energy by convection and evaporation.

A. 1 and 2 only C. 1 and 3 only
B. 2 and 3 only D. 1, 2 and 3

17. Cooling fins are used in refrigerators, car radiator and many other cooling devices to dissipate thermal energy out of the system to the environment. Which of the following statements about the cooling fins are correct?
1. The cooling fins are made of metal to ensure that thermal energy is being conducted quickly out to the environment.
2. The cooling fins are thin for heat to be dissipated to the environment quickly via convection and radiation.
3. Cooling fins are normally black to achieve higher rate of thermal energy radiation.

A. 1 and 2 only C. 1 and 3 only
B. 2 and 3 only D. 1, 2 and 3

18. Petrol storage tanks are not painted black because

A. Black is a good conductor of heat.
B. Black is a bad conductor of heat.
C. Black is a good emitter of radiation.
D. Black is a good absorber of radiation.

19. How does a polar bear keep itself warm?By
1. Salivating 2. Having thick fur 3. Having white fur
A 1 and 2 onlyB 1 and 3 only
C 2 and 3 onlyD 1, 2 and 3

20. Which of the following is false?

A. Dog drools (salivates) to allow heat loss by evaporation.
B. Elephant sprays water over its body to allow heat loss by evaporation.
C. Jack rabbit has enormous ears with many blood vessels to dissipate thermal energy.
D. Camel has big humps to store water so that it can dissipate thermal energy by convection.

21. Which of the following is false?

A. We wear white to keep ourselves warm during winter.
B. We wear white to keep ourselves cool during summer.
C. Aluminium foil are used to keep food warm.
D. Pipes are painted black to minimize transfer of thermal energy.

22. Which of the following will increase the rate of heat transfer?
1. Increase the temperature difference
2. Paint the surface black
3. Increase the surface area

A. 1 and 2 only C. 1 and 3 only
B. 2 and 3 only D. 1, 2 and 3

23. Which of the following is true about pots?
1. Black pots are used for cooking because they increase the rate of cooking.
2. Silver pots are used for keeping food warm because they decrease the rate of heat dissipation.
3. Pots are made of clay to increase the rate of cooking.

A. 1 and 2 only C. 1 and 3 only
B. 2 and 3 only D. 1, 2 and 3

24. Which of the following can be done to increase the rate of cooking?
1. Use a black pot instead of silver pot.
2. Use a thick pot instead of thin pot
3. Cover the pot with a lid.

A. 1 and 2 only C. 1 and 3 only
B. 2 and 3 only D. 1, 2 and 3

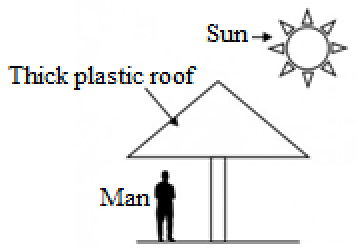
25. Container A and container B are filled with equal amount of hot water and the temperature of the water in the containers is measured with a thermometer some time later. It is observed that container A has a much lower temperature than container B. What are the possible reason(s)?
1. Container A is black and container B is silver.
2. Container A has a lid and container B is not covered.
3. Container A is made of steel and container B is made of clay.

A. 1 and 2 only C. 1 and 3 only
B. 2 and 3 only D.1, 2 and 3

26. Which of the following is true?

A. Sea breeze happens during night time when the sea is cooler than the area.
B. Sea breeze happens during day time when the land is cooler than the sea.
C. Land breeze happens during night time when the land is cooler than the sea.
D. Land breeze happens during day time when the sea is cooler than the land.

27. The diagram shows a man standing under a shelter on a sunny day. Given that the man feels hot, which of the following shows the processes of how thermal energy from the sun reaches the man?

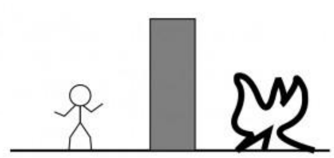


A. Radiation → Conduction → Radiation
B. Radiation → Conduction → Convection
C. Radiation → Convection → Radiation
D. Radiation → Convection → Convection

28. The diagram shows a man besides a campfire. How does thermal energy from the campfire reach the man? By;

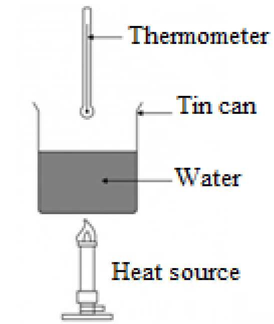
A. Radiation
B. Convection
C. radiation and convection
D. conduction and convection

29. The diagram shows a brick wall in between a man and a campfire. How does thermal energy from the campfire reach the man?



A. Radiation → Conduction → Radiation
B. Radiation → Conduction → Convection
C. Radiation → Convection → Radiation
D. Radiation → Convection → Convection

30. The diagram shows water being heated in a tin can. A thermometer hangs directly above it. How does thermal energy from the heat source reach the thermometer?



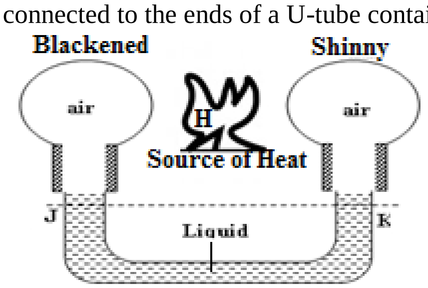
A. Radiation → Conduction → Radiation
B. Radiation → Conduction → Convection
C. Radiation → Convection → Radiation
D. Radiation → Convection → Convection

31. Expanded polystyrene is often used to make containers for storing ice-cream because the trapped air reduces loss of thermal energy by
A. Radiation only.
B. Conduction only.
C. Conduction and convection.
D. Conduction, convection and radiation.

32. Which of the following statements about the vacuum flask is incorrect?
A. Loss of thermal energy by radiation is minimized by keeping hot water in a double-walled container.
B. Loss of thermal energy is minimized by using a cork or plastic stopper to close up the neck of the glass container.
C. The vacuum in the double-walled glass container effectively prevents conduction and convection.
D. The walls of the glass container are silvered to reduce radiation.

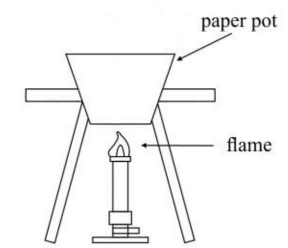
33. The chief mechanism for conduction in a typical metallic conductor involves.
A. The diffusion of atoms in the conductor from the hot end to the cooler end.
B. Atoms near the hot end vibrating with big amplitudes about their fixed positions and transferring their energy to neighboring atoms located in cooler regions by knocking against them.
C. The diffusion of free electrons from the hot end to the cooler end of the conductor carrying their energy along with them.
D. The atoms near the hot end sending out energy to atoms near the cooler end.

34. The figure below shows a source of heat, H placed mid-way between two identical flasks P and Q connected to the ends of a U-tube containing a liquid.



Which one of the following is a correct observation about the liquid level?
A. It rises in J and falls in K
B. It remains the same in both J and K
C. It falls in J and rises in K
D. It falls in both J and K.

35. Some steamboat restaurants use paper pots for their customers to boil the food themselves. What is the reason for the paper not to catch fire when in contact with the flame?



1. The paper is thin and therefore heat is conducted quickly to the water in the paper pot.
2. Water has a boiling point lower than the burning temperature of the paper.
3. The paper is thick enough to withstand the high temperature of the flame.
A. 1 and 2 only C. 1 and 3 only
B. 2 and 3 only D. 1, 2 and 3

36. Liquid-in-glass thermometer operates based on
A. The expansion and contraction of liquid when there is a difference in temperature.
B. The expansion and contraction of liquid when there is a difference in thermal energy.
C. The change in conductivity of liquid under the influence of temperature.
D. The change in mass of liquid under the influence of temperature.

37. A clinical thermometer is inserted into the mouth of a patient. Why does the doctor need to wait for about a minute before taking the thermometer out of the mouth to read the temperature?
A. To wait for the average temperature to be reached.
B. To record the maximum temperature of the patient within that 1 minute.
C. To allow time for the heat to flow into the mercury till the temperature of the mercury is the same as the temperature of the patient.
D. To wait for the temperature of the patient to cool down in the air-conditioned room.

38. The table below shows the melting point and boiling point of four liquids.

Melting point	Boiling point
Alcohol -115 C	78 C
Mercury -39 C	100 C
Water -	
Freon -	

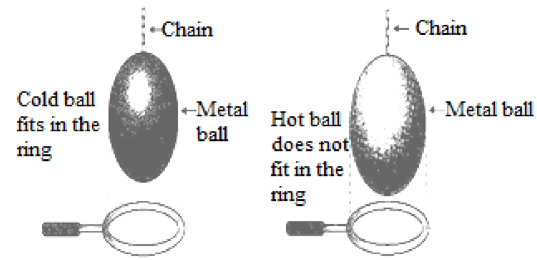
Which liquid is most suitable to be used in a thermometer for measuring a temperature range of -10^0 C to 95^{0}C?
A. Alcohol only C. Mercury only
B. Water only D. Freon.

39. On a cool day, an outside metallic door handle, feels colder to touch than the wooden door on which it is fixed because the:
A: metal contains less heat
B: metal conducts the heat away from the hand
C: temperature of the metal is less than that of the surroundings
D: temperature of the metal is the same as that of the surroundings

(c) EXPANSION OF MATTER

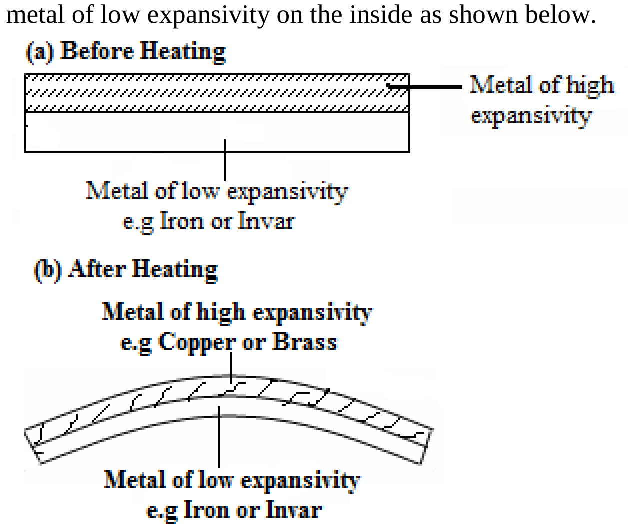
This is the increase in size of matter in all directions whenever matter is heated.

1. Expansion of solids.
Expansion of solids can be illustrated using a metal ball with a ring as shown below.



-The metal ball passes through the ring when it is cold, but when heated, the ball doesn't pass through the ring any more, showing that it has expanded.
-It passes through the hole again when it cools, meaning that the metal contracts when it loses heat.

Bi- metallic strip
Different metals expand at different rates when equally heated;
This can be shown using a metal strip made of two metals such as copper and iron bounded tightly together (bi-metallic strip) when the bi metallic strip is heated, the copper expands more than iron and the strip bends with the metal of low expansivity on the inside as shown below.

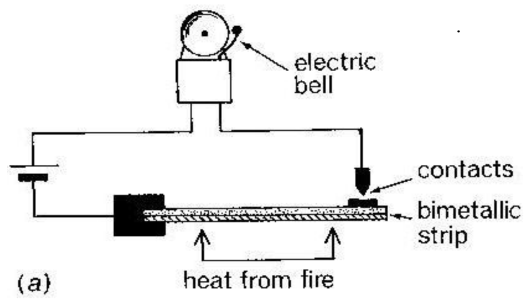


-When the bimetallic strip of iron and Brass is heated, it bends with brass on the outside of the curve.
-This is because Brass expands more than iron.

Uses of a metallic strip (application of expansion of solids)
Bimetallic strips are useful in the following devices by completing the metallic circuit.

i) Ringing alarm bells
ii) Thermostats

a) Fire alarm
Heat from the source makes the bi metallic strip bend and completes the electric circuit and the bell rings.



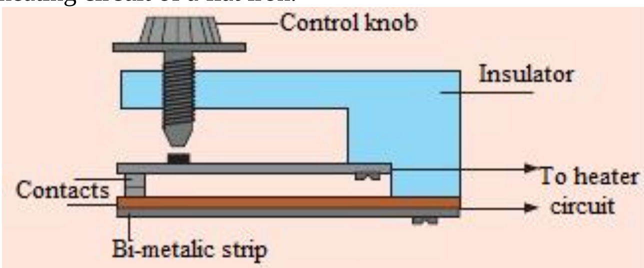
b) Thermostat
A Thermostat is a device that automatically regulates the temperature of a system by maintaining it constant or varying it over a specific range.

A bimetal thermostat uses a special strip of metal to open and close a circuit as temperature fluctuates.

Two metals with different expansion rates are bonded to make the strip. The thermostat is arranged so that when the metals are hot, the strip bends upward (toward the metal with the lower expansion rate) and disconnects the circuit.

In this particular case, the thermostat will activate a heater when the circuit is closed and electricity is flowing.

The thermostat shown below uses a bi metallic strip in the heating circuit of a flat iron.



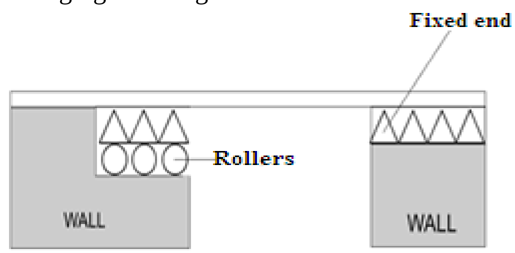
How an electric Iron works
-Setting the temperature: The control knob is set to the required temperature.
-Bimetallic strip heating: On reaching the required temperature, the bimetallic strip bends away breaking the circuit at contact C. This switches off the heater.
-Cooling bimetallic strip: On cooling just below the required temperature, the bimetallic strip makes contact and switches on the heater again. So a nearly steady temperature results.

-Knob: If the control knob is screwed more, the bimetallic strip has to bend more in order to break the heating circuit thus giving a high temperature

Disadvantage of expansion of expansion in our every day life

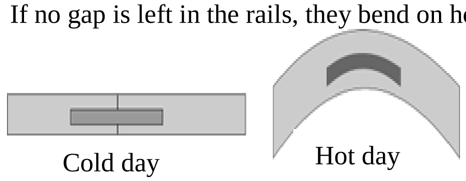
- Steel bridges

Bridges are constructed with one end fixed and the other side is placed on rollers in order for the structure to expand or contract freely with changing temperature without damaging the bridge.



- Railways:

Railway lines are constructed with gaps between the consecutive rails in order to allow free expansion of the rails is the temperature increases.
If no gaps are left between rails, the rails buckle during a hot day.
If no gap is left in the rails, they bend on hot days.



- Electricity Transmission cables

The wires which are used for the transmission of electricity or telephone wires are usually left sagging in order to allow them free expansion and contraction.

Linear expansivity
The measure of the tendency of a particular material to expand is called its Expansivity. Brass expands more than iron when heated by the same amount, therefore brass has a higher expansivity than iron.

Linear expansivity of a material is the fraction of its original length by which it expands per Kelvin rise in temperature.

$$\text{Linear expansivity} = \frac{\text{Linear expansion}}{\text{Original length} \times \text{Temperature rise}}$$

$$\propto \ = \frac{\Delta \boldsymbol{l}}{\boldsymbol{l_0} \times \Delta\boldsymbol{\theta}}$$

Where ; $\Delta \boldsymbol{l} = \boldsymbol{l_1} - \boldsymbol{l_0}$ ***and*** $\Delta\boldsymbol{\theta} = \boldsymbol{\theta_1} - \boldsymbol{\theta_0}$
Where ; l_0 = original length
l_1 = New length
θ_0 = Initial temperature
θ_1 = Final temperature

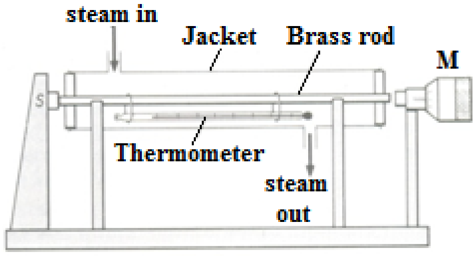
The S.I unit of linear expansivity is $\mathbf{K^{-1}}$or $\mathbf{{}^0C^{-1}}$

Linear expansivity of a substance depends on:
(i)the length of the substance.
(ii)the rise in temperature.

Measuring Linear expansivity.

Measure the original length of the rod using a metre rule.

Fit the rod inside a steam jacket and fit the thermometer in its socket.



Screw up the micrometer, M so that there is no gap at either end of the rod and take a reading of the micrometer scale x_1. Note the initial temperature of the rod θ_1.

Unscrew the micrometer to leave room for expansion of the rod and pass steam through the jacket for a few minutes.Screw up the micrometer again and take a second reading of the micrometer scale x_2. Note the final temperature of the rod θ_2.

Calculate the change in length $\Delta l = x_2 - x_1$ measured by the micrometer screw gauge.(Both $l$andΔl should be in the same units).

Calculate the rise in temperature, $\Delta\theta = \theta_2 - \theta_1$.Calculate the linear expansivity from

$$\alpha = \frac{\Delta l}{l \times \Delta\theta}$$

Hence new length =original length +expansion.

Examples:

1. In an experiment to measure linear expansivity of a metal, a rod of this metal is 800mm long is found to expand 1.36mm when the temperature rise from 15°c to 100°c.

Solution

$\Delta \boldsymbol{l} = (\boldsymbol{l_1} - \boldsymbol{l_0}) = 1.36$ mm

$l_0 = 800$mm

$\theta_0 = 15^0$C; $\theta_1 = 100^0$C; $\Delta\theta = 85$K

$$\propto \ = \ \frac{1.36}{800 \times 85} = 0.00002\text{K}^{-1}$$

Exercise:

1. A metal rod has a length of 100cm at 200°c. At what temperature will its length be 99.4cm if the linear expansivity of rod is 0.00002K^{-1}. [Ans: $\theta_1 = 173$K]

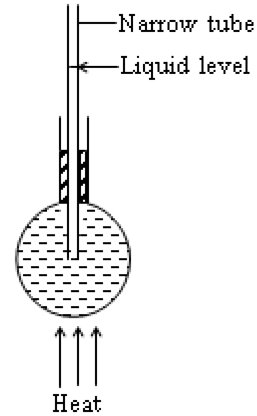
2. A steel bridge is 2.5m long. If the linear expansivity of the steel is $1.1 \times 10^5 \text{C}^{-1}$.How much will it expand when the temperature rises by 5°C? [Ans: $\Delta \boldsymbol{l} = 1.375 \times 10^{-2}$cm]

2. Expansion of liquids

Liquids expand when they are heated. Different liquids expand by different amount when equally heated.

Liquids expand much more than solids because according to the kinetic theory, liquid molecules are far apart compared to the solids and the intermolecular forces are weaker in liquids.

Experiment to demonstrate expansion of water.



-Fill the flask completely with coloured water. Pass the narrow tube through the hole of the cork and fix the cork tightly to the flask.

-Note the first level of water on a narrow tube

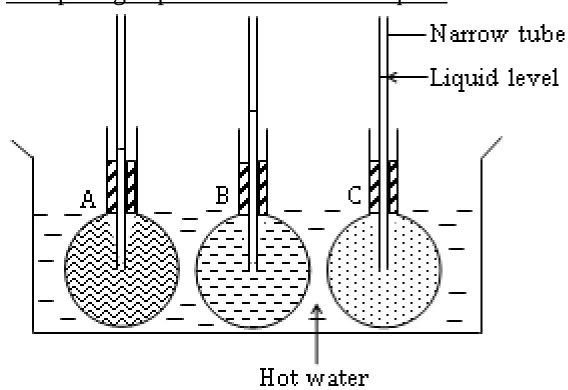
-Heat the bottom of the flask and observe the new level of water on the capillary tube. Initially there will be a momentary drop of the water level in the tube then after wards the level rises.

-Therefore liquids expand when heated since there was a rise in the levels of water in the capillary tube.

Explanation

-When the flask is heated, the flask first receives heat before the water in it so the flask expands and its volume increases causing the slight fall in level. -However, when heat reaches the water, the volume of water expands more than the increase in volume of the flask.

Comparing expansion of different liquids



- ✓ Three identical flasks A, B and C are filled with alcohol, kerosene and water respectively.
- ✓ Fit a narrow capillary tube in each flask through the cork, cool flasks to the same temperature, adjust the levels such that they are equal and mark the original levels.
- ✓ Place the flasks in a trough of hot water
- ✓ After some time, the liquid levels rise to different levels. This shows that different liquids expand differently when heated through the same temperature range.

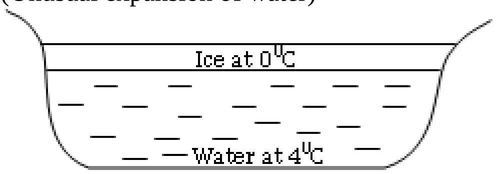
- ✓ Liquid C expands more than B and more than A in that order.

Application of expansion property of liquids

This property is used in thermometer; the liquids used include alcohol and mercury.

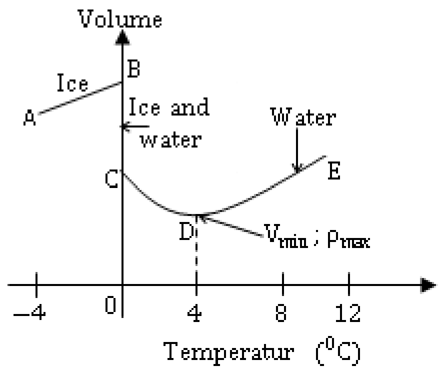
Anomalous expansion of water

(Unusual expansion of water)



For all solids except ice, when heated, they melt to form liquids. They expand just after melting but ice which melts at 0°c to form water contracts until 4°c. Water is thus exceptional or anomalous in the range 0°c to 4°c.

Sketch of volume against temperature.



From the sketch, it is noted that water has its minimum volume at 4°c.

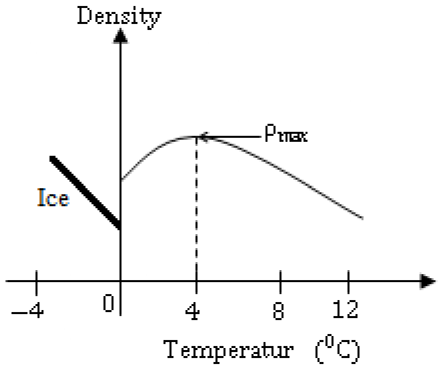
AB: As the temperature rises ice expands.

BC: The ice is melting to form water at 0°c

CD: As the temperature rises further, the formed water at 0°C contracts until 4°C. Anomalous expansion of water.

DE: At 4°C, the water expands normally just like other liquids do.

Sketch of density against temperature.



- ✓ Since density is mass/volume but mass is unaltered by warming. It is only volume which decreases between 0°c to 4°c.
- ✓ It follows that water has its maximum density at 4°c. From the sketch it is noted that ice is less dense than water.
- ✓ This is because for any given mass at 0°c the volume of ice is greater than the volume of water. This is why ice is less dense than water.
- ✓ When ice is mixed with water, ice floats on water because when ice melts to form water, density increases as volume decreases until 4°c.Therefore, ice is less dense than water.

Note: During very cold weather, pipes of water burst because at 0°c when water freezes, considerable expansion occurs resulting in increase in volume.

Biological importance of abnormal expansion

The unusual expansion of water has some biological importance in the preserving of aquatic life during cold weather.

a) Water at the top cooling

During cool weather, water at the top of the sea cools first, contracts and being denser to the bottom. The warmer and less dense water rises to the surface to be cooled.

b) At 4°C

When all the water is at 4°c the circulation stops.

c) Temperature below 4°C

When the temperature of water surface falls below 4°c, it becomes less dense and remains at the top, eventually forming a layer of ice at 0°C.

The lower layer of water at 4°C can only lose heat by conduction. So in deep water there will be always water beneath the ice in which fish and other aquatic life can thrive.

Explanation of unusual expansion of water by kinetic theory

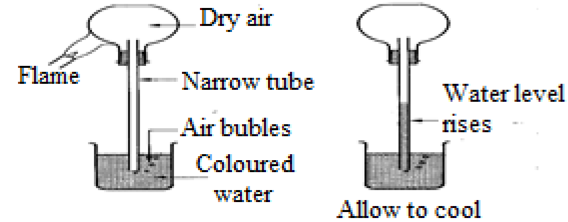
-The expansion of water between 4°c and 0°c is due to the breaking up of groups of water molecule below 4°c and formation of groups of water molecules above 4°c which require a large volume. ***So the anomalous expansion of water at 4°c is because water molecules bond together differently above and below 4°c***.

Expansion of gases

A gas expands when heated almost 10,000 times more than solids.

The greater expansion of gasses is due to very weak intermolecular forces which can be broken easily.

Experiment to demonstrate expansion in gases



In the above set up the flask is slightly heated.

Air bubbles will be seen coming out from the other end of the tube

This shows that air expand when heated.
In the second set up, when the source of heat is removed and the flask is allowed to cool by pouring cold water, the level of water will rise. This shows that air contracts when cooled.

Alternatively
When hands are rubbed together thoroughly and held around the flask as shown above, bubbles of air start coming out of water. This is because the heat produced by the hands was enough to cause the air in the flask to expand. When the hands are removed and flask left to cool, the water rises in the tube. This is because cooling the air contracts and pressure of the inside are becomes less than the atmospheric pressure.

Application of expansion of air.
Hot air balloon
Expansion of air is used in hot air balloon. When air in the balloon is heated, it expands and becomes less dense and as a result the balloon rises up.

Exercise 1: See UNEB Past papers.

1. 1988 Qn.12	6. 1999 Qn.9	11. 1989 Qn.2
2. 1988 Qn.18	7. 2004 Qn.11	12. 1994 Qn.1
3. 1988 Qn.31	8. 2004 Qn.33	13. 1998 Qn.3
4. 1991 Qn.4	9. 2006 Qn.17	14.1998 Qn.5
5. 1994 Qn.33	10.2007 Qn.36	15.

(d) GAS LAWS

Gases when heated will show a significant change in pressure volume and temperature unlike solids and liquids which show insignificant change in volume.
Gas laws are laws which express the relationships between Pressure, (P), Volume (V) and Temperature (T) of a fixed mass of a gas.

1. Boyle's law
Boyle's law states that the volume of fixed mass of gas at contact temperature is inversely proportional to its pressure.

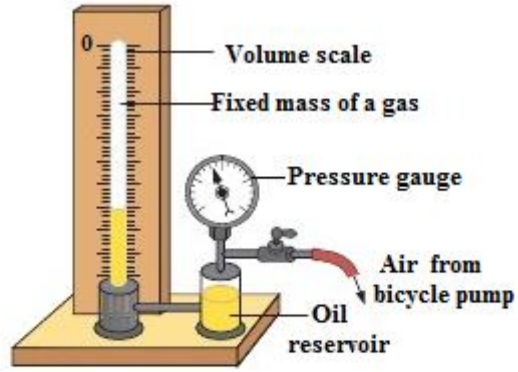
Mathematically;
$$P \propto \frac{1}{V} \text{at constant temperature.}$$
$P = k\frac{1}{v}; \Leftrightarrow PV = k; \Leftrightarrow \mathbf{PV = constant}$
$$\mathbf{P_1V_1 = P_2V_2 = constant}$$

Example: 1
The pressure of a fixed mass of gas is 5artmospheres when its volume is 200cm^3. Find its pressure when the volume
(i) Is halved (ii) Is doubled
(iii) Is increased by $1\frac{1}{2}$ times provided temperature remains constant.
Solution

(i)$P_1V_1 = P_2V_2$ $5 \times 200 = P_2(100)$ $P_2 = 10$ atmospheres	(ii) $P_1V_1 = P_2V_2$ $5 \times 200 = P_2(400)$ $P_2 = 2.5$ atmospheres

(iii) $P_1V_1 = P_2V_2$
$5 \times 200 = P_2(300)$
$P_2 = 3.333$ atmospheres
When pressure is doubled the volume is halved or vice versa

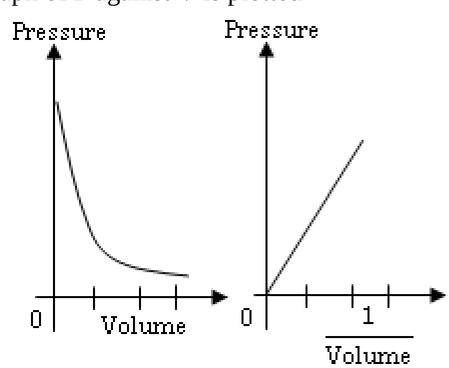
Experiment to verify Boyle's law



- ❖ Using the pump, the pressure of the air in the tube is increased without exceeding the safety limit indicated on the pressure gauge. The valve is closed and left for about 20s to allow the temperature of the enclosed air to reach equilibrium. The volume V of the air column is read from the scale and recorded.
- ❖ The corresponding pressure reading, P of the trapped air is read from the gauge and recorded.
- ❖ The pressure P is reduced by opening the valve slightly. This causes an increase the volume of the trapped air column. Again the temperature of the enclosed air is allowed to reach equilibrium.
- ❖ The corresponding values for the volume V and pressure P are read and recorded.
- ❖ The experiment is repeated to obtain atleast six pairs of results.

Pressure, P (Pa)	Volume, V(cm^3)
-	-
-	-

- ❖ A graph of P against V is plotted



Example 1:
The volume of a fixed mass of gas at constant temperature when the pressure is 76mHg. Calculate the volume when the pressure is 38 cmHg.
the volume when the pressure is 38 cmHg.
Solution
(i)$P_1V_1 = P_2V_2$
$150 \times 76 = V_2(38)$
$V_2 = 300\text{cm}^3$

Note: from the above example, it is found when pressure halved the volume doubles.

Example:2
The volume of a fixed mass of gas at constant temperature increases from 300cm^3 to 500cm^3 . Find the new pressure if the initial pressure was 70cmHg.

Solution

$v_1 = 300cm^3, P_1 = 70cmHg,$ $v_2 = 500cm^3; P_2 = ?$
$P_1V_1 = P_2V_2 \Leftrightarrow 70 \times 300 = P_2 \times 500$ $21000 = 500P_2$ $P_2 = 42cmHg$

Example:3
The pressure of a fixed mass of 0.5litres of a gas is 30cmHg. Find the volume if the pressure increases to 70cmHg.

Solution

$v_1 = 0.5litres, P_1 = 30cmHg,$ $v_2 = ?; \quad P_2 = 70cmHg$
$P_1V_1 = P_2V_2 \Leftrightarrow 30 \times 0.5 = 70 \times V_2$ $15 = 70V_2$ $V_2 = 0.211litres$

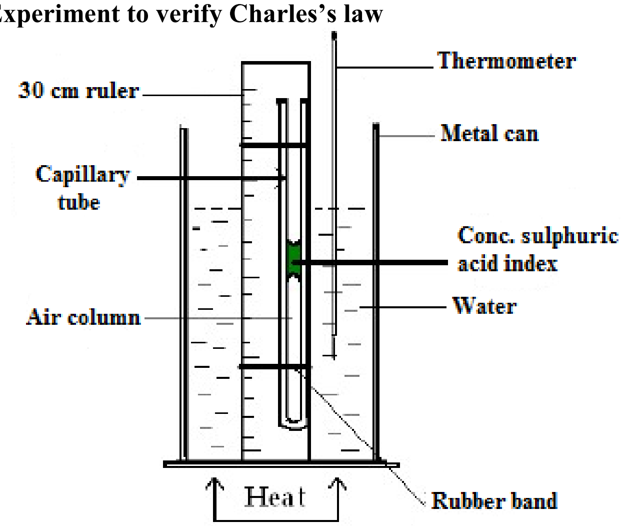
2. Charles' Law
Charles' law states that the volume of a fixed mass of a gas at constant pressure is directly proportional to the absolute temperature.

$$V \propto T \text{ at constant pressure.}$$

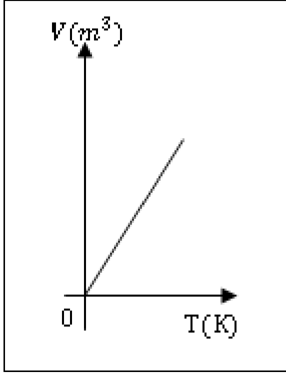
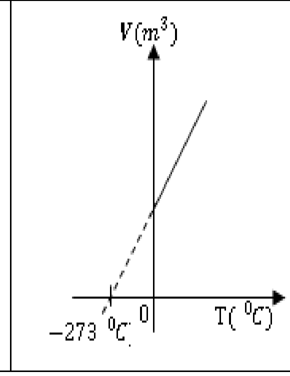
$$\mathbf{\frac{V}{T} = constant}$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} = \text{constant}$$

Experiment to verify Charles's law



- ✓ Dry air is trapped using the index of concentrated sulphuric acid in a capillary tube. The tube is tied on the metre-rule using a rubber band.
- ✓ The apparatus is placed in a metal can containing water and the water is heated slowly while stirring gently.
- ✓ The length, ***l*** of the trapped air column and the temperature, **T** are read and recorded.
- ✓ The procedures are repeated for different temperatures and the results tabulated.
- ✓ A graph of *l* against temperature, T.

A graph of v against T	A graph of V against T
	

<u>Observation:</u>
-The graph is a straight line through the origin.
-In the second graph, at $\mathbf{-273^0C}$, the gas occupies zero volume. This temperature is called **absolute zero**.

<u>Conclusion:</u>
-The graph shows that ***l*** (which is proportional to volume), is directly proportional to the absolute temperature at constant pressure. This verifies charles' law.
Absolute temperature *is the Kelvin temperature scale which has zero value coinciding with -273 ^{0}C.*
Absolute temperature is also called thermodynamic temperature. On this scale, temperature is measured in Kelvin (K). Where temperature 0^{o}C in Kelvin is obtained from ; $\mathbf{\theta^0c = (\theta + 273)K}$

e.g. temperature of -73^{0}c
$T = (-73^0C + 273)$
$T = 200K$

Absolute zero is the temperature of 273^{o}c at which the volume of the gas would become zero as the gas is cooled. However, the volume of the gas can not actually shrink to zero. This is because the gas first liquidifies, then turns to solid before the temperature of 273^{o}c is reached.

***Absolute zero** can also be defined as the temperature at which the gas molecules have the lowest possible kinetic energy.*

The volume-temperature and pressure-temperature graphs for a gas are straight lines. This is because gasses expand uniformly with temperature. So equal temperature increase cause equal volume or pressure increases.

Example 1
The volume of a fixed mass of gas at constant pressure is 400cm^3 at a temperature of -73^{o}c. Calculate the volume when the temperature is raised to 27^{o}c.

Solution

$v_1 = 400cm^3, T_1 = (-73 + 273) = 200K,$ $v_2 = ?; \quad T_2 = (27 + 273) = 300K$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \Leftrightarrow \frac{400}{200} = \frac{V_2}{300} \Leftrightarrow V_2 = 600\text{cm}^3$$

Example 2
The volume of a fixed mass of gas at a given pressure is 1.5m^3 at a temperature of 300K. Calculate the temperature when the volume will be 0.5m^3 at the same pressure.

Solution

$v_1 = 1.5\text{m}^3, T_1 = 300\text{K},$
$v_2 = 0.5\text{m}^3, T_2 = ?$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \Leftrightarrow \frac{1.5}{300} = \frac{0.5}{T_2} \Leftrightarrow T_2 = 100\text{K}$$

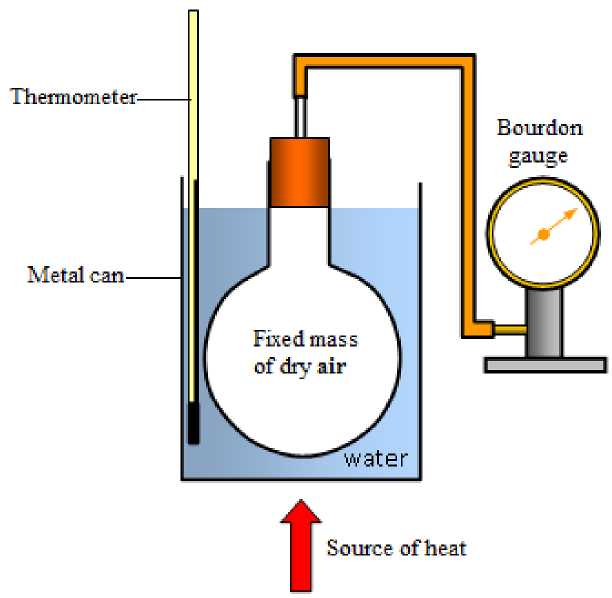
3. Pressure law.
The pressure of a fixed mass of gas at constant volume is directly proportional to its absolutetemperature. The constant pressure is directly proportional to the absolute temperature.

P $\propto$ Tat constant pressure.

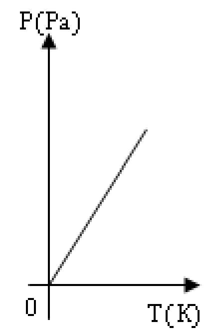
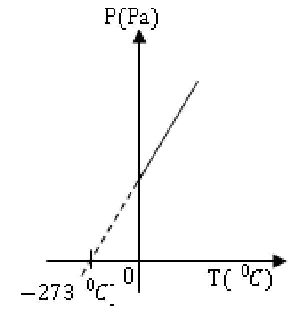
$$\mathbf{\frac{P}{T} = constant}$$

$$\mathbf{\frac{P_1}{T_1} = \frac{P_2}{T_2} = constant}$$

Experiment to verify Pressure law



Procedure:
- ❖ The apparatus is set up as shown above. The rubber tubing from the flask to the pressure gauge should be as short as possible.
- ❖ The flask containing dry air is placed in water in a can such that water is almost to the top of its neck.
- ❖ The can is heated from the bottom while stirring and the pressure, P is then recorded for different temperature values.
- ❖ The heating is stopped to allow steady gauge reading for each reading taken.
- ❖ The results are tabulated and a graph of pressure against temperature plotted.

For temperature in K	For temperature in ^{0}C
	

Observation:
- ❖ A straight line graph touching the temperature axis at -273^{o}C verifies pressure law.

Example 1
The pressure of gas in a cylinder is 15atm at 27°C.
(i) what will be the pressure at 177°C?
(ii) at what temperature will the pressure be 10 atmospheres?

Solution
(i)

$P_1 = 15\text{atm.}, T_1 = 27 + 273 = 300\text{K},$
$P_2 = ?, T_2 = 177 + 273 = 450K$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \Leftrightarrow \frac{15}{300} = \frac{P_2}{450} \Leftrightarrow P_2 = 22.5\text{atm.}$$

(ii)

$P_1 = 15\text{atm.}, T_1 = 27 + 273 = 300\text{K},$
$P_2 = 10\text{atm.}, T_2 = ?$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \Leftrightarrow \frac{15}{300} = \frac{10}{T_2} \Leftrightarrow T_2 = 200\text{K.}$$

Equation of state
The combination of the three gas law equations forms a single equation called the equation of state. Or the general gas law.
It is an equation that expresses the relationship between Volume, V, pressure, P and temperature, T. It is given by the formula;

$$\mathbf{\frac{PV}{T} = constant}$$

$$\mathbf{\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}}$$

Example 1
Air in a 2.5 litre vessel, at 127^{o}c exert a pressure of 3 atmospheres. Calculate the pressure that the same mass of air would exert if contained in a 4 litre vessel at -73^{o}c.

Solution

$V_1 = 2.5\text{litres.}, T_1 = 127 + 273 = 400\text{K},$

$P_1 = 3atm$ $V_2 = 4litres \quad , T_2 = -73 + 273 = 200K$ $P_2 = ?$
$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \Leftrightarrow \frac{3(2.5)}{400} = \frac{4P_2}{200} \Leftrightarrow P_2 = 1.08atm.$

Example 2

A bicycle pump contains $50cm^3$ of air at 17^0C and a pressure of one atmosphere. Find the air pressure when it is compressed to $10cm^3$ and its temperature rises to 27^0C.

Solution

$V_1 = 50cm^3., T_1 = 17 + 273 = 290K, P_1 = 1\ atm$ $V_2 = 10cm^3, T_2 = 27 + 273 = 300K, P_2 = ?$
$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \Leftrightarrow \frac{1(50)}{290} = \frac{10P_2}{300} \Leftrightarrow P_2 = 5.17atm.$

Standard temperature and pressure (S.T.P)

This is the physical condition of temperature equal to 0℃ and pressure is equal to 76cmHg at S.T.P, one mole of any gas occupies a volume of 22.4*l*.

Gas laws and kinetic theory.

Kinetic theory of matter states that, matter is made up of small particles called atoms or molecules that are in a constant random motion and the speed of movement of the particles is directly proportional to temperature.

-The theory considers the molecules of a gas to be like elastic spheres.

-Each time one of the molecules strikes the wall of the container it rebounds.

-The force produced on the on the wall by a molecule is the momentum change per second. So the gas pressure due to all bombarding molecules is proportional to their average total momentum per second (Force) normal to the wall.

Kinetic theory can be used to explain the cause of; -Gas pressure

(i) Boyle's law
(ii) Charles's law
(iii) Pressure law

a) Causes of gas pressure.

-Gas molecules are in constant random motion colliding with each other and bombarding the walls of the container.

-As they bombard the walls of the container, they exert a force on the walls. These forces cause the gas pressure.

Boyle's law

❖ At constant temperature, the average speed of gas molecules is constant.
❖ When the volume of the container decreases, the rate of collision and bombardment increases resulting in increase of force exerted on the walls and increase in pressure.
❖ Likewise increase in volume at constant temperature result in decrease in pressure.

Charles 's law.

❖ When temperature of gas molecules increases, they move faster.
❖ To maintain the pressure constant, the volume of gas must increase so that molecules travel further between collisions with the walls.
❖ This results in fewer collisions per second.

Pressure law.

❖ When the temperature of gas increases, molecules move faster.
❖ Raising the temperature of a fixed mass of gas at constant volume increases the average kinetic energy of the molecules so that the molecules make more frequent collisions with walls at high velocity.
❖ This decreases the rate of bombardment (few molecules collide), resulting in decrease in gas pressure.

b) Effect of Temperature on pressure

❖ When a gas is heated and its temperature rises, the average kinetic energy of the molecules increases and the average speed of the molecules increases.
❖ The frequency of the collisions of the molecules with the walls of the container increases hence the pressure of the gas increases.
❖ If the container is flexible, the volume of the gas increases in order to maintain the pressure constant.
❖ If the volume of the gas is to remain constant the pressure of the gas increases due to more frequent and more violent collisions of the molecules with the walls.
❖ The above explanation is used to explain why a balloon inflated with air bursts when left in sunshine.

-This is because the temperature rises yet volume remains constant so the pressure increases due to more frequent and more violent collision of the molecules with the walls.

EXERCISE 2:

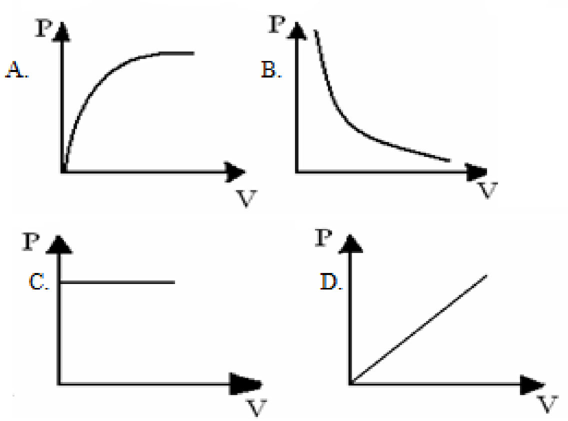
SECTION A

1. When air is pumped in a tube at constant temperature, the pressure increases because
A. the molecules are large
B. the molecules are moving faster
C. the molecules are closer together
D. more molecules are hitting the tube.

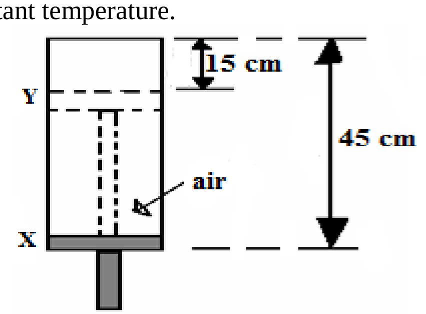
2. The volume of a fixed mass of gas at 27.0^0c and a pressure of 750mm of mercury is $300cm^3$. What is its volume when the pressure is raised to 900mm mercury and the temperature is 327^0c?
A. $125cm^3$ C. $180cm^3$
B. $500cm^3$ D. $720cm^3$

3. When the pressure of a mixed mass of a gas is reduced by half, its volume,
A. doubles at constant temperature.
B. is halved at constant temperature.
C. is halved if the temperature is also halved.
D. remains the same at constant temperature

4. Which of the following graphs shows the variation of the pressure of a gas as the volume changes at a constant temperature?



5. In figure above the piston is moved from X to Y at constant temperature.



The air pressure is:

A. Tripled C. doubled

B. reduced by a third D. unchanged

6. The pressure of a fixed mass of a gas at 17^0C is 10^5Pa. Find its pressure at 27^0C if the volume remains constant.

A. $\frac{27}{17} \times 10^5 Pa$ C. $\frac{17}{27} \times 10^5 Pa$

B. $\frac{300}{290} \times 10^5 Pa$ D. $\frac{290}{300} \times 10^5 Pa$

7. The pressure exerted by a gas decreases when its volume is increased at a constant temperature because the molecules,

A. move faster
B. move closer to one another.
C. hit the walls more often.
D. hit the walls less frequently.

8. Which of the following statements is incorrect when a tin containing air tightly sealed is heated?

A. the average speed of molecules increases.
B. the molecules of air hit the walls of the tin harder.
C. the molecules of the air strike the walls of the tin less often.
D. the pressure inside the tin increases.

9. The particles in a solid at room temperature are

A. close together and vibrating.
B. close together and stationary.
C. far apart and moving at random.
D. close together and moving at random.

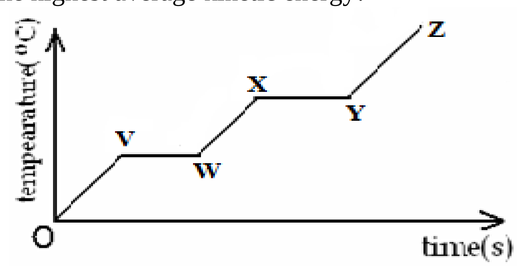
10. The temperature at which all the heat energy is removed from the substance is called:

A. Kelvin temperature
B. Celsius temperature
C. Freezing temperature
D. Absolute zero temperature

11. Which one of the following statements is true?

A. The average kinetic energy of the molecules of a gas depends on temperature.
B. Each molecule of a gas at a given temperature has a different speed.
C. The pressure of a fixed mass of gas decreases as the temperature increases.
D. The volume of a fixed mass of gas increases as the temperature decreases

12. The graph in the figure below is that of the temperature against time for a substance, which is heated at a constant rate. Which part of the graph corresponds to the situation when the molecules of the substance have the highest average kinetic energy?



A. OV B. VW C. VX D. YZ

13. At room temperature, air is less dense than water because air molecules

A. move faster
B. are smaller
C. have greater force of attraction
D. are more widely separated from each other.

14. When a liquid is heated,

A. its density decreases
B. boiling occurs at all temperatures
C. its molecules move with the same speed
D. evaporation takes place throughout the liquid.

15. It is more difficult to compress a liquid than a gas because

A. the speed of liquid molecules is lower than that of gas molecules.
B. liquid particles attract one another when compressed while gas particles repel each other.
C. the distances between liquid particles are less than those between gas particles.
D. liquid molecules repel one another when compressed while gas molecules repel one another

SECTION B

16. (a) State Boyle`s Law and verify the law.
(b) State Charles` Law and verify the law.
(b) State Pressure Law and verify the law.

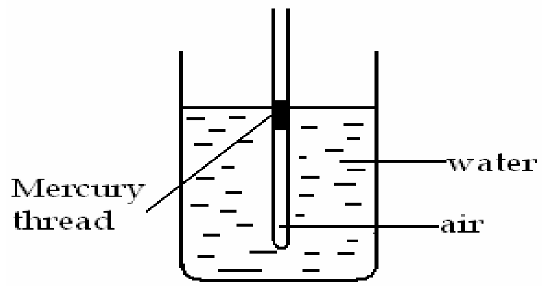
17. (a) What is an equation of state of a gas?
(b) (i) With the aid of a sketch graph, describe how absolute zero of temperature can be defined.

(ii) Use the kinetic theory of gases to explain the existence of absolute zero of temperature.

18. A gas of volume 1000cm^3 at a pressure of 4.0 x 10^5 Pa and temperature 17 ^{0}C is heated to 89.5 ^{0}C at constant pressure. Find the new volume of the glass. ***(Ans: 1250 cm^3)***

19. A cylinder with a movable piston contains 0.35 m^3 of air at a temperature of 73 ^{0}C. Calculate the volume of the gas if it is cooled to 27 ^{0}C at constant pressure. ***(Ans: 0.3 cm^3)***

20. (a) A graduated glass-tube containing air trapped below a mercury thread is immersed in a beaker of water and the water is heated as shown in the figure above below.



(i) Sketch a graph showing how the volume of the trapped air varies with absolute temperature.
(ii) When t he temperature of the water is 27 ^{0}C, the volume of the trapped air is 1.2x10^{-1} cm^3. Calculate the volume of air when its temperature is 77 ^{0}C. ***(Ans: 0.14 cm^3)***

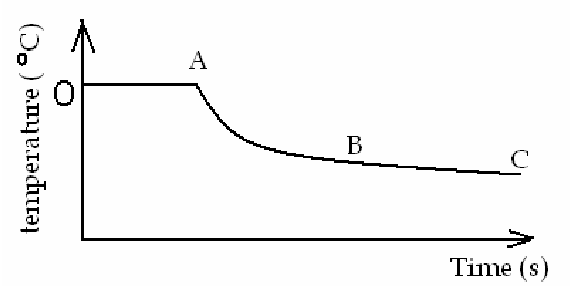
(b) With aid of labeled diagram, describe an experiment to show how to volume of a gas varies with pressure at constant temperature.

21. (a). With the aid of a labeled diagram, describe an experiment to show the relationship between the volume and temperature of a fixed mass of gas at atmospheric pressure.

(b).A volume of a fixed mass of a gas increases from 300 cm^3 to 500 cm^3 at a constant temperature. Find the new pressure if the initial pressure is 70 cm Hg.
(Ans: 116.7 cmHg)

22. (a). A volume of 2500 cm^3 of hydrogen gas is collected at 77 ^{0}C at a pressure of 730 mmHg. Calculate the volume of the gas at s.t.p. ***(Ans: 1873 cm^3)***

23. The figure shows temperature versus time curve for a liquid.

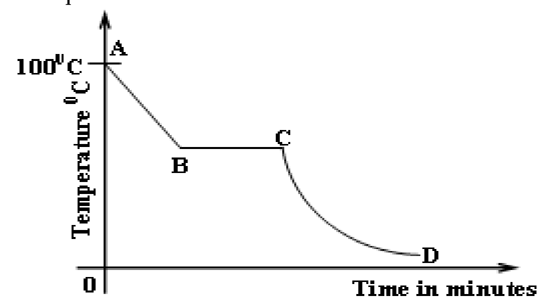


(a) State what is happening along BC
(b) Use the kinetic theory of matter to explain what is happening along OA.

24. (a) Sketch the variation of volume with temperature in Kelvin, for a gas at constant pressure.
(b) State any two advantages of mercury as a thermometric substance.

25. Explain the following observations**;**
(a) the increase in temperature of the gas
(b) the increases in the pressure of the gas

26. (a) State the kinetic theory of matter.
(b) The figure shows a cooling curve for a substance, which is in liquid form at 100^{0}C.



(i) In what states is the substance over the regions AB, BC and CD of the curve?
(ii) Use the kinetic theory of matter to explain the difference between the states of the substance over the regions AB and CD.

(e) MEASUREMENT OF HEAT (QUANTITY OF HEAT)

(a). Heat Capacity
Heat capacity is the quantity of heat required to raise the temperature of a body by 1 Kelvin.
In general, the amount of heat required to raise the temperature of a substance by one Kelvin. The S.I. unit of heat capacity is Joules per Kelvin ($\mathbf{JK^{-1}}$).

$$\text{Heat Capacity, } \mathbf{C} = \frac{\text{Quantity of Heat}}{\text{Temperature Channge}} = \frac{\mathbf{Q}}{\mathbf{\Delta\theta}}$$

(b). Specific Heat Capacity
The word specific refers to a unit quantity of physical property.
Specific Heat Capacity is the quantity of heat required to raise the temperature of a 1Kg mass of a substance by 1K.
The S.I unit of specific heat capacity is Joules per kilogram Kelvin () or Joules per kilogram per Kelvin ($\mathbf{JKg^{-1}K^{-1}}$).

$$\text{Specific Heat Capacity} = \frac{\text{Quantity of Heat}}{\text{Mass} \times \text{Temp. Channge}}$$

$$\text{C} = \frac{\text{Q}}{\text{m}\Delta\theta}$$

$$\text{Heat Energy} = \text{Mass} \times \text{S. H. C} \times \text{Temp. change}$$

$\mathbf{Heat\ Energy = mC\Delta\theta}$

Where $\Delta\theta$ is the temperature rise from initial temperature θ_1 to final temperature, θ_2.
Then $\Delta\ \boldsymbol{\theta} = (\theta_2 - \theta_1)$
m = mass of substance, C= specific heat capacity.

$$\text{Heat capacity} = \text{mass} \times \text{Specific Heat Capacity}$$

NOTE:
When using H $= \mathbf{mC\Delta\theta}$ **;**
1. The mass, m must be in in S.I unit (Kg).
2. In questions with the phrase "the temperature rises by …^{0}C or the temperature rose by…^{0}C; the temperature value given is the change in temperature, $\boldsymbol{\Delta\theta}$.

Example:
If the temperature of substance change from 20^{o}c to 40^{o}c. Then the temperature rise is;
$\Delta\ \boldsymbol{\theta} = (\theta_2 - \theta_1) = (40 - 20) = 20^0$C

Note: The value of C is different for different substances. The table shows values of specific heat capacities of some common substances.

Substance	Specific Heat Capacity ($\mathrm{J}\mathbf{Kg^{-1}K^{-1}}$)	Substance	Specific Heat Capacity ($\mathrm{J}\mathbf{Kg^{-1}K^{-1}}$)
Aluminium	900	Zinc	380
Brass	380	Mercury	140
Copper	**400**	Methylated	2400
Glass	670	**Water**	**4200**
Lead	130	Ice	2100
Iron	460		
N.B: The high specific heat capacity of water makes water a very good liquid for cooling machines.			

Importance of the high specific heat capacity of water
Because of its high specific heat capacity water is most suitable liquid used in the cooling system of engines and radiator of central heating system because less amount of liquid is needed to draw heat energy from the engine as compared to other liquids.

i.e **HEAT = MC$\boldsymbol{\theta}$**. The higher the value of **C,** the greater the heat removed keeping **M** and $\boldsymbol{\theta}$ Constant.
The high specific heat capacity of water makes the temperature rise and fall to be slower for water.
-The other reason why water is used is because it is cheaper and readily available compared to other liquids.

The specific heat capacity of water is $4200\mathrm{JKg^{-1}K^{-1}}$ and that of soil is about $800\mathrm{JKg^{-1}K^{-1}}$. This results in the temperature of the sea to rise and fall more slowly than that of land.
The specific heat capacity of water being $4200\mathrm{JKg^{-1}K^{-1}}$ means that heat of 4200J is required by 1kg of water to raise its temperature by 1K.

Islands are surrounded by water as they experience much smaller changes of temperatures from summer to winter because the specific heat capacity of water is high so that temperature rises and falls more slowly.

Example 1
How much heat is needed to rise the temperature from 30^{0}c to 0^{o}c for an iron of 5kg. Specific heat capacity of iron is 440J/KgK.
Solution:

$\boldsymbol{\Delta\theta} = (\theta_2 - \theta_1) = (40 - 30) = 10^0$C
$\mathbf{Heat\ Energy = mC\Delta\theta}$ $= 5 \times 440 \times 10$ $= 22000\mathrm{J}$

Example 2: (2000 Qn. 4)
When a block of iron of mass 2Kg absorbs 19KJ of heat, its temperature rises by 10^{0}C. Find the specific heat capacity of iron.

Solution:

$\mathrm{Q = 19KJ = 19 \times 1000 = 19000};\ \boldsymbol{\Delta\theta} = 10^0$C; C?
$\mathbf{Heat\ Energy, Q = mC\Delta\theta}$ $19000 = 2 \times \mathrm{C} \times 10$ $19000 = 20\mathrm{C}$ $\mathrm{C} = 950\mathrm{JKg^{-1}K^{-1}}$

Example 3: (2003 Qn. 13)
Find the amount heat required to raise the temperature of a 0.5Kg salt solution from -5^0C to 15^0C. Specific heat capacity of salt solution is $4000\mathrm{JKg^{-1}K^{-1}}$.

Solution:

$\mathrm{Q} = ?\ \mathrm{m} = 0.5\mathrm{Kg};\ \theta_1 = -5\ ^0\mathrm{C},\ \theta_2 = 15\ ^0\mathrm{C}$; $\Delta\ \boldsymbol{\theta} = (\theta_2 - \theta_1) = (15 - -5) = 20\ ^0\mathrm{C}$
$\mathbf{Heat\ Energy, Q = mC\Delta\theta}$ $= 0.5 \times 4000 \times 20$ $= 40000\mathrm{J}$

Example 4: (1992 Qn. 4)
Find the amount heat required to raise the temperature of a 20g of water from 30^{0}C to 60^{0}C. Specific heat capacity of water is $4200\mathrm{JKg^{-1}K^{-1}}$.

Solution:

$\mathrm{Q} = ?\ \mathrm{m} = 20\mathrm{g} = \frac{20}{1000} = 0.02\mathrm{Kg}$; $\boldsymbol{\Delta\theta} = (\theta_2 - \theta_1) = (60 - 30) = 30\ ^0\mathrm{C}$
$\mathbf{Heat\ Energy, Q = mC\Delta\theta}$ $= 0.02 \times 4200 \times 30$ $= 2520\mathrm{J}$

Example 5: **UNEB 1997. Qn. 15**
Calculate the specific heat capacity of paraffin if 22000 joules of heat are required to raise the temperature of 2.0 Kg of paraffin from 20^0Cto 30^0C.

(c) CALORIMETRY

Calorimetry is the measurement of heat exchanged.
The device used in calorimetry is a calorimeter. It is usually made of copper.
The calorimeter is lagged with an insulator and placed in a jacket with a plastic cover which has two holes for a thermometer and a stirrer.

Methods of Measuring Specific Heat Capacity

(i) Method of mixtures
(ii) Mechanical method
(iii) Electrical Method (not on syllabus)

Describing the method of mixture

- ✓ The method of mixture involves mixing a solid with a liquid at different temperature but the specific heat capacity of either solid or liquid should be known.
- ✓ In this method a hot substance is mixed with a cold substance and then stirred. Then heat will flow from a hot substance to the cold substance until both are at the same temperature.
- ✓ If no heat is lost to the surrounding then heat lost by the hot substance = heat gained by cold substance.

NOTE:

1.-If the heat capacity of the calorimeter (or container) is NOT neglected, then heat lost by the hot object is gained by both the calorimeter and its content.

-Both the calorimeter and its content always have the same temperature values. Thus

$$\begin{pmatrix}\text{Heat lost by}\\ \text{hot body}\end{pmatrix} = \begin{pmatrix}\text{Heat}\\ \text{gained}\\ \text{by cold}\\ \text{body}\end{pmatrix} + \begin{pmatrix}\text{Heat}\\ \text{gained by}\\ \text{calorimeter}\end{pmatrix}$$

$$(\mathbf{m_s C_s \Delta\theta}) = (\mathbf{m_l C_l \Delta\theta}) + (\mathbf{m_c C_c \Delta\theta})$$

2. If the heat capacity of the calorimeter is neglected, then the heat gained by the calorimeter is neglected and is not included in the calculation.

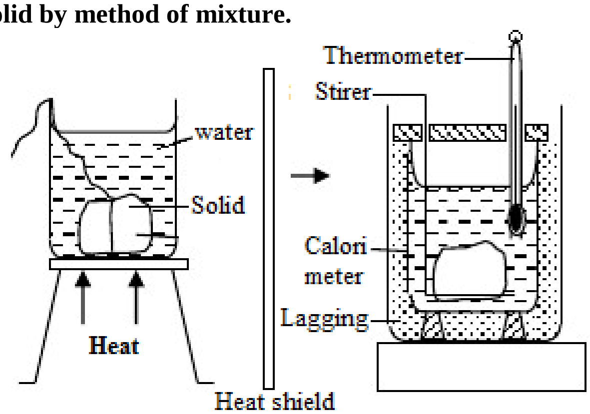
$$\begin{pmatrix}\text{Heat lost by}\\ \text{hot body}\end{pmatrix} = \begin{pmatrix}\text{Heat gained}\\ \text{by cold body}\end{pmatrix}$$

$$(\mathbf{m_s C_s \Delta\theta}) = (\mathbf{m_l C_l \Delta\theta})$$

Where, $\mathbf{m_s}, \mathbf{m_l}, \mathbf{m_c}$ = masses of hot body, cold body and calorimeter respectively

$\mathbf{C_s}, \mathbf{C_l}, \mathbf{C_c}$ = Specific Heat Capacity of hot body, cold body and calorimeter respectively

Experiment to determine the specific heat capacity of a solid by method of mixture.



Procedure

- ✓ Water of mass m_1 is put in a container of heat capacity c_1
- ✓ The calorimeter and its contents is placed in a calorimeter jacket and their initial temperature θ_1 recorded.
- ✓ Meanwhile, the solid of mass m is put in boiling water in a beaker as shown in figure (i) above for some minutes. The boiling point θ_2 is read and recorded.
- ✓ The solid is quickly transfered from the boiling water to the calorimeter using a string.
- ✓ The water is stired until the final steady temperature θ_3 is obtained (the heat shield is to prevent the heating from boiling water to reach the calorimeter).
- ✓ Assume negligible heat to the surrounding.

$$\begin{pmatrix}\textbf{Heat lost by}\\ \textbf{hot body}\end{pmatrix} = \begin{pmatrix}\textbf{Heat}\\ \textbf{gained}\\ \textbf{by cold}\\ \textbf{water}\end{pmatrix} + \begin{pmatrix}\textbf{Heat}\\ \textbf{gained by}\\ \textbf{calorimeter}\end{pmatrix}$$

$$(\mathbf{m_s C_s \Delta\theta}) = (\mathbf{m_w C_w \Delta\theta}) + (\mathbf{m_c C_c \Delta\theta})$$

$$m_s C_s(\theta_3 - \theta_2) = m_w C_w(\theta_2 - \theta_1) + m_c C_c(\theta_2 - \theta_1)$$

$$C_s = \frac{m_w C_w(\theta_2 - \theta_1) + m_c C_c(\theta_2 - \theta_1)}{m_s(\theta_3 - \theta_2)}$$

Knowing values of C_1,M_1, M_2, C_2,M and temperature changes, specific heat capacity of a solid C_s can be obtained from the above expression.

Possible sources of errors in calorimetry.

(i) Heat is lost from the calorimeter by conduction to the sorounding.
(ii) Heat is lost from the calorimeter by radiation.
(iii) Heat is lost from the water by convection and evaporation.

Precautions taken to minimese the above errors

- The specimen must be transferred as fast as possible but with care to avoid splashing of water from calorimeter.
- The calorimeter must be insulated and placed on an insulating stand in a constant temperature bath. This minimizes heat losses by conduction
- The calorimeter must be polished on its inner and outer surface to reduce heat loss by radiation.
- The calorimeter must be covered with a lid to minimize heat loss from water by convection.
- Stirring must be done to ensure uniform distribution of heat.

NOTE:

To determine the specific Heat capacity of the liquid, the same procedure above is used. However in this case, a solid of known specific heat capacity is used and C_l is made the subject of the formula.

$$m_s C_s(\theta_3 - \theta_2) = m_l C_l(\theta_2 - \theta_1) + m_c C_c(\theta_2 - \theta_1)$$

$$C_l = \frac{m_s C_s(\theta_3 - \theta_2) - m_c C_c(\theta_2 - \theta_1)}{m_l(\theta_2 - \theta_1)}$$

Example 1:

A piece of metal of mass 0.5kg is heated to 100^oc and then placed in 0.4kg of water at 10^oc. If the final temperature of

the mixture is 30°c. calculate the specific heat capacity of the metal.
(The S.H.C of water is $4200\text{JKg}^{-1}\text{K}^{-1}$)

Solution:

$\theta_3 = 100^0\text{C}; m_s = 0.5\text{kg}$ $\theta_2 = 30^0\text{C};\ m_w = 0.4\text{kg}$ $\theta_1 = 10^0\text{C};$
Assume negligible heat to the surrounding. $\begin{pmatrix}\text{Heat lost by} \\ \text{hot body}\end{pmatrix} = \begin{pmatrix}\text{Heat gained} \\ \text{by cold water}\end{pmatrix}$ $m_s C_s(\theta_3 - \theta_2) = m_w C_w(\theta_2 - \theta_1)$ $0.5 \times C_s \times (100 - 30) = 0.4 \times 4200(30 - 10)$ $35C_s = 0.4(4200)(20)$ $C_s = 960\text{JKg}^{-1}\text{K}^{-1}$

Note:
Liquid take up the volume of the container when filled so when a liquid is filled in a container the volume of the container is equal to the volume of liquid filling it.

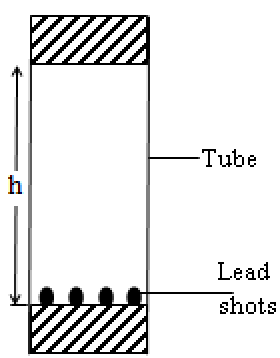
$$\begin{pmatrix}\text{Mass of} \\ \text{liquid}\end{pmatrix} = \begin{pmatrix}\text{volume of} \\ \text{liquid}\end{pmatrix} \text{x} \begin{pmatrix}\text{density of} \\ \text{liquid}\end{pmatrix}$$

Example 2: <u>UNEB 1993. Qn. 3(d)</u>
A copper block of mass 250g is heated to a temperature of 145^0C and then dropped into a copper calorimeter of mass 250g containing $250cm^3$ of water at 20^0C.

(i) Calculate the maximum temperature attained by the water. (S.H.C of water is $4200\text{JKg}^{-1}\text{K}^{-1}$).
(ii) Sketch a graph to show the variation of temperature of water with time.

Example 3:
A piece of copper, of mass 40g at 200^0C is placed in a copper calorimeter of mass 60g containing 50cm^3 of water at 10^0C. Ignorng heat losses, find the final steady temperature of the mixture after stiring.

Finding Specific Heat Capacity by Mechanical method



- ✓ Lead shots of measured temperature θ_1 and mass "m" are placed in a tube as shown above. When the tube is inverted, they fall through distance "h". so potential energy of the lead shots is **mgh**.
- ✓ This energy becomes kinetic energy which in turn becomes internal molecular energy when the lead shots are brought to rest. The internal molecular energy is heat energy which rises the temperature of lead shot from $\theta_1$toθ_2.
- ✓ Heat energy gained by the lead shots is equal to the potential energy lost by lead shot.

$$\mathbf{mc(\theta_2 - \theta_1) = mgh}$$

- ✓ When the tube is inverted N times then the total potential energy is calculated as **Nmgh** so that heat gained is equal to potential energy lost.

$$mc(\theta_2 - \theta_1) = Nmgh$$
$$c(\theta_2 - \theta_1) = Ngh$$
$$\mathbf{c = \frac{gh}{(\theta_2 - \theta_1)}}$$

Where **N** is the number of time the tube is inverted. **g** is acceleration due to gravity and **h** is the distance through which the lead shots have fallen.
The distance "h" is the same as the length of the tube. This method is more advantageous than the method of mixtures because here the mass of substance is not required.

Example:
A tube length 10cm contains leads shots. If the tube is inverted 1000 times such that the temperature of the shots changes from 40°c to 100°c. calculate the specific heat capacity of the lead shots.

$h = 10\text{cm} = 0.1\text{m}; g = 10\text{ms}^{-2}; N = 1000\text{times}$
$c = \frac{gh}{(\theta_2 - \theta_1)} = \frac{1000 \times 10 \times 0.1}{100 - 40}$ $= \frac{1000}{60}$ $= 16.7\text{JKg}^{-1}\text{K}^{-1}$

Example:
A tank holding 60kg is heated by 3KW electric immersion. If the specific heat capacity is 4200J/kgk. Calculate the time taken for the temperature to rise from 10°c to 60°c.

Solution:

m=60kg P=3KW =3 x 1000W=3000W
$\text{Energy} = \text{Power} \times \text{Time}$ $mc(\theta_2 - \theta_1) = Pt$ $60 \times 4200 \times (60 - 10) = 3000t$ $t = 4200s$

Question:
A liquid of mass 200 g in a calorimeter of heat capacity 500 JK^{-1} is heated such that its temperature changes from 25 °C. Find the specific heat capacity of the liquid if the heat supplied is 14000 Joules. (2mrks)

LATENT HEAT (HIDDEN HEAT)

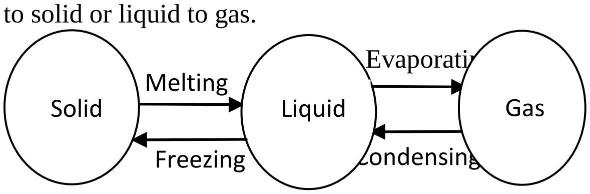
(a) Latent Heat
Latent heat is the quantity of heat absorbed or released at constant temperature by a substance during change of state.

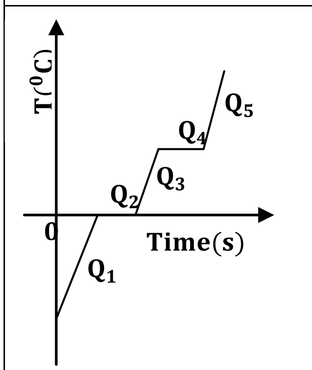
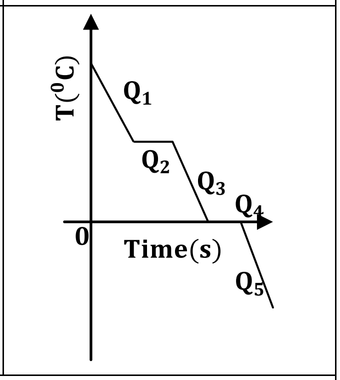
Specific latent heat is the heat required to change one kilogram of substance from one state of matter to another without changing its temperature.

When a substance changes state from solid to liquid or liquid to solid liquid to gas the temperature remains constant although heat is supplied.

This can be explained by the kinetic theory.
When a solid is changing in state there is no temperature change because the supplied heat energy is being used by molecules to break away the intermolecular force holding them in one state.

Latent heat therefore is the heat which causes no change in temperature but changes the state, say solid to liquid, liquid to solid or liquid to gas.



(a) Heating Curve	(b) Cooling curve
	
Q = Quantity of heat, m = mass, l_f = Latent heat of fusion, l_v = Latent heat of vapourisation c = Specific heat capacity $\Delta\theta$ = Change in temperature	
$\mathbf{Q_1}$: Temperature of ice increasing $\mathbf{Q_1 = mc\Delta\theta}$ $\mathbf{Q_2}$: Ice changing to water $\mathbf{Q_2 = ml_f}$ $\mathbf{Q_3}$: Temperature of water increasing $\mathbf{Q_3 = mc\Delta\theta}$ $\mathbf{Q_4}$: water changing to vapour $\mathbf{Q_4 = ml_v}$ $\mathbf{Q_5}$: Temperature of steam increasing $\mathbf{Q_5 = mc\Delta\theta}$	$\mathbf{Q_1}$: Temperature of steam decreasing $\mathbf{Q_1 = mc\Delta\theta}$ $\mathbf{Q_2}$: Steam condensing $\mathbf{Q_2 = ml_v}$ $\mathbf{Q_3}$: water cooling $\mathbf{Q_3 = mc\Delta\theta}$ $\mathbf{Q_4}$: water changing to ice $\mathbf{Q_4 = ml_f}$ $\mathbf{Q_5}$: Ice cooling $\mathbf{Q_5 = mc\Delta\theta}$

(b) Types of latent Heats

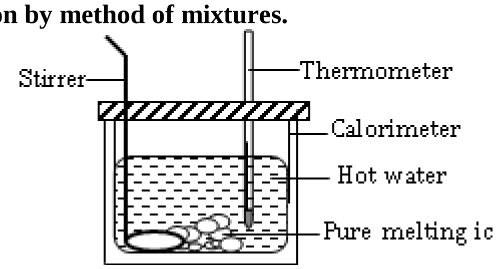
(i) Latent heat of fusion; L_v

Latent heat of fusion is the quantity of heat required to change the state of a substance from solid to liquid at constant temperature.

Specific Latent heat of fusion is the quantity of heat required to change the state of a 1kg mass of substance from solid to liquid at constant temperature.
The S.I unit is a $\mathbf{Jkg^{-1}}$.

$$Q = mL_f$$

Experiment to determine the specific latent heat of fusion by method of mixtures.



- ✓ Pour pure hot water of known mass, $\mathbf{m_{Hw}}$and specific heat capacity $\mathbf{C_w}$ in a well lagged calorimeter of mass, $\mathbf{m_c}$and specific heat capacity $\mathbf{C_c}$.
- ✓ Record the initial temperature of,$\theta_1$of hot water.
- ✓ Place small pieces of pure melting ice at 0^0C into the calorimeter and stir the mixture gently until all the ice melts.
- ✓ Read and record the final temperature of,$\theta_2$of the mixture in the calorimeter.
- ✓ Reweigh the calorimeter and its content to determine the mass of melted ice $\boldsymbol{m_i}$from the formula;

$$m_i = (m_i + m_{Hw} + m_c) - (m_{Hw} + m_c)$$

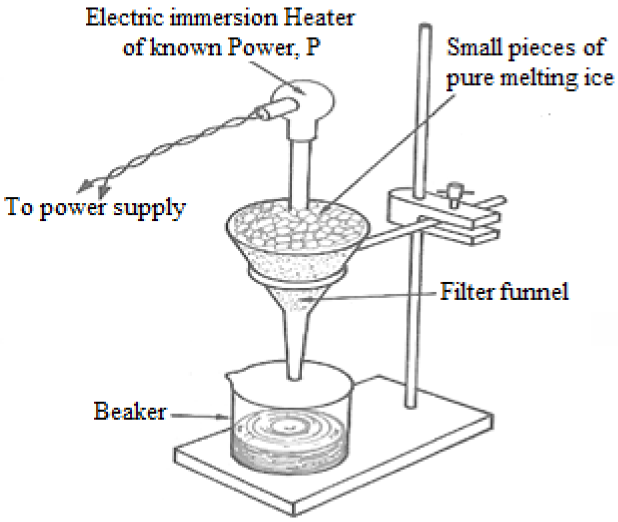
- ✓ Heat lost by hot water and calorimeter is equal to heat gained by ice and cold water from ice

$$\boldsymbol{m_{Hw}C_w\Delta\theta + m_cC_c\Delta\theta = m_il_f + m_wC_w\Delta\theta}$$

$$\begin{bmatrix} m_{Hw}C_w(\theta_1 - \theta_2) \\ + m_cC_c(\theta_1 - \theta_2) \end{bmatrix} = m_il_f + m_wC_w(\theta_2 - 0)$$

$$\boldsymbol{l_f = \frac{\begin{bmatrix} m_{Hw}C_w(\theta_1 - \theta_2) \\ + m_cC_c(\theta_1 - \theta_2) \end{bmatrix} - m_wC_w(\theta_2 - 0)}{m_i}}$$

Experiment to determine the specific latent heat of fusion by Electrical method.



Procedures:

- ✓ Placing heater;An electric heater of known power "**p**" is placed in filter funnel.

- ✓ Packing small pieces of ice; Small pieces of ice are packed around the electric heater.
- ✓ Switching on and timing;The heater is switched on for a known time "t" and mass "m" of water collected in the beaker is weighed and determined from the formula:

$$\begin{pmatrix}\text{Mass of}\\ \text{melted ice}\end{pmatrix} = \begin{pmatrix}\text{Mass of empty}\\ \text{beaker + water}\end{pmatrix} - \begin{pmatrix}\text{Mass of}\\ \text{beaker}\end{pmatrix}$$

Conclusion:

The specific latent heat of fusion of ice,$\mathbf{L_f}$ is calculated from the formula;

$$\mathbf{Pt = mL_f}$$

Assumption;

- ❖ No heat is absorbed from the surrounding.
- ❖ All heat supplied by the heater has been absorbed by the ice only.

Significance of high value of specific latent heat of fusion [$\mathbf{L_f = 340,000Jkg^{-1}}$]

Ice is often used as a cooling agent e.g. ice cubes are added to juice to keep it cold.

(ii) Latent heat of vapourisation

Latent heat of vapourisation is the quantity of heat required to change the state of a substance from liquid state to gas at constant temperature.

Specific Latent heat of fusion is the quantity of heat required to change the state of a 1kg mass of substance from liquid state to a gas at constant temperature.

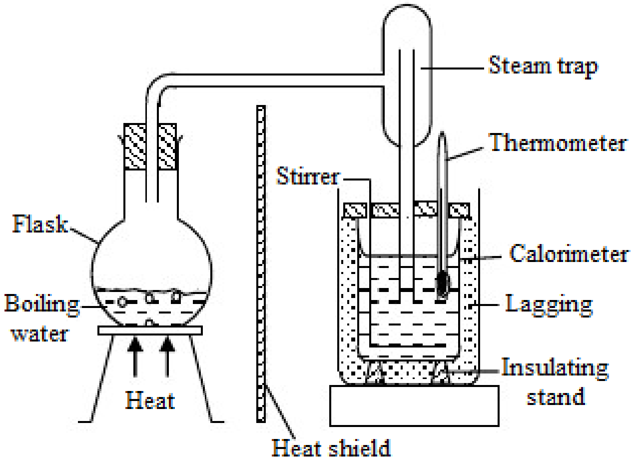
The S.I unit is a $\mathbf{Jkg^{-1}}$

$$Q = mL_v$$

Importance of the very high value of specific latent heat of vapourization of steam
[$\mathbf{L_v = 2,260,000Jkg^{-1}}$]

- ✓ Because of high value, steam is used as a heating agent e.g. In cookers (cooking)
- ✓ Can be used for sterilizing medical tools e.g. blades, forceps, e.t.c.

Experiment to determine the specific latent heat of vapourization by method of mixtures.



- ✓ Pour pure cold water of known mass, $\mathbf{m_{cw}}$and specific heat capacity $\mathbf{C_w}$ in a well lagged calorimeter of mass, $\mathbf{m_c}$and specific heat capacity, $\mathbf{C_c}$.
- ✓ Record the initial temperature of,$\theta_1$of cold water.
- ✓ Pass steam from boiling pure water at 100^0C into cold water in the calorimeter for some time and stir the mixture gently until all the temperatures are steady.
- ✓ Read and record the final temperature of,$\theta_2$of the mixture in the calorimeter.
- ✓ Re weigh the calorimeter and its content to determine the mass of melted ice $\boldsymbol{m_s}$from the formula;

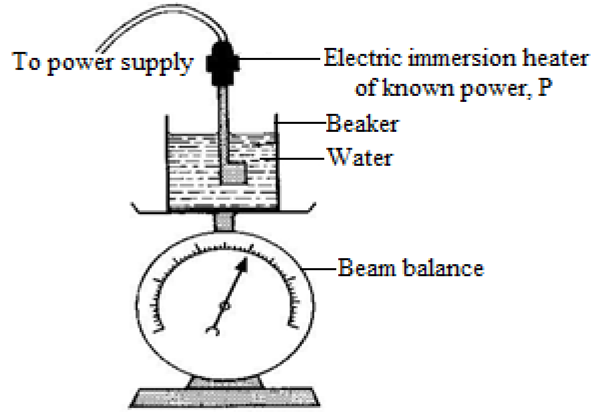
$$m_s = (m_s + m_{cw} + m_c) - (m_{cw} + m_c)$$

A. Heat lost by hot steam and condensed water from steam is equal to heat gained by cold water and calorimeter

$$\boldsymbol{m_s l_v + m_s C_w \Delta\theta = m_{cw} C_w \Delta\theta + m_c C_c \Delta\theta}$$

$$l_v = \frac{\begin{bmatrix} m_{cw} C_w (100 - \theta_2) \\ + m_c C_c (\theta_2 - \theta_1) \end{bmatrix} - m_s C_w (\theta_2 - \theta_1)}{m_s}$$

Determination of specific latent heat of vaporization of steam by electrical method



Procedures:

- ✓ Weigh the mass of water and the beaker and record it as m_1.
- ✓ Placing heater; An electric heater of known power "p" is placed in the water in a can placed on top of a beam balance.
- ✓ Switching on and timing; The heater is switched on for a known time "t" and Weigh the mass of water and the beaker again and record it as m_2.
- ✓ Finding mass of steam; The mass "m" of steam escaped is determined from the formula:

$$\binom{\text{Mass of}}{\text{steam}} = (m_1) - (m_2)$$

Conclusion:

The specific latent heat of vapourisation of steam $\mathbf{L_v}$ is calculated from the formula;

$$\mathbf{Pt = mL_v}$$

Latent heat and kinetic theory

(a) Latent heat of fusion.

During change of state from solid to liquid (melting) at constant temperature, the heat supplied weakens the intermolecular forces of attraction, the molecular spacing increase, changing from static mo88lecules of solid to fast moving molecules in liquid state.

The average K.E of molecules remaining constant because melting takes place at constant temperature.

(b) Latent heat of vaporization;

During change of state from liquid to vapour, (Boiling) at constant temperature, the heat supplied weakens the intermolecular forces of attraction, the molecular spacing increase, so that they gain freedom to move about independently.

As a result, the heat supplied is used to overcome these forces resulting in gain molecular potential energy but not their kinetic energy and also the work to expand against atmospheric pressure.

Why specific latent heat of vaporization of a substance is always greater than specific latent heat of fusion for the same substance.

Specific latent heat of vaporization is always greater than L_f because for molecules of a liquid to escape, they require a lot of heat which increases the K.E in order to overcome the intermolecular forces of attraction.

While for latent heat of fusion very low amount of heat is required to weaken the intermolecular forces of attraction.

Effect of latent heat of vaporization

When steam at 100°c condenses on your body, it produces more serious burn than one would have from an equal mass of water at 100°c because when steam condenses latent heat is given out.

How to apply the formula in calculations

The following should be noted;

1. When applying the heat formula for change of state from either solid to liquid or liquid to solid the value of specific latent heat of fusion should be used.
2. The substance must either be at the melting point temperature for solid to liquid or at freezing point temperature for liquid to solid.

a) <u>For a solid at melting point changing to liquid at freezing point.</u>

Example I: How much heat is required to melt 10g of ice at 0°c given specific latent heat of fusion is 3.36×10^5 J/Kg.

Solution

$\text{Heat} = mL_f$

$\text{Heat} = \left(\frac{10}{1000}\right) \times (3.36 \times 10^5)$

$\text{Heat} = 336000\text{JKg}^{-1}$

<u>b) When the solid is not at the melting point changing to a liquid at freezing point</u>

In this case heat energy for changing the temperature to melting point is required. The heat for change the solid to liquid is applied, so heat energy required = Heat for change of temperature to melting point.+ Heat for change of state

$\text{Heat} = mc\Delta\theta + mL_f$

$\text{Heat} = mc(\theta_2 - \theta_1) + mL_f$

Where: m is mass the substance

C is the specific heat capacity of the solid

θ_2 is the melting temperature of the solid

θ_1 is the initial temperature of the solid.

Example 2:

How much heat is required to change 10g mass of ice at –10°c to water at 0°c. Given that the specific heat capacity of ice is 2100J/KgK. and the special latent fusion of ice is 3.36×10^5 J/Kg.

Solution

$\text{Heat required} = mc(\theta_2 - \theta_1) + mL_f$

$$\text{Heat required} = \left(\frac{10}{1000}\right)(2100)(0 - -10) + \left(\frac{10}{1000}\right)(3.36 \times 10^5)$$

$\text{Heat required} = 336000\text{ J}$

(c) <u>For a solid not at melting point to a liquid not at freezing point</u>.

Heat required = Heat for change of temperature of solid to melting point + Heat for change of state from solid to liquid + Heat for change of temp at melting point to a given temperature.

$\text{Heat} = mc_1\Delta\theta_1 + mL_f + mc_2\Delta\theta_2$

WHERE

m is mass of the solid which is also the same as the mass of the liquid formed

$\Delta\theta_1$ is the change in temperature of the solid from its initial temperature to melting temperature.

$\Delta\theta_2$ is the change in temperature of the liquid formed from temperature to the final temperature of the liquid.

C_1 is the specific heat capacity of a liquid

C_2 is the specific heat capacity of the solid

L_f is the specific latent heat of fusion

Example

10g of ice at -10°c is heated to water at 30°c given that the S.H.C of ice is 2100 J/KgK, the S.H.C of water 4200J/

KgK. The specific latent heat of fusion of water is $3.36\ x\ 10^5$J/Kg. Calculate the heat energy supplied.

Solution:
States involved
i) Solid at -10^{o}c ii) solid liquid at melting point 0^{o}C
iii) Liquid at 30^{o}C

$m = 10g = 0.01kg$;
$\theta_2 = 0^0C$;
$\theta_1 = -10^0C$;

$$\begin{pmatrix}\text{Heat}\\ \text{supplied}\end{pmatrix} = mc_1\Delta\theta_1 + mL_f + mc_2\Delta\theta_2$$

$$\begin{pmatrix}\text{Heat}\\ \text{supplied}\end{pmatrix} = \begin{matrix}0.01(2100)(0+10)\\ +0.01(336000)\\ +0.01(4200)(30-0)\end{matrix}$$

$$\text{Heat supplied} = 210 + 3360 + 1260 = 4830\ J$$

Example
A 3kw electrical heater is left on for two minutes when its placed in a container packed with ice. If 100g of ice was melted to water, calculate the specific latent heat of fusion of ice.
Solution:

$P = 3KW = 3000W; m = 100g = 0.1Kg; t = 2min$

Solution
$Heat = mL_f$
$pt = mL_f$

$3000 \times 120 = 0.1 \times L_f$
$360000 = 0.1L_f$
$L_f = 3600000\ Jkg^{-1}$

Note:
When the body changes state from liquid to solid, the same amount of latent of fusion is given out.

Example
When the 1.5kw heater was switched on for 26 minutes, the top balance recorded that the mass of the beaker was reduced by 1kg. Calculate the specific latent heat of vaporization of water.

Solution:
$P = 1.5KW = 1500W; m = \text{mass lost as steam} = 1kg$;
$t = 26min = 1560s$

$Heat = mL_v$
$pt = mL_v$

$1500 \times 1560 = 1 \times L_v$
$2340000 = L_v$
$L_v = 2340000\ Jkg^{-1}$

Note:
If it's a change of state from liquid to gas (vapour) or gas to liquid then the specific latent heat of vaporization should be used.

The heat received by a substance depends on the following factors:
- Temperature
- Mass
- Nature of substance

Exercise
1. Calculate the mass of steam at 100^{o}c needed to raise temperature of water by 1kg from 20^{o}c to 80oc. Specific heat capacity of water is 4000J/Kgk.
[Ans: m = 0.10 Kg]

2. Calculate the heat required to convert 5kg of ice at -20^{0}C to steam at 100^{0}C. [Given that the S.H.C of ice is 2100 J/KgK, the S.H.C of water 400J/KgK. The specific latent heat of fusion of water is $3.4\ x\ 10^5$J/Kg and the specific latent heat of vapourizationis $2.3\ x\ 10^6$J/Kg.
[Ans: Q = 15,510,000 J]

3. Musa was carrying out an experiment. He heated 200g of copper metal block to 98^{0}C. He then transferred it quickly to 300g of water in a copper calorimeter of mass 100g at 30^{0}C.Calculate the final temperature of the mixture.{Specific heat capacities of water and copper are 4200J/KgK and 400J/KgK respectively}.

4. A heater rated 840W, 240V takes 50 minutes to raise the temperature of water from 25^{0}C to 85^{0}C. Calculate:
   (i) The mass of the water.
   (ii) The volume of the water

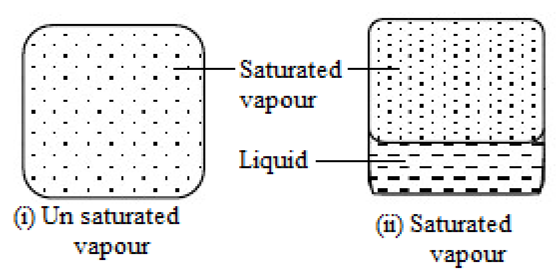
5. A liquid of mass 2kg at 10^{0}C is supplied with 42000J of heat. If the specific heat of the of the liquid is 4200Jkg^{-1}K^{-1}. Find the new temperature of the liquid.

6. See **UNEB Paper I**

1989 Qn. 33	2001 Qn.34	1988 Qn.3
2006 Qn.8	2007 Qn.8	2000 Qn.3
1987 Qn.14	**Section B**	1992 Qn.8
1988 Qn.19	1988 Qn.5	
1999 Qn.15	1998 Qn.2	

(f) VAPOURS

(i) Vapour is the gaseous state of a substance below its critical temperature i.e. ***Critical temperature*** *(T_c)* is the minimum temperature above which the gas cannot be liquidized no matter how much pressure is applied.



(ii) Saturated vapour is the vapour which is in thermal dynamic equilibrium with its own liquid i.e. whose rate of evaporation = rate of condensation.

(iii) Un saturated vapour is the vapour which is not in thermal dynamic equilibrium with its own liquid i.e. whose rate of evaporation ≠ rate of condensation.

(iv) **Supper saturated vapour** is the vapour whose rate of evaporation > its rate of condensation.

(v) Thermal dynamic equilibrium is the liquid's thermal state at which its rate of evaporation is equal to its rate of condensation.

(vi)Vapour pressure is the pressure exerted on the walls of the container by the vapour molecules.

(vii) Saturated vapour pressure (s.v.p) is the pressure exerted by vapour which is in thermal dynamic equilibrium with its own liquid.

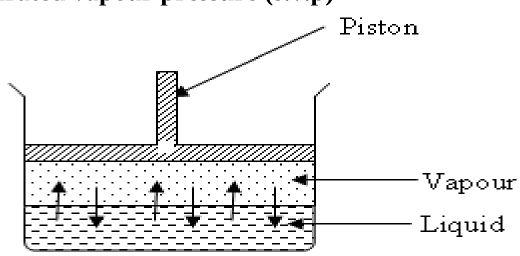
(viii) Un saturated vapour pressure is the pressure exerted by vapour which is not in thermo dynamic equilibrium with its own liquid.

(ix) Supper saturated vapour pressure is the pressure exerted by vapour whose rate of evaporation > its rate of condensation.

(x) Dew point is defined as temperature of saturated atmospheric air.

NB: *A cloudy film forms on screens of cars being driven in rain because of the condensation of the excess water vapour in atmospheric moist air as a result of exceeding its dew point.*

Kinetic theory explanation for the occurrence of saturated vapour pressure (s.v.p)



- ✓ When a liquid in a closed container is heated, the energy which goes into it becomes mechanical energy to the molecules.
- ✓ Some of the liquid molecules get enough kinetic energy and break the intermolecular bonds and escape from the surface of the liquid and occupy the space just above it.
- ✓ These molecules constitute what we call **vapour** and the pressure they exert to the walls of the container as they collide with themselves and the walls of the container is called vapour pressure.

<u>**Vapour pressure** is the pressure exerted by the escaping molecules of the vapour from the surface of the liquid.</u>

- ✓ When these molecules bounce off from the walls of the container, they strike the liquid surface and re-enter the liquid until when a state of thermal dynamic equilibrium is attained i.e. (rate of evaporation = rate of condensation).
- ✓ In this state, the vapour is said to be saturated exerting saturated vapour pressure and before this state, vapour is un saturated (with rate of condensation > rate of evaporation) exerting un saturated vapor pressure**.**

<u>**Saturated vapour pressure (s.v.p**) is the pressure exerted by vapour which is in thermal dynamic equilibrium with its own liquid.</u>

NB: Saturated vapours do not obey ideal gas laws because its mass changes due to condensation or evaporation as conditions change yet gas laws only apply to a constant mass of a gas.
It should be noted that saturated vapor occurs for a very short time and constant temperature (boiling point).

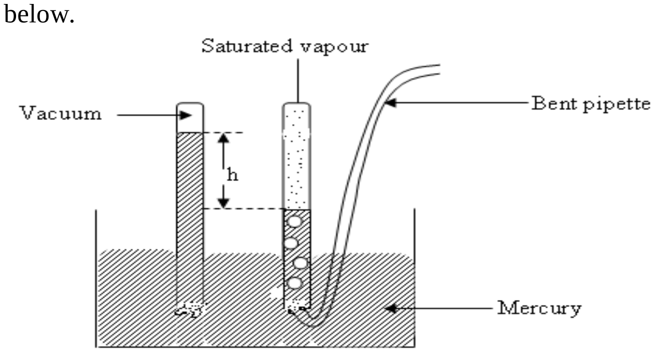
Comparison of vapour pressure

Saturated vapour.	**Un saturated vapour**.
It does not obey ideal gas laws.	It obeys ideal gas laws.
It is achieved at thermal dynamic equilibrium.	Its rate of evaporation ≠its rate of condensation.
Its pressure remains constant at particular temperature.	Its pressure increases with increase in temperature.

Determining saturated vapor pressure
Bent-pipette method
This method is used to determine the **s.v.p** of a volatile liquid at a particular temperature.

- **Procedure.**

Two barometers A and B are filled with mercury and inverted over a trough of mercury as shown. At first the mercury is at the same level.
The liquid whose **s.v.p** is to be determined is introduced with the help of a bent pipette in the vacuum space above the mercury level in one of the barometric tubes as shown below.



<u>Observation</u>
Some of the liquid evaporates immediately and the mercury column falls by "h".

<u>Explanation</u>
This is because the introduced lquid evaporates and forms a vapour which exerts a pressure on the mercury causing the column to fall.

When mercury has stopped dropping, the vapour is said to be in dynamic equilibrium, thus saturated vapour.
The pressure **hρg** is the **s.v.p** of the volatile liquid and **ρ** is its density.

Merits of mercury for this experiment

- Mercury is very dense compared to many liquids
- Mercury is opaque thus easily seen and read.

If too much water is introduced on top of mercury column

Observation

Some water evaporates and some remains on top of the mercury column.

Explanation

Some water remains on the top because the space above becomes a saturated vapour so that the rate at which molecules leave the liquid surface is equal to the rate at which other molecules return to the liquid.

Effect of compression on a saturated vapour

The saturated vapour is compressed by lowering the tube.

Observation

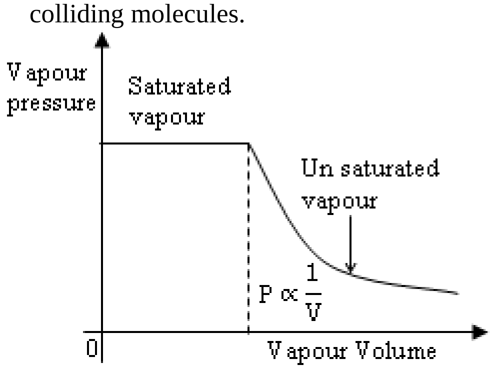
The height "h" of mercury column remains constant but amount of water on top of the mercury column increases.

Explanation

The height "h" remains constant because saturated vapour pressure is not affected when the vapour is compressed. However, the amount of water increases because more vapour condenses when the vapour is compressed.

More Explanation:

- ✓ A reduction in vapour volume of saturated vapour mainly leads to an equal reduction in the number of vapour molecules above the liquid surface.
- ✓ Since s.v.p is achieved at constant temperature (boiling point), the vapour remains in thermal dynamic equilibrium.
- ✓ This means that the force per square meter (pressure) exerted on the walls of the container remains constant due to an equal reduction in the surface of the walls for colliding molecules.



Effect of expansion on saturated vapour

The saturated vapour is expanded by raising the tube

Observation

The height "h" of the column remains but the amount of water on top of the column decreases.

Explanation

The height "h" remains constant because the expansion of the saturated vapour becomes unsaturated on expansion so more water evaporates.

Vapour Pressure and Temperature

Effect of temperature on saturated vapour

When a saturated vapour is heated, it increases with temperature.
Although saturated vapour increases as temperature increases, a saturated vapour does not obey Boyle's law and Charles's law because;

- ✓ The mass of a saturated vapour is not fixed with temperature change but varies with temperature changes.
- ✓ The volume of saturated vapour is independent of pressure.

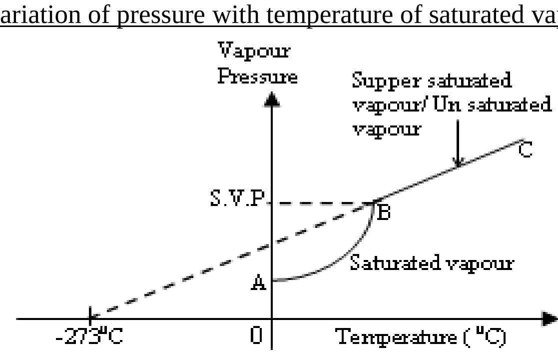
The mass of unsaturated vapour depends on the pressure. The mass of unsaturated vapour can be fixed while temperature changes.

More Explanation:

- Initially vapour pressure increase slowly with increase in temperature exponentially because fewer molecules are energetic enough to leave the liquid surface but as the liquid's boiling point is approached, vapour pressure rapidly increases i.e. un saturated vapour pressure.
- At boiling point vapour pressure remains constant (saturated vapour pressure) since vapour is saturated.

- Heating the liquid beyond its boiling point results into supper saturated vapour whose rate of evaporation is greater than its rate of condensation and vapour pressure (un saturated vapour pressure) increases linearly with increase in temperature due to increased multiple collisions of vapour molecules with the walls of the container

Variation of pressure with temperature of saturated vapour



Explaining the graph

AB-Saturated vapour increases with increases in temperature, but does not obey the gas laws because:
(i) The volume of saturated vapour is independent of pressure.
(ii) The mass of a saturated vapourcannot be fixed as temperature changes.

BC-unsaturated vapour increase as temperature increases and obeys Boyle's law and Charles' law because:

(i) Volume of unsaturated vapour depends on the pressure
(ii) Mass of unsaturated vapour can be fixed when temperature changes.

Definition of saturated vapour pressure
A saturated vapour pressure is the pressure of a vapour which is in dynamic equilibrium with its liquid or solid.

Saturated vapourpressure and boiling point
A liquid will only boil when its saturated vapour pressure is equal to the atmospheric pressure.

What happens when a liquid boils?
When a liquid is heated its temperature rises. This makes the saturated vapour pressure to increase until it becomes equal to the atmospheric pressure.

At this stage further addition of heat, cause bubbles of the vapour to form inside liquid. This is boiling; therefore boiling point is the temperature at which saturated vapour pressure becomes equal to the external atmospheric pressure.

From the above it will be noted that the boiling point of a liquid depends on altitude because boiling occurs only when the saturated vapour pressure becomes equal to atmospheric pressure which depends on altitude.

Dew point
Dew point is the temperature at which the water vapour present in air is just sufficient to saturate it.

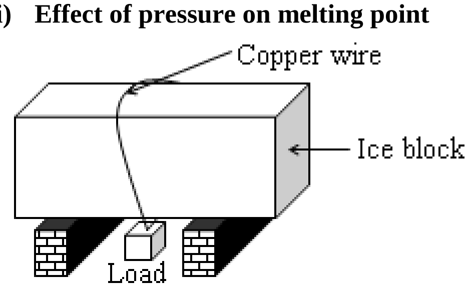
(g) MELTING POINT, BOILING POINT AND EVAPORATION

(a) Melting
This is defined as the process by which a solid turns to liquid at constant temperature called melting point i.e.

Melting point is constant temperature at which a solid substance liquidifies at constant atmospheric pressure.

Freezing point is constant temperature at which a molten substance solidifies at constant atmospheric.

(i) Effect of pressure on melting point



When pressure is increased by the weighted copper wire

- Observation

The weighted copper wire passes through the block of ice without cutting it into two pieces.

- Explanation

This is because increasing pressure by the weighted copper wire lowers the melting point of ice, so the copper wire sinks through water and water which is no longer under pressure refreezes and gives out latent heat to the copper wire to enable melting of ice below.
In general increasing pressure decreases the melting point of solid and decreasing pressure increases the melting point.

(ii) Effect of impurities on the melting and Freezing points (Melting and Freezingpoint depressions**)**
Soluble Impurities like salts lower the melting and freezing points of solids. E.g. the melting temperature of a well stirred ice water mixture is normally 0^oC but when an impurity such as salt is added it may fall to -20^oC after desolving the solid.

Reason:
This is because foreign substances in a crystalline solid disrupt the repeating patern of forces that hold the solid together. Thus a small amount of energy is needed to melt the part sorounding the impurity. Hence the melting point depression.

For freezing point depression, impurities lower the vapour pressure of the impure liquid. Hence a lower freezing point.

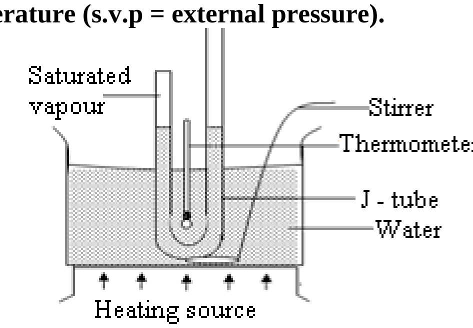
(b) Boiling
Boiling is a change of state from liquid to vapour that occurs within the liquid at constant temperature called boiling point.

Boiling point is the constant temperature of a liquid at which its saturated vapour pressure is equal to external atmospheric pressure.

Steam point is the constant temperature at which (pure water ↔vapuor) at 760mmHg. It is 100℃.

NB:
It should be noted that boiling of any liquid occurs only when its saturated vapour pressure equalizes with external pressure implying that when a liquid is boiling, there is change of state thus occurring at a constant temperature called boiling point.

Experiment to show that boiling occurs at constant temperature (s.v.p = external pressure).



- **W**ater is trapped in a closed end of J-shaped tube and the tube is placed in a beaker containing water being heated from the base as it is stirred to ensure uniform distribution of heat throughout the liquid.

- When water in the beaker starts boiling, its vapour escapes and exerts pressure on water in the open limb of the J- shaped tube.
- At this point the thermometer reading remains constant and water in the J- shaped tube levels up indicating that saturated vapor pressure is equal to external pressure.

(i) Effect of pressure on boiling point

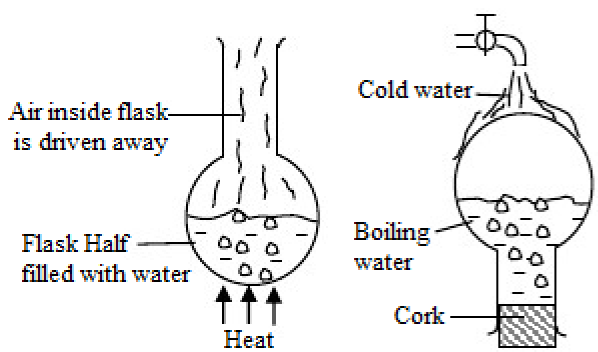
The boiling point of a liquid is directly proportional to the pressure above the liquid.

❖ If the pressure above the liquid is increased, the boiling point of the liquid rises. This is because more external pressure compresses the water molecules into the liquid. This requires more heat energy to break such molecules, hence increasing the boiling temperature.

❖ But if the pressure above the liquid is decreased the boiling point of the liquid is lowered.

❖ In a pressure cooker, food cooks more quickly because the pressure of steam above water in the cooker can rise to twice the normal atmospheric value.

Experiment to show the effect of pressure on boiling points



✓ Water boiled to drive away air before the cork is fitted.
✓ Flask is turned upside down under tap of cold water.

Observation

✓ Water is seen to boil again through there is no heating.

Explanation

✓ This is because when the flask is cooled the water vapour or steam above the water condenses leaving a partial vacuum above the water resulting in the pressure above to decrease. This decreases the boiling point. So water boils well below its boiling point.

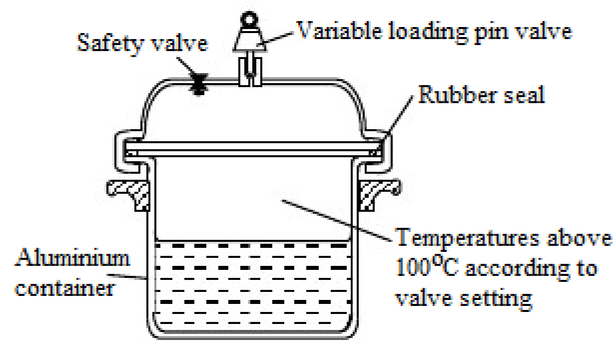
NOTE: While boiling water, molecules escape to the space with the heat supplied hence making cooking take longer.
Cooking depends on two factors; Time and temperature.

$$\textbf{Cooking (Hard boiling)} = \textbf{Time} \times \textbf{Temperature}$$

Thus from the above, cooking to occur;

❖ At reduced temperature, increase the cooking time
❖ Very quickly, increase the cooking temperature. Eg in **a pressure cooker.**

The Pressure cooker



❖ Up on a mountain (High altitude), the air (atmospheric) pressure is low so water boils at a temperature less than 100^{o}c. This is because the pressure on the surface of the water decreases on the mountain therefore boiling is faster but cooking takes longer.

❖ If we raise the boiling point of water we can reduce the time taken to cook food. This is possible using a pressure cooker.

Pressure cookers are useful in places where atmospheric pressure is low like at the top of a mountain (high altitudes). Cooking with a pressure cooker is faster than ordinary cooking because most of its top surface is covered leaving just a small opening to let out vapour.
This covering reduces the space of escape for vapour molecules which increase the pressure inside due to random collisions of vapour molecules thus raising the boiling point to about 120^{o}C, hence faster cooking due to much heat.

Effect of impurities on boiling point

Soluble Impurities such as salt when added to a liquid e.g. water the boiling point of the liquid rises.
Addition of impurities **raises** the boiling point of a liquid.

Reason:

This is because; impurities ***absorb some of the supplied heat and thus lower the vapour pressure of the solution making the liquid to boil at a higher temperature than its normal boiling point thus faster cooking.*** This is because the solution has to be heated more to make the vapour pressure equal to the atmospheric pressure.

(c) Evaporation

This is defined as the process by which a liquid turns to vapour molecules which occurs at the liquid surface. It takes place at all temperatures but it is greatest when the liquid is at its boiling point.
So evaporation is the conversion of a liquid into its gaseous state.

Rate of evaporation

This is the rate at which molecules of a liquid escape from the liquid surface per second.
The rate of evaporation of a liquid is increased by;

- Increasing the surface area of the liquid e.g. same amount of water put in a basin and cup exposed to the same drought, one in a basin reduces faster than that in a cup.

- Increasing the temperature of the liquid since increase in temperature directly increases the average kinetic energy of the molecules escaping.
- Providing drought which removes the vapour molecules from the liquid surface before returning to it e.g. water exposed to direct sunshine evaporates faster than that under a shade.
- Reducing the pressure of the air above the liquid surface (atmospheric pressure) e.g. evaporation is faster on a mountain than on a leveled ground.

Factors affecting evaporation

Factor	**Effect/Explanation**
Surface area	Increasing the surface area increases the rate of evaporation. Explanation This is because the increased surface area makes more molecules to be at the surface of the liquid where they can easily escape.
Temperature	Increasing temperature increases the rate of evaporation. Decreasing temperature decreases the rate of evaporation. Explanation This is because more molecules will move faster enough to escape from the surface of the liquid. This is because fewer molecules will move fast enough to escape from the surface of the liquid.
Drought (Air current)	The rate of evaporation increases when there is too much wind blowing over the liquid surface. Explanation Because wind blows away the energetic molecules that have already escaped from the liquid. This gives chance for more molecules to escape.
Pressure	High pressure above the liquid surface means there is a high exertion on the liquid surface thus preventing molecules from escaping
Concentration of the liquid vapour in air	If the air already has a high concentration of the substance evaporating, then, such substance will evaporate very slowly.
Intermolecular forces	The stronger the forces keeping the molecules together, the more energy needed to put them apart and escape. Hence the slower the rate of evaporation.

<u>Explanation of evaporation according to the kinetic theory of matter (**How evaporation causes cooling**).</u>

- ✓ At a particular temperature, molecules of a liquid have an average speed but some molecules are moving faster than other.
- ✓ Evaporation occurs when faster moving molecules reach the surface and escape from the attractions of all the molecules.
- ✓ At the same time the slower molecules remain in the liquid causing the average kinetic energy of the molecules to fall.
- ✓ This causes cooling as temperature falls with falling averages kinetic energy.

<u>Cooling</u>

This is defined as the continuous fall of temperature of a body placed in drought until when it attains an equilibrium state.

Applications of evaporation:

Cooling as a result of evaporation is seen in:

- ❖ Panting of dogs.
- ❖ Making ice by evaporation of a volatile liquid
- ❖ Refrigerators. A volatile liquid is contained in a coiled pipe around the freezer of a refrigerator. Whe the volatile liquid evaporates, it takes away latent heat of vapourization from the soroundings hence causing cooling.
- ❖ Evaporation is applied by the human skin to remove excess heat from the body and so maintain a constant body temperature. When water from the stin evaporates during *sweating*, it takes away latent heat of vaporization from the body. In this way, heat is lost and the body temperature is maintained a constant body temperature.
- ❖ Evaporation is applied in plants' leaves to lose excess heat by a process called *transpiration*. During transpiration, water from the leaves evaporate and the necessary latent heat of vapourization is taken from the leaves hence cooling the plant.

(a) THE REFRIGERATOR

A refrigerator is a cooling appliance which uses the mechanism that transfers heat from it to the external environment.

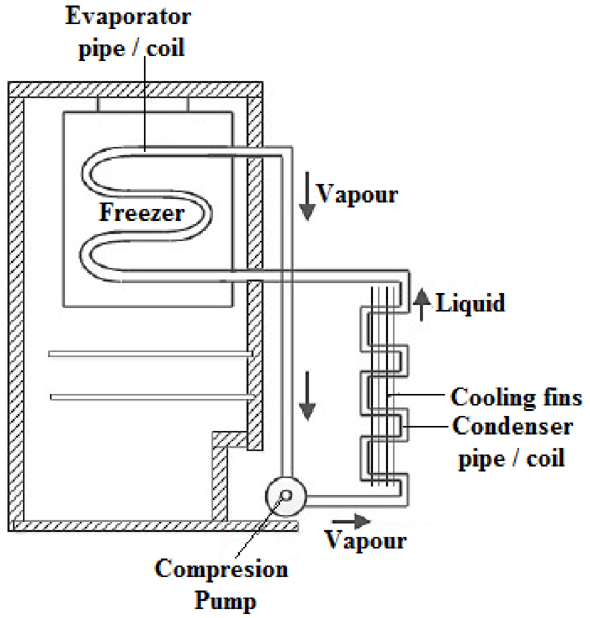
It is used in preservation of;

- ✓ Food – in homes and supermarkets.
- ✓ Blood – in blood banks in hospitals.
- ✓ Medicines – in pharmacies/hospitals/health centres.

How it works principle

A refrigerator works on the principle that heat is taken in at one point and given out at another point by the refrigerating substance (**Freon**) as it is pumped around the circuit.

When the rsrigerator is switched on, the liquid goes through the sequence, Compression, Condensation and Evaporation.



Compressor/Pump:
1. Freon (a volatile liquid) or the refrigerant is compressed by the pump against the expansion valve, its pressure rises, and pushes it into the coils (cooling fins) on the outside of the refrigerator.

Condenser and cooling fins:
2. When the hot high pressure gas in the coils meets the cooler air temperature of the outside the cabinet, it is condensed to a liquid.

3. Now in liquid form at high pressure, the refrigerant cools down as it flows into the coils inside the freezer and the fridge. *It dissipates all the latent heat of vaporization*to the surrounding by the cooling fins.

Evaporator:
4. The refrigerant *absorbs the heat of vapourisation*from the material contents inside the freezing box, cooling down the surrounding air and hence the contents.

5. Lastly, the refrigerant evaporates to a gas, and then flows back to the compressor, where the cycle starts again.

Functions of the main parts of refrigerator

Pump or Compressor
- ❖ The pump removes the vapour formed in the freezer
- ❖ The pump forces the vapour into the heat exchanger.

Heat exchanger or Condenser

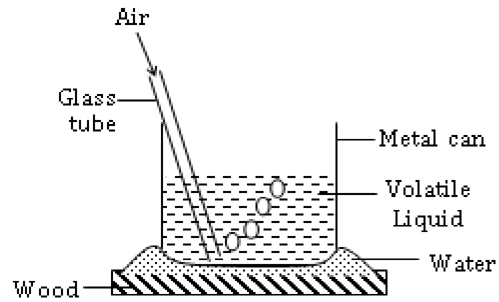
It is where the vapour is compressed and liquefies giving out latent heat of vaporization.

Cooling fins

The cooling fins give out the latent heat of vaporization to the surrounding air.

Note: The cooling fins are painted black so that they can quickly give or emit heat radiations.

(b) MAKING ICE BY EVAPORATION OF A VOLATILE LIQUID LIKE ETHER



Procedures:
- ✓ A metallic can is filled with a volatile liquid like ether and placed on a film of water at the top of a wooden block.
- ✓ Air current is blown through a glass tube or straw into the ether in the can as shown above.

Observation:
- ✓ The water underneath the can freezes and turns to ice.

Explanation:
- ✓ When a current of air is bubbled through ether, the ether evaporates in the bubbles which carry it to the surface and burst.
- ✓ This means that the bubbling of air through ether results in increasing the rate of evaporation. This rapid change of state from liquid to vapour requires latent heat which is conducted through the beaker from the water below it causing it to cool and form ice.

Note: *The metallic can, may be replaced by a beaker.*

Differences between evaporation and boiling

Evaporation	**Boiling**
i) Occurs at any temperature	Occurs at a fixed temperature called boiling point
ii) Occur at the surface of the liquid. No bubbles	Occurs within the liquid. Bubbles appear
iii) Depends on the surface area	Does not depend on the surface area
iv) Can occur even when atmospheric pressure is not equal to saturated vapour pressure	Occurs only when atmospheric pressure is equal to saturated vapour pressure
v) Causes cooling	Does not cause cooling

However evaporation and boiling are similar in that:
- ❖ Both evaporation and boiling need latent heat of vaporization.
- ❖ Both evaporation and boiling involve change of state from liquid to gas.

Application of good and bad conductors

(i) Frying and cooking pans are made of metals because metals allow heat to pass through them easily.

(ii) A metal always feels cold when touched on a cold day because it removes heat from the body and transfers it away very fast.This shows that metals are good conductors of heat as they draw the heat from the body.

(iii) A handle of a frying pan is made of insulators such as wood or plastic because they are poor conductors.

Related explanations

- ✓ Metallic utensils being good conductors of heat, they absorb heat (from food) which would be carried away by the volatile liquid to the cooling fins thus delaying the refrigerating process. Such utensils are not recommended to be used in refrigerators.

- ✓ Milk in a bottle wrapped in a wet cloth cools faster than that placed in a bucket exposed to a drought. This is because the wet cloth speeds up the rate of evaporation thus more cooling.

- ✓ It advisable for a heavily perspiring person to stand in a shade other than drought because drought speeds up evaporation thus faster cooling which may lead to over cooling of the body and eventually this over cooling may lower the body's resistance to infections.

- ✓ When taking a bath using cold water, the individual feels colder on a very shiny day than on a rainy day because on a shiny day, the body is at high temperatures such that on pouring cold water on the body, water absorbs some of the body's heat thus its cooling. Yet on a rainy day the body is at a relatively low temperature implying that less heat is absorbed from it when cold water is poured on it.

Two individuals; **A** (suffering from serious malaria) and **B** (normal) taking a bath of cold water at the same time of the day, **A** feels colder than **B** because the sick person's body is at relatively higher temperature than of a normal person. When cold water is poured on the sick person's body, much heat is absorbed from it compared to that absorbed from a normal person thus more coldness.

Two normal identical individuals; **A** (takes a bath of water at 35℃) and **B** (takes a bath of water at 25℃) after the bath, **A** experience more coldness than **B**. This is because Water at 35℃ raises the body's temperature more than that at 25℃. This means that after the bath, the individual who takes a bath of water at 35℃ looses more heat to the surrounding than what one who takes a bath of water at 25℃ would lose to it.

Water bottles are made of plastic other than glass and not fully filled because when water cools, it expands such that ice takes up a bigger volume. The un filled space is to cater for increase in volume on solidification and the bottle is made plastic to with stand breaking due to increase in volume.

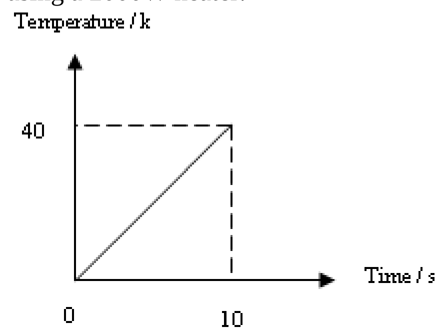
EXERCISE:

See UNEB

1987 Qn.15	**1997 Qn.16**	**1988 Qn.10**
1989 Qn.35	**2001 Qn.6**	**1997 Qn.9**
1990 Qn.10	**2008 Qn.4**	**1995 Qn.4**
1991 Qn.31	**Section B**	**2008 Qn.41**

SECTION A

1. The Figure below shows a graph of the temperature rise with time when a body of mass 4kg is heated using a 2000W heater.



Find its specific heat capacity in $Jkg^{-1}K^{-1}$.

A. 40x10/2000x4 C. 2000x10/40x4
B. 2000x4/40x10 D. 40x4/2000x10

2. The specific heat capacity of a substance is:
A. Heat required to raise it through 1^0C
B. Heat required to raise the temperature of 1kg mass of the substance through 1^0C
C. Heat required to change 1kg mass of the substance into liquid at the same temperature.
D. Heat required raising its temperature the specific no of degrees

3. The amount of heat required to raise the temperature of a 0.5kg mass from -5^0C to 15^0C is (specific heat capacity of salt solution is 4000 J $kg^{-1}K^{-1}$)
A. 8000J C. 20000J
B. 40000J D. 160000J

4. A 100g quantity of water at 24 ^0C is added to 50g of water at 36 ^0C. The temperature of the mixture is.
A. 28^0C C. 32^0 C
B. 30^0 C D. 34^0 C

5. The amount of heat required to raise the temperature of 0.5kg of iron from 25 ^0C to 50 ^0C is (specific heat capacity of iron is 460 joules kg^{-1} K^{-1})
A. 0.5 x 460/25 C. 460 x 25/0.5
B. 0.5 x 25 x 460 D. 0.5 x 25/460

6. A block of lead of mass 1000g hits a hard surface without rebounding with a velocity of 23 ms^{-1}. if the temperature rises from 25 ^0C to27 ^0C. Calculate the specific heat capacity of lead.
A. 5.75 J $kg^{-10}C^{-1}$ C. 9.79 J $kg^{-10}C^{-1}$
B. 132.25 J $kg^{-10}C^{-1}$ D. 264.50 J kg^{-10} C

7. 450g of water at 60 ^0C is to be cooled to be 35 ^0C by addition of cold water at 20 ^0C. How much cold water is to be added?
A. 0.169kg C. 0.270kg
B. 0.281kg D. 0.75kg

8. Calculate the time required for a kettle taking 10 A from a 240 V supply, to heat 5kg of water through 80 ^0C , assuming no heat is lost.
A. 700s C. 292s
B. 8.8s D. 1.7s

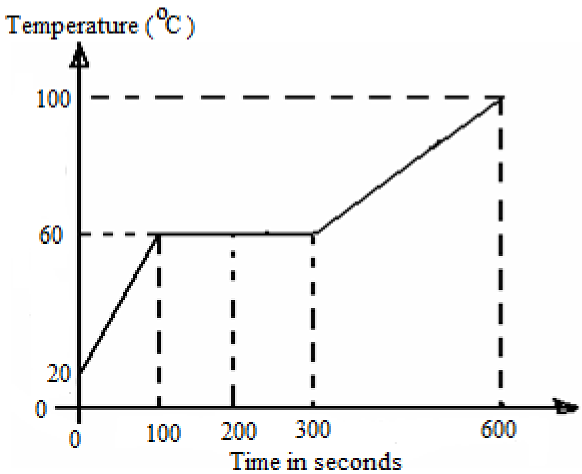
9. When 1kg of a certain liquid is heated for 10s, its temperature rises by 25 ^{0}C. If the power supplied is 1000 watts, find the specific heat capacity of the liquid.
A. 40 J kg^{-1}K^{-1} C. 400 J kg^{-1}K^{-1}
B. 1000 J kg^{-1} K^{-1} D. 2500 Jkg^{-1} K^{-1}

10. An electric heater is rated 240V, 400W. If the efficiency of the heater is 80% find the amount of energy wasted per second.
A. 48J. B. 80J. C. 192J. D. 320J.

11. Calculate the specific heat capacity of paraffin if 22000 J of heat are required to raise the temperature of 2.0 kg of paraffin to 30 ^{0}C from 20 ^{0}C.
A. 1100Jkg^{-1} K^{-1} C. 1200Jkg^{-1}K^{-1}
B. 2200Jkg^{-1}K^{-1} D. 2100Jkg^{-1}K^{-1}.

12. An electric heater is immersed in 0.05kg of oil in a calorimeter of negligible heat capacity. The temperature of the oil rose from 20 ^{0}C to 50 ^{0}C in 100 s. If the specific heat capacity of the oil is 2000 j kg^{-1}, calculate the power supplied by the heater, assuming that there is no heat loss.
A. 30W C. 50W
B. 140W D. 600W

13. When 100W heater is used to heat 1kg of solid wax, the temperature of the wax is observed to change with time as shown below.



Find the specific latent heat of fusion of the wax
A. 1.0 x 10^4 Jkg^{-1} C. 2.0 x 10^4 Jkg^{-1}
B. 3.0 x 10^4 Jkg^{-1} D. 6.0 x 10^4 Jkg^{-1}

14. A heater with a power rating of 100W is placed in 0.5kg of ice at 0 ^{o}C. How long will it take the heater to melt all the ice? (Specific latent heat of fusion of ice = 3.34 x 10^5 Jkg^{-1})
A. 1.67 x 10^{-3}s C. 1.67 x 10^{3}s
B. 3.34 x 10^{-3}s D. 3.34 x 10^{-3}s

15. How much heat is required to raise the temperature of 20g of water from 30 ^{0}C to 60 ^{0}C?
A. 2520J C. 6300J
B. 8400J D. 126000J

SECTION B

16. (a) What is meant by specific latent heat of vaporization?
(b) State two factors, which affect boiling points of water.
(c) Calculate the heat required to convert 0.8 kg of water at 100 ^{0}C to steam. [Specific latent heat of vaporization of water = 2.26 x 10^6 J/kg]. ***(*Ans: 1.808x10^6 J*)***

17. (a) What is meant by latent heat of vaporization?
(b) With the aid of a labeled diagram, describe how a refrigerator works.

18. (a) What is meant by specific heat capacity of a substance? And state its SI unit
(b) When a block of iron of mass 2 kg absorbs 19 kJ of heat, its temperature rises by 10^{o}C. Find the specific heat capacity of the iron. **(Ans: 950 J kg^{-1} K^{-1})**
(c) The specific heat capacity of water is **4200 J kg^{-1} K^{-1}**. What is meant by the above statement?

19. (a) Define the term *specific latent heat of vaporization*.
(b) Describe an experiment to determine the specific latent heat of vaporization of steam.

20. (a) Define the term **specific latent heat of fusion**.
(b) A copper can of mass 0.2kg contains 0.20kg of water at 10 ^{0}C. The can and its contents are placed in a refrigerator. Calculate the quantity of heat given out if the temperature of the can and its contents falls to –2 ^{0}C.*(c_{copper} = 400 J kg^{-1} K^{-1} , c_{ice} = 2100 J kg^{-1} K^{-1}, L_{fusion} = 340000 J kg^{-1}).* **(Ans: 78200 J)**

21. An immersion heater rated 1000 W, 250 V supplies heat to 80kg of liquid in a tank. If the temperature of the liquid rises by 40 ^{0}C in 48 minutes, what is the specific heat capacity of the liquid? **(Ans: 900 J kg^{-1} K^{-1})**

22. (a) Distinguish between **specific heat capacity** and **specific latent heat** of a substance.
(b) A copper block of mass 250g is heated to a temperature of 145 ^{0}C and then dropped into a copper calorimeter of mass 250g, which contains 250cm^3 of water at 20 ^{0}C.
(i) Calculate the maximum temperature attained by the water. (specific heat capacity of copper = 400 J kg^{-1}K^{-1}). **(Ans: 30 ^{0}C).**
(ii) Sketch a graph to show the variation of water temperature with time.

23. (a) What is meant by **saturated vapor pressure**?
(b) Explain what may happen when one is to cook food from a very high altitude.
(c) The cooling system of a refrigerator extracts 0.07kW of heat. How long will it take to convert 500g of water at 20 ^{0}C into ice?*(L_f = 0.336x10^6 J kg^{-1}).* **(Ans: 300 s)**
(c) Explain how evaporation takes place.

24. (a) A copper container of heat capacity 60J kg^{-1} K^{-1} contains 0.5kg of water at 20^{0}C. Dry steam is passed into the water until the temperature of the container and water reaches 50^{0}C. Calculate the mass of steam condensed.
(L_v = 2.26 x 10^{6}J kg^{-1}). **(Ans: 0.02867 kg)**

(b)Equal volumes of water at the same temperature are poured in a basin and in a jug. State, giving a reason, which water will evaporate faster.

51. A pan contains 4.0kg of waterat 0^oC. A jet of steam 100^oC is passed through the water. Assuming no heat is lost or absorbed by the pan, what is the temperature of the water when 0.2 kg of steam have condensed in it.

Solution:
Heat H_1 gained by water inwarming from 0 to θ_3 is;
$H_1 = m_w C_w(\theta_3 - 0)$
$H_1 = 4 \times 4200 \times \theta_3 \Rightarrow H_1 = 16800\theta_3$ J.

Heat H_2 lost by steam in condensing from 100^0C to water at 100^0C is;
$H_2 = m_s l_s$
$H_2 = 0.2 \times 2.26 \times 10^6 \Rightarrow H_2 = 4.52 \times 10^5$ J.

Heat H_3 lost by the condensed steam in cooling water in warming from 100^0C to θ_3 is;
$H_3 = m_s C_w(100 - \theta_3)$
$H_3 = 0.2 \times 4200 \times (100 - \theta_3) \Rightarrow H_3 = 84000 - 840\theta_3$

Assuming that no heat is lost or absorbed by the pan,

$$H_1 = H_2 + H_3$$
$$16800\theta_3 = 4.52 \times 10^5 + 84000 - 840\theta_3$$
$$(16800 + 840)\theta_3 = 5.36 \times 10^5$$
$$17640\theta_3 = 5.36 \times 10^5$$
$$\theta_3 = 30.4^0\ C$$

52. UNEB 2015 PP2 No. 5 (b) (i): A colorimeter of mass 200 g and specific heat capacity 800 $Jkg^{-1}K^{-1}$ contains 500 g of water at 30^0C. Dry steam at 100^0C is passed through water in the calorimeter until the temperature of water rises to 70^0C. Calculate the mass of steam condensed.
(specific latent heat of vapourization is 2, 260, 000 Jkg^{-1})
(Ans: 0.035 kg)

53. UNEB 2013 PP2 No. 2 (c): A metal block of 3kg at 100^0C is placed 2.5 kg of water at 31^0C in a copper calorimeter of 0.4 kg. The water is then stired until it attains a steady temperature of 43^0C. Calculate the specific heat capacity of the metal block.
(specific heat ocapacity of copper is $400Jkg^{-1}K^{-1}$)
(Ans: C = 748.07$Jkg^{-1}K^{-1}$)

54. UNEB 2014 PP2 No. 5 (c): A copper calorimeter weighs 0.1 kg when empty and 0.3 kg when partially filled with water at 40^0C. A mass of 0.005 kg of steam is passed into the calorimeter until a final steady temperature is reached. Neglecting heat loses to the soroundings, calculate the final steady temperature of the calorimeter and its contents.
(specific latent heat of vapourization is 2, 260, 000 Jkg^{-1} and specific heat ocapacity of copper is $400Jkg^{-1}K^{-1}$)
(Ans: θ= 53.9 ^{0}C)

55. UNEB 2007 PP2 No. 2 (d): The same quanity of heat was supplied to 5 kg of sea water and 12of methylated spirit. The temperature rise was 3 ^{0}C and 2 ^{0}C respectively. Find the ratio of the specific heat capacity of sea water to that of methylated spirit. **(Ans: $C_1 : C_2 = 8 : 5$)**

SECTION A

56. The transfer of heat by the actual movement of molecules matter takes place
A. Only in liquids. B. Only in gasses
C. In solids and liquids D. In liquids and gasses

57. The process of using a material of low thermal conductivity to prevent heat loss is called.
A. cooling B. lagging
C. absorption D. contraction

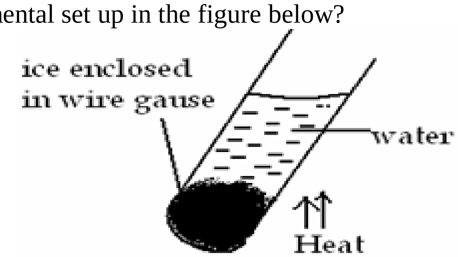
58. A domestic refrigerator uses a volatile liquid. Which of the following represents the order of the process the liquid undergoes?
A. Evaporation, compression, condensation, evaporation.
B.Cooling, condensation, evaporation, compression evaporation.
C.Compression,evaporation, condensation, cooling, evaporation.
D.Condensation, cooling, evaporation, compression, evaporation.

59. The rate of evaporation from a body is increased by
(i) temperature (ii) pressure
(iii) liquid with greater cohesive forces
(iv) dryness of air around the body
A. (i) and (ii) only B. (ii) and (iii) only
C. (i) and (iv) only D. (iii) only.

60. A dull black surface feels hotter even though it is at the same temperature as a shiny surface because it
A. Has more heat than the shiny surface
B. Emits more heat than a shiny surface
C. Reflects more heat than a shiny surface
D. Conducts more heat than a shiny surface.

61. A sea breeze occurs.
A when cool air blows towards the land
B. when warm air blows towards the land.
C. during the night.
D. when cool air blows towards the sea.

62. Which of the following is/are true about the experimental set up in the figure below?



1. The ice takes long to melt because of the gauze.
2. The wire gauze keeps the ice at the bottom of the test tube. .
3.The ice does not melt because the heating is from above.
4.The ice takes long to melt because water is a poor conductor.
A. 1 only B. 2 and 3 only
C. 4 only D. All

63. Which one of the following statements is/are true about heat radiation?
1. A cold body emits invisible radiation of long wave length
2.Very hot objects emit radiations of short wave lengths
3.All good radiators of heat are good absorbers
4. All radiations emitted by hot objects are invisible.

A. 1 only B. 2 and 4 only
C. 4 only D. All

64. Metals are good conductors of heat because
A. they are ductile
B. they contain free protons
C. they contain loose electrons
C. their atoms can be easily displaced

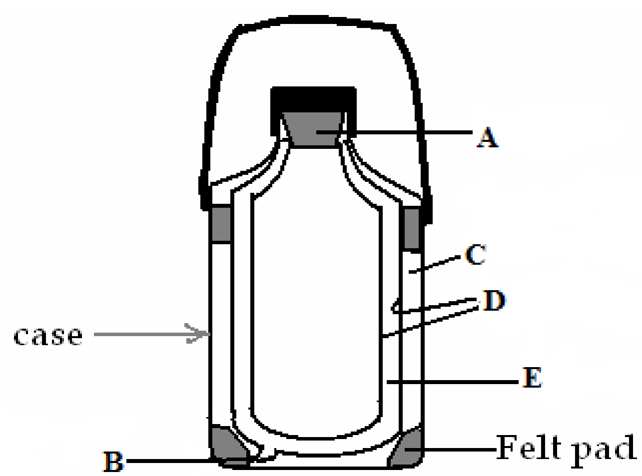
65. On a cool day, a metal feels cold to the touch because
A. metals contain less heat.
B. the temperature of the metal is the same as that of the surroundings. C. the temperature of the metal is less than that of the surroundings
D. the metal conducts the heat away from the hand.

SECTION B

1. (a) Explain why the sea remains cooler than land during daytime and warmer than land at night.
(b) State any one factor on which the rate of heat transfer along a metal bar depends.

2. (a) What is meant by **conduction**?
(b) Draw a diagram of a thermos flask and explain how it is able to keep a liquid cool for a long time.
(c) Explain the observation that a bare cement floor feels colder than a carpeted one.

3. The figure below shows a thermos flask.



(a) Name the parts labelled A, B, C, D and E.
(b) State the use of part labelled A
(c) Why do the contents of the flask ultimately get cold?

5.What are the functions of the following in a refrigerator**.**
i) Compressor ii) Cooling fins?

Definition:

Light is a form of energy transmitted in form of an electromagnetic wave and produces a sensation of vision. Or the form of energy that enables us to see.
Light can travel through a vacuum because light is in the form of electromagnetic waves. All electromagnetic waves have a speed of $3.0 \times 10^8\ ms^{-1}$ in a vacuum, hence the speed of light.
An object is seen only when light from the object enters the eyes.

Sources of light.

(i) *Luminous light sources*:
These are objects which give their own light. Examples include the sun, stars, glow warms – these are natural. And the man made include electric bulbs, lamps, candles, etc.

(ii) *Non – luminous light sources:*
These scatter or reflect light from other sources e.g the moon, mirror, reflecting surface.

Transmission of light:
Light travels from its source onto another place through a vacuum or a medium; the media include:

(i) *Transparent Medium*
A media which allows almost all of the light to pass through it and allows objects to be seen. E.g. colourless water, paraffin and colourless glass.

(ii) *Translucent Medium*
A medium which allows some light to pass through it but does not allow an object to be seen clearly. E.g. cloudy liquid, frosted glass and oily paper.

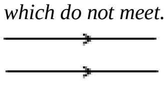
(iii) *Opaque Medium*
A medium which does not allow light to pass through it at all and we cannot see thru them. E.g wood, bricks, plastic etc

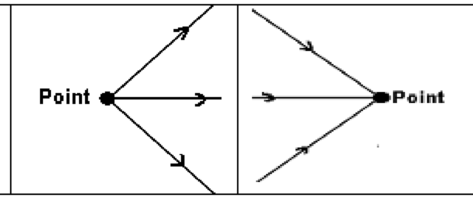
Note:
Incandescent bodies give off light because they are hot while fluorescent bodies give off light without being hot.

Fluorescence: the emission of light by a material after it has absorbed heat for some time.

RAYS AND BEAMS
A ray is the direction of the path in which light is travelling. It is represented by a straight line with an arrow on it.

A beam is a collection of rays or a stream of light energy. There are three kinds:

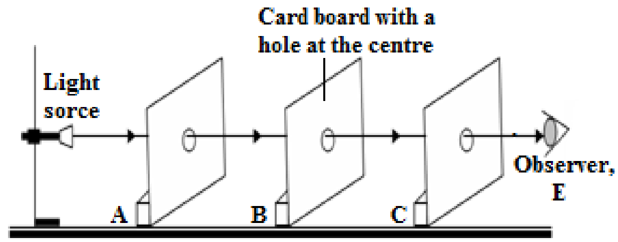
(i) **Parallel beam**	*(ii)* **Divergent beam**	*(iii)* **Convergent beam**
A collection of rays which do not meet. 	*A collection of rays which originates from one point and spread out in different directions*	*A collection of rays originating from different directions and coinciding /collecting at the same point*



RECTILINEAR PROPAGATION OF LIGHT

Definition:
This is the process by which light travels in straight lines when produced from a source.
It is propagated (sent outward) and it travels in straight lines.

Experiment to show that light travels in a straight line



Procedures
Arranging cardboards
Three cards A, B, and C are arranged with their holes in a straight line such that they are some distance apart.
This is ensured by passing a string through the holes of the cardboards and drawing a string taut.(straight n tight)

Observation
When the eyes is placed at E, light from the source is seen.
The cardboards are displaced such that their holes are not in straight line, no light is seen at E.

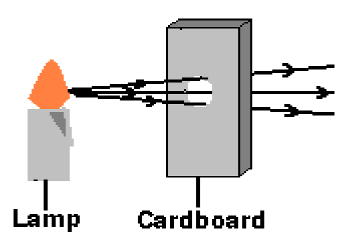
Conclusion
This shows that light travels in a straight line

SHADOWS

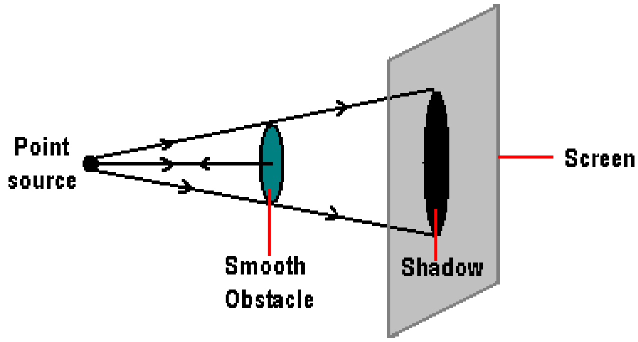
A **shadow** is a region of darkness formed when an opaque object obstructs the path of light.
Shadows are formed because light travels in a straight line.

Shadow formation

a) Point Source:
A point source is a very small source of light. It can be obtained by placing a cardboard with a small hole in front of a lamp as shown below.



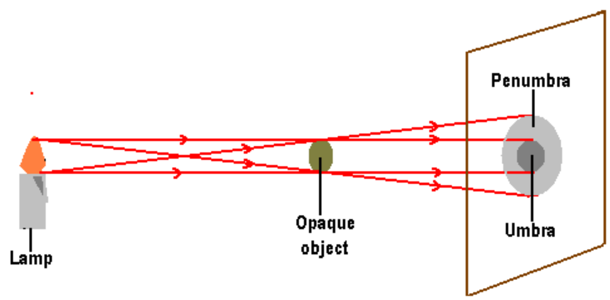
Shadow formation by a point source of light.



For a point source, a sharp shadow is formed, i.e. the shadow is also equally dark all over.
For a point source: When the opaque object is moved near the source, then the size of the shadow increases. However, when the object is moved near the screen, the size of the shadow is decreased.

b) Extended Source

When the cardboard is removed then the lamp becomes an extended source



The shadow has the central dark patch called umbra surrounded by a lighter ring called penumbra.

Umbra

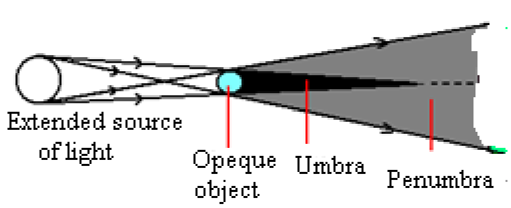
A region of shadow where no light reaches at all.

Penumbra

A region of the shadow where some light reaches.

Note:

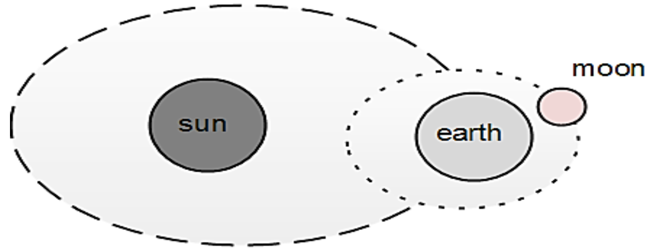
For an extended source: When the opaque object is moved near the source, the size of umbra decreases, but the size of penumbra increases. When the object is moved near the screen, the size of umbra increases, but the size of penumbra decreases.



The umbra may fail to reach the screen if the opaque object is very far away from the screen

ECLIPSE:

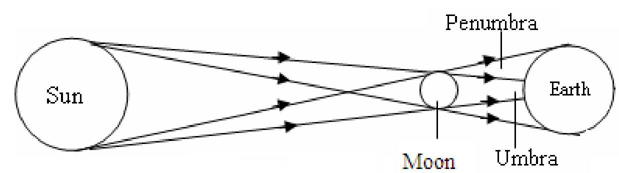
An eclipse is the obscuring of light from the sun by either the moon or the earth.
An eclipse occurs when the sun, moon, and earth are in a straight line.



There are two types of eclipses namely:
(a) Solar, annular (Eclipses of the sun)
(b) Lunar. (Eclipse of the moon)

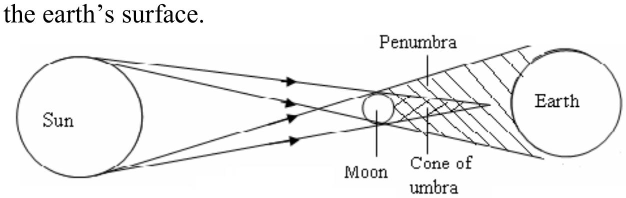
a) Solar Eclipse:

Solar eclipse also called eclipse of the sun. It occurs when the moon is between the sun and the earth, such that both umbra and penumbra reaches the earth. The area on earth covered by umbra has total eclipse and the sun cannot be seen **at al**l. The area covered by penumbra has partial eclipse and only part of the sun is seen.

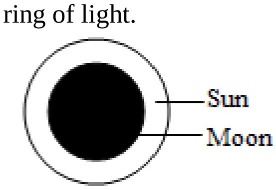


❖ ***Annular Eclipse:***

Annular eclipse of the sun occurs when the sun is very far from the earth and the moon is between the earth and the sun, such that the tip of the umbra is the one that reaches the earth's surface.



From one place on the earth, the sun is represented by the appearance of a ring of light.



Note: The distance between the earth and the moon varies slightly since the moon's orbit around the earth is **elliptical.** This explains the variation in the moon's distance around the earth.

Note:

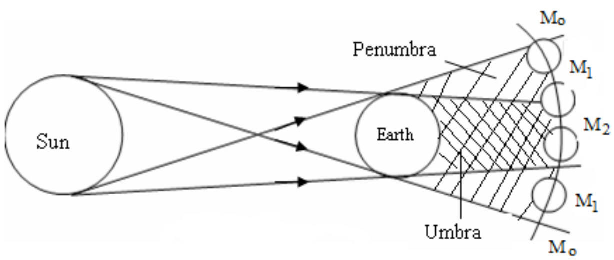
(i) *In areas outside the band swept by the moon's umbra but within the penumbra, the sun is only partly obscured, and a partial eclipse occurs.*

(ii)*The illumination from the sun gradually decreases and during totality (and near totality) declines to the intensity of bright moonlight.*

(ii) *A total solar eclipse occurs about every 18 months*.

b) Lunar Eclipse:

Lunar eclipse is also called eclipse of the moon. Lunar eclipse occurs when the earth is between the sun and the moon. During the eclipse of the moon, the earth's shadow is casted on the moon such that when the moon is at position M_2, total eclipse occurs. In position M_1, partial eclipse occurs and when the moon is in position M_o, no eclipse occurs, but the moon is less bright than usual.



Note: Total eclipse of the moon lasts longer than total eclipse of the sun because for the moon, the earth which is in the middle is larger than the moon for the sun.

Flourescence and phosphorence substance

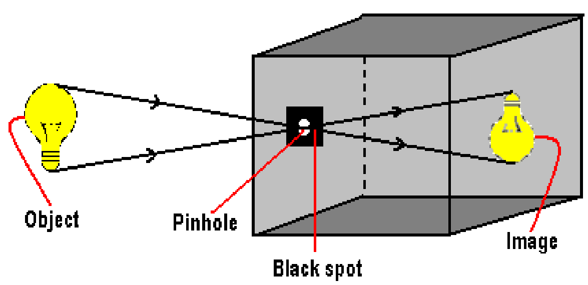
i. Fluorescence Substance:

A substance which absorbs energy and immediately release the energy in the form of light e.g. zinc sulphide. The screen of a T.V and C.R.O are made of a fluorescent substance.

ii. Phosphorescence Substance:

A substance which absorbs the energy falling on it, store it, and when energy stops falling on it, it release energy in the form of light, e.g. calcium sulphide.

THE PIN HOLE CAMERA



Pin hole camera consists of a closed box with a small hole(pin hole) on face and a screen of tracing paper on the opposite face.

Description of Image Formation:

The image is real and inverted. Each point of the image on the screen will be illuminated only by the light travelling in a straight line from a particular point.

Effect of image formation for pin hole camera if;

(i) Pin hole is enlarged; image become blurred and brighter

Explanation:

The blurring of the image is because the large hole will be the same as a number of pin holes put together, each forming their own image and overlap of these images causes a single blurred image.

Note:

The box is blackened inside to prevent reflection inside a camera. The image comes brighter because of increased quantity of light.

(ii) Moving the object closer to the pin hole: The size of the image increases the but the image becomes less bright.

Explanation:

The image becomes less bright as its size increases because the same amount of light as before spread over large area of the screen.

MAGNIFICATION

Definition:

Magnification is the ratio of image height to object height or image distance to object distance.

Mathematically, magnification is given by:

$$\text{Magnification, M} = \frac{\text{Image distance, V}}{\text{Object distance, U}}$$

OR

$$\text{Magnification, M} = \frac{\text{Image height, h}}{\text{Object height, H}}$$

Larger magnification is obtained when the object is nearer the pin hole and smaller magnification is produced when the object is farther away.

Example: 1

Calculate the height of a building 150m away from a pinhole camera, which produces an image 5 cm high if the distance between the pinhole camera and screen is 10 cm.

Solution

Given; object distance=150 cm

Image height= 5 cm

Image distance= 10 cm

From definition of magnification

$$M = \frac{\text{Image height, h}}{\text{Object height, H}} = \frac{\text{Image distance, V}}{\text{Object distance, U}}$$

$$\frac{h}{H} = \frac{V}{U}$$

$$\frac{5\text{ cm}}{H} = \frac{10\text{ cm}}{150\text{ cm}}$$

$$10H = 5 \times 150$$

$$H = 75\text{ cm}$$

Alternatively, you can first calculate magnification using first equation and then substitute in second equation to obtain object height; i.e.

From

$$M = \frac{\text{Image distance, V}}{\text{Object distance, U}}$$

$$M = \frac{10\text{ cm}}{150\text{ cm}} = \frac{1}{15} \ldots (i)$$

But also;

$$M = \frac{\text{Image height, h}}{\text{Object height, H}}$$

$$M = \frac{5\text{ cm}}{H} \qquad \ldots (ii)$$

Equating (i) and (ii)

$$\frac{5\text{ cm}}{H} = \frac{1}{15}$$

$$H = 5 \times 15$$

$$H = 75\text{ cm}$$

Example: 2
The length of a pinhole camera is 25 cm. An object 2 m, high is placed 10 m from the pinhole. Calculate the height of the image produced and its magnification.

Solution:

Given; Image distance = 25 cm = 0.25 m Object height = 2 m Object distance = 10 cm = 0.1 m Image height=?	
From definition of magnification; $M = \frac{\text{Image distance, V}}{\text{Object distance, U}}$ $M = \frac{10\text{ cm}}{150\text{ cm}}$ $M = 2.5$	$\frac{h}{H} = \frac{V}{U}$ $\frac{h}{2} = \frac{0.25}{0.1}$ $0.1h = 2 \times 0.25$ $h = 0.5\text{ cm}$

See UNEB Paper I

1997	2000	2002	2006	2006
Qn.22	Qn. 34	Qn. 27	Qn. 29	Qn.27

1. A girl is 1.6m tall and stands 4m away from the pin hole camera which is 20 m long. Find the:
   i) Image height
   ii) The magnification if the camera is only 10cm long.

2. UNEB 1992 Qn. 1
(a) What is meant by rectilinear propagation of light?
(b) An opaque object is placed in front of a source of light. Draw ray diagrams to show the formation of shadows when;
(i) A point source is used
(ii) An extended source is used

3. . UNEB 1997 Qn. 4
(b) Draw diagrams to show the formation of total and partial solar eclipse.

4. . UNEB1998 Qn.7
(a) Describe an experiment to show that light travels in a straight line.
(b) An object of height 4cm is placed 5cm away from a pin hole camera. The screen is 7cm from the pin hole.
(i) Draw a scale ray diagram to show the formation of an image by a pin hole camera.
(ii) What is the nature of the image?
(iii) Find the magnification.
(iv) Explain what happens to the image if the pin-hole is made larger.

REFLECTION OF LIGHT ON PLANE SURFACES

Definition:
Reflection is the process by which light energy falling on a body surface bounces off.
The surface from which reflection occurs is called the reflecting surface.

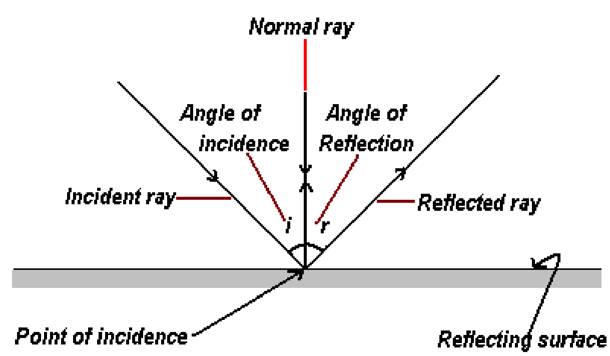
Types of Rays
(i) Incident rays; is a ray of light from the light source falling onto/striking the reflecting surface.

(ii) Reflected rays*;* is a ray leaving/bouncing off the reflecting surface at the point of incidence.

Normal: is a line at 90 degrees with the reflecting surface the ray is incident.

Types of Angle:
(i) Angle of incidence "**i**"; is the angle between the incident ray and the normal at the point of incidence i.e. it's the angle made by the incident ray with the normal at the point of incidence.

(ii) Angle of reflection "**r**"; is the angle between the reflected ray and the normal at the point of incidence i.e. it's the angle made by the reflected ray with the normal at the point of incidence.



✓ Point 0 (point of incidence)
This is the point on the reflecting surface where the incident ray is directed.

✓ Normal (0N)
Is a line drawn from point 0 perpendicular to the reflecting surface.

✓ Incident ray (A0)
Is the path along which light is directed on to the reflecting surface.

✓ Angle of incidence (i)
This is the angle that the incident ray makes with the normal at the point of incidence.
✓ Reflected (0B)
Is the path along which light incident on a surface is reflected

- ✓ Angle of reflection (r)

This is an angle between the reflected ray and the normal at the point of incidence.

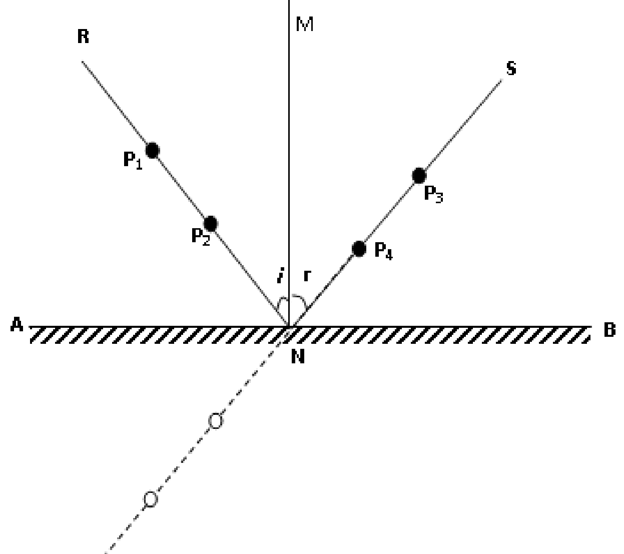
The Laws of Reflection

The laws of reflection state that:

i) The incident ray, reflected ray, and normal at the point of incidence all lie in the same plane.

ii) The angle of incidence is equal to the angle of reflection.

Experiment to verify the laws of reflection of light



Procedure:

- ❖ A white sheet of paper is fixed on a soft board and a plane mirror is placed vertically on the paper with its reflecting surface facing the object.
- ❖ The mirror line is traced and the mirror is removed and the line is drawn and labeled AB.
- ❖ A normal MN bisecting the mirror line AB is drawn.
- ❖ A line RN is drawn at an angle θ to the normal. e.g $\theta = 30^0$
- ❖ Pins P_1 and P_2 are fixed along line RN.
- ❖ The mirror is placed back on the board so that its reflecting surface coincides exactly with the mirror line AB.
- ❖ The images of P_1 and P_2 are viewed in the mirror and other pins P_3 and P_4 are fixed such that they are in line with the images of P_1 and P_2.
- ❖ The pins P_3 and P_4 are removed and a line NS is drawn.
- ❖ Angle r is measured and recorded.

Observation:

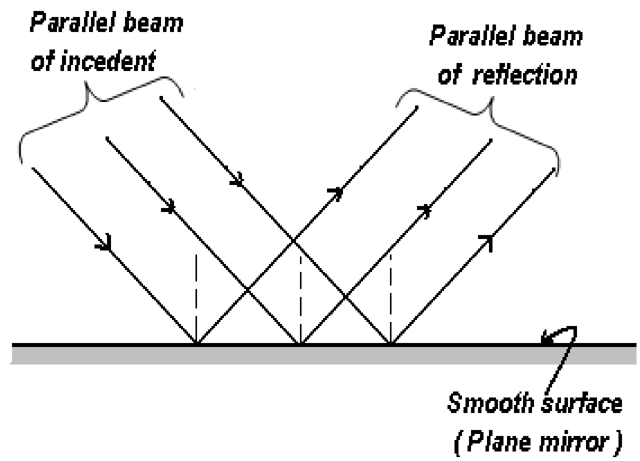
- ✓ Angle **i** = angle **r.**
- ✓ The incident ray, the normal and the reflected ray at the point of incidence all in the same plane.

Conclusion: hence verifying the laws of reflection

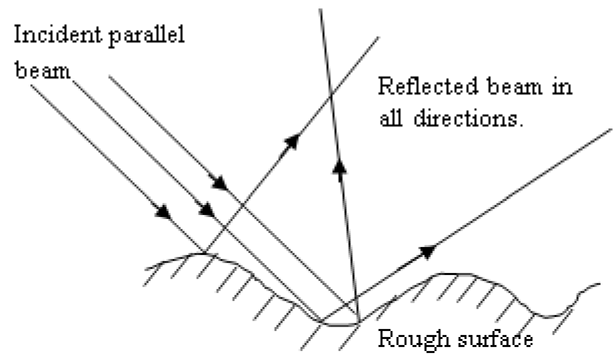
Types of Reflection

1. **Regular Reflection:**

Regular reflection occurs when a parallel incident beam falls on a place smooth surface and it is reflected across a parallel beam. Example of smooth plane surface is a plane mirror.

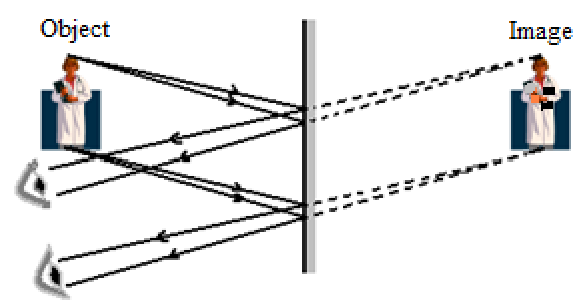


2. **Irregular or Diffused Reflection:**



Diffused reflection occurs when a parallel incident beam falls on a rough surface and the reflected beam is scattered in different directions.

IMAGE FORMATION BY A PLANE MIRROR



Characteristics of the image formed

- ✓ Image is of the same size as the Object
- ✓ Laterally inverted
- ✓ Virtual (cannot be formed on the screen)
- ✓ Same distance behind the mirror as the Object is in front of the mirror

Definition:

Real image: Is the image which is formed by rays that actually intersect and can be formed on the screen.

Real images are always inverted.

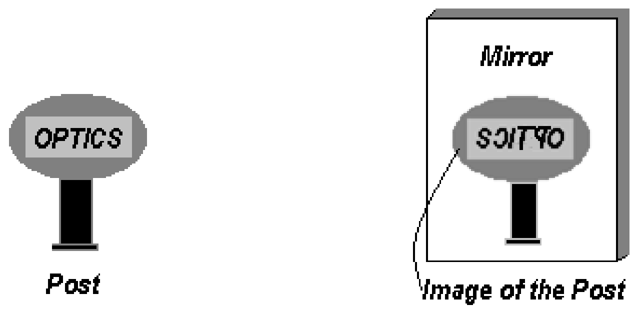
Examples of real images: Images formed in a pin hole camera, concave mirrors except when the object is between the pole, P and the principle focus, F and images formed in convex lenses except when the object is between the optical centre, C and the principle focus, F.

Virtual image: Is the image formed by the apparent intersection of light rays. i.e the rays which have been extended and it cannot be formed on the screen.
Virtual images are always upright (erect).
Examples of Virtual images: Images formed in a plane mirror, Convex mirrors and concave lenses.

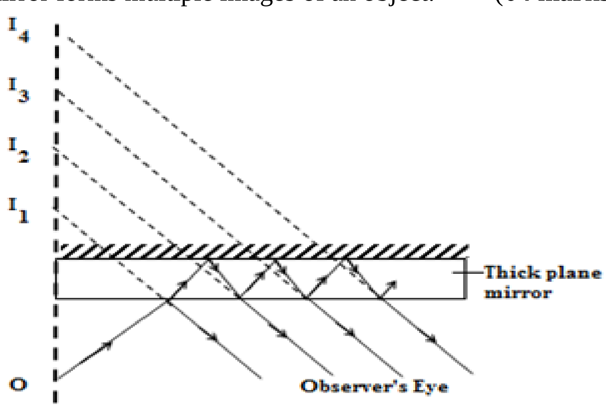
Explanation of virtual image in plane mirror:
The image in a plane mirror is virtual in that the rays from a point object are reflected at the mirror and appear to come from the point behind the mirror where the eyes imagine the reflected rays to meet when produced backward.

NB: virtual objects and images should be represented by dotted lines.

Lateral Inversion:
In a mirror image, right and left are interchanged and the image is said to be laterally inverted. The effect occurs whenever an image is formed by one reflection.

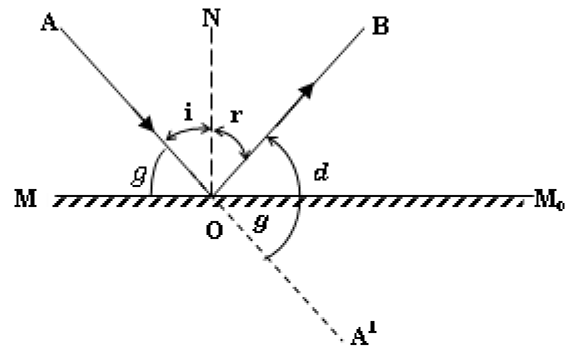


Question:
With the aid of a ray diagram, explain how a thick plane mirror forms multiple images of an object. (**04 marks**)



In a thick plane mirror, multiple images I_1, I_2, I_3, I_4, etc of an object, O are formed.
This is due to reflection from the front of the mirror and also due to multiple total internal reflection inside the glass as shown above.
The sharpness of the images go on decreasing from I_1, and **I_4 is very faint** due to susquent loss of light energy ateach reflection.

The glancing angle and the angle of deviation.
Deviation of light at a plane surface

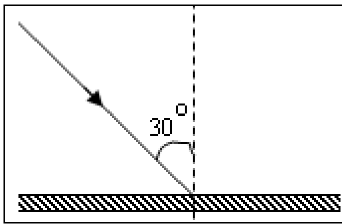


g – **Glancing angle**
The angle between the incident ray and the reflecting surface.

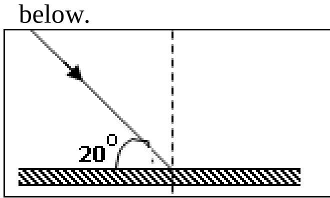
d- **Angle of deviation**
it is the angle between the initial direction of the incident ray (extended incident ray) and the reflected ray.
Angle of Deviation, d;
$d = \text{Angle } A^1OB$
$d = g + \text{Angle } M_0OB$
$d = g + (90 - r)$

But $i = r$ (From the law of reflection).
$d = g + (90 - i)$
But;
$(90 - i) = g$ (Vertically opposite angles)
$d = g + g$
$d = 2g$

Examples
1. A light ray is incident to a smooth surface as shown below.

	Find the: (i) Angle of reflection (ii) Glancing angle (iii) Angle of deviation

2. A light ray is incident to a smooth surface as shown below.

	Find the: (i) Angle of reflection (ii) Angle of incidence (iii) Angle of deviation

3. A girl sits 5 m away from a plane mirror. If a table is placed 2 m away from the girl, find the :
(i) Distance between the table and its image.
(ii) Distance between the girl and the tables' image.
(iii) Distance between the table and the girls' image.
(iv) A boy stands 10m away from a plane mirror. What distance should he move towards the plane mirror such that the distance between him and his image is 8m.

INCLINED MIRRORS

Image formed by an inclined mirror at an angle θ

When two mirrors are inclined to each other at an angle θ, the number of images (n) is given by:

$$\mathbf{n = \frac{360}{\theta} - 1}$$

The table below summarizes how one can obtain the number of image formed by 2 mirrors inclined at an angle.

Angle between mirrors θ (°)	$(\frac{360}{\theta})$	Number of image in **n:** $= \frac{360}{\theta} - 1$
90	4	3
60	6	6
45	8	7
30	12	11
15	24	23

Questions

1. Two plane mirrors are inclined at an angle 50^0 to one another find the number of images formed by these mirrors.

$$n = \left(\frac{360}{\theta} - 1\right)$$

$$n = \left(\frac{360}{50} - 1\right) = 7.2 - 1 = 6.2 \approx 6 \text{ images}$$

2. Two plane mirrors are inclined at an angle θ to each other. If the number of image formed between them is 79, find the angle of inclination θ.

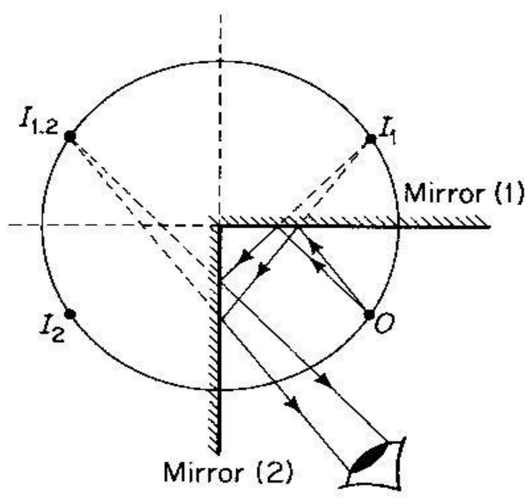
Solution

$$n = \left(\frac{360}{\theta} - 1\right) \Leftrightarrow 79 = \left(\frac{360}{\theta} - 1\right)$$

$$\theta = 4.5^0$$

3. Find the number of images formed when an object is placed between mirrors inclined at; (i) 90^0 (ii) 60^0 (iii) 120^0

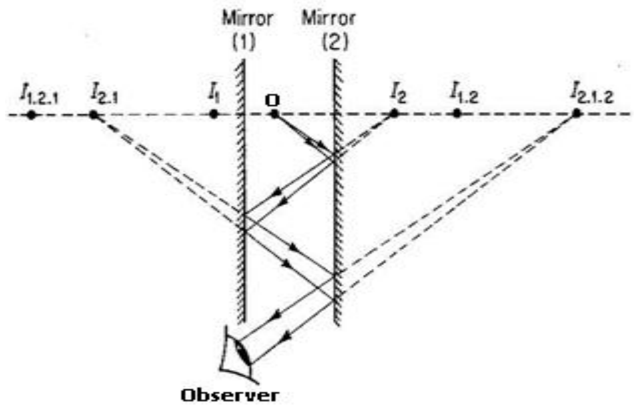
(a) Image formed in two plane mirrors inclined at 90^0



When two mirrors are inclined at 90^0 to each other, images are formed by a single reflection in addition to two extra images formed by 2 reflections.

(b) Image formed in parallel mirrors

An infinity number of image is formed on an object placed between two parallel mirrors each image seen in one mirror will act as virtual object to the next mirror.



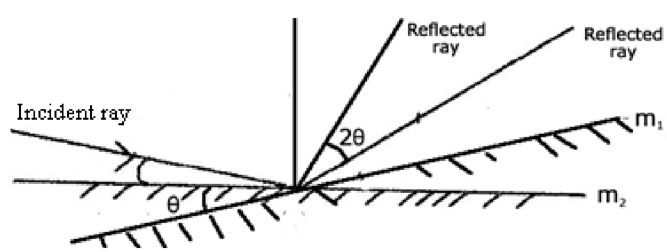
-The object O, gives rise to image I_1, on mirror m_1 and I_2 on m_2 .I_1 acts as virtual object to give an image $I_{(1,2)}$ in mirror m_2 just as I_2 gives an image $I_{(2,1)}$ in mirror m_1. $I_{(1,2)}$ in mirror m $I_{(1,2)}$ gives $I_{(1,2,1)}$ after reflection in m_1 while $I_{(2,1,2)}$ after reflecting in Mirror m_2.

Number of images n = When two mirrors are parallel, the angle θ between them is zero and the number of images formed between them is

N = ($\frac{360}{\theta} - 1$) = 0(infinite)

This shows infinite number of image when two plane mirrors are parallel. The image lies in a straight line through the object and perpendicular to the mirrors.

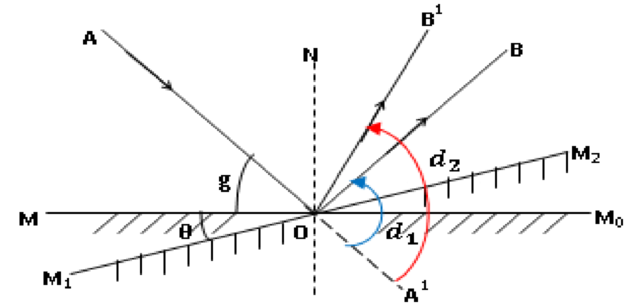
ROTATION OF REFLECTED RAY BY ROTATING THE MIRROR WHEN THE INCIDENT RAY IS FIXED



When a mirror is rotated through any angle, the reflected ray will rotate through an angle 2θ provided the direction of the incident ray remains the same e.g the angle between a fixed ray of light and a mirror is 25^0, if the mirror rotates through 20^o. Find by how many degrees do a reflected ray rotates.

Required angle = 2θ = 2 x 20 = 40^0

N.B the angle through which the reflected ray is rotated does not depend on the angle of incidence but depends on the angle of rotation on the reflecting surface.



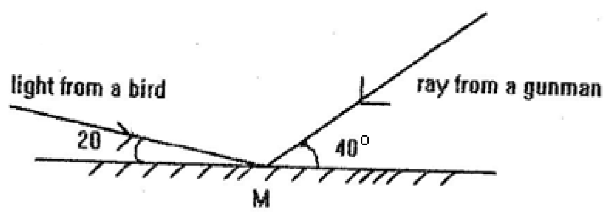
Deviation produced by mirror in position MM_0 is twice the glancing angle

$d_1 = \text{Angle BO } A^1 = 2g \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(i)}$

Deviation produced by mirror in position $M_1M_2,$ is twice the glancing angle
$d_2 = \text{Angle } B^1O\,A^1 = 2(g+\theta) \ldots\ldots\ldots\ldots\text{(ii)}$

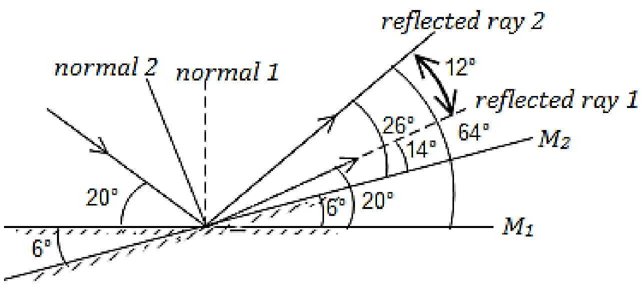
Angle of rotation of reflected ray = Angle $B^1O\,B$
But;
Angle $B^1O\,B$ = Angle $B^1O\,A^1 -$ AngleBO A^1
Angle $B^1O\,B = 2(g+\theta) - 2g$
Angle $B^1O\,B = 2\theta$

Questions



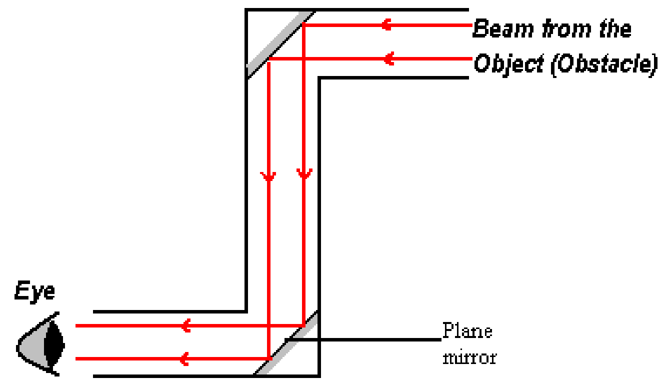
An incident ray makes an angle of 20^0 with the plane mirror in position m_1 as shown in the diagram
a) What will the angle of reflection be if the mirror is rotated through 6^0 to position m_2 while direction of incident ray remains the same?
b) An object is placed 6cm from a plane mirror. If the object is moved further, find the distance between the object and its image.

Solution:
(a) Total glancing angle $= \mathbf{20^0 + 6^0 = 26^0}$
$\Leftrightarrow \mathbf{26^0 + r = 90^0 \Leftrightarrow r = 64^0}$



Angle $B^1O\,B = 2\theta$
Angle $B^1O\,B = 2(6^0) = 12^0$

Application of reflections
Uses of Plane Mirrors
(a) Periscope.
This is the instrument used for looking over top obstacles. It is made of 2 plane mirrors inclined at each other at 45^0. It is mainly used in submarines.



The arrangement has two plane mirrors facing each others and fixed at 45^0. Light from a distant object is turned through 90^0 at each reflection.

(b) Used in pointer instrument to facilitate correct reading of values by preventing errors due to parallax.

(c) They are attached to optical lever such as galvanometer to reflect light falling on the mirror over the galvanometer scale as it rotates.
Used in optical lever instruments to magnify angle of rotation.

(d) Inclined mirrors are used in kaleidoscope for producing different patterns of objects placed between them.
A kaleidoscope consists of two plane mirrors inclined at an angle of 60^0 to each other in a tube.
When one looks through the tube, five images of the same object are seen, which together with the object form a symmetric pattern of six sectors. The patterns change as the object moves.

(e) Used in small shops and supermarkets, take away and saloons to give a false magnification as a result of multiple reflections.

Exercise See UNEB Paper I

1999 Qn.25	1996Qn.28	1997Qn.24	2005Qn.40	2007 Qn.16

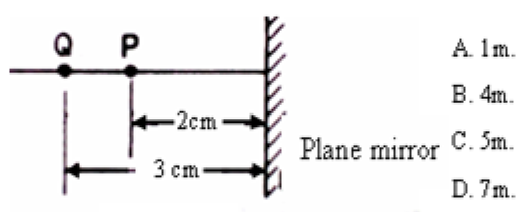
SECTION A

1. light energy is reflected when.
A. angle of incidence is greater than angle of reflection
B. angle of incidence is equal to angle of refraction.
C. angle of incidence is equal to angle of reflection
D. the normal at the point of incidence makes the same angle as the incident ray.

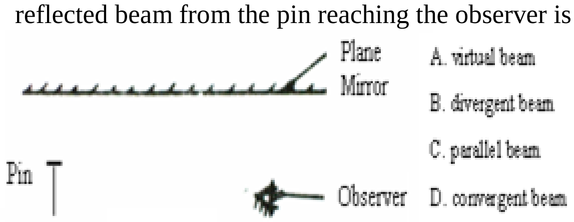
2. When reflection occurs in a plane mirror, the;
(i) image is real, erect and magnified
(ii) angle of reflection is equal to the angle of incidence
(iii) incident ray and reflected ray lie in different planes
(iv) object and the image are at the same distance from the mirror
A. (i), (ii) and (iii) only B. (ii) and (iv) only
C. (i), (ii) and (iv) only D. (iv) only

3. An object is placed 30 cm in front of a plane mirror. If the mirror is moved a distance of 6 cm towards the object, find the distance between the object and its image.
A. 24 c m B. 36 cm
C. 48 cm D. 60 cm

4. Objects P and Q are placed at distances of 2 m and 3 m respectively from a plane mirror as shown in the figure below. Find how far the image of P is from Q.

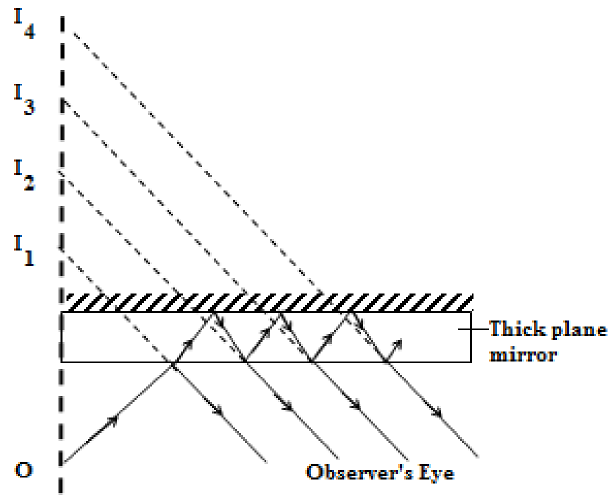


5. A person observes the image of a pin placed in front of a plane mirror as shown in the figure 14.2 below. The reflected beam from the pin reaching the observer is a;



6. Which of the following statements about eclipses is NOT correct?
A. During the eclipse of the sun, the shadow of the moon falls on the earth.
B. During the eclipse of the moon, the earth is between the sun and the moon.
C. During the eclipse of the sun, the moon is between the sun and the earth.
D. During the eclipse of the moon, the shadow of the moon falls on the earth.

7. The diagram below shows a thick plane mirror forming multiple images of an object at O.



Which image is the sharpest?
A. I_1 B. I_2 C. I_3 D. I_4

8. Parallel rays can be obtained practically from a point source of light if the source of light is placed at
A. the principal focus of a concave mirror
B. the centre of curvature of a concave mirror
C. the principal focus of a convex mirror .
D. the centre of curvature of a convex mirror

9. The eclipse of the sun takes place when the shadow of the
A. earth falls on the moon
B. sun falls on the moon
C. moon falls on the sun
D. moon falls on the earth

10. Two plane mirrors $M_1$and $M_2$are inclined to each other at an angle of 70°.

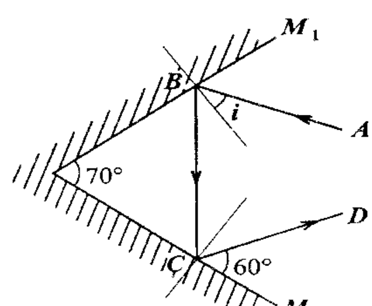
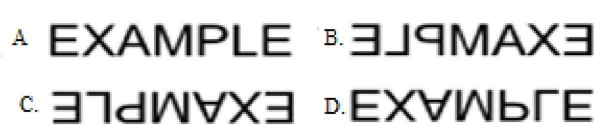


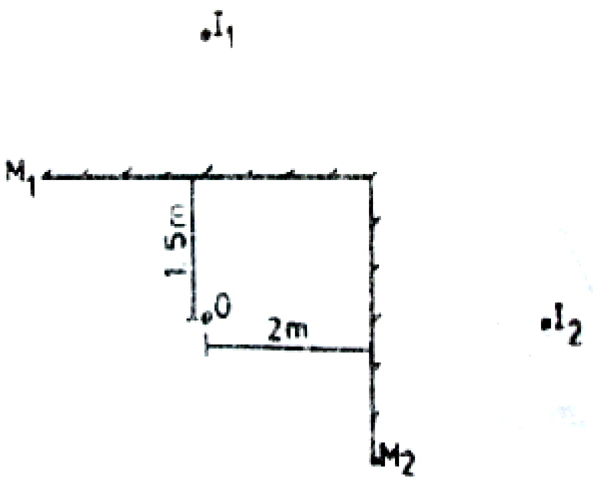
Fig. 2

If the ray AB incident on *M* is reflected as shown in figure 2, find the angle of incidence, *i*.
A. 40°. B. 50°. C. 60°. D. 70°.

11. Which of the following is the mirror image of the word "**EXAMPLE**" when it is placed facing the plane mirror?



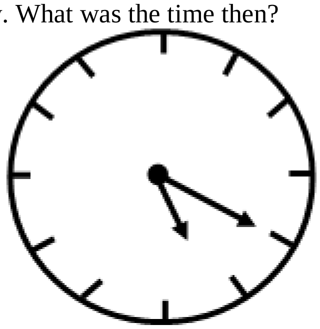
12. The images of an object O placed 2m and 1.5m from plane mirrors m_1 and m_2 respectively are I_1 and I_2 as shown in the figure below. Find the shortest distance between I_1 and I_2.



A. 2.5m B. 3.5m C.5m D.7m

12. Two plane mirrors placed at angle θ to each other. If the number of images seen are 7. Find θ.
A: 51.4^o B: 60^o C: 45^o D: 90^o

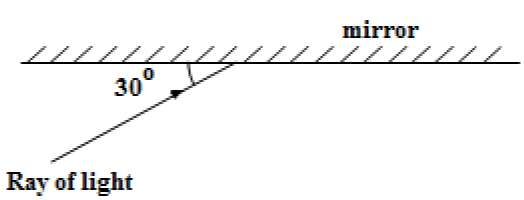
13. A man looked into a plane mirror and saw the clock as shown below. What was the time then?



A. 5: 20 B. 6: 40. C. 11: 50 D. 12: 1

14. The image of a distant object formed by a pinhole camera is;
(i) Real (ii) diminished (iii) erect
A. (i) only B. (i) and (ii) only
C. (ii) and (iii) only D. (i) ,(ii) and (iii)

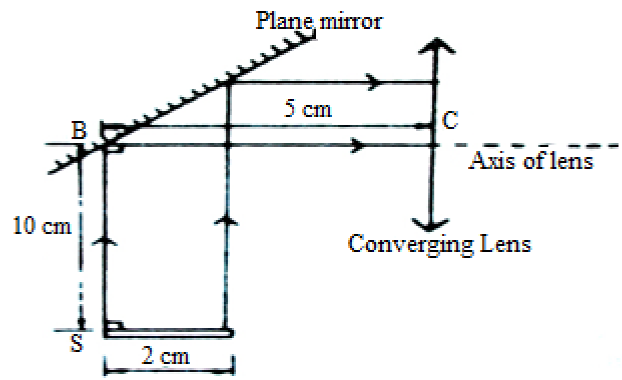
15. A ray of light is incident on a plane mirror as shown.



The ray of light reflects from the mirror. Which row in the table shows the values of the angle of incidence and the angle of reflection?

Angle of incidence	**Angle of reflection**
A. 30	30
B. 30	60
C. 30	150
D. 60	30

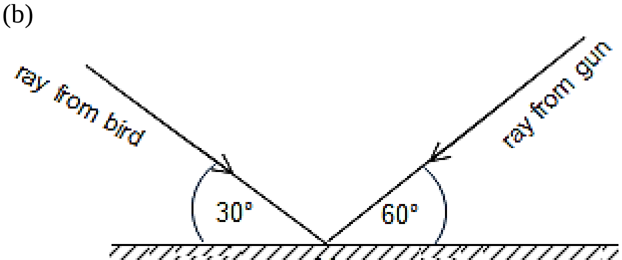
16. The figure below shows a stick, S, lying on a horizontal ground. Two parallel rays from the stick strike the mirror and are reflected on to the converging lens whose centre is C. The focal length of the lens is 10cm and the distance SB and BC are 10cm and 5cm respectively.



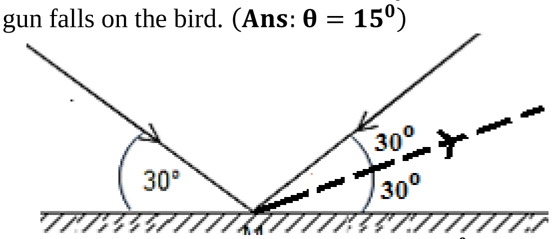
(i) State the nature of the image of the stick formed by the lens.
(ii) Use the graphical method to locate the position of the two images of the stick.
(iii) Find the magnification of the final image.

17. (a) With the aid of diagrams, distinguish between diffuse and regular reflection

(b)



A ray from a bird makes an angle of 30^0 with a plane reflector and a ray from the barrel of a gun makes an angle of 60^0 to the same reflector at the same point, M as shown in the figure. Find the angle through which the reflector must be rotated about M such that the ray from the barrel of the gun falls on the bird. (**Ans**: $\boldsymbol{\theta = 15^0}$)



The reflected ray should be rotated through $\mathbf{30^0}$.

$$\begin{pmatrix} \text{Angle of rotation} \\ \text{of reflected ray} \end{pmatrix} = 2\begin{pmatrix} \text{Angle of rotation} \\ \text{of the mirror} \end{pmatrix}$$
$$30 = 2\theta$$
$$\theta = 15^0$$

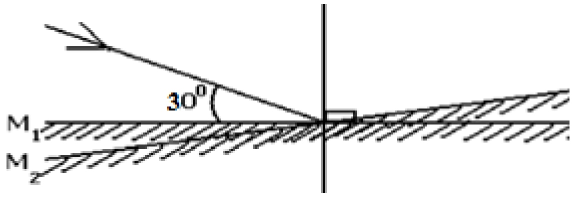
(c) With the aid of the diagram explain why a parabolic mirror is most suitable for use in car head lights.

(d) List three uses of a concave mirror

18. (a) Describe a simple experiment to demonstrate the principle of reversibility of light. (05marks)

(b) An object is released from a height of 10m above a plane mirror. What distance must it drop through in order to be 5m away from its image. (02marks)

(c) An incident ray makes an angle of 30^0 with the plane mirror in position M_1, as show in the figure above.



What will be the angle of reflection, if the mirror is rotated through 15^0 to position M_2 while direction of the incident ray remains the same? (03marks)

(d) With the aid of a ray diagram, explain how a thick plane mirror forms multiple images of an object. (04marks)

1. (a) Define the following terms as used in optics;

(i) Light
(ii) Transparent material
(iii) Translucent material
(iv) Opaque material
(v) A ray
(vi) A beam of light

(b) (i) What is meant by **rectilinear propagation** of light?
(ii) With the aid of a labelled diagram, describe an experiment to show that light travels in a straight line.
(iii) State two evidences which prove that light travels in a straight line.

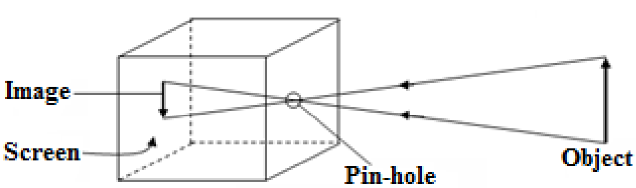
2. (a) What is meant by **a shadow**?
(b) Draw a ray diagram to show the formation of a shadow by;

(i) A point source of light	(ii) An extended source of light

(c) Define an **eclipse,**
(d) With the aid of a clear ray diagram, describe the formation of the following eclipses;

(i) Solar eclipse
(ii) Annular eclipse
(iii) Lunar eclipse

(d) The diagram below shows a pin hole camera,



(i) State the characteristics of the image formed in the pin hole camera.
(ii) Explain what happens when the pin hole is made wider
(iii) Explain the effect of ;

- adjusting the object distance
- Increasing the length of the camera

3. (a) Define the term **magnification**.
(b) Calculate the height of a building which is 150m away from a pinhole camera of length 10cm, which produces an image 5cm high.

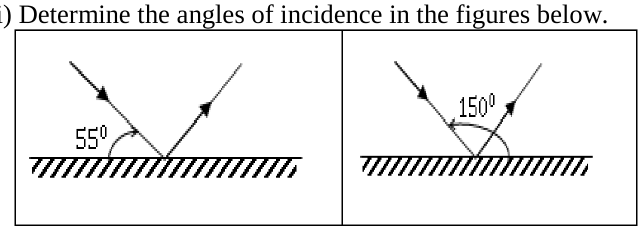
(c) An object 2m high placed 10m from the pin whole camera forms an inverted image 25cm from the pin hole. Find the size of the image and hence or otherwise determine the magnification of the image.

(d) An object of height 2.5m is placed at a distance of 150cm from the hole of a pin hole camera. Given that the screen is mounted at a distance of 7.2cm to receive the image of the object, calculate the image height.

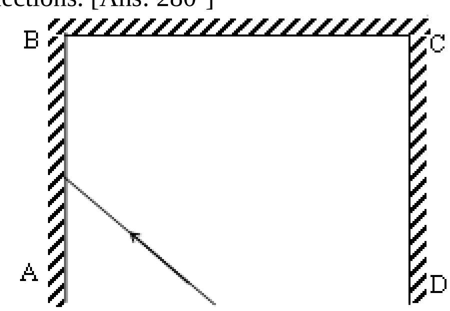
4. (a) Define **reflection** of light
(b) With the aid of ray diagrams, explain the following terms as used in reflection of light;

(i) Specular (Regular) reflection	(ii) Diffuse (Irregular) reflection

(b) (i) State the **laws of reflection** of light.
(ii) Briefly describe an experiment to verify the laws of reflection.
(ii) Determine the angles of incidence in the figures below.



5. (a) Three plane mirrors AB, BC, and CD are arranged such that a light ray is incident on AB at an angle of 40^0 as shown below. Complete the diagram and sketch the subsequent path of the light ray. Hence calculate the angle through which the ray is turned after three reflections. [Ans: 280^0]



(b) (i) State the characteristics of the images formed in a plane mirror.
(ii) With the aid of a diagram, explain what is meant by **lateral inversion**.

(iii) With the aid of a diagram, show the formation of all the images when two plane mirrors are inclined at;

(a) 90^0 to each other	(b) 180^0 to each other

(c) Complete the table below where, **θ** is the angle of inclination between two plane mirrors and **n** is the corresponding number of images formed.

θ (^{0})	n
30	
	7
60	
120	
	23

6. (a) State the applications of plane mirrors

(b) With the aid of a diagram, describe the action of the following instruments;

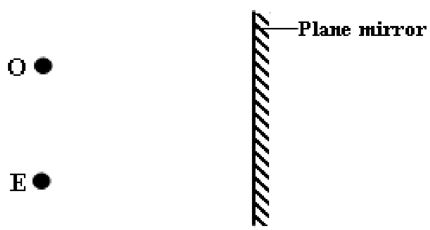
(a) Periscope	(b) Kaleidoscope

(c) Explain why lenses are normally fitted in periscopes.

(a) State the **principle of reversibility of light**

(b) A ray from a bird makes an angle of $30^0$with a plane reflector and a ray from the barrel of the gun makes an angle of 60^0 to the same reflector. Find the angle through which the reflector must be rotated such that the ray from the barrel of the gun falls on the bird.

(d) By use of two rays from the object, O, show how an observer, E, is able to see the image of O in the figure below.

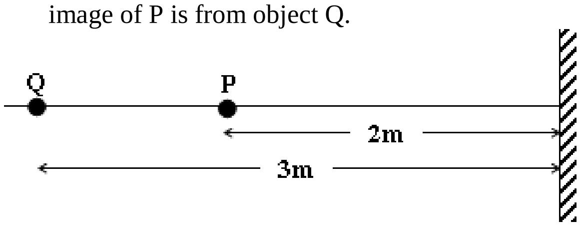


7. (a) Draw a ray diagram to show that a vertical mirror need not be 180cm long in order for a man 180 cm tall to see his full height in the mirror.

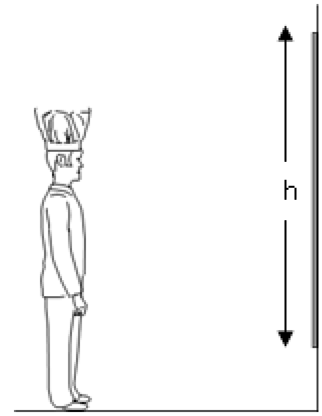
(b) If a man's eyes are 12 cm below the top of his head, find the shortest length of the mirror necessary and the height of its base above the floor level.

(c) Rachael runs towards a large mirror 10m away at a speed of $3ms^{-1}$. With what speed does the image appear to move and in which direction? What is the distance between Rachael and her image after 5 seconds?

8. (a) Objects P and Q are placed at distances of 2m and 3m respectively from a plane mirror. Find how far the image of P is from object Q.



(b) The figure below shows a man looking at his reflection in a rectangular plane mirror whose vertical side has length **h**.



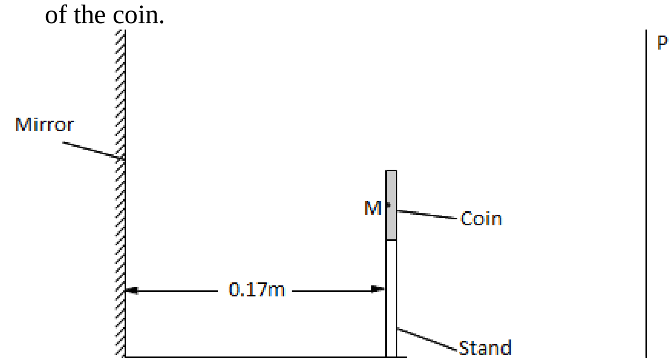
(i) On the figure, draw a ray of light from feet of the man that is reflected by the mirror to his eye.

(ii) On the figure, mark the angle ofincidence, i.

(iii) On the figure, draw a ray of light from the top of the man's hat that is reflected by the mirror to the man's eye

(c) Given that on the diagram, 1cm represents 0.5m, Use your rays to determne the smallest value of h, that allows the man to see the full image in the mirror, from the top of his hat to his toes.

9. (a) The figure below shows an old coin displayed in a museum. The coin is vertical and is supported by a transparent stand. A vertical mirror 0.17 m behind the coin ensures that the back of the can be seen by a visitor looking from the line P. M is a point on the back of the coin.



(i) On the figure, draw two rays of light from M to show how its image is produced. Label the image I.

(ii) State the distance from point M on the coin to its image.

(iii) An object of height 4cm is placed5cm away from a pin hole camera. The screen is placed 7cm from the pin hole. Draw to scale a ray diagram to show the formation of the image and use it to find the nature and magnification of the image.

CURVED (SPHERICAL) MIRRORS

Curved mirrors are spherical mirrors made by cutting part of the sphere.

Terms used in curved mirrors

Pole, P.

Pole is the mid-point of the actual mirror surface.

Pole is the centre portion of the mirror

Aperture.

This is the width of the mirror. The aperture is the distance between two opposite points on the edge of the mirror.

Centre of Curvature, C.
This is the center of the sphere from which the mirror forms a part.

Radius of Curvature, r.
The radius of curvature is the distance from the pole to the centre of curvature.

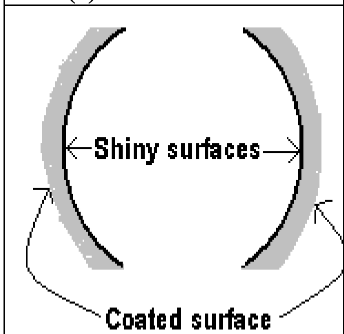
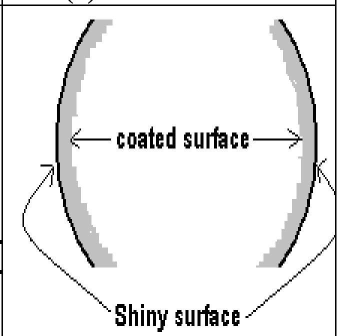
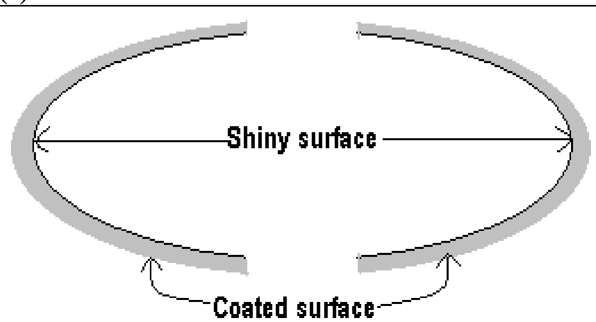
Principal axis.
This is the straight line joining the pole to the centre of curvature.

Focal length, f.
Focal length is the distance from the pole to the principal focus.

Principal focus, F.
Principal focus is half the distance between the centre of curvature and the pole.

Summary for terms used in curved mirrors i.e. Concave mirror.

Types of curved mirrors

(a) Concave mirror	(b) convex mirror
	
(c) Parabolic mirror	
	

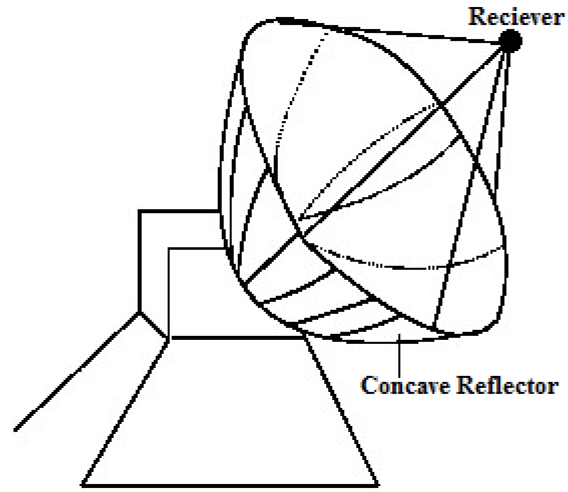
(a) CONCAVE MIRROR

A concave mirror is the type of curved mirror in which the reflecting surface is curved inwards.

Uses of concave mirror

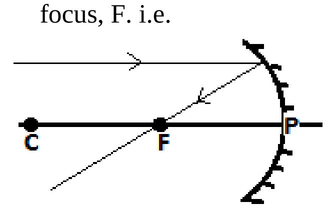
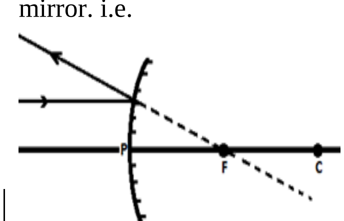
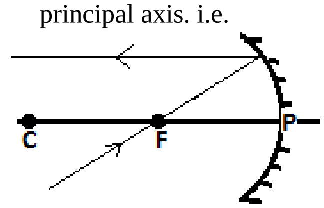
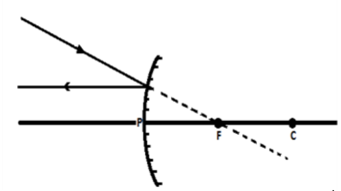
- ✓ Used in astronomical telescopes.
- ✓ Used for shaving because it magnifies the object.
- ✓ Used as solar concentrators.
- ✓ Used by dentists for magnification i.e Dentist mirror.
- ✓ Used in car head lamps , torches

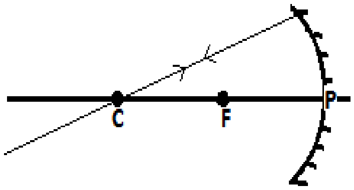
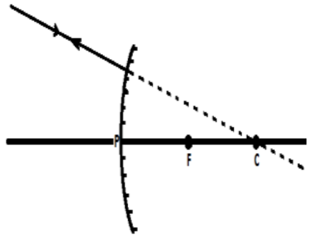
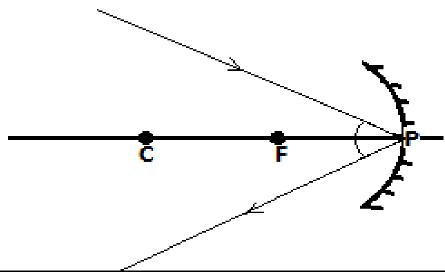
The dishes (paraboloidal material) usuallyplaced on the house so as to collect waves usedto watch inaccessible TV stations like DSTV, M-net, Arab-sat, Euro-sat and others. Modern technology has led to the invention of various types of antennas with various shapes anddesigns.



Defect of concave mirror:
When a wide beam of parallel rays fall on a concave mirror of large aperture, not all are brought to a focus at the focal point but instead form a caustic curved.
N.B Caustic curve is an illusory curve that is seen to touch the reflected rays when a wide parallel beam of light falls on a concave mirror.

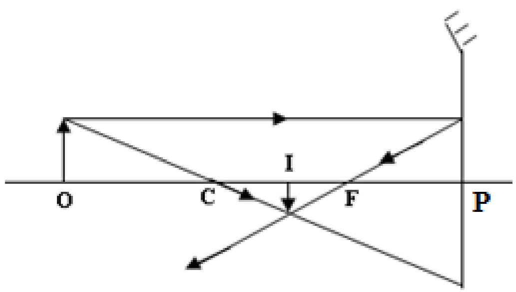
Useful rays used in construction of ray diagrams.

Concave mirror	**Convex mirror**
1. A ray parallel to the principal axis is reflected through the principal focus, F. i.e. 	A ray parallel to the principal axis is reflected such that it appears to come from the principal focus, F behind the mirror. i.e. 
2. A ray passing through the principal focus, F is reflected parallel to the principal axis. i.e. 	A ray through the principle focus F, behind the mirror is reflected parallel to the principal axis. i.e. 
This ray is only used when the object is beyond the principle focus, F.	
3. A ray passing though the	A ray which if produced

	centre of curvature, C is reflected back along the same path because it is the normal to the surface. i.e. 	would pass through the centre of curvature is reflected back along the same path. i.e. 
4.	A ray striking the pole is reflected so as the incident ray and the reflected ray make the same angle with the principal axis. i.e. 	

(a) Characteristics of the image, I formed by concave mirror at different positions.

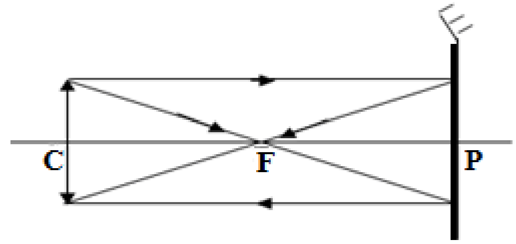
(i) Object, O beyond the centre of curvature, C.



The image, I formed is;

- ❖ Position: Between F and C
- ❖ Nature : Real and Inverted
- ❖ Size : Diminished

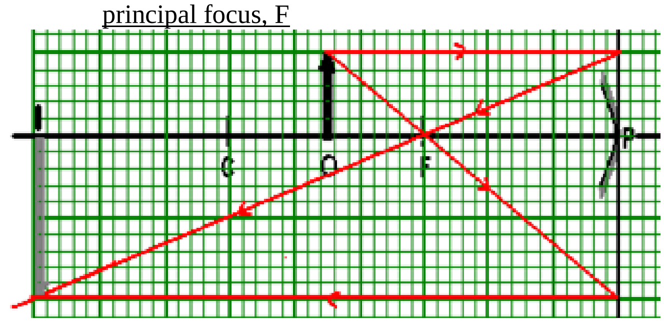
(ii) Object, O at centre of curvature, C.



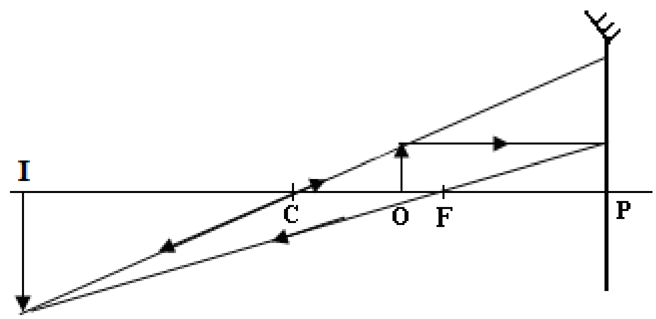
The image, I formed is;

- ❖ Position: At C
- ❖ Nature : Real and Inverted
- ❖ Size : Same size as the object

(iii) Object, O between centre of curvature, C and the principal focus, F



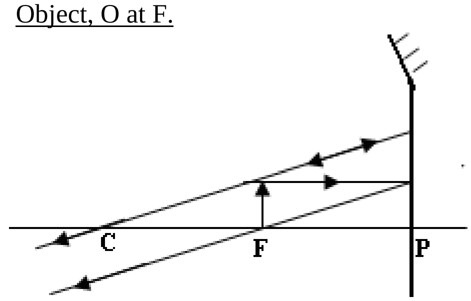
Note: Alternatively, a ray through C, may be used. As shown below.



The image, I formed is;

- ❖ Position: Beyond C
- ❖ Nature : Real and Inverted
- ❖ Size : Magnified

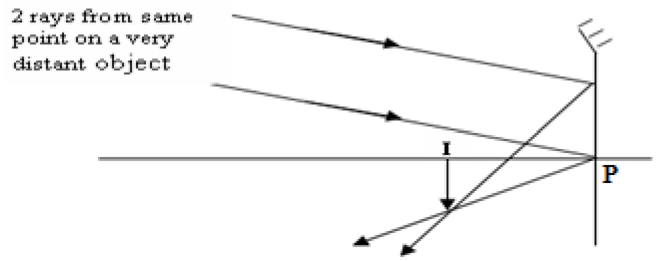
(iv) Object, O at F.



The image, I formed is;

- ❖ Position: At infinity
- ❖ Nature : Real and Inverted

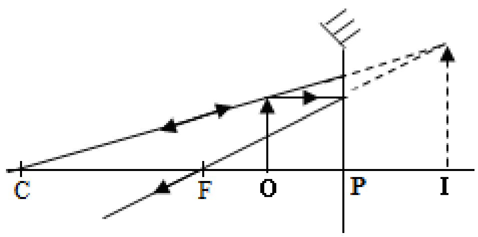
(v) Object, O at Infinity.



The image, I formed is;

- ❖ Position: At F
- ❖ Nature : Real and Inverted
- ❖ Size : Diminished

(vi) Object, O between principal focus, F and pole, P.



The image, I formed is;

- ❖ Position: Behind the mirror
- ❖ Nature : Virtual and Upright (erect)
- ❖ Size : Magnified

NB. A concave mirror can be used as a **magnifying mirror** when the object is placed between the focal point, F and the pole, P to produce an erect magnified image.

CONVEX MIRRORS

Convex mirror is a type of curved mirror in which the reflecting surface curves outward.

Uses of convex mirror

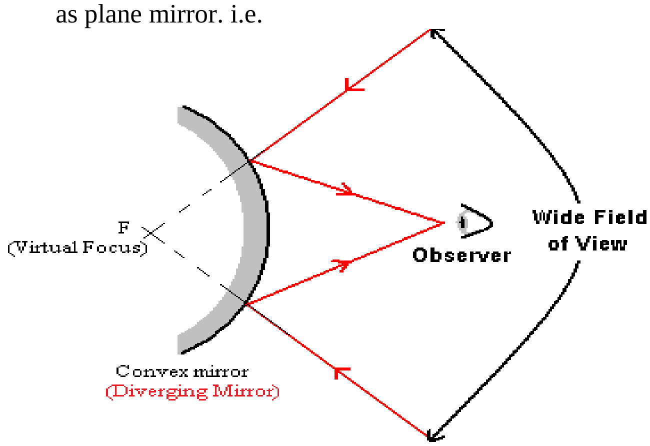
Convex mirrors are used as;

i) security mirrors in supermarket

ii) driving mirrors

This is **because** a convex mirror;

- ✓ Gives an erect (upright) virtual image of the objects.
- ✓ Provides a wider field of view than other mirrors such as plane mirror. i.e.

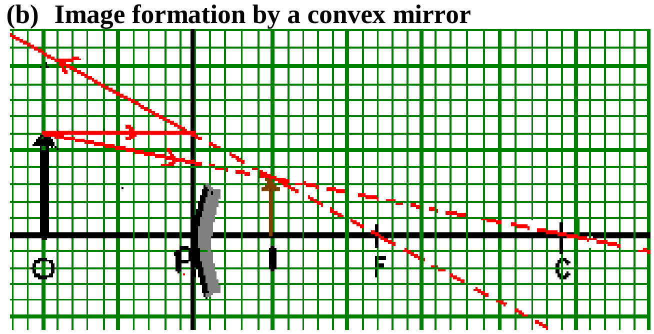


Disadvantage of convex mirrors:

- The image formed is diminished.
- It gives a false impression of the distance of an object

Therefore, convex mirrors give erect diminished images and this makes it difficult for the driver to judge the distance when reversing the vehicle.

(b) Image formation by a convex mirror



Characteristics of the image, I formed by convex mirror.

Irrespective of the position of the object, the images formed in convex mirrors are;

- ❖ Position: Behind the mirror
- ❖ Nature : Virtual and upright (erect)
- ❖ Size : Diminished

NOTE: 1. Magnified images are the images which are larger than the objects.

2. Diminished images are the images which are smaller than the objects.

(b) PARABOLIC MIRRORS

These are used to produce a parallel beam of light in spot light, car head lamps or hand torches.

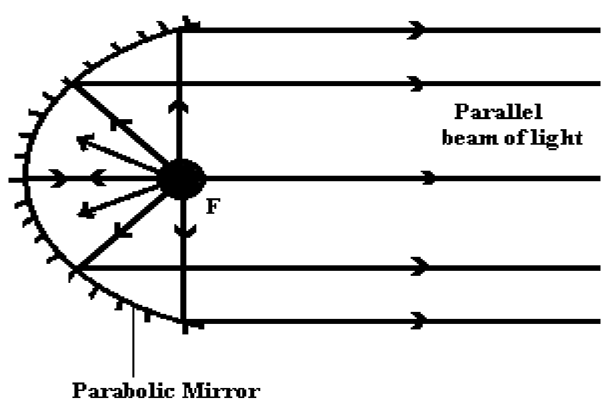
However the parabolic mirror is disadvantageous in that when a wide beam of parallel rays falls on a concave mirror of image aperture; not all rays are brought to a focus at the focal point, instead they form a caustic curve.

Parallel beam from curved mirror

A narrow parallel beam of light may be obtained from a point source light by placing the point source of light at the principal focus of a concave mirror of small aperture.

The image is regarded as being at infinity. If a wide parallel beam is required as from a car head lamp then the section of the mirror must be in the form a **parabola**.

Illustration:



Magnification

Magnification is defined as;

- *The number of times the image is larger than the object.*
- *The ratio of image size to object size.*

Linear or transverse magnification is the ratio of one dimension of the image to a corresponding dimension of the object i.e.
Linear magnification is;

- The ratio of image distance to object distance.

$$\text{Magnification} = \frac{\text{Image Distance}}{\text{Object Distance}} = \frac{v}{u}$$

- The ratio of image height to object height.

$$\text{Magnification} = \frac{\text{Image Height}}{\text{Object Height}} = \frac{h}{H}$$

(c) Construction of accurate ray diagrams on graph paper

Step 1: On graph paper draw a central horizontal line (which acts as the principal axis) with a perpendicular line to act as the curved mirror.

Step 2: Where distances are given, choose a scale for object size and position.

Step 3: Measure the focal length "f" and radius of curvature "r" from the mirror and mark C and F as centre of curvature and principal focus respectively.

Step 4: Draw two of the principal rays to obtain the position of the image.

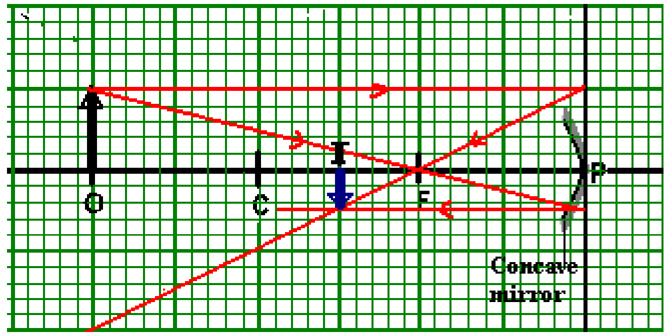
Step 5: Measure the position (distance) and the size (height) of the image and multiply by the corresponding scale.

Example 1:
An object of height 10cm is placed at a distance of 60cm from a concave mirror of focal length 20cm. Find by scale drawing the;

(i) Image position.
(ii) Nature of the image formed.
(iii) Magnification of the image formed.

Solution

Axis	**Scale**	**Conversion**
Vertical axis	**1 : 10 cm**	❖ $10\text{cm} \rightarrow \frac{10}{10} \rightarrow 1\text{cm}$
Horizontal axis	**1 : 10 cm**	❖ $60\text{cm} \rightarrow \frac{60}{10} \rightarrow 6\text{cm}$ ❖ $20\text{cm} \rightarrow \frac{20}{10} \rightarrow 2\text{cm}$



Position:
The image distance as measured from the scale drawing is 3cm; using the above scale,

$$\begin{aligned} \textit{Image distance} &= (3 \times 10)\ cm \\ &= 30\ cm \end{aligned}$$

Size:
The height of the image on the scale drawing is 0.5cm; using the scale,

$$\begin{aligned} \textit{Image height} &= (0.5 \times 10)\ cm \\ &= 5\ cm \end{aligned}$$

Nature:
The image formed is; Real, Inverted and Diminished.

Magnification:

$$\text{Magnification} = \frac{\text{Image Distance}}{\text{Object Distance}} = \frac{30}{60} = 0.5$$

Or

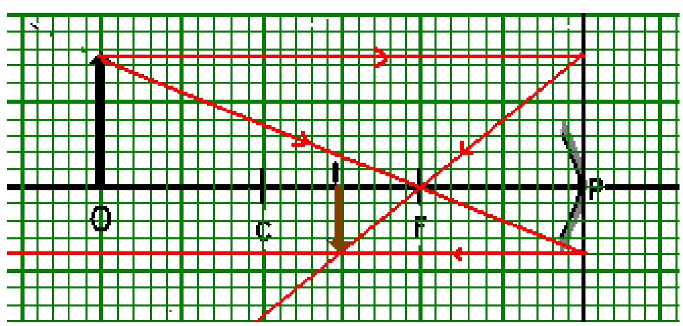
$$\text{Magnification} = \frac{\text{Image Height}}{\text{Object Height}} = \frac{5}{10} = 0.5$$

Example 2:
The focal length of a concave mirror is 4cm. An Object 1.5cm high is placed 12cm in front of the mirror.

(i) Use a ray diagram to locate the position and size of the image on the graph paper.
(ii) Describe the features of the image formed.
(iii) Find the magnification of the image formed.

Solution

Axis	**Scale**	**Conversion**
Vertical axis	**1 : 1 cm**	❖ $1.5\text{cm} \rightarrow \frac{1.5}{1} \rightarrow 1.5\text{cm}$
Horizontal axis	**1 : 2 cm**	❖ $4\text{cm} \rightarrow \frac{4}{2} \rightarrow 2\text{cm}$ ❖ $12\text{cm} \rightarrow \frac{12}{2} \rightarrow 6\text{cm}$



(i) Position:

The image distance as measured from the scale drawing is 3cm; using the above scale,

$Image\ distance = (3 \times 2)\ cm$
$= 6\ cm$

Size:

The height of the image on the scale drawing is 0.8cm; using the scale,

$Image\ height = (0.75 \times 1)\ cm$
$= 0.75\ cm$

(ii) Nature:

The image formed is; Real, Inverted and Diminished.

(iii) Magnification:

$$\text{Magnification} = \frac{\text{Image Distance}}{\text{Object Distance}} = \frac{6}{12} = 0.5$$

Or

$$\text{Magnification} = \frac{\text{Image Height}}{\text{Object Height}} = \frac{0.75}{1.5} = 0.5$$

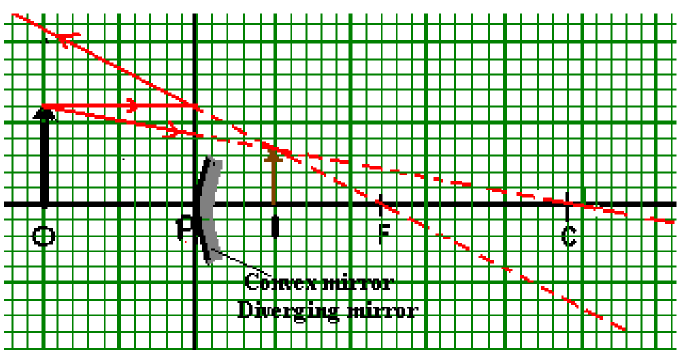
Example 3:

An object of height 6cm is 10cm in front of a convex mirror of focal length 12cm. Find by graphical method, the size, position and nature of the image.

Solution

Let 5 cm be represented by 1 cm

Axis	**Scale**	**Conversion**
Vertical axis	**1 : 5 cm**	❖ $6\text{cm} \rightarrow \frac{6}{5} \rightarrow 1.2\text{cm}$
Horizontal axis	**1 : 5 cm**	❖ $10\text{cm} \rightarrow \frac{10}{5} \rightarrow 2\text{cm}$ ❖ $12\text{cm} \rightarrow \frac{12}{5} \rightarrow 2.4\text{cm}$



(i) Position:

The image distance as measured from the scale drawing is 1cm; using the above scale,

$Image\ distance = (1 \times 5)\ cm$
$= 5\ cm$

The image 5.0cm behind the mirror.

Size:

The height of the image on the scale drawing is 0.8cm; using the scale,

$Image\ height = (0.6 \times 1)\ cm$
$= 0.6\ cm$

(ii) Nature:

The image formed is; virtual, Inverted and Diminished.

(iii) Magnification:

$$\text{Magnification} = \frac{\text{Image Distance}}{\text{Object Distance}} = \frac{5}{10} = 0.5$$

Magnification and the image size of the object.

Magnification, M	Image size, I
When M is greater than 1	The image is magnified i.e. the image is larger than the object
When M is equal to 1	The image size is the same as the object
When M is less than 1	The image is diminished i.e. the image is smaller than the object

THE MIRROR FORMULA

The mirror formula for the concave mirror and convex mirror is given by;

$$\frac{1}{\mathbf{f}} = \frac{1}{\mathbf{u}} + \frac{1}{\mathbf{v}}$$

Where; **u** = object distance from the mirror
v = image distance from the mirror
f = focal length

An image may be formed in front or behind the curved mirror. It is necessary to have a sign convention for the values of **u**, **v** and **f** so as to distinguish between the two cases and obtain the correct answer when substituting into the formula.

Real is positive and virtual is negative sign convention:

According to this sign convention;

- All distances are measured from the pole of the mirror as the origin.
- Distances of real objects and the images are positive.
- Distances of virtual objects and images are negative.
- The principal focus, F of the concave mirror is real hence its focal length, f is positive while a convex mirror has a virtual principle focus, F and so its focal length, f is negative.

Example 1:

An object is placed 20cm in front of a concave mirror of focal length 12cm. Find the nature and position of the image formed.

Solution

u = 20cm; f = 12cm ; v = ?

Using the mirror formula; $\frac{1}{\mathbf{f}} = \frac{1}{\mathbf{u}} + \frac{1}{\mathbf{v}}$ $\frac{1}{12} = \frac{1}{20} + \frac{1}{v}$ $\frac{1}{12} - \frac{1}{20} = \frac{1}{v}$	$\frac{1}{v} = \frac{5-3}{60} = \frac{2}{60} = \frac{1}{30}$ $\frac{1}{v} = \frac{1}{30}$ v = 30 cm A real image was formed 30cm from the mirror on the same side as the object.

Example 2:

Calculate the distance of the image from the concave mirror of focal length 15cm if the object is 20cm from the mirror.

Solution

f = 15cm ; u = 20cm; v = ?

Using the mirror formula; $\frac{1}{\mathbf{f}}=\frac{1}{\mathbf{u}}+\frac{1}{\mathbf{v}}$ $\frac{1}{15}=\frac{1}{20}+\frac{1}{v}$ $\frac{1}{15}-\frac{1}{20}=\frac{1}{v}$	$\frac{1}{v}=\frac{4-3}{60}=\frac{1}{60}$ $\frac{1}{v}=\frac{1}{60}$ $v = 60$ cm A real image was formed 60cm from the mirror on the same side as the object.

Example 3:

Find the distance of the image from a convex mirror of focal length 10cm if the object is 15cm from the mirror.

Solution

u = 15cm; f = -10cm (for convex mirror); v =?

Using the mirror formula; $\frac{1}{\mathbf{f}}=\frac{1}{\mathbf{u}}+\frac{1}{\mathbf{v}}$ $\frac{1}{-10}=\frac{1}{15}+\frac{1}{v}$ $\frac{1}{-10}-\frac{1}{15}=\frac{1}{v}$	$\frac{1}{v}=\frac{-3-2}{30}=\frac{-5}{30}$ $\frac{1}{v}=\frac{-1}{6}$ $v = -6$ cm A virtual image was formed 6 cm from the mirror on the opposite side as the object.(i.e behind the convex mirror)

Example 4:

A convex mirror of focal length 18cm produces an image of on its axis 6cm from the mirror. Calculate the position of the object.

Solution

u =?; f = -18cm (for convex mirror); v = -6cm

Using the mirror formula; $\frac{1}{\mathbf{f}}=\frac{1}{\mathbf{u}}+\frac{1}{\mathbf{v}}$ $\frac{1}{-18}=\frac{1}{u}+\frac{1}{-6}$ $\frac{1}{-18}+\frac{1}{6}=\frac{1}{u}$	$\frac{1}{u}=\frac{-1+3}{18}=\frac{2}{18}=\frac{1}{9}$ $\frac{1}{u}=\frac{1}{9}$ $u = 9$ cm A real object was 9cm in front of the convex mirror.

Exercise

1. Find the distance of the image from the concave mirror of focal length 10cm if the object is 5cm from the mirror.

2. A concave mirror of focal length 15cm has an object placed 25cm from it. Find the position and nature of the image.

3. An object is 32cm in front of a convex mirror of focal length 16cm. Describe the image and give its position.

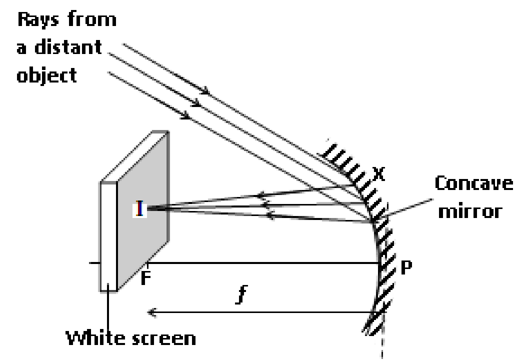
4. When an object is 42cm from a concave mirror, the object and the image are of the same height. What is the focal length of the mirror?

5. An object 5cm high is placed 30cm in front of the concave mirror. The image is 60cm in front of the mirror. Find the;
   (i) Focal length of the mirror.
   (ii) Magnification.
   (iii) Height of the object.

NOTE: Currently, the use of the mirror formula and lens formula is out of the O- level syllabus. Therefore students are encouraged to practice the use of accurate ray diagram (graphical) method to find the position of images and objects or the focal length of the mirror.

Determining the focal length of Concave mirrors

i) Focusing distant object (Approximate Method)

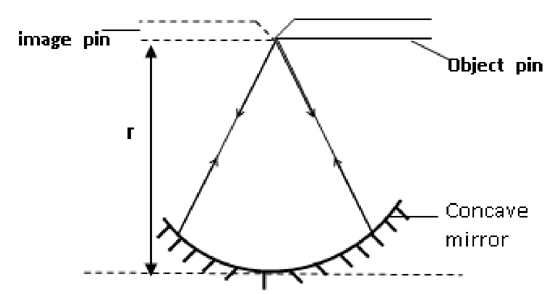


Light from a distant object such as a tree is focused on the screen.

Distance between the image (screen) and the pole of the mirror are measured using a metre- rule.

It is approximately equal to the focal length .f of the mirror.

ii) **By determining first the radius of curvature.**
(Self conjugate method) or the no parallax method.



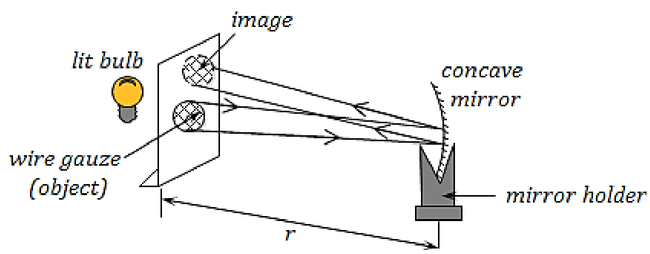
A concave mirror is placed horizontally on a bench. An optical pin is clamped horizontally on a retort stand so that the tip lies along the principal axis of the mirror.

The position of the pin is adjusted until the position is obtained where it coincides with its image and there is no parallax between the two, i.e. there is no relative motion between the object and the image when the observer moves the head from side to side or up and down.

The distance r of the pin from the pole is measured and focal length determined,

$$\boldsymbol{f}=\frac{\boldsymbol{r}}{2}$$

iii) Using an illuminated object at C



Procedures:

The apparatus is set up as shown in the diagram.

A concave mirror is moved to and fro in front of the screen until a sharp image of the cross wire is obtained on the screen.

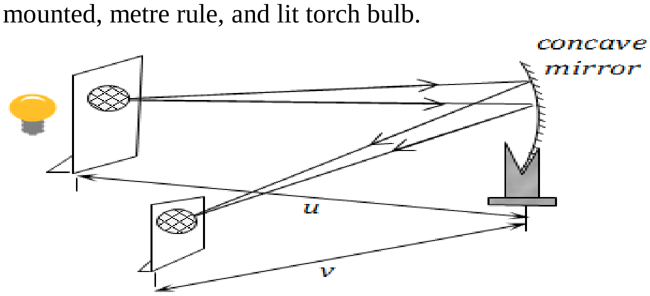
The distance between the screen and the mirror, r is measured and recorded.

The focal length, f, of the mirror is then determined from;

$$f = \frac{r}{2}$$

iv) Measurement of image and object distances

Apparatus: concave mirror, 2 screens one with wire gauze mounted, metre rule, and lit torch bulb.



Procedure

- ✓ The apparatus is arranged as in the figure above.
- ✓ A mirror is placed at a known distance, ***u*** from the wire gauze.
- ✓ The screen is moved to and fro until a clearly focused image isobserved.
- ✓ The distance, ***v*** between the mirror and the screen is measured andrecorded.
- ✓ Focal length is obtained from$f = \frac{uv}{u+v}$.
- ✓ Experiment is repeated for different values of and the mean valueof***f*** gives the focal length of the mirror.

N.B: .

1. An object coincides with its image when the object is at the centre of curvature of the mirror.
2. The focal length is one half of the distance from the centre of curvature to the mirror.

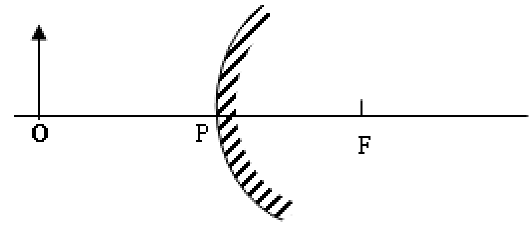
13. Parallax is the apparent relative movement of two objects due to a movement on the part of the observer.

Exercise: See UNEB Paper I

2002 Qn.8	2003 Qn.20	2005 Qn.29	2007 Qn.2

1. UNEB 1995 Qn. 5

(a) The figure below shows an object, O placed in front of a mirror. If F is the principle focus of the mirror. Complete the diagram to show the formation of the image.



(b) State two applications of convex mirrors.

2. UNEB 1997 Paper 2 Qn. 4

(c) An object 10cm high is placed at a distance of 25cm from a convex mirror of focal length 10cm.

(i) Draw a ray diagram to locate the position of the image.

(ii) Calculate the magnification.

(d) State the reasons for use of convex mirrors in vehicles.

3. UNEB 2002 Paper 2 Qn. 5

(c) With the aid of a diagram, explain why a parabolic mirror is most suitable for use in car head lights.

(d) List **three** uses of concave mirrors

1. A concave mirror can be used as a shaving mirror because when an object is placed between the focus and the pole, the image formed is,

A. magnified, virtual and erect
B. magnified, real and inverted
C. diminished, real and inverted
D. diminished, virtual and erect

2. Which of the following information is true about the concave and convex mirrors?

	Concave mirror	Convex mirror
A	Converges light	Diverges light
B	Diverges light	Converges light
C	Refracts light	Reflects light
D	Has a wide field of view	Has a narrow field of view

3. The focal length of a concave mirror is the:

A. distance btn the pole of the mirror and the focal point
B. distance between the center of curvature and the mirror
C. distance between the object and the image
D. diameter of the mirror

Paper II Questions

4. (a) With the aid of the diagram explain why a parabolic mirror is most suitable for use in car head lights.

(b) List three uses of a concave mirror.

5. (a) Draw a ray diagram to show the formation of an image of an object O placed in front of a convex mirror shown in the figure below. F is the principal focus of the mirror.

(b) A convex mirror whose radius of curvature is 30 cm forms an image of a real object which has been 20 cm from the mirror. Calculate the:

(i) position of the image (ii) Magnification produced.

(c) State any **two** reasons for use of convex mirrors in vehicles.

6. (a) An object 10cm high is placed 20cm in front of a convex mirror of focal length 10cm. Use an accurate ray diagram to determine the, position, size, nature and Magnification of the image.

(b) An object of 3cm tall stands 30cm in front of a concave mirror of focal length 12 cm. By scale drawing, determine the nature, position, size and magnification of the image formed.

(c) An object of height 5cm is placed 12cm in front of a converging mirror whose radius of curvature is 36 cm. By construction of a ray diagram, find the nature, position, size and magnification of the image formed.

(d) A tree 1.5m tall is focused using a concave mirror placed 40cm away from the tree. The mirror forms an image which is 4.5cm tall on a screen placed 120cm from the mirror. By graphical method, determine the focal length of the mirror used.

(e) An object is placed 15cm in front of a concave mirror. An upright image of magnification 4 is produced. By graphical method; determine the nature of the image, focal length of the mirror and distance of the image from the mirror.

(f) An erect image 3 times the size of the of the object is obtained with a concave mirror of radius of curvature 36cm. Find the object distance [24 cm]

(g) (i) Explain the applications of spherical mirrors giving a reason for each application.
(ii) Briefly describe an experiment to determine the focal length of a concave mirror using an illuminated object.

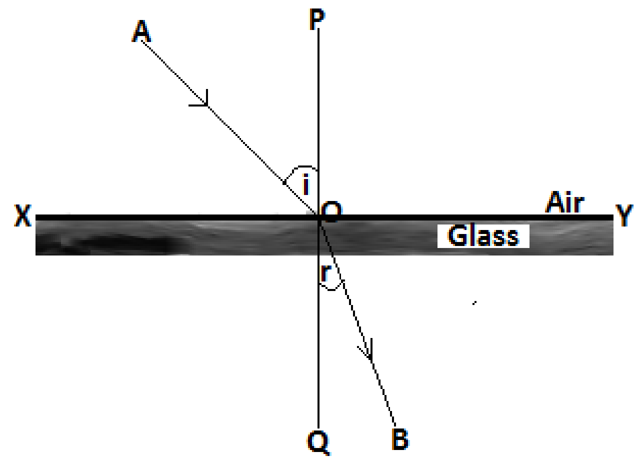
(h) Define the following term as used in curved mirrors;
- (i) Pole, P of a mirror
- (ii) Aperture of a mirror
- (iii) Principle axis
- (iv) Principle Focus, F
- (v) Focal length, f
- (vi) Centre of curvature, C
- (vii) Radius of curvature

REFRACTION OF LIGHT

Definition:
Refraction is the bending of light ray(s) as it passes from one transparent medium to another of different densities.

Refraction is the change in speed of propagation of light due to change in optical density.
When light propagating in free space is incident in medium, the electrons and protons interact with the electric and magnetic fields of the light wave. This result in the slowing down of a light.

Illustration.



Refraction occurs because light travels at different speed in the different media.

Description

(a) Rays and lines

Ray AO is called incident ray.
This is the ray that fall/strikes the boundary at the normal in the first medium.

Ray OB is called the refracted ray.
Refracted ray is the ray that leaves the boundary at the normal in the second medium and o the opposite side of the incident ray.

Line PQ is called the normal.
The normal is an imaginary line at right angle to the boundary and separates the incident ray and the refracted ray.

Line XY is called the boundary.
The boundary is the line that separates the two media. It is the line where refraction occurs.

(b) Angles

Angle, i is the angle of incidence.
This is the angle formed between the incident ray and the normal.

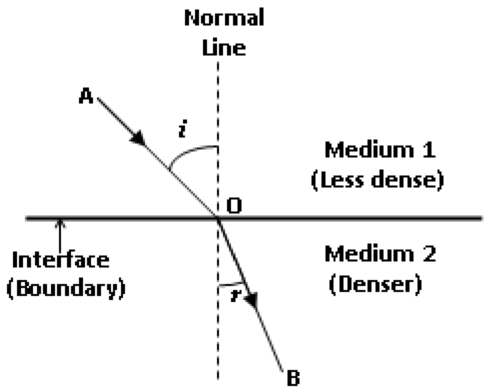
Angle, r is called angle of refraction.
The angle of refraction is the angle formed between the refracted ray and the normal.

NOTE: The light ray is refracted towards the normal when it travels from a less dense medium to a denser medium and then refracted away from the normal if it travels from a denser medium to a less dense medium.

Principle of Reversibility of light
It states that if a light ray (path) after suffering a number of refractions is reversed at any stage, it travels back to the source along the same path with the same refraction.

Law of refraction
When light passes from one medium to another, say from air glass part of it is reflected back into the previous

medium and the rest passes through the second medium with its direction of travel changed.



AO = Incident ray

i = Angle of incidence

OB = Refracted ray

r = Angle of refraction

Generally, if light is incident from a less dense medium, to a more optically dense medium, its speed reduces and it is refracted towards the normal at the point of incidence.
However, if light travels from a denser to a less dense medium, its speed increases and it is refracted away from the normal.

Laws of Refraction
Law 1. The incident ray, refracted ray and the normal at point of incidence all lie on the Same plane.

Law 2. For any two particular media, the ratio of the sine of angle of incidence to sine of angle of refraction is constant.

i.e.$\frac{\sin i}{\sin r} = \textbf{aconstant}(\cap)$

The constant ratio $\frac{\sin i}{\sin r}$ is called the refractive index for light passing from the first to second medium.

Hence; $_1\cap_2 = \frac{\sin i}{\sin r}$

Definition:
Refractive Index *is the ratio of sine of angle of incidence to the sine of angle of refraction for a ray of light traveling from one medium to another of different densities.* i.e.
If light travel from air to glass, then the refractive index of glass with respect to air is given by;

$$_{air}\cap_{glass} = \frac{\sin i}{\sin r}$$

It can also be defined as the ratio of the speed of light in one medium to the speed of light in another medium.

Hence; $_1\cap_2 = \frac{v_1}{v_2} = \frac{\text{Speed of light in medium 1.}}{\text{Speed of light in medium 2}}$

If medium 1 is a vacuum, we refer to the ratio as the **absolute refractive index of medium 2**, denoted by $\mathbf{n_2}$.

If medium 1 is a vacuum, then;

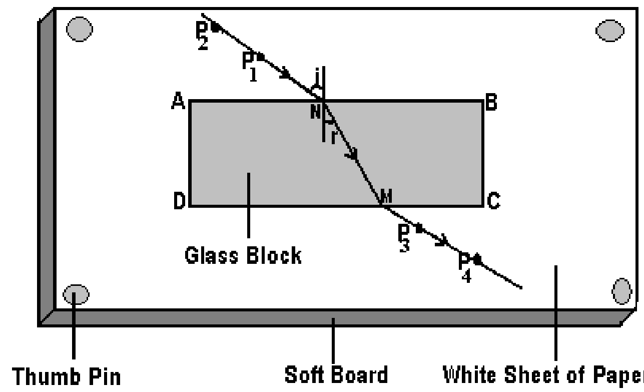
$$\cap_2 = \frac{C}{v_2} = \frac{\text{Speed of light in vacuum.}}{\text{Speed of light in medium 2}}$$

$Where, \boldsymbol{C} = 3.0 \times 10^8 \boldsymbol{ms}^{-1}$

Note: For practical purposes, $\cap_{\mathbf{Vacuum}} = \cap_{\mathbf{Air}} = 1$

DETERMINATION OF REFRACTIVE INDEX
<u>Apparatus:</u>
- Rectangular Glass Block
- Four Optical Pins and 4 thumb pins
- Soft Board
- White Sheet of Paper
- Mathematical Set

<u>Set up</u>

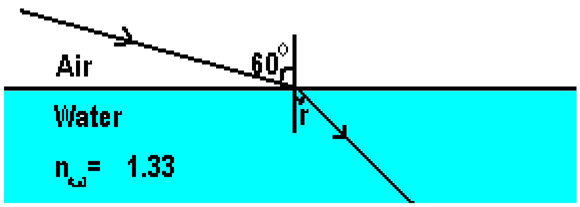


<u>Procedure</u>
a) Place the rectangular glass block on the white sheet of paper stuck on the soft board.
b) Trace the outline of the glass block on the white sheet of paper.
c) Remove the glass block and draw a normal at N.
d) Using a protractor, measure from the normal the angle of incidence, i = 20^o to draw the incident ray of the angle measured and pin two optical pins P_1 and P_2 on the ray drawn.
e) Replace the glass block back to its outline and aim from face DC to fix pins P_3 and P_4 such that they appear to be in line with the images of P_1 and P_2.
f) Remove the glass block and draw a line through P_3 and P_4 to face DC.
g) Draw a line from normal to meet the line trough P_3 and P_4 to measure the angle of refraction, r.
h) Repeat the procedure d) to g) for i = 30^o, 40^o, 50^o, 60^o and 70^o.
i) Tabulate your result in a suitable table including values of sin i and sin r.
j) Plot a graph of sin i against sin r and determine the slope n of the graph.
<u>Conclusion</u>
- ❖ The graph sini against sinr is a straight line this verifies Snell's law.
- ❖ The slope of the graph is the refractive index of the glass block.

Example 1:
A ray of light travels from air into water at angle of incidence of 60^o. Calculate the angle of refraction given that the refractive of water is 1.33.

Solution
Given; i = 60^o n = 1.33 r = ?

Ray Diagram



From Snell's law

$\cap_{air} \sin i_{air} = \cap_{water} \sin i_{water}$

$1 \sin 60 = 1.33 \sin r$

$$\sin r = \left(\frac{0.866}{1.33}\right)$$

$$r = \sin^{-1}\left(\frac{0.866}{1.52}\right)$$

$r = 41.7^0$

Example 2:

A ray of light traveling through air strikes glass at an angle of 40° to the surface. Given that the refractive index of glass is 1.45, find the;

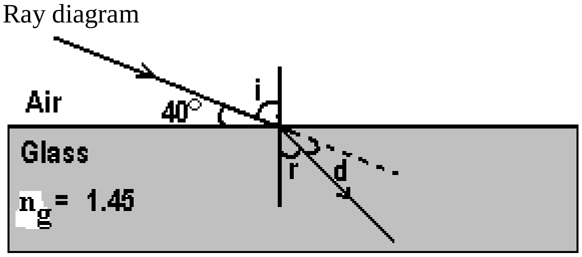
(i) Angle of refraction

(ii) Angle of deviation (angle through which the ray is bent from its original direction).

Solution

Given; Ɵ = 40° n = 1.45 r = ?

Ray diagram



Where; r = angle of refraction

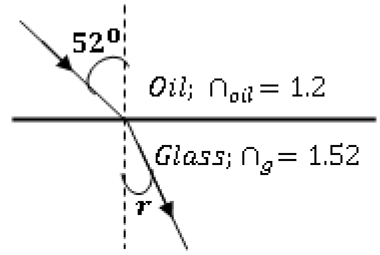
d = angle of deviation

From the angle properties	Angle of deviation, d
$40^0 + i = 90^0$ $i = 90^0 - 40^0$ $i = 50^0$ From Snell's law $\cap_{air} \sin i_{air} = \cap_{water} \sin i_{water}$ $1 \sin 50 = 1.45 \sin r$ $\sin r = \left(\frac{0.766}{1.45}\right)$ $r = \sin^{-1}\left(\frac{0.766}{1.45}\right)$ $r = 31.9^0$	*From the diagram,* $r + d = i$ $31.9^0 + d = 50^0$ $d = 18.1^0$

Examples 3:

If the angle of incidence in oil is 52^0, find the angle of refraction in glass for a ray of light travelling from oil to glass. ($\cap_{oil} = 1.2$ and $\cap_{glass} = 1.52$)

Solution:



Using Snell's law;

$\cap \sin i = \text{constant}$

$\cap_{oil} \sin i_{oil} = \cap_{glass} \sin i_{glass}$

$1.2 \sin 52 = 1.52 \sin r$

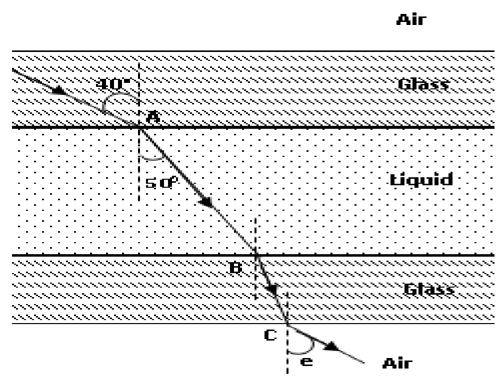
$$\sin r = \left(\frac{0.9456}{1.52}\right)$$

$$r = \sin^{-1}\left(\frac{0.9456}{1.52}\right)$$

$r = 38.47^0$

Examples: 4

The diagram bellow shows a liquid sandwiched between two glass slabs of refractive index 1.5. A ray of light begins from the upper glass slab and it latter emerges into air.



Find the;

(i) Refractive index of the liquid.[$n_L = 1.26$]

(ii) Angle of emergency in air. [$e = 74.6^0$]

Example 5:

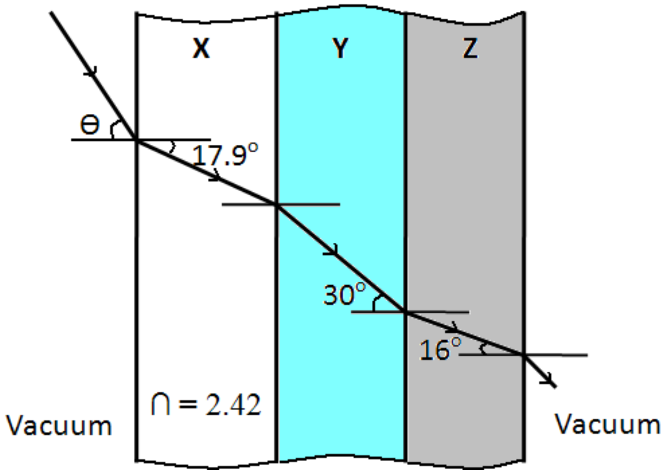
White light was observed to travel from vacuum through multiple boundaries of transparent media X, Y and Z, parallel to each other as shown below. Calculate the;

(i) Angle Ɵ

(ii) Refractive index of Y

(iii) Speed of light in X

(iv) Refractive index of Z with respect to X



Real and Apparent Depths

Real depth

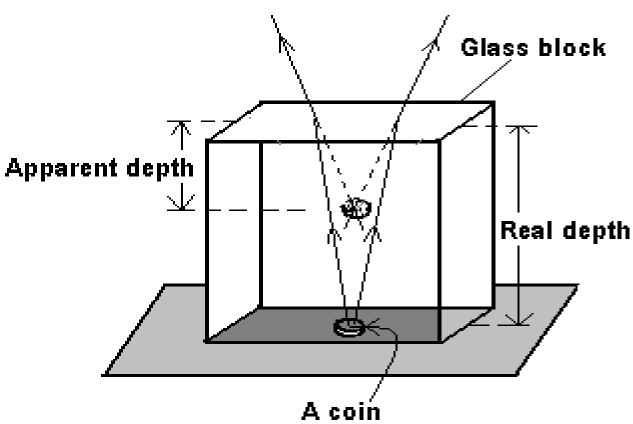
Real depth is the depth where the object is actually placed or laying under the transparent medium of different optical density to the surrounding medium. i.e. Real depth is the actual height of the medium in its desired dimension.

Apparent depth

Apparent depth is the depth where the object appears to be when observed through the transparent medium of different optical density to the surrounding medium.

The real and apparent depth of an object viewed through a transparent material can be used to determine the refractive index of the transparent material.

Illustration of real depth and apparent depth

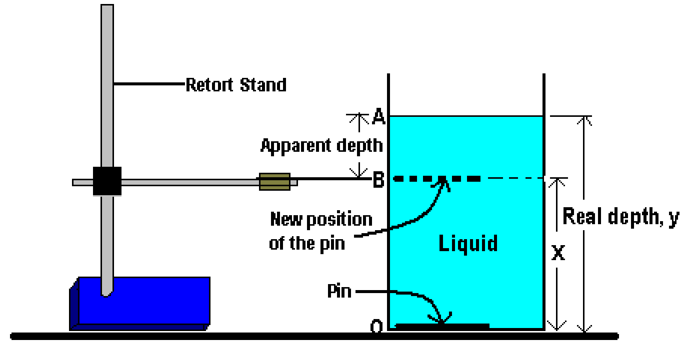


Determination of refractive index of Liquid using real depth and apparent depth.

Apparatus:

Beaker, Retort stand, Pins, Liquid, Half metre rule

Diagram:



Procedure:

Pour liquid in a beaker and measure the height, y (real depth) of the liquid in the beaker

Place a pin at the bottom of the beaker with its point touching the side of the beaker.

Support another pin on the clamp at the side of the beaker using plasticine.

Observe from the edge of the beaker and adjust the pin on the clamp until it appears to be on the same level with the pin in the beaker.

Now measure the height, x from the bottom of the beaker where the pin in liquid appears to determine the apparent.

Divide the real depth of the pin in liquid by the apparent depth of the same pin to determine the refractive index, n of the liquid.

$$\text{Refractive index, n} = \frac{\text{Real depth}}{\text{Apparent depth}}$$

$$n = \frac{y}{y - x}$$

Example: 1

A pin placed at the bottom of the liquid appears to be at a depth of 8.3 cm when viewed from above. Find the refractive index of the liquid if the real depth of the liquid is 11 cm.

Solution

Given, Real depth = 11 cm

Apparent depth = 8.3 cm

$$\text{Refractive index, n} = \frac{\text{Real depth}}{\text{Apparent depth}}$$

$$n = \frac{11}{8.3}$$

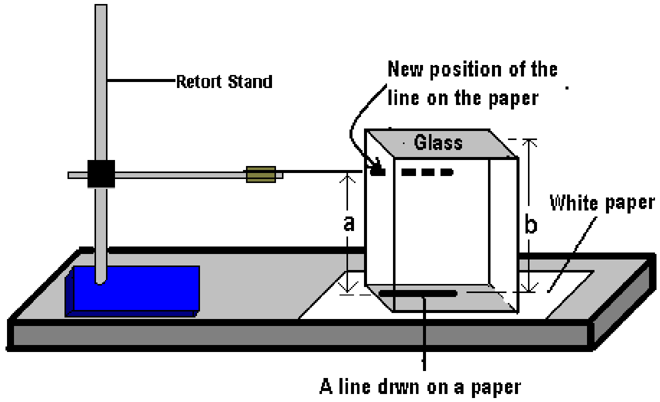
$$n = 1.33$$

Determination of refractive index of glass using real depth and apparent depth.

Apparatus:

Glass block, Retort stand, optical Pin, White sheet of paper Half metre rule

Diagram:



Procedure:

Draw a line on a white sheet of paper and place a glass block a above it as shown.

Look down at the edge of the glass perpendicular to the tip of the line drawn on the paper.

Adjust the search pin on the clamp until it is at the same level as the line drawn on the paper. Ensure no parallax i.e. the pin and the image of the line should appear to be one on moving the head to and fro the line of observation.

Measure the distance, a and b respectively to determine the apparent depth of the line

Refractive index of the glass block is then obtained from;

$$\text{Refractive index, n} = \frac{\text{Real depth}}{\text{Apparent depth}}$$

$$n = \frac{b}{b - a}$$

Example: 2

A glass block of height 9 cm is placed on a coin of negligible thickness. The coin was observed to be at 3 cm from the bottom of the glass block when viewed from above. Find the refractive index of the glass.

Solution

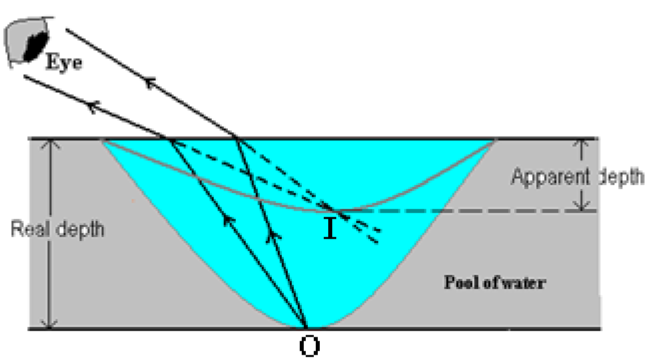
$$\text{Refractive index, n} = \frac{\text{Real depth}}{\text{Apparent depth}}$$

$$n = \frac{9}{9 - 3} = \frac{9}{6}$$

$$n = 1.5$$

Effects of refraction:

(i) A swimming pool appears shallower that its actual depth

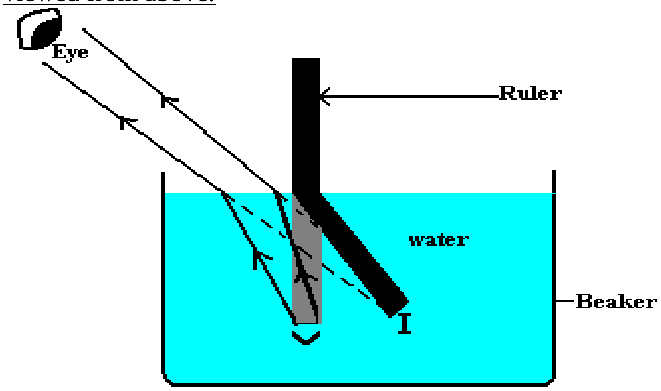


Explanation

This is because light rays from the bottom are refracted away from the normal at the water to air boundary.

These rays appear to come from the point I not O, so at the point I the pool appear shallower than it is.

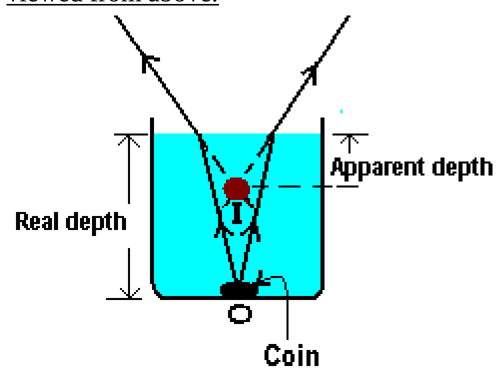
(ii) A ruler placed in a glass of water appears bent when viewed from above.



Explanation

Rays of light from the point V of the ruler pass from water to air and are bent away from the normal as it emerges to the less dense medium. As it enters the eye, it appears to be coming from the point I above V.

(iii) A coin or even written mark placed at the bottom of water in a beaker or basin appears to be on top when viewed from above.



Explanation

This is due to refraction of light from the coin at O. As light passes through the water to air boundary, the ray is refracted away from the normal in air and appear to be originating from the point I (apparent depth) above the actual point O (Real depth) at the bottom of the container.

This effect and explanation is also factual for an object or mark under other medium like glass block and even glass prism.

(iv) Twinkling of the stars in the sky at night. Stellar or astronomical scintillation)

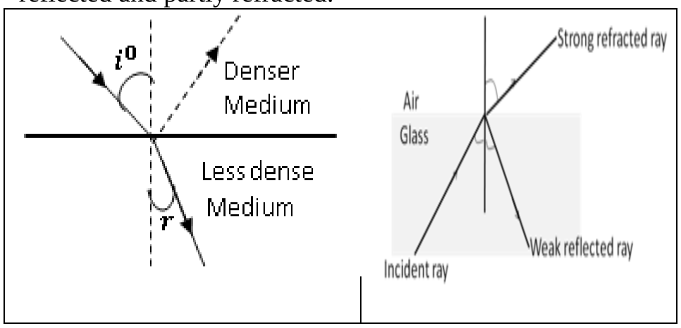
Stars in the sky twinkle because they are so far from the earth and so they appear as tiny pin points as seen from the earth, even through telescopes. Light from the star is refracted many times and in random directions by different temperature and density turbulent (moving) thick air layers of the earth's atmosphere.

Thus the random refraction causes the star to look as though it moves a bit, and our eyes interpret this as twinkling.

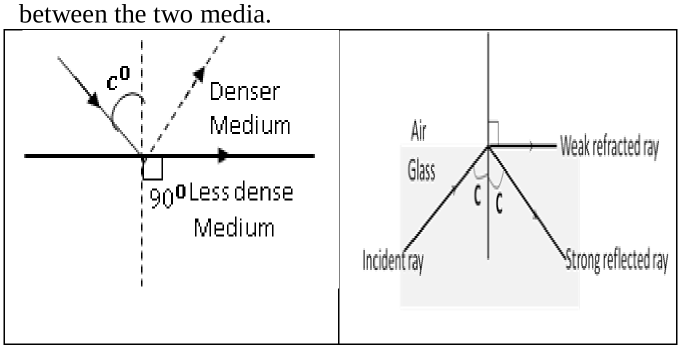
Distant stars twinkle more than those near because light from distant stars has to be subjected to more refractions than that from near by stars.
Planets do not twinkle because they are close, and thus appear larger in our sky, or tiny disks instead of pin points.

TOTAL INTERNAL REFLECTION AND CRITICAL ANGLE

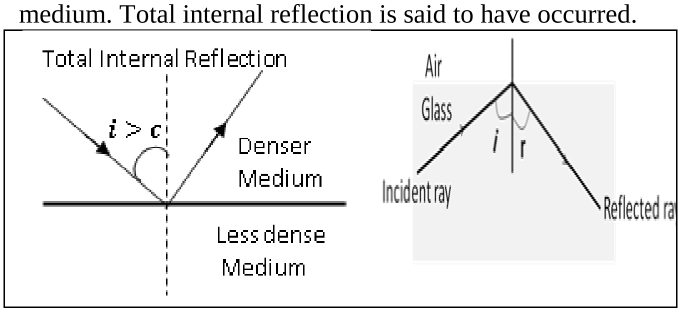
Consider monochromatic light propagating from a dense medium and incident on a plane boundary with less dense medium at a small angle of incidence. Light is partly reflected and partly refracted.



As the angle of incidence is increased gradually, a stage is reached when the refracted ray grazes the boundary between the two media.



The angle of incidence **c** is called the critical angle.
Hence **critical angle** *is the angle of incidence in a denser medium which makes the angle of refraction in a less dense medium 90°.*
When the angle of incidence is increased beyond the critical angle, the light is totally internally reflected in the denser medium. Total internal reflection is said to have occurred.



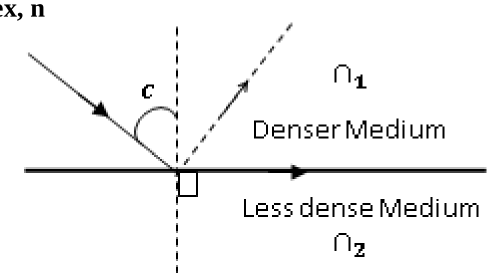
Hence **Total Internal Reflection** is the process where all the incident light energy is reflected back in the optically denser medium when the critical angle is exceeded.

Conditions for Total Internal reflection to occur.

(i). Light must be moving from an optically denser medium (e.g glass) to a less dense medium (e.g air).

(ii). The angle of incidence in the optically denser medium must exceed (greater than) the critical angle. **[$i > c$].**

Relationship between critical angle, c, and refractive index, n



Using Snell's law:

$\cap_1 \sin i_1 = \cap_2 \sin r_2$

$\cap_1 \sin c = \cap_2 \sin 90$

$$\sin c = \frac{\cap_2}{\cap_1}$$

If the lens dense medium is air or a vacuum;

$$\sin c = \frac{1}{\cap_1}$$

Calculation involving critical angle and refractive index

At critical angle, the angle of refraction is 90° i.e. r = 90°. And the ray is from more optically dense medium i.e glass to a less optically dense medium i.e. air. So,
From Snell's Law:

$\cap_g \sin i_g = \cap_{air} \sin r_{air}$

$\cap_g \sin C = \sin 90^o$; But $\sin 90^o = 1$

$$\cap_g \sin C = 1 \quad \Leftrightarrow \quad \cap_g = \frac{1}{\sin C}$$

Where $\cap_g =$ Refractive index of the glass and C is the critical angle.

Example: 1

Calculate the refractive index of the glass if the critical angle of the glass is 48°.

Solution:

Give; C = 48°, $\cap_g = ?$

$\cap_g \sin i_g = \cap_{air} \sin r_{air}$

$\cap_g \sin 48 = 1 \times \sin 90^o$; But $\sin 90^o = 1$

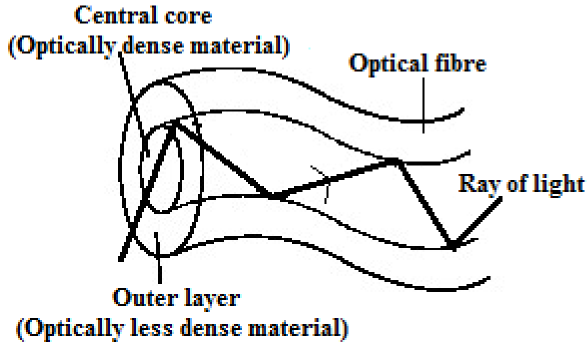
$\cap_g = 1.5$

Applications of total internal reflection

(i) Optical fibbers
(ii) Submarine periscopes
(iii) Erecting and Reversing prisms
(iv) Transmission of radio signals

(i) Light pipes and Optical fibres

An optical fibre is a flexible and transparent material mad by drawing glass (silica) or plastic.
An optical fibre is made up of two types of materials; the central core made from a more optically dense materialsurrounded by a an outer less optically dense material (called a cladding) as shownbelow;

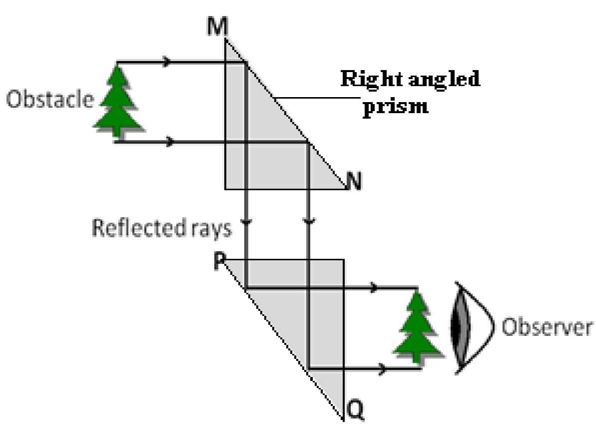


Total internal reflection is how optical fibers (long strands of optically pure glass with a high index of refraction) are used to transmit information over long distances, using pulses of light.

Optical fibres are used to transmit picturesor pictures images. A special type of an opticalfibre known as an **endoscope** is used tostudy the inner layers of the alimentary canalby passing it through the patient's mouth orotherwise and the degree of infection due tostomach ulcers can be determined.

for example, by doctors as an 'endoscope to obtain an image from inside the body or by engineers to light up some awkward spot for inspection. The latest telephone cables' are optical (very pure glass) fibres carrying information as pulses of laser light.

(ii) Submarine periscope:

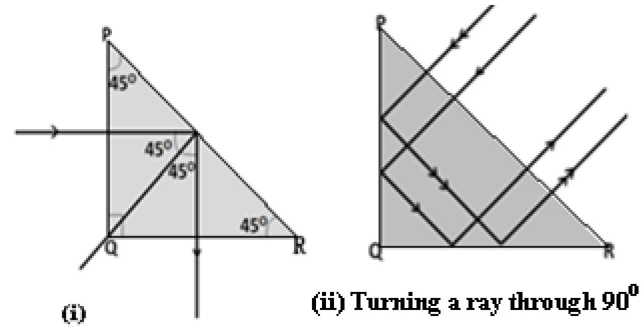


Light from a distant object meets the surface MN at 45°; so light is totally internally reflected downwards.

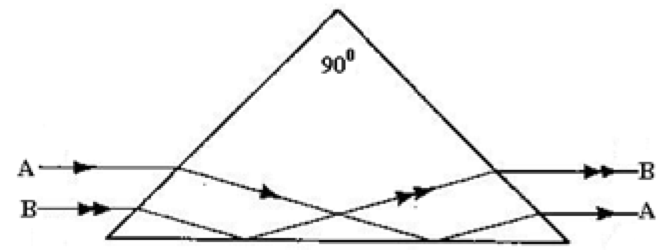
The reflected light is incident to the surface PQ where it is totally internally reflected to give the emergent light to the observer.

(iii) Totally reflecting prism

The critical angle of a glass prism is **42°** and a ray is normally incident on face PQ thus un deviated i.e. not refracted. Total internal reflection occurs and a ray is turned through 90°.



(i) (ii) Turning a ray through 90°



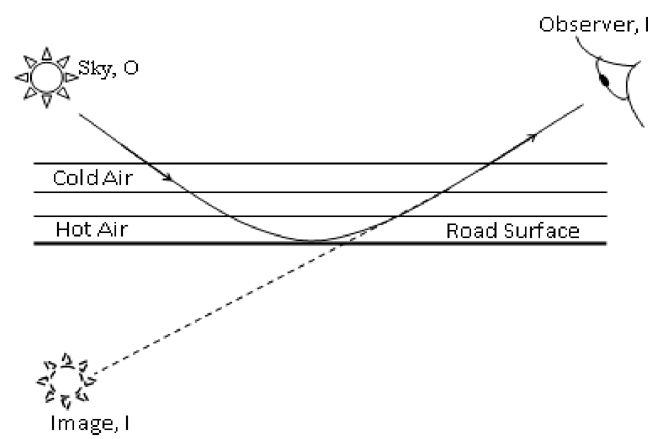
(iii) Turning a ray through 180°

The critical angle of glass is 42° and rays are incident normally on face PR. At face PQ, the rays are incident at 45° so total internal reflection occurs.

Effects of total internal reflection (Natural phenomenon of Total Internal reflection)

(i) Mirage

On a sunny day or in desert areas, it is common to observe something like water on the ground, but when you travel to that point there is no water. This is what we call a mirage (an optical illusion).



Explanation

- ✓ Gradual refraction:

On a hot day light from the sky is gradually refracted away from the normal as it passes through layers of warm but less dense air near hot road.

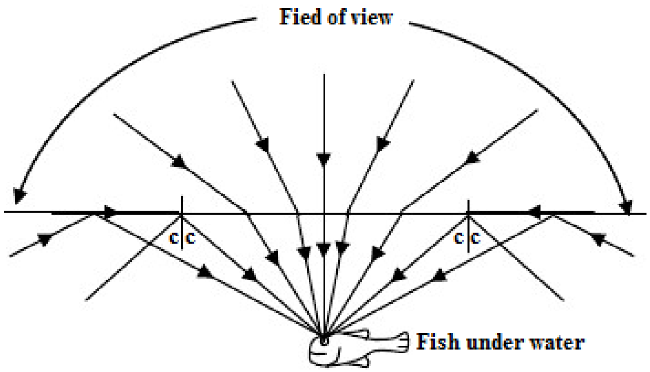
- ✓ Total internal reflection:

The refractive index of warm air is slightly smaller than that of cool air, so when light meets a layer at critical angle, it suffers total internal reflection thus to the observer the road appears to have a pool of water.

(ii) Fish's view:

The fish in water enjoys a wider field of view in that it views all objects under water and those above the water surface as long as the water surface is calm.

Objects above the water surface are viewed as a result of refraction while those under the water surface are viewed as a result of total internal reflection. However this is only true if the water surface is calm.



The use of prisms are preferred to plane mirror

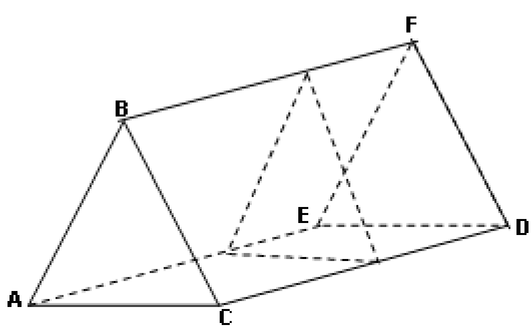
- ✓ Prisms produce clear image
- ✓ Prisms do not tarnish and deteriorate as mirror.

However, plane mirrors are not used in submarine periscope because:

- Several images of one object are formed at the back by plane mirror due to multiple reflection inside the glass i.e. plane mirror produces blurred images.
- Plane mirrors absorbs more light than prisms so the image produced is fainter.

REFRACTION THROUGH A TRIANGULAR PRISM

Refraction by glass prism



BF= Refracting edge

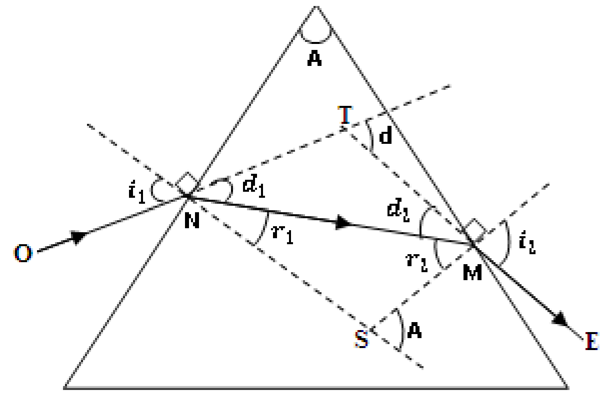
AB and BC = Refracting surface

AC and ED = Base

ABC and DEF = Principle section (or any other plane perpendicular to the refracting edge).

Angle ABC = Refracting angle or angle of the prism.

Representation of a Prism.



Rays: ON = Incident ray; Angle i_1 = angle of incidence

NM = Refracted ray; Angle r_1 = angle of refraction

ME = Emergent ray; Angle i_2 = angle of emergence

Lines: NS and MS = Normal lines on either sides.

Angle A = angle of the prism or refracting angle.

Deviation of light by a prism

Considering Deviation at N,

$i_1 = r_1 + d_1 \Leftrightarrow d_1 = i_1 - r_1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (i)$

Considering Deviation at M,

$i_2 = r_2 + d_2 \Leftrightarrow d_2 = i_2 - r_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (ii)$

From Triangle NMT:

$d = d_1 + d_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (iii)$

Putting equations (i) and (ii) into Equation (iii) gives:

$d = (i_1 - r_1) + (i_2 - r_2)$

$d = (i_1 + i_2) + (-r_1 - r_2)$

$d = (i_1 + i_2) - (r_1 + r_2) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (iv)$

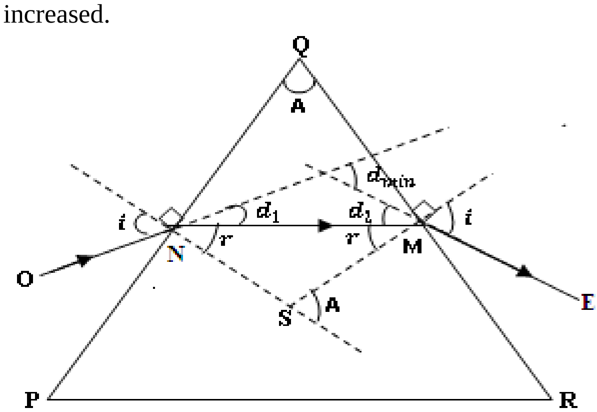
From Triangle NMS:

$A = r_1 + r_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (v)$

$\boldsymbol{d = (i_1 + i_2) - A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (vi)$

Minimum Angle of Deviation

<u>Definition:</u> is the smallest angle to which angle of deviation decreases when the angle of incidence is gradually increased.

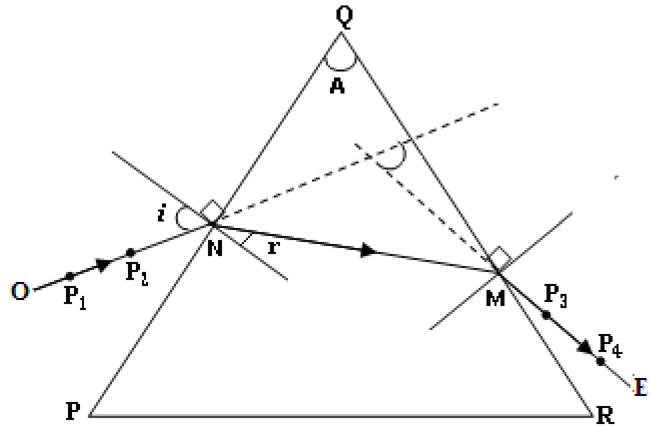


<u>Condition for minimum deviation position:</u>

- ✓ Ray of light MN in the prism is parallel to the base of the prism.
- ✓ Incidence angle and emergency angles are equal.
- ✓ Light passes symmetrically rough the prism.

The angle of incidence, i = angle of emergency, e

Experiment to measure the refractive index of a triangular glass prism.



✓ Outline of the prism

The prism is placed on a paper and its outline ABC is drawn and then the prism is removed. Draw the normal at M and measure the angle of incidence, i. Place the pins P_1 and P_2 on the incident ray.

✓ Obtaining the refracted ray.

Replace the prism to its outline. By looking through the prism from side QR, pins $\mathbf{P_3}$ and P_4 are placed such that they are in a straight line with images of P_1 and P_2 in the prism.

Draw a line to join point N to M from which the angle of refraction on AC is measured.

✓ Repeating the procedures and tabulating the results

Repeat the procedures for different values of i and obtain different values of r.

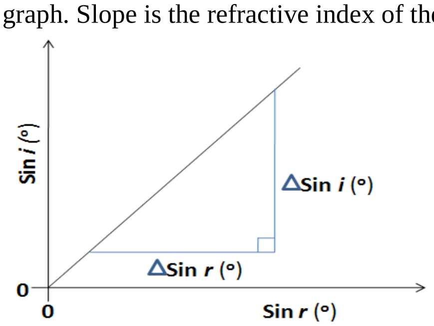
Record the results in a suitable table including values of sin i and sin r as shown below

Table of result:

$i(^0)$	$r(^0)$	Sini	Sinr

✓ Plotting the graph

Plot a graph of sin i against sin r to determine the slope of the graph. Slope is the refractive index of the prism.



Note: For a light ray travelling in a medium like water to glass, then the refractive index of glass with respect to water is calculated from:

$${}_w\cap_g = \frac{\cap_g}{\cap_w} = \frac{\sin r_2}{\sin i_2}$$

In general, the refractive index of any medium X with respect to another first medium Y is given by:

$${}_Y\cap_X = \frac{\cap_X}{\cap_Y}$$

Where; $\cap_X =$ refractive in dex of X

$\cap_Y =$ refractive index of Y

For calculation, your are required to use;

$$\cap_Y \sin i_Y = \cap_X \sin r_X$$

Example 1:

A ray of light is incident on water – glass boundary at 41o. Calculate r if the refractive indices of water and glass are 1.33 and 1.50 respectively.

Solution:

Given; $\cap_g = 1.5$, $\cap_w = 1.33$, $\mathbf{i_w} = 41^o$ and $\mathbf{r_g} = ?$

From ;$\cap_Y \sin i_Y = \cap_X \sin r_X$

$\cap_w \sin i_w = \cap_g \sin r_g$

$1.33\sin 41^o = 1.50 \sin r$

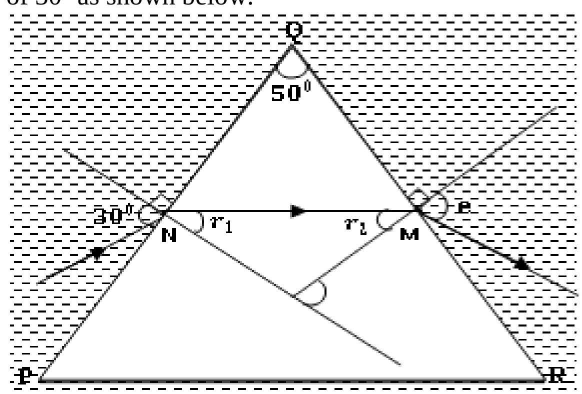
$$\sin r = \frac{1.33\sin 41^o}{1.50}$$

$$r = \sin^{-1}\left(\frac{1.33\sin 41^o}{1.50}\right)$$

$$r = 35.5^o$$

Example: 2

A ray of light propagating in a liquid is incident on a prism of refractive angle 50^0 and refractive index 1.6, at an angle of 30^0 as shown below.



If light passes through the prism symmetrically, calculate the;

(i). Refractive index of the liquid.

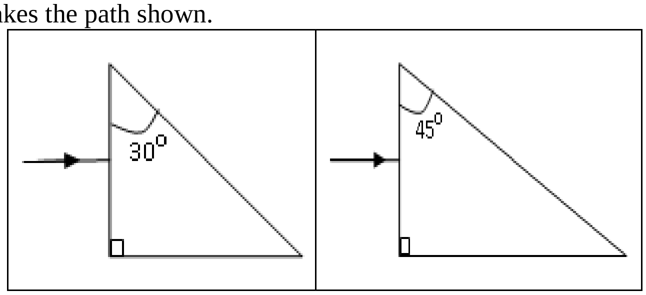
(ii). Angle of deviation.

Solution.

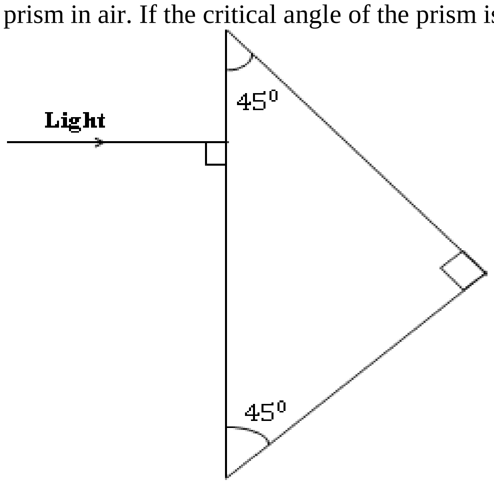
(i) Applying Snell's law at N: $\cap_L \sin i = \cap \sin r_1$ $\cap_L \sin 30 = 1.6 \sin r_1 \dots (i)$ Applying Snell's law at M: $\cap \sin r_2 = \cap_L \sin e$ $1.6 \sin r_2 = \cap_L \sin e \dots (ii)$ But, also; $r_1 + r_2 = A$ $r_1 + r_2 = 50 \dots\dots\dots (iii)$ But since light passes through the prism symmetrically, then;	❖ $r_1 = r_2 = r$; Thus $2r = 50 \Leftrightarrow r = 25^0 \Leftrightarrow r_1 = r_2 = 25^0$ ❖ $e = i \Leftrightarrow e = 30^0$ Thus from equation (i); $\cap_L \sin 30 = 1.6 \sin r_1$ $\cap_L \sin 30 = 1.6 \sin 25^0$ $\cap_L = \frac{1.6 \sin 25^0}{\sin 30}$ $\cap_L = 1.35$

(ii).
$d = (i_1 + i_2) - A$
$d = (i + e) - 50$
$d = (30 + 30) - 50$
$d = 10^0$

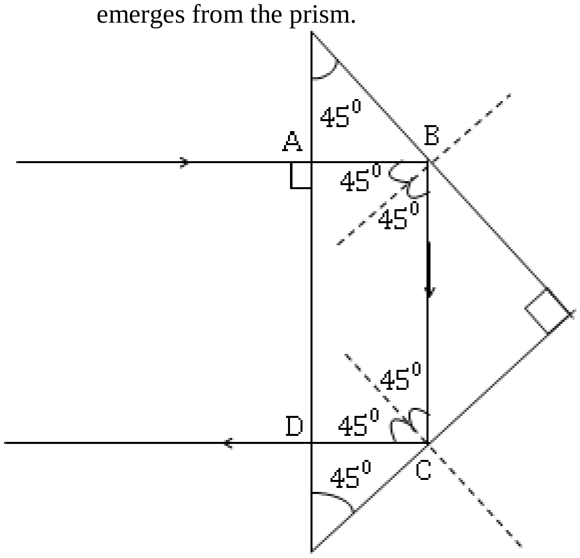
Example 3.
The figures below show two right angled prisms of refracting angles 30^0 and 45^0respectively. Rays of light are incident normally on the faces of the prisms below. Complete the diagrams to show the path taken by the incident ray through each prism hence explain why light takes the path shown.



The figure below shows light incident normally on a glass prism in air. If the critical angle of the prism is 42^0.



(i) Complete the diagram t o show the path of light as emerges from the prism.



At points B and C, light is moving from a denser to a less dense medium and angle of incidence is greater than the critical angle. [45^0> 42^0]. Thus, total internal reflection occurs.

At points A and D, the incident light is not deviated because it is incident normally to the surface of glass.
The angle of incidence, $i = 0^0$ and from Snell's law,

$$\cap_a \sin i = \cap_g \sin r$$
$$1 \times \sin 0 = \cap_g \sin r$$
$$0 = \cap_g \sin r$$
$$\sin r = 0$$
$$r = 0$$

Hence the ray is not deviated

(ii) Calculate the refractive index of the glass prism
Applying Snell's law at B

$$\cap_Y \sin i_Y = \cap_X \sin r_X$$
$$n \sin C = 1x \sin 90$$
$$n \times \sin 42 = 1 \times \sin 90$$
$$n = 1.49$$

TRIAL QUESTIONS

1. A prism of refractive 1.5 and refractive angle 60^0 has an angle of refraction of 28^0 on the 1^{st} face. Determine
   a) angle of incidence i [44.7^0]
   b) angle of refraction on 2^{nd} face r_2 [$r_2 = 32^0$]
   c) angle of emergency i_2 [$i_2 = 52.6^0$]
   d) angle of deviation d [37.34^0]

2. Critical angle of a certain precious stone is **27^0**. Calculate the refractive index of the stone.

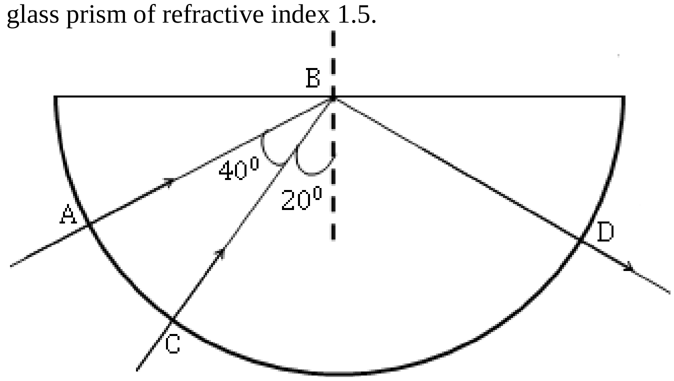
3. See UNEB Paper I

1994 Qn.40	1995 Qn.24	1996 Qn.1	1996 Qn.35

4. UNEB 1990 Qn. 4
(a) (i) State the laws of refraction.
(ii) What is meant by refractive index?
(b) Describe a simple experiment to determine the refractive of the glass of a triangular prism.
(c) The angle of refraction in glass is 320. Calculate the angle of incidence if the refractive index of glass is 1.5.

5. UNEB 1996 Qn. 3 PII
(a) What is meant by the following terms;
(i) Critical angle
(ii) Total internal reflection
(b) State; (i) two conditions for total internal reflection to occur.
(ii) One application of total internal reflection.

6. UNEB 1993 Qn. 9 . Check UNEB 2005 PP1 No. 41
The diagram below shows rays of light in a semi-circular glass prism of refractive index 1.5.



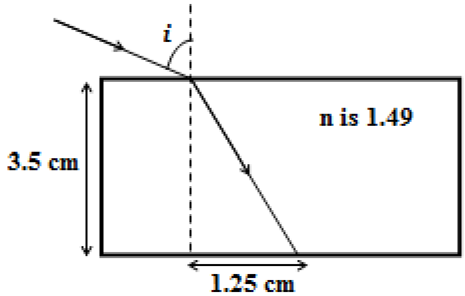
(a) Explain why ray AB;

(i) Is not refracted on entering the block at A.

(ii) Takes path BD on reaching B.

(b) Ray CB is refracted at B. Calculate the angle of refraction.

7. A ray of light is incident on a glass block of refractive index 1.49 as shown below.



Calculate the angle of incidence, ***i***.

8. UNEB 1996 Qn. 4; UNEB 1987 Qn. 7; UNEB 2001 Qn.46. UNEB 2017 PP2

REFRACTION THROUGH LENSES

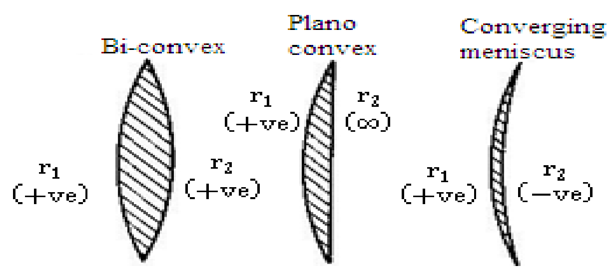
Definition:

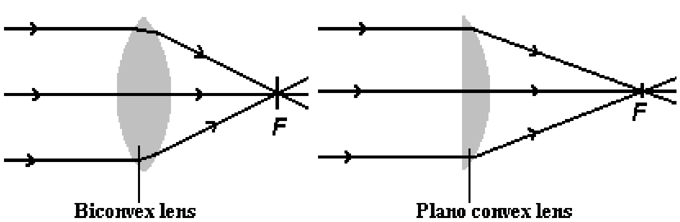
Lenses are spherical surfaces of transparent materials. The materials may be glass, plastics, water, etc.

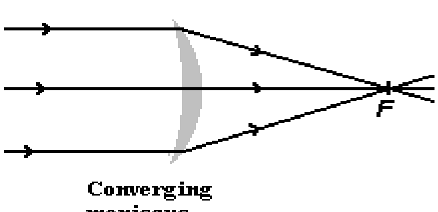
Types of Lenses:

(i) Converging Lenses (Convex Lens):

A convex lens is thick in the center. It is also called a converging lens because it bends light rays inwards. There are three examples if convex lenses, namely:



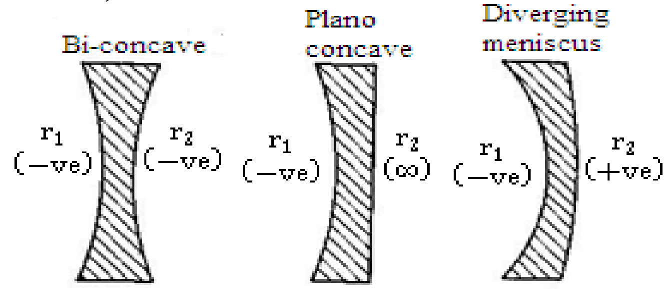


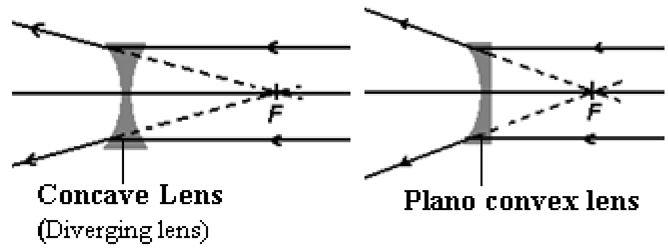


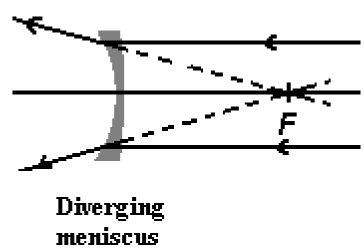
A converging lens (Convex lens) is one in which all parallel beams converge at a point (principle focus) after refraction.

(ii) Diverging Lens (Concave Lens):

A concave lens is thinnest in the central and spreads light out. A concave lens is also called a divergent lens because all rays that are parallel to the principal axis diverge after refraction;

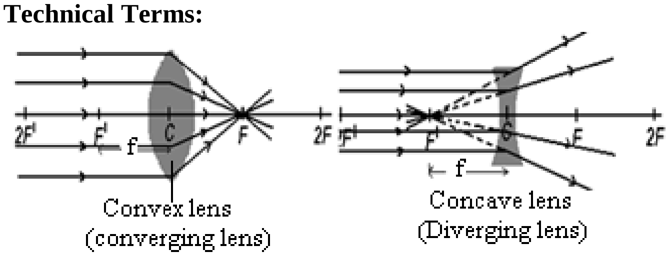






In a diverging lens, refracted ray seems to come from the point after refraction.

Technical Terms:



- Pole of a lens:

Is the centered point of the surface of the lens through which the principal axis passes.

- Optical Centre: (C)

Is the point on the principle axis mid way between the lens surfaces. It is the centre of the lens at which rays pass un deviated.

- Principal Axis:

Is the line through the optical center of the lens on which the principal focus lies.

- Principal Focus, F:

<u>Convex lens.</u>

Is the point on the principal axis at which all rays parallel and close to the principal axis meet after refraction thru the lens.

Concave lens.
This is the point on the principal axis of a concave lens at which all rays parallel and close to the principal axis appear to diverge from after refraction thru the lens.

- Focal Length, f:

Is the distance between the optical center and the principal focus.

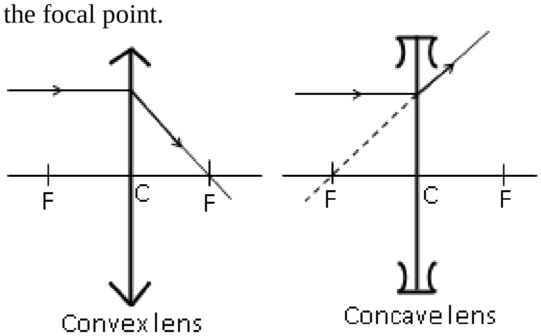
Note: The principal focus of a converging lens is real while that of a diverging lens is virtual.
Real principal focus is one at which actual rays meet after refraction.

1. Centers of curvature, 2F: Is the centre of the sphere of which the lens surfaces form part. OR It is a point on the principle axis where any ray through it hits the lens at right angles.

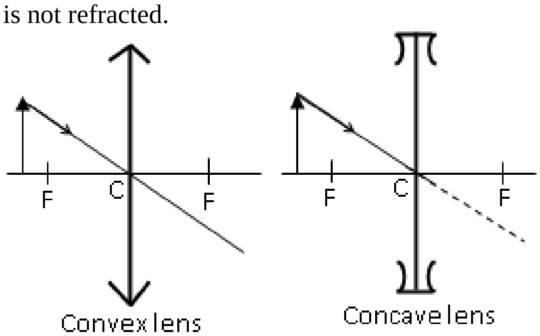
2. Radius of curvature: Is the radius of the sphere of which the lens forms part. OR It is the distance between the optical centre and the centre curvature of the lens.

Ray Diagram for a Convex (Converging) Lens.
In constructing ray diagram, 2 of the 3 principal rules are used.

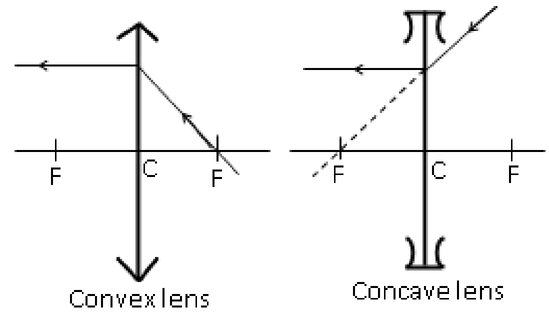
1. A ray parallel to the principal axis is refracted through the focal point.



2. A ray through the optical centre passes un deviated i.e. is not refracted.

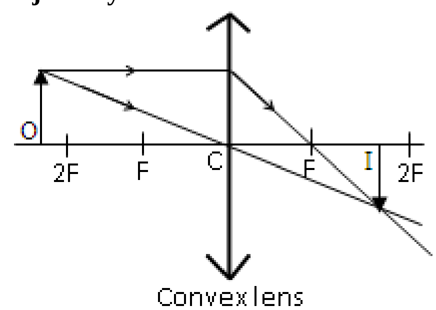


3. A ray through the principal focus emerge parallel to the principal axis after refraction.



Images formed by convex lenses:
The nature of the image formed in a convex lens depends on the position of the object from the lens.

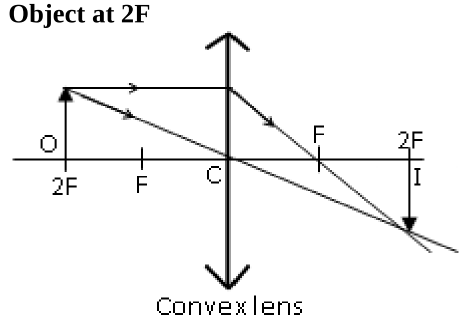
(a) **Object beyond 2F**



Characteristics of the image:

- Nature: Real and Inverted.
- Position: Between F and 2F.
- Magnification: Diminished

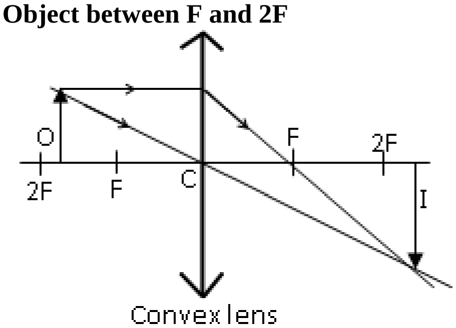
(b) Object at 2F



Characteristics of the image:

- Nature: Real and Inverted.
- Position: At 2F.
- Magnification: Same size as object.

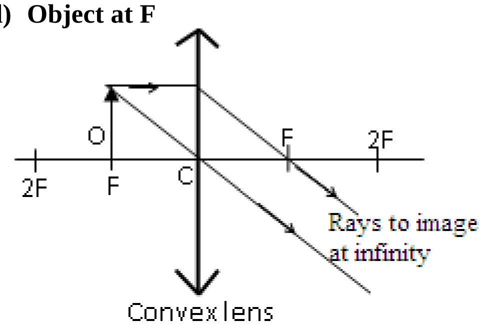
(c) Object between F and 2F



Characteristics of the image:

- Nature: Real and Inverted.
- Position: Beyond 2F.
- Magnification: magnified.

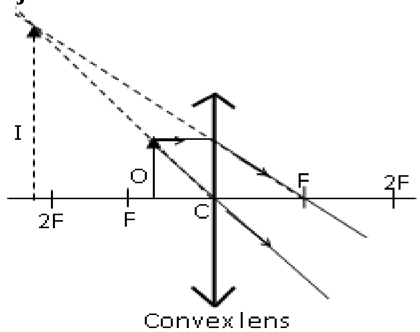
(d) Object at F



Characteristics of the image:

- Nature: Real and Inverted.
- Position: At infinity.
- Magnification: magnified.

(e) Object between F and C



Characteristics of the image:

- Nature: Virtual and Upright or erect.
- Position: On the same side as the object.
- Magnification: magnified.

When the object is placed between F and C, the image is magnified and this is why the convex lens is known as a magnifying glass.

Summary of the useful rays

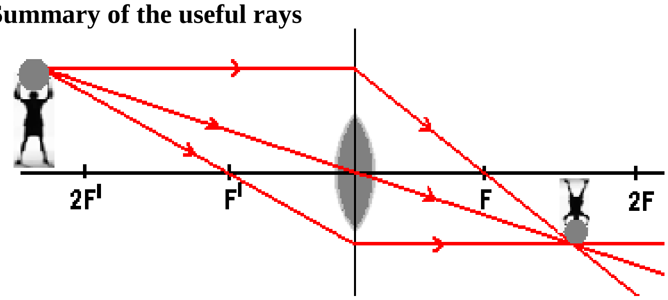
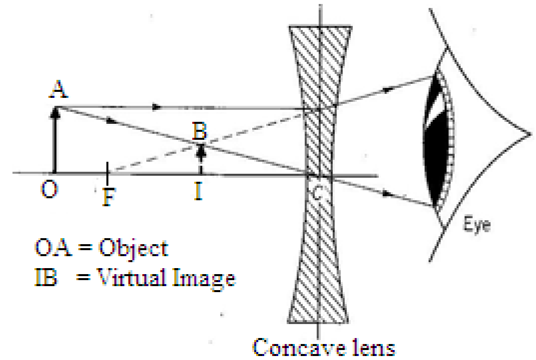
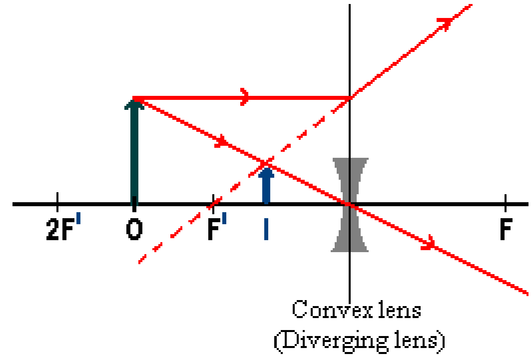


Image Formation in a Concave Lens

Irrespective of the position of the object, a concave lens forms an image with the following characteristics:

- Nature: Virtual and Upright or erect.
- Position: Between F and C.
- Magnification: Diminished.





Magnification of lens:

$$\text{Magnification, M} = \frac{\text{image height, h}}{\text{object height, H}}$$

$$= \frac{\text{Image distance, V}}{\text{Object distance, U}}$$

$$M = \frac{h}{H} = \frac{V}{U}$$

The lens formula:

If an object is at a distance, u forms the lens and image, v distance from the lens, then focal length, f is given by:

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

This applies to both concave and convex.

Real is positive and virtual is negative sign convention:

According to this sign convention;

- All distances are measured from the optical centre of the lens as the origin.
- Distances of real objects and the images are positive.
- Distances of virtual objects and images are negative.
- The principal focus, F of the convex lens is real hence its focal length, f is positive while a concave lens has a virtual principle focus, F and so its focal length, f is negative.

Example 1:

An object of height 10cm is placed at distance 50cm from a converging lens of focal length 20cm. Calculate the;

(i) Image position.

(ii) image height

(iii) magnification

Solution:

Given, H = 10 cm, u = 50 cm, f = 20 cm

v = ? h = ?

Using the mirror formula;

$$\frac{1}{\mathbf{f}} = \frac{1}{\mathbf{u}} + \frac{1}{\mathbf{v}}$$

$$\frac{1}{20} = \frac{1}{50} + \frac{1}{v}$$

$$\frac{1}{20} - \frac{1}{50} = \frac{1}{v}$$

$$\frac{1}{v} = \frac{5-2}{100} = \frac{3}{100}$$

$$\frac{1}{v} = \frac{3}{100}$$

v = 33.33 cm

A real image was formed 33.33cm from the lens.

Using the definition of magnification,

$$M = \frac{h}{H} = \frac{V}{U}$$

$$\frac{h}{10} = \frac{33.33}{20}$$

h = 6.67 cm

Magnification:

$$M = \frac{h}{H} = \frac{V}{U}$$

$$M = \frac{(\frac{100}{3})}{20}$$

M = 0.67

Questions: (Students' Exercise)

1. An object is placed: a) 20 cm b) 5 cm, from a converging lens of focal length 15 cm. Find the;
   - (i) nature of the image in each case .
   - (ii) position, v of the image in each case. (V_a = 60cm ; V_b = 7.5)
   - (iii) Magnification, M of the image in each case. (Ma = 3 ; Mb = 1.5)

2. A four times magnification virtual image is formed of an object placed 12cm from a converging lens. Calculate the;
   (i) position of the image (v = 48 cm)
   (ii) focal length of the lens (f = 10 cm) .

3. Find the nature and position of the image of an object placed 10cm from a diverging lens of focal length 15cm. (Virtual : v = 6cm).

Finding position by graph (scale drawing):

Step I: Select a scale for drawing

Step II: Make a sketch of the drawing; this should include two major rays from a point on the object i.e.

- ✓ A ray parallel and close to the principal axis should be refracted through the focal point for a converging lens while for a diverging lens, the ray parallel and close to the principal axis is refracted in such a way that it appears to come from the virtual focal point.
- ✓ A ray through the optical center should be drawn un deviated.

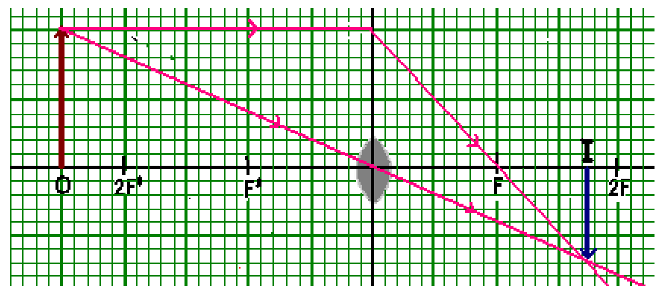
Examples:

An object of height 10cm is placed at a distance of 50cm from a converging lens of focal length 20cm. Find by scale drawing the;

- (i) Image position
- (ii) Image height
- (iii) Nature of the image formed

Solution

Axis	Scale	Conversion
Vertical axis	**1 : 5 cm**	❖ 10 cm $\rightarrow \frac{10}{5} \rightarrow$ 2cm
Horizontal axis	**1 : 10 cm**	❖ 50cm $\rightarrow \frac{50}{10} \rightarrow$ 5cm ❖ 20cm $\rightarrow \frac{20}{10} \rightarrow$ 2cm



(i) Position:

The image distance as measured from the scale drawing is 3cm; using the above scale,

$Image\ distance = (3.4\ x\ 10)\ cm$

$= 34cm$

Size:

The height of the image on the scale drawing is 0.8cm; using the scale,

$Image\ height = (1.4\ x\ 5)\ cm$

$= 7\ cm$

(ii) Nature:

The image formed is; Real, Inverted and Diminished.

(iii) Magnification:

$$\text{Magnification} = \frac{\text{Image Distance}}{\text{Object Distance}} = \frac{34}{50} = 0.68$$

Or

$$\text{Magnification} = \frac{\text{Image Height}}{\text{Object Height}} = \frac{7}{10} = 0.7$$

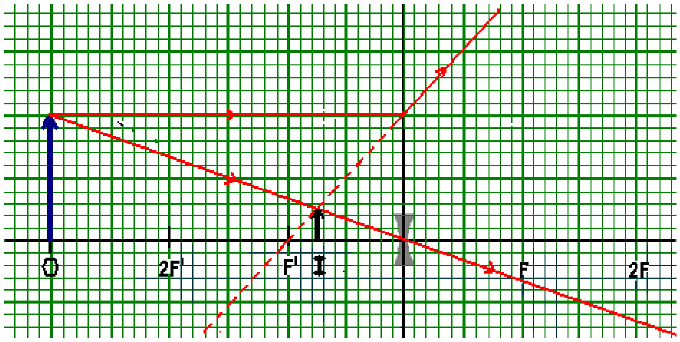
Example: 2

An object of the height 10cm is placed at a distance of 60 cm from a diverging lens of focal length 20cm. Find by scale drawing, the;

- (i) Image position, v
- (ii) Height, h of the image
- (iii) Nature of the image
- (iv) Magnification, M

Solution

Axis	Scale	Conversion
Vertical axis	**1 : 5 cm**	❖ 10 cm $\rightarrow \frac{10}{5} \rightarrow$ 2cm
Horizontal axis	**1 : 10 cm**	❖ 60cm $\rightarrow \frac{60}{10} \rightarrow$ 6cm ❖ 20cm $\rightarrow \frac{20}{10} \rightarrow$ 2cm



(i) Position:
The image distance as measured from the scale drawing is 3cm; using the above scale,
Image distance = (1.5 x 10) cm
= 15cm

Size:
The height of the image on the scale drawing is 0.8cm; using the scale,
Image height = (0.5 x 5) cm
= 2.5 cm

(ii) Nature:
The image formed is; Virtual, Upright and Diminished.

(iii) Magnification:

$$\text{Magnification} = \frac{\text{Image Distance}}{\text{Object Distance}} = \frac{15}{60} = 0.25$$

Students' Exercise

1. An object 1cm tall stands vertically on principal axis of a converging lens of, focal length, f = 1cm, and at a distance of 1.7cm from the lens. Find by graphical construction, the position, size, magnification and nature of the image.

2. An object is 32.5 cm from a diverging lens of focal length 12 cm. by scale drawing;
   (i) Locate the numerical position and the height of the image formed.
   (ii) Calculate the ratio of image magnitude to object height.
   (iii) Describe the image formed using the result in (ii) above.

3. An object is placed 10 cm in front of a concave lens of focal length 20 cm to form an image. Determine the position, nature and magnification of the image using a ray diagram.

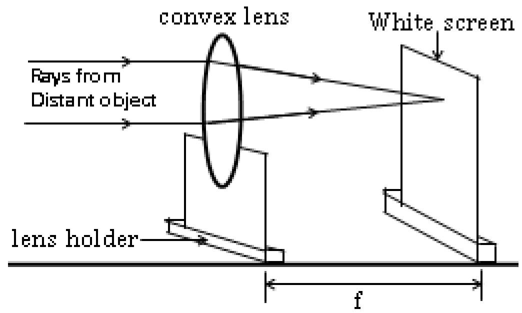
4. An object 5cm tall is placed 15 cm away from a convex lens of focal length 10cm. By construction, determine the position size and nature of the final image.

5. An object 5cm high is placed 20cm in front of a converging lens of focal length 15cm. Find the power of the lens and the magnification of the lens.

6. An object of height 20cm is placed vertically on the axis of a convex lens of focal length 10cm at a distance of 30cm from the lens. Use the graphical method to find the position, nature and magnification of the image.

Experiments to measure focal length of convex lens (Converging lens)

1. Rough method
(Using a distant object, e.g window)

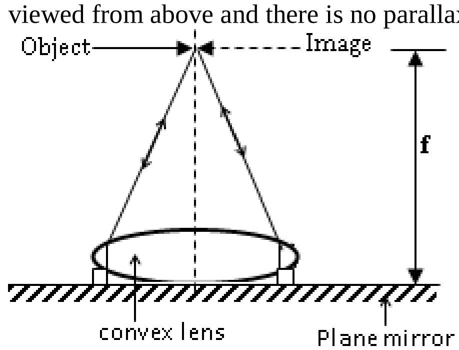


Position the lens and a white screen on a table as shown above.
Move the lens towards and away from the screen until a sharply focused image of the distant object is formed on the screen.
Measure the distance, f between the lens and the screen. It is approximately equal to the focal length of the lens used.

Note:
To improve the accuracy of the results, it is advisable that the experiment is repeated at least three times and the average focal length calculated.

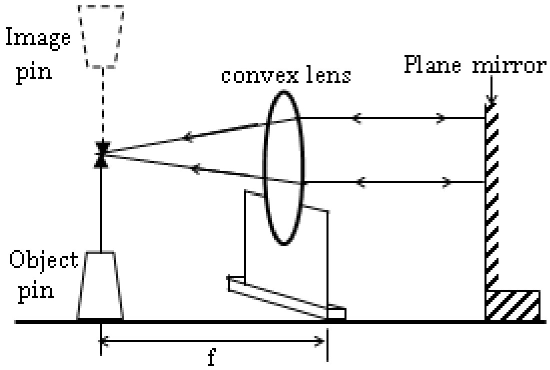
f_1(cm)	f_2(cm)	f_3(cm)	f(cm)
a	b	c	$\frac{(a+b+c)}{3}$

2. Plane mirror method and no parallax
A plane mirror M is placed on a table with its reflecting surface facing upwards. The lens L is placed top of the mirror.
An optical pin, O is then moved along the axis of the lens until its image I coincide with the object O, when both are viewed from above and there is no parallax.



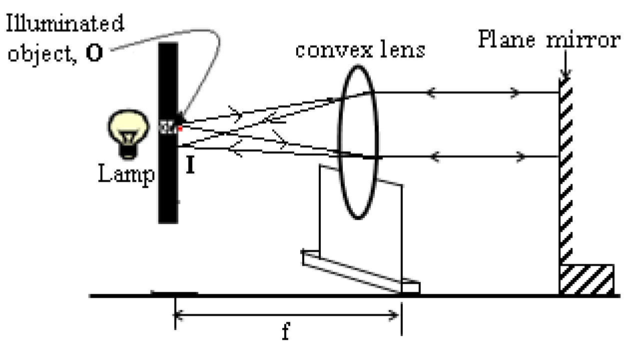
The distance from the pin O to the lens is thus measured and it is equal to the focal length, f, of the lens.

Alternatively, the set up bellow may be used.



NOTE: Rays from O passing through the lens are reflected from the plane mirror M and then pass through the lens a gain to form an image. When O and I coincides the rays from O incident on the mirror must have returned a long their incident path after reflection from the mirror. This happens if the rays are incident normally on the plane mirror, M. The rays entering the lens after reflection are parallel and hence the point at which they converge must be the principle focus.

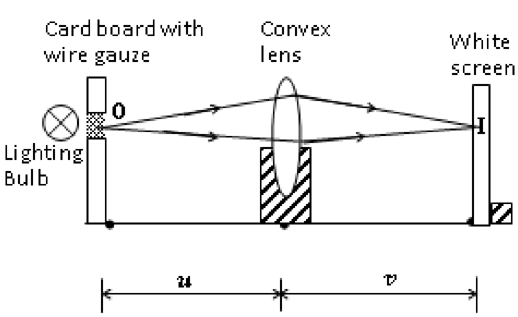
3. **Using illuminated object and plane mirror**



The position of the lens holder is adjusted until a sharp image of the object is formed on the screen alongside the object itself. The object will now be situated at the focal point (focal plane). The distance between the lens and screen is measured and this is the focal length f.

Note: The focal point or focal plane of a lens is a point or a plane through the principal focus at right angle to the principal axis. At this point, rays from any point on the object will emerge from the lens as a parallel beam and are reflected back through the lens.
When the plane mirror is moved away from the lens, the image becomes faint and finall disappears.

4. **Lens formula method**



Using an illuminated object, O at a measured distance, u, move the screen towards and away from the lens until a clear image of the cross wires is obtained on the screen.
The image distance, v is measured and recorded.
The procedure is repeated for various values of u and the corresponding values of v measured and recorded.
The results are tabulated including values of $\frac{1}{u}\, and\, \frac{1}{v}$.

u(cm)	v(cm)	$\frac{1}{u}$(cm^{-1})	$\frac{1}{v}$(cm^{-1})
-	-	-	-

The focal length can be calculated from the equation $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ and the average of the values obtained .

Power of a lens:
Power of a lens is the reciprocal of its focal length expressed in meters. The S.I of power of lens is dioptres (D).
Note: The Focal length of convex les is real so it's positive and hence its power is positive.
The focal length of a concave lens is virtual so it's negative hence its power is negative.

The power of the combination of lenses can be calculated from:

$$\text{The power of the lens; } \mathbf{P} = \frac{\mathbf{1}}{\textbf{focal length in metres}}$$

$$= \frac{\mathbf{1}}{\mathbf{f}}$$

$$\begin{pmatrix}\text{Power of}\\ \text{combination,}\end{pmatrix} = \begin{pmatrix}\text{Power of}\\ \text{first lens}\end{pmatrix} + \begin{pmatrix}\text{Power of}\\ \text{second lens}\end{pmatrix}$$

$$P_{\text{combination}} = \frac{1}{\text{focal length, } f_1 \text{ of first lens}} + \frac{1}{\text{focal lenth, } f_2 \text{ of second lens}}$$

$$P_{\text{combination}} = \frac{1}{f_1} + \frac{1}{f_2}$$

Examples:

1. Two converging lenses of focal lengths 15cm and 20cm are placed in contact, find the power of combination.

Solution
Given, $f_1 = 15 \text{ cm} = 0.15 \text{ m};\ f_2 = 20 \text{ cm} = 0.20 \text{ m}$

$$P_{\text{combination}} = \frac{1}{f_1} + \frac{1}{f_2}$$

$$P_{\text{combination}} = \frac{1}{0.15} + \frac{1}{0.20}$$

$$P_{\text{combination}} = 11.67 \text{ D}$$

2. A convex lens of focal length 20cm is placed in contact with concave lens of focal length 10cm. Find the power of the combination (Ans: -5D).

Solution

Given, $f_1 = 20 \text{ cm} = 0.20 \text{ m}; \ f_2 = 10 \text{ cm} = 0.10 \text{ m}$

$$P_{combination} = \frac{1}{f_1} + \frac{1}{f_2}$$

$$P_{combination} = \frac{1}{0.20} + \frac{1}{-0.10}$$

$$P_{combination} = -5 \text{ D}$$

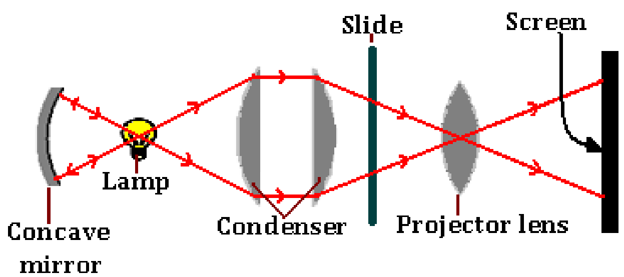
Uses of lenses

- The eye uses it to focus images on the retina
- In spectacles to correct eye defects.
- In lens cameras to focus images on the screen or film.
- In slide projectors to magnify/focus images on the screen.
- In compound microscopes to magnify/ focus images of tiny near objects.
- As simple magnifying glasses, to magnify images of smaller objects without inverting them.

Simple Optical Instruments:

(i) Projector (or Projection Lantern)

A projector is used for projecting the image of a transparent slide onto the screen. Thus the image formed is real.



Mode of Operation

The powerful **source of light (lamp):** is placed at the principal focus of a concave mirror so as to illuminate the slide if the image is to be bright.

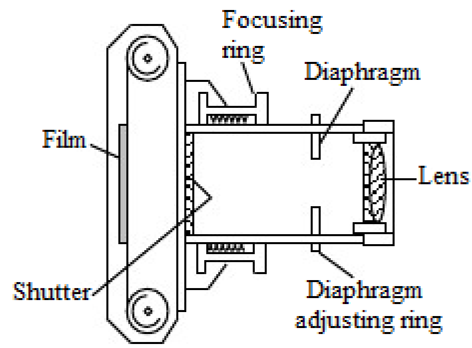
Concave mirror: reflects back light which would otherwise be wasted by being reflected away from the film.
Condenser; this is the combination of two Plano convex lenses. The main function is to collect the rays from the light source and concentrate them onto the slide.

Slide: It contains the object whose image is to be projected on the screen.

Projector lens: is mounted on a sliding tube so that it may be moved to and fro to focus a sharp real image on the screen.

(ii) Lens Camera

A camera is alight tight box in which a convex lens forms a real image on a film.



PART	FUNCTION
Diaphragm	Regulates the amount of light reaching the film.
Shutter	Opens for light to reach the film and determines for how long it does so.
Lens	Focuses a real image on the film
Film	Keeps records of the image that was formed
Focusing ring	Adjusts the distance between the lens and the film for focusing

The film contains chemicals that change on exposure to light. It is developed to give a negative. From the negative the photograph is printed.
The inner surface of the camera is **painted black** in order to prevent reflection of stray rays of light.
A camera is fitted with the provision for adjusting the distance between the film and then lens so that the object can be focused on the film by the convex lens.

(i) **Converging lens**; is to focus the object on the film.

(ii) **Shutter;** It controls the amount of light entering the camera by the length of times the shutter is open. Fast moving objects require short exposure.

The brightness of the image on the film depends on the amount of light passing through the lens. The shutter opening is controlled by the size of the hole in the diaphragm.

(iii) **Diaphragm**, this changes the size of the aperture. The stop is made of a sense of metal plates which can be moved to increase the aperture size.

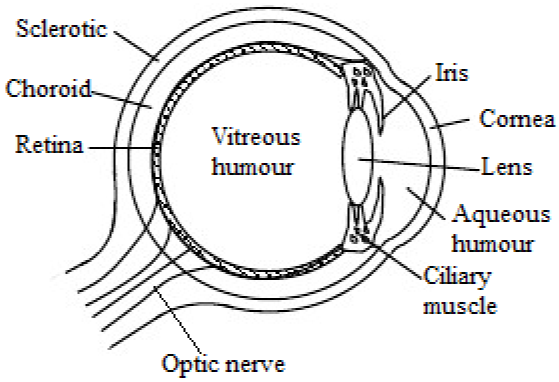
Thus it controls the amount of light entering the camera by its size.

Note: The correct setting of the lens for an object at any given distance from the camera is obtained from a scale engraved on the lens mount.

(iv) **Film:** It is a light sensitive part where the image is formed.

THE HUMAN EYE

Light enters the eyes through the cornea, the lens and then is focused on the retina. The retina is sensitive to light and sends messages to the brain through optic nerves. The iris changes in size to vary the amount of light entering through the pupil. The size of the pupil decreases in bright light and increases in dim light.



Functions of the parts of the eye.

1. **Lens:** The lens inside the eye is convex. It's sharp; it changes in order to focus light.

2. **Ciliary muscle:** These alter the focal length of lens by changing its shape so that the eye can focus on image on the retina.

3. **The iris**: This is the coloured position of the eye. It controls the amount of light entering the eye by regulating the size of the pupil.

4. **The retina**: This is a light sensitive layer at the back of the eye where the image is formed.

5. **The optic nerve**: It is the nerve that transmits the image on the retina to the brain for interpretation.

6. **The cornea:** It is the protective layer and it also partly focuses light entering the eye .

Accommodation

This is the process by which the human eye changes its size so as to focus the image on the retina. This process makes the eye to see both near and far objects.

Note: Accommodation is the process by which objects at different distances are focused by the ciliary muscles changing shape, so that the focal length of the lens changes. Accommodation can also be the ability of the eye to focus objects at various distances.

Near point: this is the closest point at which the eye can accommodate a most clear vision. Its 25m for a normal eye.

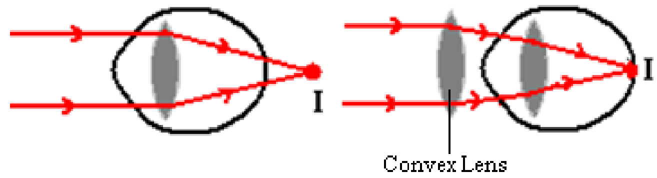
Far point: this is the most distant point at which the eye can accommodate a clear vision. It's at infinity since rays travel in a straight line.

Defects of vision and their corrections

a) Long Sightedness. (Hypermetropia)

This is an eye defect where a person can see distant objects clearly but near objects are blurred.
It is due to either;
- (i) Too long focal length, or
- (ii) Too short eye ball.

Because of these effects, the ciliary muscles have weakened and cannot make the eye lens fatter (i.e. decrease its focal length) to focus near object on the retina.
Thus, the image is formed behind the retina.

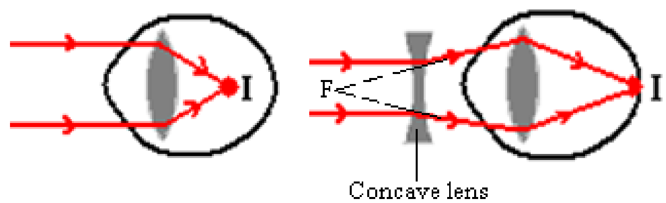


This defect is corrected by using spectacles containing converging lens which increase the convergence of the rays and brings it to focus on the retina.

b) Short Sightedness: (Myopia)

This is an eye defect where person can see near objects clearly but distant ones are blurred.
It is due to either;
- (i) Too short focal length, or
- (ii) Too long eye ball.

Because of these effects, the ciliary muscles do not relax sufficiently and consequently, distant objects are focused in front of the retina.



This defect is corrected by using spectacles containing diverging lens which increase the divergence of the light rays before they enter the eye and brings them to focus on the retina.

Similarities between the camera and the eye

- Both the eye and camera have light sensitive parts i.e. the retina for an eyes and film for camera.
- Both the eyes and camera have lenses.
- Both have a system which regulates the amount of light entering them i.e. iris for the eye and the diaphragm for the camera.
- The camera has black light proof inside the camera while the eye has a black pigment inside.

Differences between the human eye and camera:

Human eye	**Camera**
Lens: - Is biological. - Is flexible	-Lens is artificial - Is a rigid glass or plastic
Focal length: f of lens for the eye is variable.	-focal length of lens the for camera is fixed.
Distance: The distance between the lens and retina is fixed.	-The distance between the lens and film is variable.
Focusing: By changing the shape of the lens.	-By moving the lens relative to the film.
Aperture: Controlled by the iris.	-Controlled by the diaphragm.

Exposure: Is continuous.	- Controlled by shutter.
Light sensitive surface: Retina	- Film

Exercise:

1. See UNEB Paper I

1993 Qn.7	**2000 Qn. 21**	**2001 Qn. 30**	**2004 Qn. 14**	**2007 Qn. 10**

2. Section B

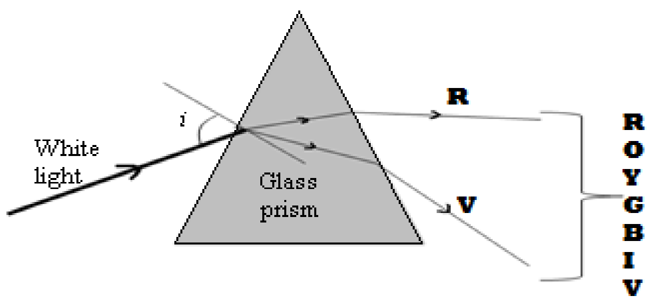
1993 Qn.7 PII	**1994 Qn. 2**	**1998 Qn.6**	**2000 Qn.8**

COLOURS AND DISPERSION OF LIGHT

Colours of objects we see depend on the colours of the light which reach our eyes from them.
Its by experiments conducted that we can prove that white light is made up of a mixture of seven colours called a **spectrum.**
A spectrum is a range of seven colours that form white light. (Day light)

DISPERSION OF LIGHT

Definition:
Dispersion *of light is the separation of white light into its component colours.*
When white light is passed through a prism, it is deviated and separated into seven colours.
This is because of the refractive index of glass being different for each colour which makes the different colours to move at different speeds.



When light is bent by a prism, the ratio of indices of refraction is the inverse of the ratio of wavelengths. Thus we can expand Snell's Law as follows:

$$\frac{\sin i}{\sin r} = \frac{V_1}{V_2} = \frac{\lambda_1}{\lambda_2} = \frac{\cap_2}{\cap_1}$$

If light passes through a prism (from air into the prism and back out) and the two interfaces are not parallel, the different indices of refraction for the different wavelengths of light will cause the light to spread out in different directions.

Note: *White light is separated into the seven colours by a prism because the prism has different refractive indices for the different colours of white lights.*

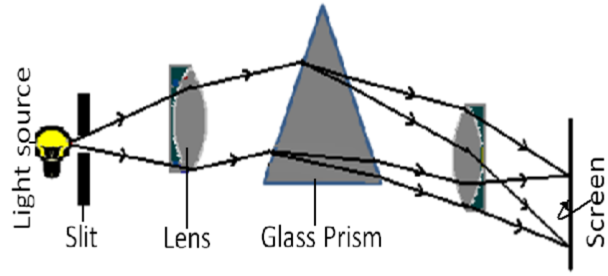
An object colour depends on:

- Colour of light falling on it.
- Colour it transmits or reflects i.e. green light appears green because it absorbs all other colours of white light and reflects green

Impure spectrum: this is the type of spectrum in which the boundaries between the different component colours are not clearly defined. i.e when there is overlapping of colours of white light.

Pure spectrum: this is a spectrum in which light of one colour only forms on the screen without over lapping.

Production of a Pure Spectrum



An illuminated slit is placed at the principle forces of a converging lens so that a parallel beam of white light emerges and falls on the prism.
Refraction through the prism splits up the light into separate parallel beams of different colours each of which is brought to its own focus.
Note: the combination of the slit and first lens is called the **collimator** (To collimate means to make parallel).
Note: The slit should be made narrow to reduce the overlapping of colours to a minimum so as to produce a fairly pure spectrum.

COLOURS

Colour is the appearance of an object that results from their ability or capacity to reflect light.

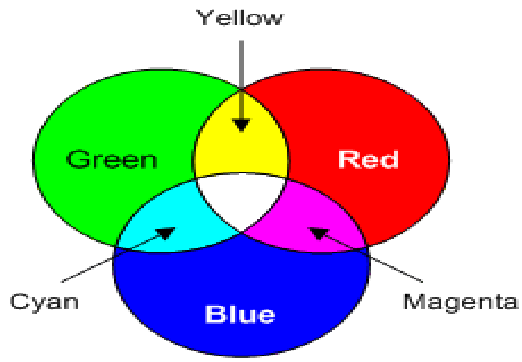
Types of Colour

(i) Primary Colours:

Primary light colours are colours of light that excite only one type of cone cells.
Because our cone cells in the eye only respond to red, green, and blue light, we call these colors the primary colors of light.
Primary Colours that can't be obtained by mixing any other colours.
Examples: Red, Green, Blue

(ii) Secondary Colours:

Secondary colours are colours obtained by mixing any two primary colours.
Examples: Yellow, Magenta, Cyan (Peacock Blue)



Additive (light)

Colour Addition:
When two colours of light are projected on a screen, they overlap to give a different colour. The new colour is said to be formed by colour addition.

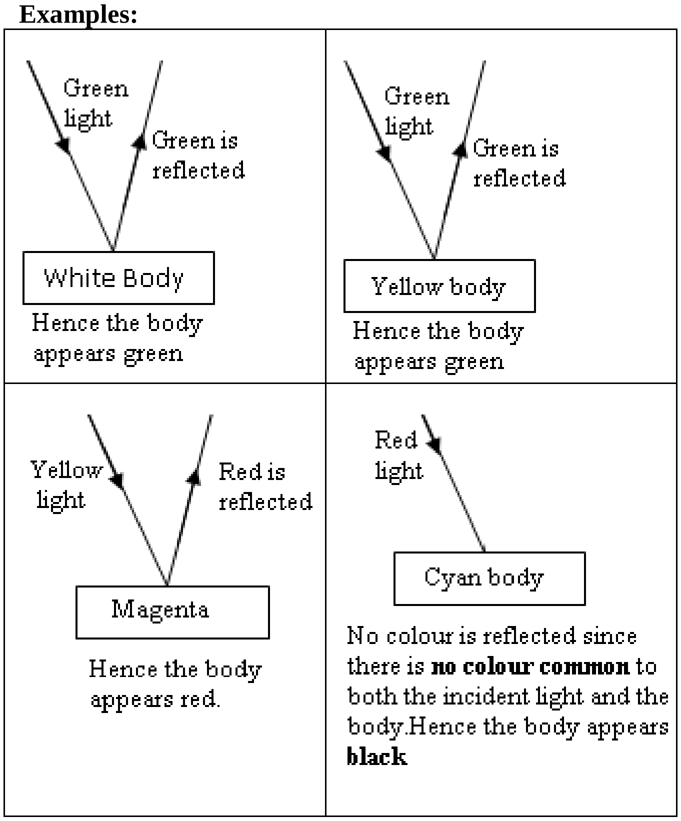
(iii) Complementary Colours:
This is a pair of one primary colour and one secondary colour which when mixed gives white light.

Examples:

Red + Cyan = White
Blue + Yellow = White
Green + Magenta = White

Coloured objects in white light
An object is coloured because it reflects and transmits its own colour and absorbs all other colours incident on it.

Examples:



Question
Describe and explain the appearance of a red tie with blue spots when observed in.
a) Red light
b) Green light – the whole tie appears black because both colours are primary colours and none is reflected back.
c) Red light – in the red light the tie appears red and blue spots blacks.
This is because the red reflects the red colour and observes blue colour.

Question2
A plant with green leaves and red flowers is placed in
a) green b) blue c) Yellow
d) what colour will the leaves and flowers appear in each case . Assume all colours are pure

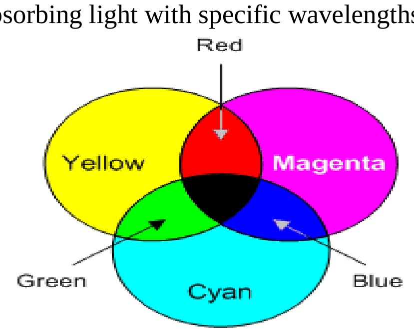
a) green -: the leaves remain green but the flower black
b) blue -: the leaves will appear black and flowers black
c) Yellow -: the leaves appear green and flowers appear red.

Mixing pigments;
Is a phenomenon when a impure colour reflects more than one colour light. Mixing coloured pigment is called mixing by subtraction and mixing coloured light is called mixing by addition.
When two pigments are mixed, they reflect the colour which is common to both and absorb all the other e.g. yellow paint reflects orange, yellow and green. While blue paint reflects green, blue and indigo.
Yellow and blue reflect green but absorb orange, yellow, blue and indigo.

Reflected Light: Subtractive Mixing
When light shines on an object, properties of that object cause it to absorb certain wavelengths of light and reflect others.
The wavelengths that are reflected are the ones that make it to our eyes, causing the object to appear that colour.

Colour subtraction.
When light falls on a surface of an object, three things may happen to it in varying proportions. Some light may be;
(i) Reflected,
(ii) Transmitted,
(iii) Absorbed.
The light which is absorbed disappears. The absorption of light is known as **subtraction of coloured light.**

Pigment: a material that changes the colour of reflected light by absorbing light with specific wavelengths.



Subtractive (paint)

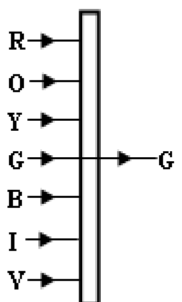
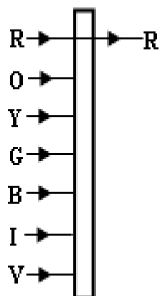
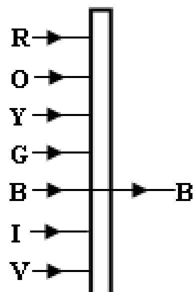
Primary pigment: a material that absorbs light of only one primary color (and reflects the other two primary colors). The primary pigments are cyan, magenta, and yellow.
Note that these are the secondary colors of light.

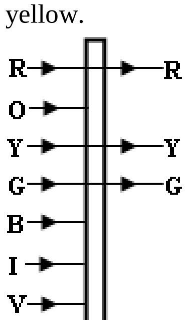
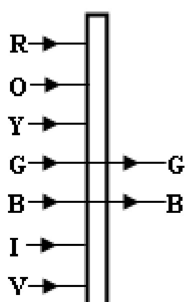
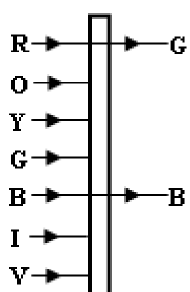
Secondary pigment: a pigment that absorbs two primary colors (and reflects the other). The secondary pigments are red, green, and blue. Note that these are the primary colors of light.

COLOUR FILTERS

Definition:

A filter is a coloured sheet of plastic or glass material which allows light of its own type to pass through it and absorbs the rest of the coloured lights i.e. a green filter transmits only green, a blue transmits only blue, a yellow filter transmits red, green and yellow lights.

Effect of filters of primary colours on white light		
A green filter absorbs all other colours of white light and transmits only green.  Green filter	A red filter absorbs all other colours of white light and transmits only red.  Red filter	A blue filter absorbs all other colours of white light and transmits only blue.  Green filter

Effect of filters of secondary colours on white light		
A yellow (R+G) filter absorbs all other colours of white light and transmits only Red green and yellow.  Yellow filter	A Cyan (G + B) filter absorbs all other colours of white light and transmits only Green and Blue.  Cyan filter	A magenta (R + B) filter absorbs all other colours of white light and transmits only Red and blue.  Magenta filter

Infrared and Ultra-violet light

The spectrum from the sun has both the visible and invisible spectrum. The invisible spectrum consists of ultra-violet at the extreme end of the violet light and the Infra red found just beyond the red light.

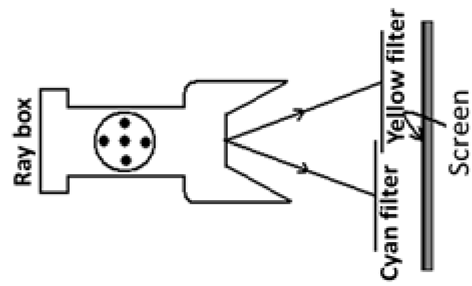
Ultra-violet	**VIBGYOR**	**Infra-red**
Invisible spectrum	Visible spectrum	Invisible spectrum

The invisible spectrum can be detected by;

(i) A thermopile connected to a galvanometer which shows a deflection on its detection.

(ii) A photographic paper which darkens when the invisible spectrum falls on it.

Mixing Coloured Filters and Pigments



When a yellow filter and cyan filter are placed at some distance from a ray box such that half of their portions overlap.

Observation: Green light is seen where white light passes through both filters

Explanation:

For the overlap of yellow and cyan, cyan filters absorb the red

Light and transmit green and blue, but yellow filter absorbs blue light and transmits green and red (which is absorbed by

Cyan filter) so only **green** light is transmitted.

Exercise:

1993 Qn.4	**1996 Qn.16**	**2000 Qn.32**	**2001 Qn. 37**

Section C

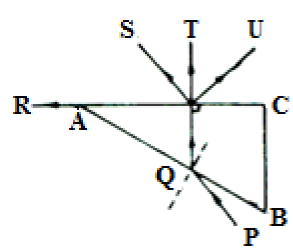
UNEB 1994 Qn. .4 PII; UNEB 1994 Qn. .4 PII;

1. A stick with one end immersed in water appears bent on the water surface because

A. diffraction B. reflection

C. interference D. refraction

2. A ray of light PQ is incident on the face AB of a glass prism ABC as shown in the diagram in the figure below.



Which one of the rays R, S, T, and U indicates the correct direction of the emergent ray?
A. R B. S C. T D. U

3. Which one of the following is a wrong formula in the study of optics?
A. $M = \frac{u}{v}$ B. $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$
C. $\sin C = \frac{1}{n}$ D. $M = \frac{v}{u}$

4. A ray of light is incident on a glass block at an angle of incidence of 45^0 and the angle of refraction 21^0. Find the critical angle of the glass
A. 42.0^0 B. 40.0^0 C. 33.8^0 D. 35.0^0

5. Total internal reflection occurs when
(i) the incident angle is equal to the critical angle
(ii) light travels from a dense to a less dense medium
(iii) light travels from a less dense to a dense medium
(iv) the incident angle in a dense medium is greater than the critical angle.
A. (i), (ii) and (iii) only B. (ii) only
C. (iv) only D. (ii) and (iv) only

6. A pin is placed in front of convex lens at a distance less than the focal length of the lens. What type of image is formed?
A. Real, inverted diminished.
B. Virtual, erect, magnified
C. Real, erect, diminished.
D. Virtual, inverted, magnified.

7. An object 2 cm tall is placed 5 cm in front of a convex lens. A real image is produced 20 cm from the lens. Calculate the magnification of the lens.
A. 4 B. 2 C. 0.5 D. 0.25

8. An object is placed between a converging lens and its principal focus. The image formed is
A. real, magnified, upright
B. real, magnified, inverted
C. virtual, diminished, upright
D. virtual, magnified, upright

9. An image 5 cm high is formed by a converging lens. If the magnification is 0.4, find the height of the object
A. 2.0cm B. 4.6cm C. 5.4cm D. 12.5cm

10. An object is placed at a distance of 20 m from a convex lens of focal length 15cm. the type of image formed is
A. inverted and magnified
B. inverted and diminished
C. upright and diminished
D. upright and magnified

11. A lens of power **4** dioptres is used to focus an object at infinity. How far the screen must be placed from the lens so that a clearly focused image is seen.
A. 0.20cm B. 0.25cm C. 20cm D. 25cm

12. The velocity of light in air is 3×10^8 ms $^{-1}$ and the velocity of light in water is 2.25×10^8 ms $^{-1}$. The refractive index of water is;
A. $\frac{4}{3}$ B. $\frac{3}{4}$ C..3 x 2.25 D: 3 + 2.25

13. The ability of the eye to vary its focal length in order to focus light from different objects is referred to as
A: long sightedness B: shortsightedness
C: Astigmatism D: Accommodation

14. An explosion emits light, infrared and sound waves. What waves will be received first by the person some distance away?
A: infra-red and sound B: all the three together
C: infra red and light D: light and sound

Paper II Questions

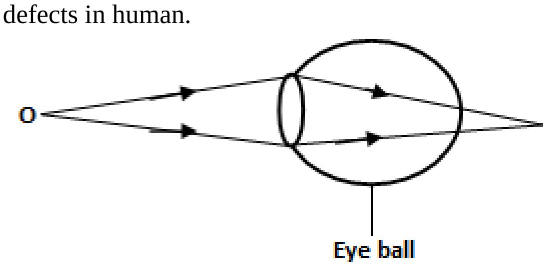
11. (a) State the types of the two common lenses.
(b) Define the following terms as used in the study of lenses.
(i) principal focus.
(ii) focal length of a converging lens.
(c) With the help of a ray diagram show how a converging lens can be used as a magnifying glass.

12. (a) Define: (i) real image. (ii) Virtual image.
(b) State any two properties of an image of a real object formed in a diverging lens.
(c) An object 8 cm high is placed perpendicularly on the principal axis 12 cm away from the diverging lens. With the aid of a ray diagram, find the focal length of the lens, if the height of the image formed is 2 cm.

13. The focal length of a converging lens is 10.0 cm. What is its power?
(b) State two applications of converging lenses
(c) An object of height 4 cm is placed perpendicularly on the principal axis at a distance of 45 cm from a converging lens of focal length of 15 cm. By graphical construction, determine
(i) the position of the image. (ii) the magnification.

14. (a) Define focal length of a converging lens.
(b) With the aid of a labelled diagram, describe a simple experiment to determine the focal length of a converging lens.
(c) Give one use of converging lenses

15. The diagram in figure below shows one of the eye defects in human.



(a) (i) State the type of eye defect shown in the diagram.

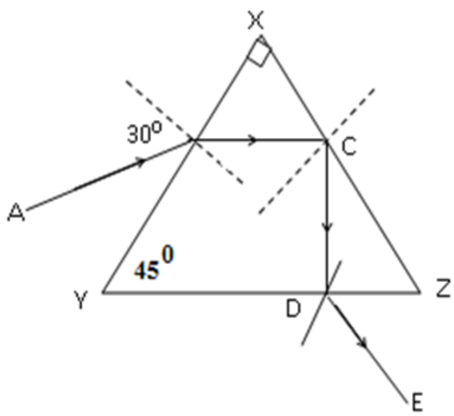
(ii) Explain with a help of diagram how the defect can be corrected.

(b) What is meant by **accommodation**?

(c) With a help of ray diagram, describe how a projector is used to project a magnified image on to a giant screen.

(d) With the aid of a labelled diagram, describe how a lens camera works.

15. The figure below shows the path of a ray AB incident on the glass prism XYZ with angles of 90^0 and 45^0 and finally emerging along DE.



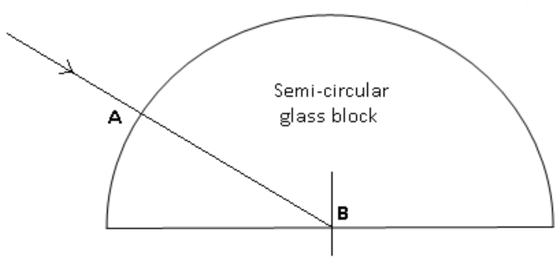
(i) Explain the statement "The refractive index of the glass is 1.5"

(ii) Why does the ray AC not emerge into the air at C?

(iii) Why does the ray CD refracted away from the normal at D to the side YZ?

(iv) When the angle of incidence the ray AB makes with the normal at point B is 30^o. What is the value of angle r and angle BCP.

(b) The figure below shows light incident on a semi-circular glass block of refractive index 1.62.



(a) Explain why light is not deviated at A.
(b) Calculate the critical angle of the material of the glass block.
(c) State the application of total internal reflection.
(d) Briefly describe the formation of a mirage

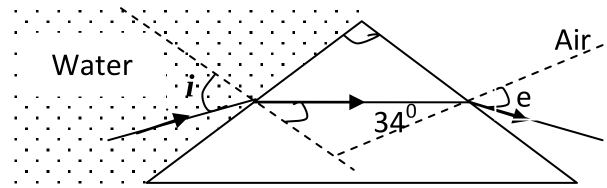
16.A light ray is incident at various angles at an air-glass boundary. The corresponding angles of incidence and refraction are given below .

Angle of incidence **i** (degrees)	0	20	40	60	80
Angle of refraction **r** (degrees)	0	13	25	35	41

(i) Using the information above draw a graph of sin i (along vertical axis) against sin r (along horizontal axis)

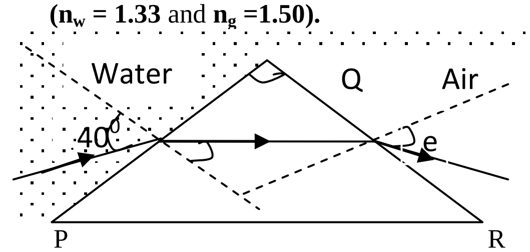
(ii) Use your graph to determine the refractive index of glass.

17.A ray of light travels from water and is incident on an equilateral glass prism at an angle *i* as shown in the figure above. If the refractive index of water and glass is 1.33 and 1.52, find the value of i and e.



18. The figure below shows a ray of light incident on an equilateral a triangular glass prism from Water.

(n_w = 1.33 and **n_g =1.50).**



Find the :

(i) the angle of refraction at PQ.

(ii) the angle of emergence at QR.

(iii) the total deviation caused by the prism.

(iv) Explain why prisms are preferred to plane mirrors in manufacture of periscopes.

SECTION A

1. A pin is placed in front of convex lens at a distance less than the focal length of the lens. What type of image is formed?

A. Real, inverted diminished.
B. Virtual, erect, magnified
C. Real, erect, diminished.
D. Virtual, inverted, magnified.

2. An object 2 cm tall is placed 5 cm in front of a convex lens. A real image is produced 20 cm from the lens. Calculate the magnification of the lens.

A. 4. B. 2 C. 0.5 D. 0.25

3. An object is placed between a converging lens and its principal focus. The image formed is

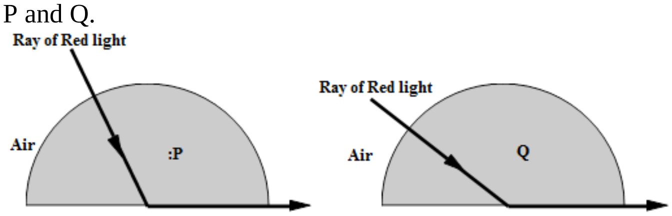
A. real, magnified, upright.
B. real, magnified, inverted
C. virtual, diminished, upright
D. virtual, magnified, upright

4. An image 5 cm high is formed by a converging lens. If the magnification is 0.4, find the height of the object

A. 2.0cm B. 4.6cm
C. 5.4cm D. 12.5cm

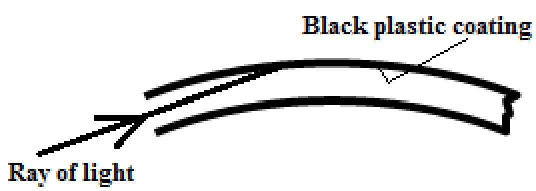
5. An object is placed at a distance of 20 m from a convex lens of focal length 15cm. the type of image formed is
   A. inverted and magnified
   B. inverted and diminished
   C. upright and diminished
   D. upright and magnified

6. A student makes the following statements.
(I) Material P has a higher refractive index than material Q.
(II)The wavelength of the red light is longer inside material P than inside material Q.
(III) The red light travels at the same speed inside materials P and Q.



Which of these statements is/are correct?
A. I onlyB. II only C. III only
D. I and II only E. I, II and III

7. The diagram shows a ray of light in an optical fibre.



A student makes the following statements about light transmitted along the optical fibre.
(I) The light is totally internally reflected inside the glass.
(II) The light is reflected by the black plastic coating.
(III) The angle of incidence in the glass is greater than the critical angle for this glass. Which of the statements is / are correct?
A. I only B. III only C. I and II only
D. I and III only E. I, II and III

Paper II Questions

7. (i) Draw a clear ray diagram to show how converging lens can be used as magnifying glass.

(ii) An object is placed 10 cm in front of a concave lens of focal length 20 cm to form an image. Determine the position, nature and magnification of the image using a ray diagram.

(iii) An object 5cm tall is placed 15 cm away from a convex lens of focal length 10cm. By construction, determine the position size and nature of the final image. [Use the graph paper provided]

(iv) An object 5cm high is placed 20cm in front of a converging lens of focal length 15cm. Find the power of the lens and the magnification of the lens. [Use the graph paper provided]

(v) An object of height 20cm is placed vertically on the axis of a convex lens of focal length 10cm at a distance of 30cm from the lens. Use the graphical method to find the position, nature and magnification of the image. [Use the graph paper provided].

Dispersion and Colour

SECTION A

1. A piece of white cloth viewed through a blue glass appears blue because
   A. Blue light is absorbed by the glass
   B. the glass adds blue light to the light coming from the cloth
   C. the glass transmits only blue light and absorbs all other colours
   D. the colour of the glass is reflected onto the cloth.

2. A student is holding a white paper with green printing on it. If she enters a room with red lights, she will see
   A. black printing on a red paper
   B. blue printing on a red paper
   C. yellow printing on a red paper
   D. red printing on a white paper.

3. When a green plant with white flowers is placed in a yellow light, the plant will appear
   A: green leaves, yellow flowers
   B: yellow leaves, green flowers
   C: green leaves, red flowers
   D: red leaves, green flowers.

4. Which one of the following is correct?
(i) green light shone on the green surface is all absorbed
(ii) green light added equally to red light appears yellow
(iii) green light passes through a red filter
   A. (ii) only B. (i) and (ii) only
   C. (ii) and (iii) only D. (i), (ii) and (iii)

5. White light is separated into its component colours due to;
   A. absorption B. dispersion
   C. reflection D. Transmission

6. Which of the following are secondary colours only?
   A. Red, green and yellow.
   B. Blue, yellow and magenta.
   C. Yellow, cyan and magenta.
   D. Red, green and blue.

7. Which of the following statements are true?
(i) Surfaces which reflect all colours of light appear white
(ii) Red surfaces absorb all colours and reflect only red light
(iii) black surfaces appear black because they reflect all colours
   A. (i) only B. (i) and (ii)only
   C. (i) and (iii) only D. (ii) and (iii) only

8. The secondary colours of light are cyan, magenta and yellow. Which of the following sets of addition of colours of light will produce white light
   (i) cyan + blue and magenta + red
   (ii) cyan + red and magenta + green
   (iii) yellow + red and magenta + blue
   (iv) cyan + green and yellow + blue
   A. (i) only B. (ii) only

C. (iii) only D. (iv) only

9. Which of the following statements are **true**?
(i) A magenta filter absorbs green light and transmits red and blue lights.
(ii) A magenta filter absorbs blue light and transmits red and green lights
(iii) A cyan filter absorbs red light and transmits blue and green lights
(iv) A cyan filter absorbs blue light and transmits red and green lights
A. (i) only B. (ii) only
C. (ii) and (iv) only D. (i) and (iii) only

10. Dispersion of light is:
A. the rectilinear propagation of light.
B. the spreading of light around an obstacle.
C. the splitting of white light into its constituent colours.
D. the changing of direction by light when it moves from one media to another.

11. When a yellow dress with blue dots is placed in a room lit with pure red light, the dress appears
A. red with black dots B. yellow with blue dots
C. green with red dots D. black with yellow dots

12. A piece of white cloth viewed through a blue glass appears blue because
A. Blue light is absorbed by the glass
B. Glass adds blue light to the light coming from the cloth
C. Glass transmits only blue light and absorbs all other colours
D. the colour of the glass is reflected onto the cloth.

13. What is the appearance of a blue curtain with red flowers in green light?

	Appearance of curtain	**Appearance of Flower**
A	Blue	Red
B	Black	Green
C	Black	Black
D	Red	Black

14. A student is holding a white paper with green printing on it. If she enters a room with red lights, she will see
A. black printing on a red paper
B. blue printing on a red paper
C. yellow printing on a red paper
D. red printing on a white paper.

15. Which one of the following is correct?
(i) Green light shone on the green surface is all absorbed
(ii) Green light added equally to red light appears yellow
(iii) Green light passes through a red filter
A. (ii) only B. (i) and (ii) only
C. (ii) and (iii) only. D. (i), (ii) and (iii)

16. White light is separated into its component colours due to:
A. absorption B. dispersion
C. reflection D. Transmission

17. Which of the following are secondary colours only?
A. Red, green and yellow.
B. Blue, yellow and magenta.
C. Yellow, cyan and magenta.
D. Red, green and blue.

18. Which of the following statements are true?
(i) surfaces which reflect all colours of light appear white
(ii) red surfaces absorb all colours and reflect only red light
(iii) black surfaces appear black because they reflect all colours
A. (i) only B. (i) and (ii) only
C. (i) and (iii) only D. (ii) and (iii) only

19. Which of the following statements are true?
(i) A magenta filter absorbs green light and transmits red and blue lights
(ii) A magenta filter absorbs blue light and transmits red and green lights
(iii) A cyan filter absorbs red light and transmits blue and green lights
(iv) A cyan filter absorbs blue light and transmits red and green lights
A. (i) only B. (ii) only
C. (ii) and (iv) only D. (i) and (iii) only

20. Dispersion of light is
A. the rectilinear propagation of light.
B. the spreading of light around an obstacle.
C. the splitting of white light into its constituent colours.
D. the changing of direction by light when it moves from one media to another.

21. When a yellow dress with blue dots is placed in a room lit with pure red light, the dress appears
A. red with black dots B. yellow with blue dots
C. green with red dots D. black with yellow dots.

Paper II Questions

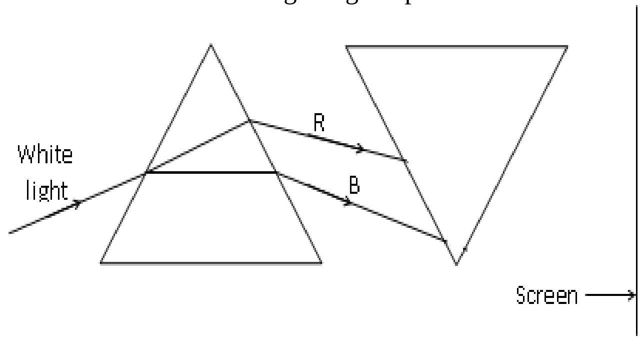
22. (a) Explain the phenomenon of dispersion applied to white light.
(b) Draw a ray diagram to show the dispersion of white light by a glass prism
(c) With the aid of a diagram, explain briefly how a pure spectrum may be produced.
(d) Explain briefly what happens when white light falls on a green body.

23. (a) Distinguish between secondary and primary colours. Give one example of each.
(b) Name the colour that would be obtained when the following coloured lights are mixed.
(i) Green and red. (ii) cyan and red.

(c) Explain why an object illuminated by white light appears. (i) coloured (ii) black

(d) State why most hind car registration number plates are printed black on a yellow background.

(e) The figure below shows white light being dispersed by an equilateral triangular prism, which is then made incident onto another inverted triangular glass prism.



Explain what is observed on the screen.

(f) Explain the appearance of a blue dress with red stripes in, yellow light, and when in blue light.

(g) Explain why **the hind car registration number plates** are printed **black** on a **yellow** back ground.

(h) (i) With the aid of a labelled diagram, explain how a pure spectrum of visible light can be produced.
(ii) Explain why a glass prism is capable of dispersing white light.
(iii) Explain why the sun appears red at sunrise and sunset.

4. PHYSICAL OPTICS (WAVES)

A wave is a disturbance or vibration which travels through a medium and transfers energy from one point to another without causing any permanent displacement of the medium itself e.g. water waves, sound waves, waves formed when a string is plucked.

A wave is a periodic disturbance, which travels with finite velocity through a medium and remains unchanged in type as it travels. Or it is a disturbance which travels through a medium, and transfers energy from one location (point) to another without transferring matter.

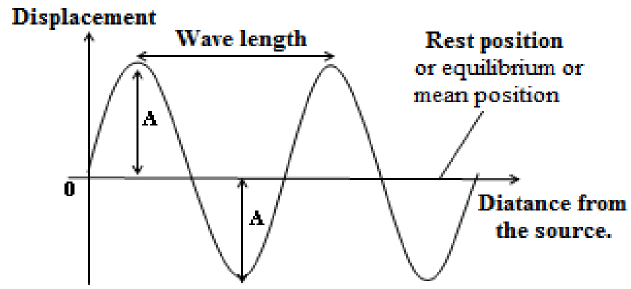
Examples of such disturbances include:
(i) Water ripples on water in a lake or ripple tank.
(ii) Tsunami (Tidal waves) produced by earth quake in oceans or sea.
(iii) Vibrations of strings in musical instruments.
(iv) Seisimic waves. Waves in the earth's crust during earth quake.

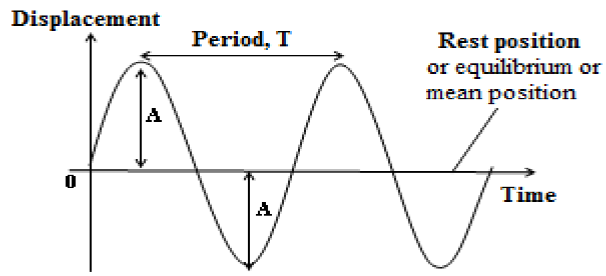
WAVE MOTION

When a wave is set up on the medium, the particles of the medium from about a mean position as the wave passes. The vibrations are passed from one particle to the next until the final destination is reached

Generation and Propagation of mechanical waves.
Waves are generated when particles of a transmitting medium at any point are disturbed and start vibrating.
As they vibrate, they cause the neighboring particles to vibrate in turn, hence causing the vibrations to continue from the source to other regions in the transmitting medium.
The disturbance thus spreads the source outwards and it constitutes the wave.

Graphical representation of a wave.
If the disturbance of the source of waves is simple harmonic, the displacement in a given time varies with distance from the source as shown below.





Terms used in describing waves,

Amplitude: This is the distance of greatest displacement of awave particle in a medium from its equilibrium rest position (or rest position).

Wave length (λ): Is the distance between two successive particles on a wave profile that are in phase.
It is the distance covered in a complete cycle of a wave.

For a transverse wave, it is the distance between two successive crests or troughs.
For a longitudinal wave, it is the distance between two successive compressions or rare factions.

Crest: It is the maximum displaced point a above the line of 0 (zero) disturbance.It isthe point of maximum positive displacement of a transverse wave. (The highest point.)

Trough: It is the maximum displaced point below line of zero disturbance.It is the point of maximum negative displacement of a transverse wave. (The lowest point.)

Wave front. Is a line or surface that joins points of the same phase in a wave travelling through a medium. OR: It is the imaginary line joining the set of particles in a wave disturbance that are in the same state of motion (in phase).

Particles are in phase if they are in the same point in their path at the same time and are moving in the same direction. (ie. When they are in the same state of motion).
The direction of travel of the wave is always at right angles to the wave front.

Cycle or Oscillation: is a complete to and fro motion of a wave. It is equivalent to moving from O to B.

Period (T): The time taken for a wave particle to undergo a complete oscillation. $T = \frac{t}{n}$. Or Time taken by a wave particle to make one complete cycle. Or Time take by a wave to cover one wave length.

Frequency (f): The number of oscillations per second.
$f = \frac{n}{t}$.

Velocity (v): The distance covered by a wave particle per second in a given direction.

Phase: Is a fraction of a cycle which has elapsed after a particle passing a fixed point.

Relationship between f and T
If a wave completes n cycles in time t, then frequency, f is given by:
Frequency, $f = \frac{n}{t}$……………………………..(i)
Period, $T = \frac{t}{n}$. ....(ii)

Eqn (i) x eqn (ii) gives;
$fT = \left(\frac{n}{t}\right) \times \left(\frac{t}{n}\right) = 1 \Leftrightarrow f = \frac{1}{T}$

Relationship between v, λ and f
If a wave of wavelength **λ** completes n cycles in time t, then the frequency, f is given by;

Each cycle is a wavelength, $\boldsymbol{\lambda}$**:**
Total distance covered in n-cycles = nλ

$$Speed, v = \frac{Distance}{Time} = \frac{n\lambda}{t} = \left(\frac{n}{t}\right)\lambda, \quad But \frac{n}{t} = f$$
$$\Leftrightarrow \quad \boldsymbol{v = f\lambda}$$

Alternatively,
If a wave covers a distance, λ, the wavelength, then the time taken is T, the period. Hence speed,
$$Speed, v = \frac{\lambda}{T} = \left(\frac{1}{T}\right)\lambda, \quad But, \frac{1}{T} = f$$
$$\Leftrightarrow \quad \boldsymbol{v = f\lambda}$$

Examples

1. A radio station produces waves of wave length 10m. If the wave speed is 3×10^8 m/s, calculate
   (i) Frequency of radio wave.
   (ii) period time, T
   (iii) Number of cycles completed in 10^8 s

Solution:

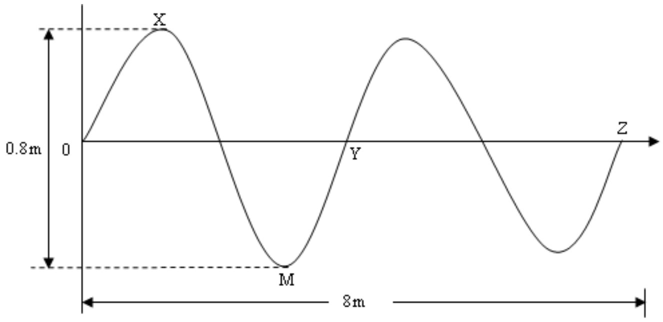
(i) Frequency of radio wave ; λ = 10m, v=3×10^8 m/s	(ii) Period ,T	(ii) Number of cycles
$v = f\lambda$ $3 \times 10^8 = f \times 10$ $f = \frac{3 \times 10^8}{10}$ $f = 3 \times 10^7 Hz$	$Period, T = \frac{1}{f}$ $T = \frac{1}{3 \times 10^7}$ $T = 3.3 \times 10^{-8} s$	$Frequency, f = \frac{n}{t}$ $n = ft$ $n = 3 \times 10^7 \times 10$ $n = 3 \times 10^8 cycles$

2. The distance between 10 consecutive crests is 36cm. Calculate the velocity of the wave. If the frequency of the wave is $12H_z$.

Solution:

The distance between n-successive crests or troughs is given by; $\mathbf{d = (n-1)\boldsymbol{\lambda}}$ $\lambda = \frac{d}{n-1}$ $\lambda = \frac{36}{10-1} = \frac{36}{9} = 0.04m$ $\lambda = 0.04$ m	$v = f\lambda$ $v = 12 \times 0.04$ $v = 0.48 ms^{-1}$

3. The diagram below shows a wave travelling in water.



(a) Name;

(i) Any two points on the wave which are in phase

(ii) The points Labeled m and x

(b) (i) Determine the amplitude of the wave.

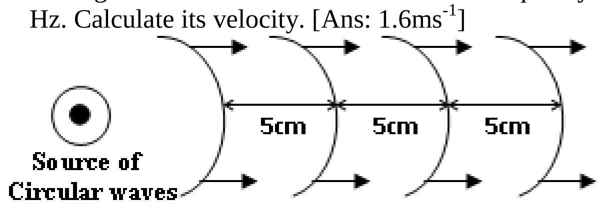
(ii) If the speed of the wave is $8000cms^{-1}$. Determine the frequency of the wave.

Questions

1. A vibrator produces waves which travel 35 m in 2 seconds. If the waves produced are 5cm from each other, calculate;

(i) wave velocity	(ii) wave frequency
$d = 35m, t = 2s$ $v = \frac{d}{t} = \frac{35}{2} = 17.5ms^{-1}$ $v = 17.5ms^{-1}$	$v = f\lambda$ $f = \frac{v}{\lambda} = \frac{17.5}{5} = 3.5Hz$ $f = 3.5Hz$

2. The figure below shows circular waves of frequency 32 Hz. Calculate its velocity. [Ans: $1.6ms^{-1}$]



3. A source produces waves which travel a distance of 140cm in 0.08s. If the distance between successive crests is 20cm, find the frequency of the source. [Ans: 87.5Hz].

4. A sound source produces 160 compressions in 10s. The distance between successive compressions is 20m. Calculate the;
   (i) frequency of sound [16HZ]
   (ii) wave speed [$320ms^{-1}$]

5. Waves on a spring are produced at a rate of 20 wavelengths per second. Find the:
   (i) frequency of the waves produced.
   (ii) wave speed.

6. A vibrator produces waves of frequency 2500Hz and the separation between eleven successive crests is 240cm. Calculate the wave length and velocity of the waves.

7. See **UNEB 1992** Qn. 7

8. A source produces waves which travel a distance of 140cm in 0.08s and the separation between two successive troughs is 20cm, find the velocity and frequency of the waves.

9. Water waves of frequency 6Hz travel a distance of 24m in 10seconds. Calculate the period and velocity of the waves.

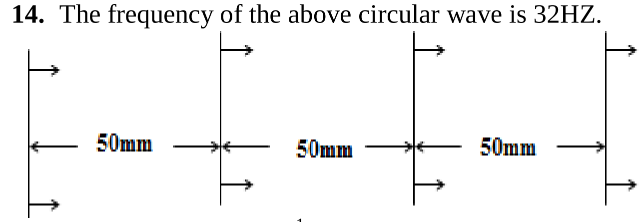
10. A vibrator sending out eight ripples per second across a water tank. The ripples are observed to be 4cm apart. Calculate the frequency and velocity of the ripples.

11. A vibrator produces waves which travel a distance of 35 cm in 2 seconds. If the distance between two successive crests is 5cm, find the velocity and frequency of the waves. **(Ans: $0.175ms^{-1}$, 3.5Hz)**

12. Waves enter a harbor at a rate of 30 crests per minute. A man watches particular wave crests passing two boys who are 12m apart along the direction of travel of the waves. The time the waves takes to move from one post to another is 2 seconds. Calculate the frequency and wavelength of the waves.

13. A student counts his heart beats and finds that it makes 75 beats per minute. Calculate the frequency and period of his heart beat.

14. The frequency of the above circular wave is 32HZ.



Calculate its speed in ms^{-1}

A: 1.6 B: 3.2 C: 6.4 D: 16.0

15. What is called a traveling disturbance that carries energy from one place to another.
    a. wave b. electricity
    c. energy d. matter

16. What part of the wave shows the amount of energy it is carrying?
    a. crest b. frequency
    c. wave length d. amplitude

17. The number of complete waves that pass a point in a given time is called?
    a. crest b. frequency
    c. wave length d. amplitude

18. A vibrator produces waves which travel a distance of 12m in 4s. If the frequency of the vibrator is 2Hz, what is the wavelength of the waves?
    A. 1.5m B. 3m C. 6m D. 24m

19. The frequency of a radio wave is 6.6×10^5Hz. Find the wave-length (velocity of light is 3.0×10^8m/s)
    A. 2.20×10^{-3}m B. 4.55×10^2m

C. 3.60×10^3m D. 1.98×10^{12}m

20. Water waves are produced at a frequency of 5Hz and the distance between 10 successive crests is 18cm. calculate the velocity of the waves in ms^{-1}.

A. $9ms^{-1}$ C. $0.09ms^{-1}$
B. $0.1ms^{-1}$ D. $1ms^{-1}$

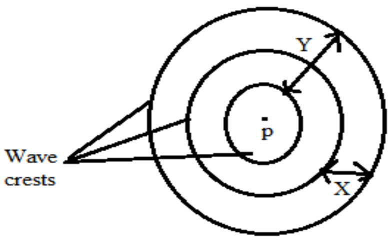
21. A vibrator produces waves which travel a distance of 35cm in 2s. If the distance between successive wave crests is 5cm, what is the frequency of the vibrator.

A. 3.5Hz B. 7.0Hz C. 14.0Hz D.87Hz.

22. Water waves travel a distance of 36cm in 6s and the separation of successive troughs is 3.0cm. Calculate the frequency of the waves

A. 2Hz C. 12Hz.
B. 18Hz D. 72Hz

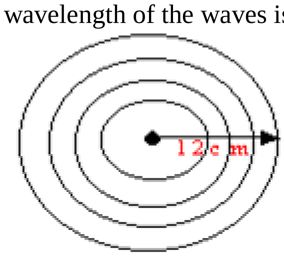
23. A vertical stick is dipped up and down in water at P. In two seconds, three waves crests are produced on the surface of the water.



Which of the statements below is true?

A. Distance X is the amplitude of the waves.
B. Distance Y is the wavelength of the waves
C. Each circle represents a wave-front.
D. The frequency of the waves is 3Hz.

24. The Figure below shows waves spreading out from a point. The wavelength of the waves is:



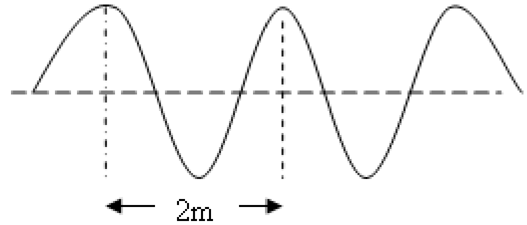
A. 3cm B. 6cm C. 9cm D. 12cm

25. The table above shows readings obtained by using a vibrator which produces waves of a constant velocity. Find the frequency of the wave Q.

Vibrator	Wave Length	Frequency
Wave P	1,500 m	0.2 MHz
Wave Q	500 m	…………

A. 0.07MHz. B. 0.3 MHz.
C. 0.6 MHz. D.1.2 MHz.

26. The Figure below shows a wave produced in a string. If the frequency is 2Hz, at what speed do the waves travel along the string?



A. $0.5ms^{-1}$ C. $1.0ms^{-1}$
B. $2.0ms^{-1}$ D. $4.0ms^{-1}$

27. The number of complete oscillations made per second is referred to as:

A. periodic time C. amplitude
B. wave length D. frequency

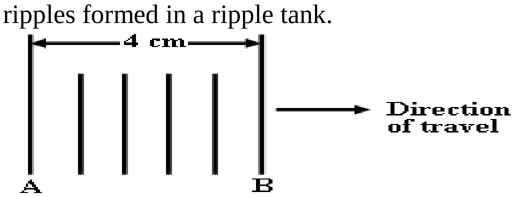
28. A source producing waves which travel a distance of 140cm in 0.08 s. If the distance between successive crests is 20cm, find the frequency of the source.

A. 0.875Hz C. 8.750Hz
B. 87.500Hz D. 8750Hz

29. A vibrator in a ripple tank vibrates at 5Hz. If the distance between 10 successive crests is 37.8cm, calculate

(i) the wavelength of the waves
(ii) the velocity of the waves

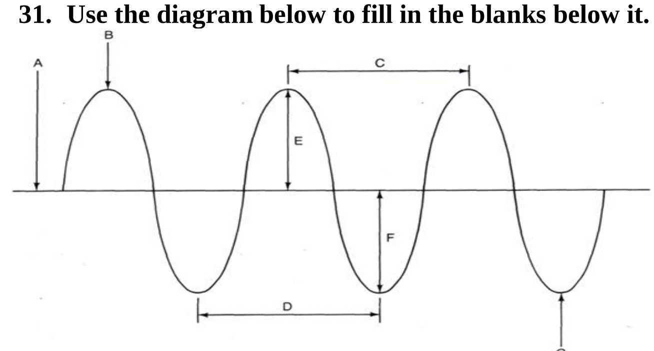
30. The lines in the figure below show crests of straight ripples formed in a ripple tank.



(i) If after 10 seconds A is in position B, calculate the velocity of the ripples. (04 marks)

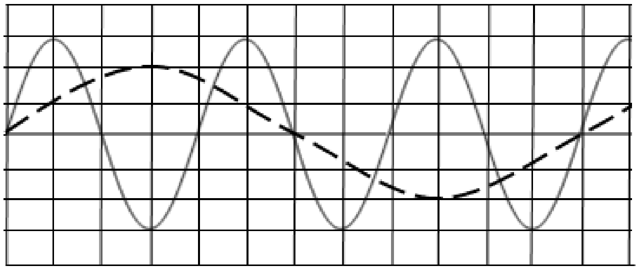
(ii) Draw a diagram showing how the ripples would pass through a wide gap of an obstacle they would meet. (02 marks)

31. Use the diagram below to fill in the blanks below it.



A. ________________ B. ________________
C. ________________ F. ________________

32. Refer to the diagram below to answer the following questions.



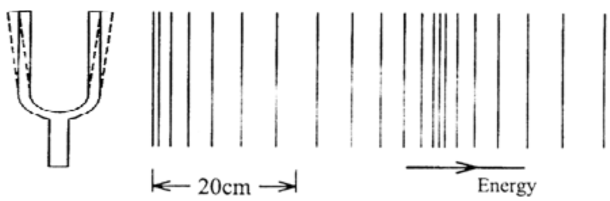
a. If each square represents one meter, what is the amplitude and wavelength of each wave?

b. Which wave has a higher frequency? How can you tell?

c. If the wave pattern formed in 20 sec, what is the period for each wave? What is their velocity?

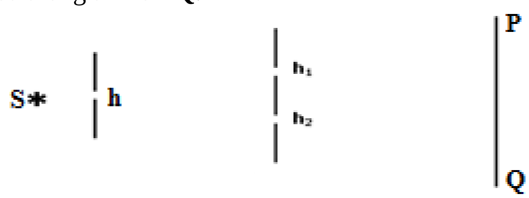
Ans: amplitude: 3m (solid), 2 m (dotted); λ = 4m (solid) λ = 12m (dotted); the solid one has a higher frequency; it has a smaller wavelength. T = 6.67s (solid) T = 20 sec (dotted), v = 0.6 m/s for both.

32.



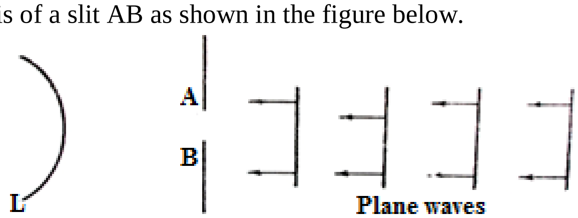
The Figure above shows a sound wave produced from a tuning fork vibrating at 800 Hz. Calculate the velocity of the wave in the medium. (02 marks)

2007PP2 6. (a) Define the term **constructive interference** as applied to sound waves. (01mark)
(b) The Figure below shows a source of sound S behind a barrier with a single hole h, place behind another barrier with two identical holes h_1 and h_2. A sound detector is moved along a line **PQ.**



. (i) With the aid of a diagram explain what is detected.
(ii) What is the significance of h_1 and h_2? (05marks)

(c) A convex obstacle, L, is placed perpendicularly to the axis of a slit AB as shown in the figure below.



Sketch the wave pattern obtained when plane waves are incident onto the slit

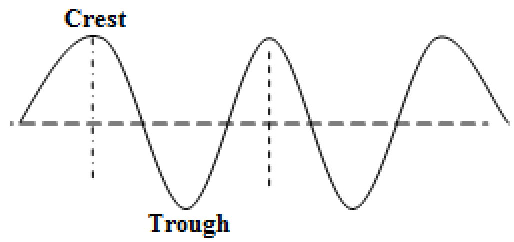
CLASSIFICATION OF WAVES

Waves may be classified using their properties as mechanical or electromagnetic waves, Progressive or Stationary, Transverse or Longitudinal.

1. PROGRESSIVE AND STATIONARY WAVES:

(a) A progressive wave or Travelling wave

A progressive wave is a wave in which energy is transmitted from one place to another and is not stored.



The profile of a progressive wave moves along the speed of the wave. It repeats itself at equal distances. The repeated distance is called the **wavelength**.

(b) Stationary or standing wave

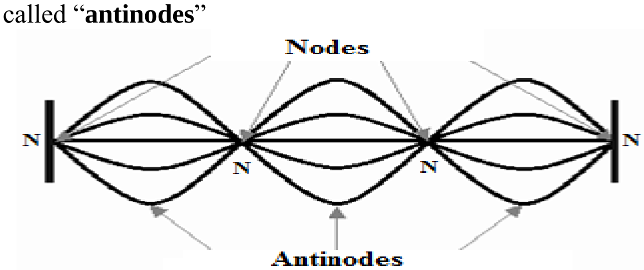
Is a wave formed when a progressive strikes a hard surface and is reflected, such that the incident and reflected waves superimpose to form nodes and antinodes.

A stationary *wave* *is a wave formed when two progressive waves of the same speed, frequency, wave length and nearly equal amplitude travelling in opposite directions meet producing nodes and antinodes.*

Or This is the resulting wave or the new wave formed when two similar waves moving in opposite directions interfere or travel together in the same media.

When the wavelength is an exact fraction of the length of a medium that is vibrating, the wave reflects back and the reflected wave interferes constructively with itself. This causes the wave to appear stationary.
Points along the wave that are not moving are called "**nodes**" (Regions of minimal or zero displacement with minimal or zero energy).

Points of maximum displacement and maximum energy are called "**antinodes**"



$$\textbf{Distance NN} = \textbf{Distance AA} = \frac{\textbf{Wave length}, \boldsymbol{\lambda}}{\textbf{2}}$$

Note*:* Within a stationary wave, there is no flow of energy through a medium. There is energy of motion between each vibrating segment but this energy is not transferred across the nodes and is stationary.

Differences between Progressive and Stationary waves

Stationary wave	***Progressive***
-All particles between successive nodes, have their vibration are in phase.	-The phase of vibration of points near each other are all different
-Each points along the wave has a different amplitude i.e. Amplitude = 2acosθ	-All points along the wave vibrate with the same amplitude.
-Do not transfer energy.	-Transfer energy from one point to another.
-The wave profile does not move along the medium	- The wave profile moves along the medium with the wave speed.
-The medium doesn't move.	-The medium moves.

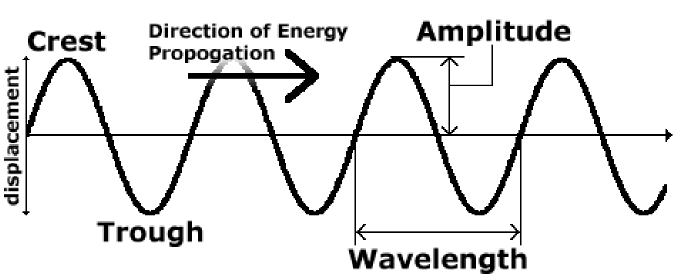
There are two kinds of progressive and stationary waves namely:
(i) Transverse waves (ii) Longitudinal waves

i) Transverse waves

These are waves in which the particles of the medium vibrate perpendicularly to the direction of propagation of the wave.

Transverse waves propagate by means of crests and troughs.

Examples:
- ✓ water waves,
- ✓ Electromagnetic waves
- ✓ waves formed when a rope is moved up and down.



ii) Longitudinal waves

These are waves in which the particles of the medium vibrate parallel to the direction in which the wave travels.

The vibrations of the particles of the medium occur in the same direction as the direction of the travel of the wave.

Longitudinal waves travel by formation of regions of compression and rare faction. Regions where particles crowd together are called compressions and regions where particles are further apart are called rare factions.
Examples:
(i) sound waves in pipes,
(ii) waves from a slinky spring.
(iii) Earth quake

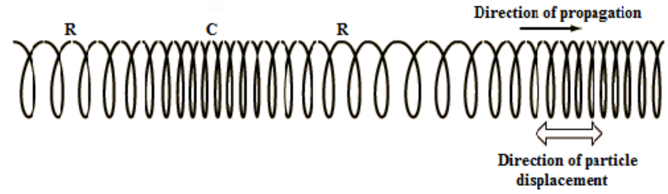
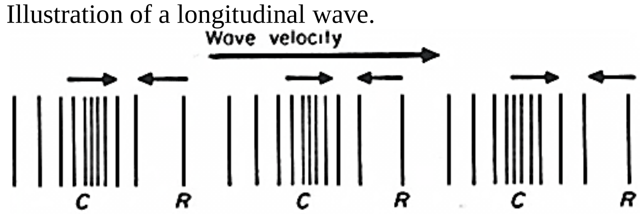


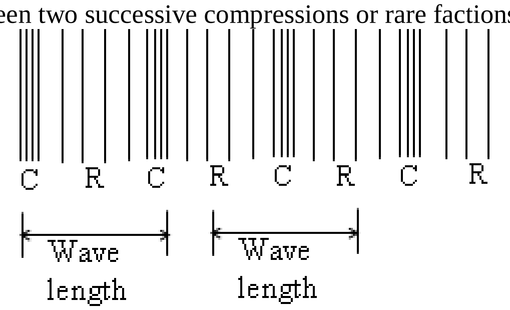
Illustration of a longitudinal wave.



A compression (C) is a region in a longitudinal where the vibrating particles are very close together.

A rare faction (R) Is a region in a longitudinal where the vibrating particles are further apart (distanced).

Wave length; of the longitudinal wave is the distance between two successive compressions or rare factions.



Differences between longitudinal and transverse waves

Transverse waves	***Longitudinal waves***
-Particles vibrate perpendicularly to the direction of propagation of the wave profile	- Particles vibrate parallel to the direction of propagation of the wave profile
-Consists of crests & troughs	-Consists of compression and rarefaction regions
-Under go polarisation	-Cannot be polarised
-No variation in particle density occurs along the wave profile.	-Particle density varies along the wave profile.

2. MECHANICAL AND ELECTROMAGNETIC WAVES:

(a) <u>Mechanical waves:</u>

Definition: These are waves which require a material medium for their propagation.

*Production:*They are waves produced by a vibrating body. They are transmitted by particles of the medium vibrating to and fro.

Examples: They include water waves, sound waves, waves on stretched strings and waves on vibrating springs., e.t.c.

Differences between water and sound waves;

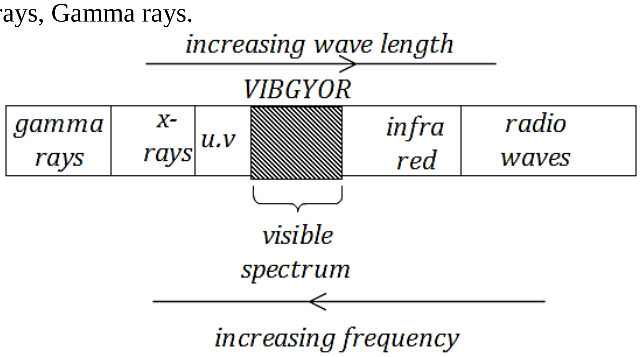
Water waves	Sound waves
-Transverse	Longitudinal
-Low speed	High speed
-Short wave length	Long water length
-Can be polarized	Cannot be polarized
-Possible only in liquid (.e.g water)	Possible in solids, liquids and gases.

(b) Electromagnetic waves:

These are waves that don't require a material medium for their propagation. Electromagnetic waves travel in a vacuum at the speed of light of $3.0 \times 10^8 ms^{-1}$.

They are waves produced by a disturbance in form of a varying electric or magnetic fields of high frequency.

Examples include: radio, infra red, light, Ultraviolet, X-rays, Gamma rays.



Properties of electromagnetic waves

- They are transverse waves.
- They can travel through vacuum.
- They travel at a speed of light (3.0×10^8 m/s).
- They can be reflected, refracted, diffracted, undergo interference and polarization.
- They can be emitted and absorbed by matter.
- They posses energy.

Question:

1. State three differences between sound and light waves.

2. What type of wave requires a medium to be able to travel?

a. mechanical b. electromagnetic
c. transverse d. light wave

3. In what wave is the motion of the medium at right angles to the direction of the wave?

a. mechanical b. electromagnetic
c. transverse d. longitudinal

WAVE PROPERTIES

The wave produced in a ripple tank can undergo.

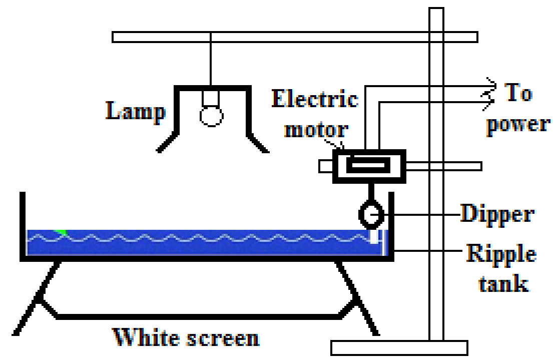
(a) Reflection	(b) Refraction	(c) Diffraction
(d) Interference	(e) Polarization	

The above properties can be studied in details using water waves on a ripple tank.

THE RIPPLE TANK

A ripple tank is an instrument used to demonstrate and study water wave properties.

It is a shallow transparent glass trough. The images of the wave are projected on the screen which is placed below it.



The waves are produced by means of a **dipper** which is either a strip of a metal or a sphere. The dipper is moved up and down by vibration of a small **electric motor** attached to it.

The sphere produces circular wave fronts and the metal strip is used to produce plane waves.

The lamp above the tank casts the shadow of the wave on the white screen placed under neath the tank.

A **stroboscope** is a disc with equally spaced slits. It is used to make the waves appear stationery and therefore allows the wave to be studied in details.

This is achieved by varying the speed of rotation of the stroboscope untillthe aves appear to be stationary when viewed on the screen through the slits of the stroboscope.

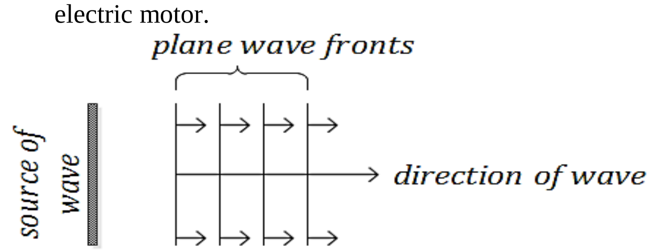
Wave fronts:

A wave front is a line or surface that joins points of the same phase in a wave travelling through a medium.

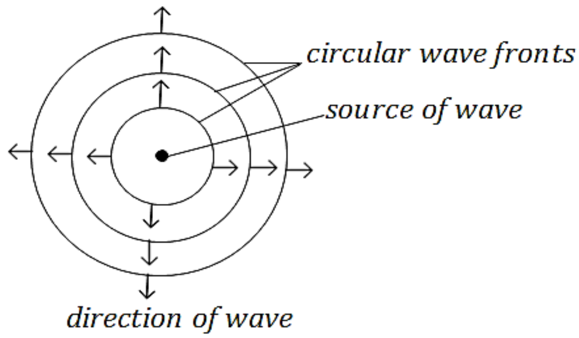
Types of wave fronts.

(i) **Straight waves (plane waves):** These are produced by dipping a straight edged object e.g. a ruler on the water surface.

(ii) **Continuous straight waves:** These are produced by fixing a straight dipper (horizontal bar) suspended by rubber bands. The whole bar is dipped in water and is made to vibrate by the vibrations generated by an electric motor.



(iii) Continuous circular waves: These are produced by attaching small total balls (using rubber bands) to metal bars and using the vibration from an electric motor.
As the bar vibrates, the vibrations cause the dipper to move up and down producing continuous circular waves.

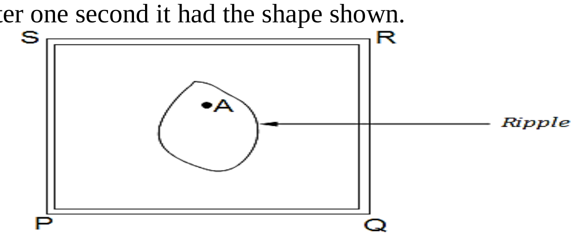


N.B: The speed of the wave in a ripple tank can be reduced by reducing the depth of water in the tank. The effect of reducing the speed of waves is that the wave length of water reduces but frequency does not. The frequency can only be changed by the source of the wave.

Measuring the frequency of a wave using a ripple tank.
The speed of the stroboscope is varied until waves appear stationary. The time taken for successive slits to cross the line of sight is measured. This is the period time, T.
The frequency of the wave is thus cslculsted from: $\mathbf{f = \frac{1}{T}}$

Measuring thewave length of a wave using a ripple tank.
The speed of the stroboscope is varied until waves appear stationary. The lamp above the tank casts a shadow of the waves on a white screen below the tank. The wave length is measured directly.

Question: 1
The figure below shows a ripple tank PQRS whose one side is raised.A ripple started by touching the water at A and after one second it had the shape shown.



(i) State which side of the tank israised**. (SR)**
(ii) Explain the shape of the ripple.
(The ripple is not circular as it would be expected. The speed of the ripple depends on depth of water. Since SR is raised, water is shallower in this direction and so the ripple travels very slowly towards SR than toward PQ. Therefore, the ripple travels a shorter distance from the source towards SR PQ in a given time interval.
The ripples travel more slowly towards SR than PQ thus SR is shallower than PQ)

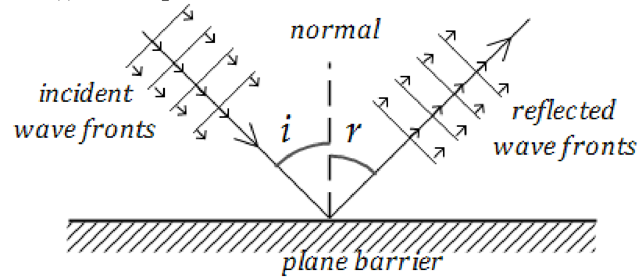
Question: 2 A vibrator in a ripple tank has a period of 0.2 seconds and the distance between 10 successive crests is 38.8cm. Calculate the ;

(i) Wavelength of the wave. **[4.31cm]**
(ii) Velocity of the wave. **[$0.22\ ms^{-1}$]**

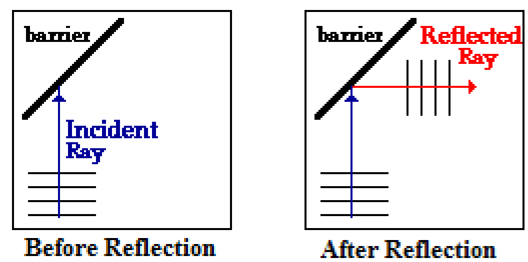
(a) REFLECTION OF WAVES
A wave is reflected when a barrier is placed in its path. The shape of the reflected wave depends on the shape of the barrier.
The laws of reflection of waves are similar to the laws of reflection of light.

❖ **Reflection of plane wave**
Plane wave fronts take the shape of the barrier(relecting surface) after reflection.

(i) On a plane surface.

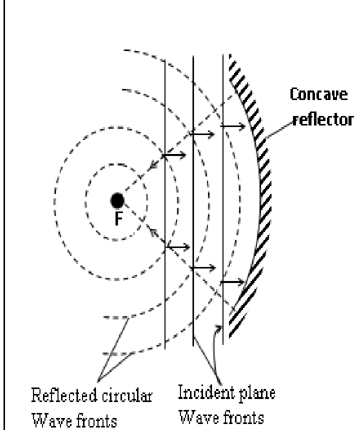


In the figure above straight water waves are represented falling on a metal strip placed in a ripple tank at an angle. The angles of reflection and incidence are always equal (r = i)

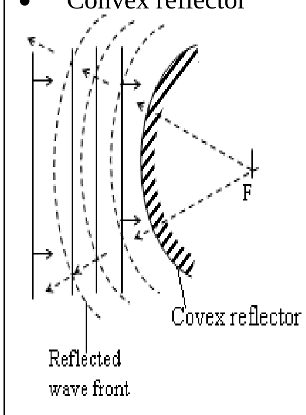


(ii) **On a curved surface**

- Concave reflector

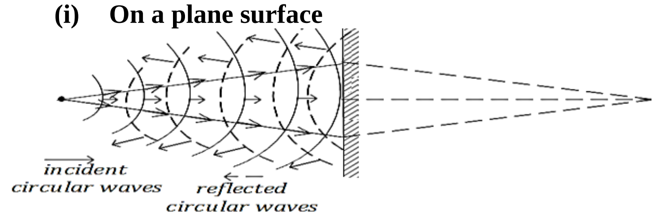


- Convex reflector

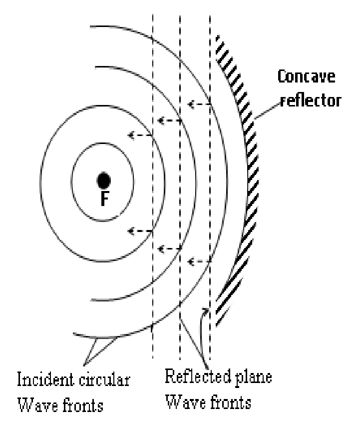
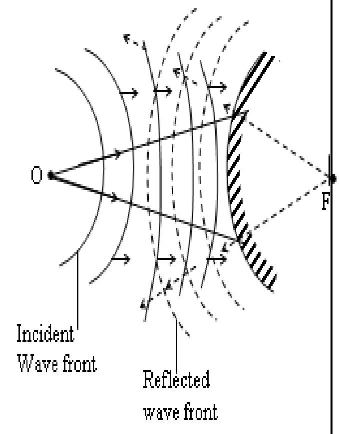


❖ **Reflection of circular waves**
Circular wave fronts are reflected circular in the opposite direction except for a concave reflector(where they are reflected plane).

(i) On a plane surface

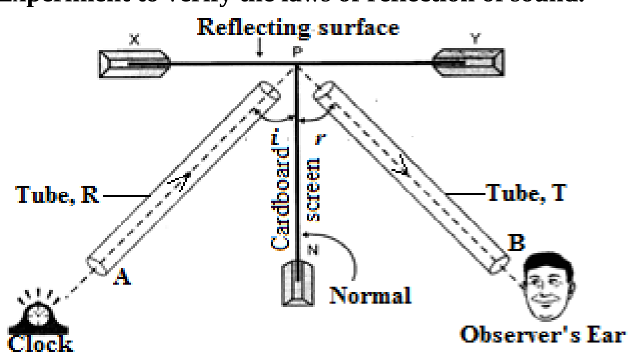


(ii) **On a curved surface**

• Concave reflector	• Convex reflector
	

Note: During reflection of water waves, the frequency and velocity of the wave do not change.

Experiment to verify the laws of reflection of sound.



XY is a hard plane surface, R is a closed tube and T is an Open tube.

- Put a ticking clock in tube R on a table and make it to face a hard plane surface e.g. a wall.
- Put tube T near your ear and move it on either sides until the ticking sound of the clock is heard loudly.
- Measure angles i and r which are the angles of incidence and reflection respectively.
- From the experiment, sound is heard distinctly due to reflection.
- Angle of incidence (i) and angle of reflection (r) are equal and lie along XY in the same plane.
- This verifies the laws of reflection.

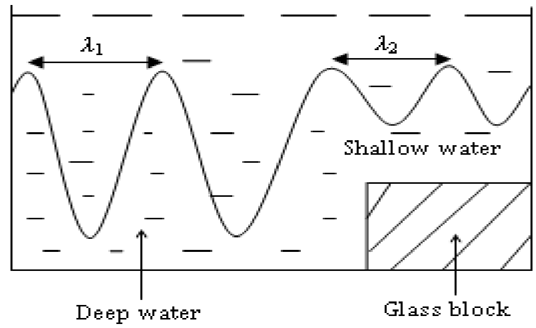
Note: Hard surfaces reflect sound waves while soft surface absorb sound waves.

(b) REFRACTION

This is the change in the direction of wave travel as it moves from one medium to another of different depth.

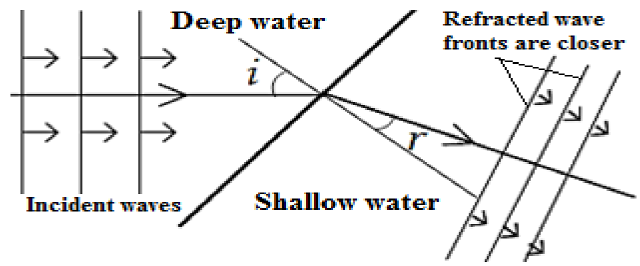
It is caused by the change of wave length and velocity of the wave. However, the **frequency and the period are not affected.**

In a ripple tank, the change in direction is brought about by the change in water depth.



When waves are incident on a shallow water boundary at an angle;

- ✓ Wave length decreases in shallow waters
- ✓ Speed decreases in shallow water
- ✓ Frequency and period remain the same.



λ_1= wave length in deep water

λ_2 = wave length in shallow water

Note:

(i) $\lambda_1 > \lambda_2$

(ii) $v_1 = f\lambda_1$ and $v_2 = f\lambda_2$

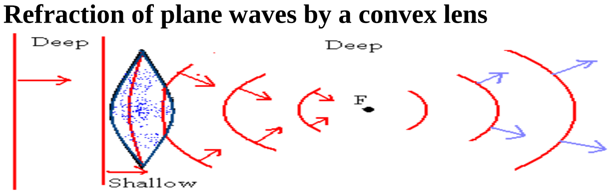
(iii) $v_1 > v_2$; When f – is constant.

$$\text{Refractive index n} = \frac{\text{velocity in deepwater}}{\text{velocity in shallowwater}}$$

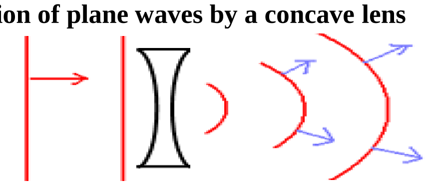
$$\text{Refractive index } n = \frac{v_1}{v_2} = \frac{f\lambda_1}{f\lambda_2}$$

$$\text{Refractive index } n = \frac{\lambda_1}{\lambda_2} = \frac{\text{Wave length in deep water}}{\text{Wave length in shallow water}}$$

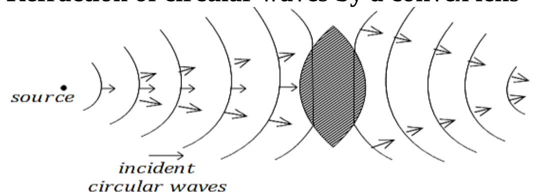
Refraction of plane waves by a convex lens



Refraction of plane waves by a concave lens



Refraction of circular waves by a convex lens

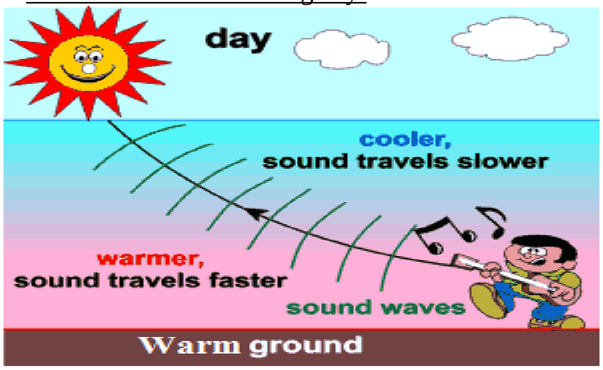


Refraction of sound waves and why sound is clearer at night than during day

Refraction occurs when speed of sound waves changes as it crosses the boundary between two media. The speed of sound in air is affected by temperature.

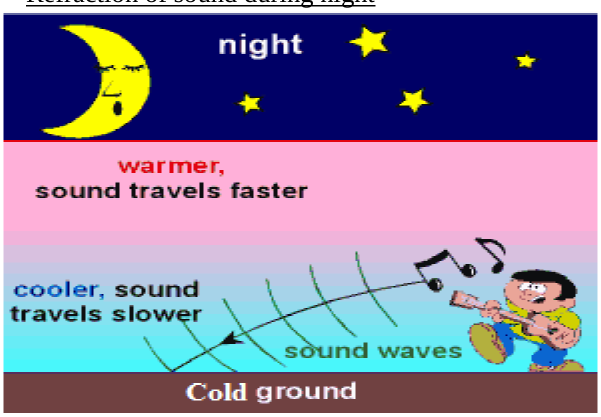
Sound waves are refracted ***away from the warmer temperatures towards the cooler temperatures***. This explains why it is easy to hear sound waves from distant sources at ni-ght than during day.

❖ Refraction of sound during day.



During day, the ground is hot and this makes *the layers of air near the ground to be hot and hence less dense while that above the ground is generally cool.* ***The wave fronts from the source are refracted away from the ground.***

❖ Refraction of sound during night



During night, the ground is cool and this makers *layers of air near the ground to be cool while above to be warm and hence less dense. The wave fronts from the source are* ***refracted towards the ground*** making it easier to hear sound waves over long distances.

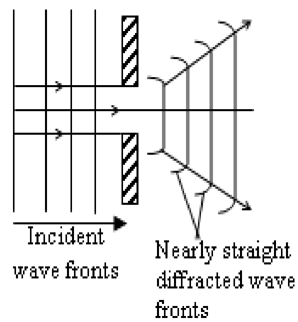
(c) DIFFRACTION OF WAVES

This is the ***spreading of waves around corners or*** *edges of an obstacle.*

It takes place when the diameter of the hole is in the order of wave length of the wave. i.e. For diffraction to occur, $\boldsymbol{\lambda}_{\mathbf{wave}} > diameter\ of\ the\ opening$. The smaller the gap the greater the degree of diffraction as shown below.

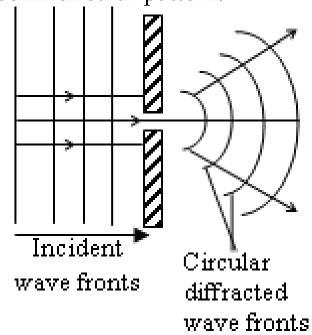
(a) Wide gap

The ripples emerge straight and curve at the ends.



(b) Narrow gap

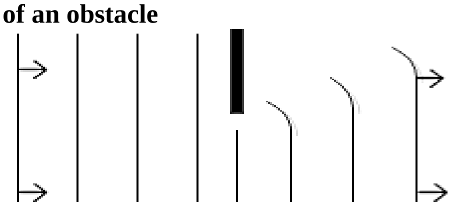
The ripples emerge in a semi-circular pattern.



✓ Diffraction (spreading) increases with decrease in the width of the slit. Wider gaps produce less diffraction.

✓ When the width of the gap is less than the wave length of the of the incident waves, the emerging waves are circular. At this width, the slit may be considered to act as a separate point source of waves.

(c) **Edge of an obstacle**



Diffraction of sound

Sound waves are more diffracted than light waves because the ***wave length of sound is greater than that of light.*** *Therefore sound can be heard in hidden corners.*

Light waves are not easily diffracted because they have a very short wave length $\left(\boldsymbol{\lambda_{light}} = \frac{1}{2}\boldsymbol{micron}\right)$*, hence it needs an object of size close to a micron for it to be diffracted strongly.*

Sound waves are easily diffracted because they have a very long wave length $(\boldsymbol{\lambda_{sound}} = \mathbf{1\ m})$*, hence any object of size close to 1metre or more precisely visible to the eye will strongly diffract sound.*

A person in one room can be heard by another person in the next room because of diffraction of sound waves.

The mouth acts as a gap and the waves from mouth spread and the person is able to hear the sound.

If you are sitting in a room and the door is open, you can hear music from a radio in the next room; the sound waves from the radio pass through the door and spread out into the room you are in.

N.B - When waves undergo diffraction, **wave length** and **velocity** remain constant.

(d) INTERFERENCE OF WAVES

This is the net effect of combination of two or more identical waves of the same frequency and neally the same amplitude travelling along the same medium to form a single wave with a larger amplitude, reduced amplitude or same amplitude.

The interfering waves should be in the same phase (matching).
Interfering of waves travelling in opposite directions produces **standing** or **stationnary** waves.

Conditions necessary for producing interference:

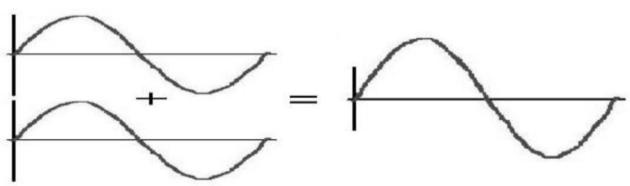
(i) The two waves must have coherent sources. (coherent sources are sources which emit identical waves with a constant phase difference).
(ii) The two waves must have the same amplitude and the same frequency (Waves should be monochromatic).
(iii) The distance between the sources must be very small.

Types of Interferences.

(a) Constructive interference

This occurs when the waves have a displacement in the same direction.
This occurs when waves add in a way that the amplitude of the resulting wave is larger than the amplitudes of the component waves.
In a transverse wave, occurs when a crest from one wave source meets a crest from another source or a trough from one source causing reinforcement of the wave i.e. increased disturbance is obtained.
The resulting amplitude is the sum of the individual amplitudes.

E.g.∩ + ∩ = ∩ OR .∪ + ∪ = ∪

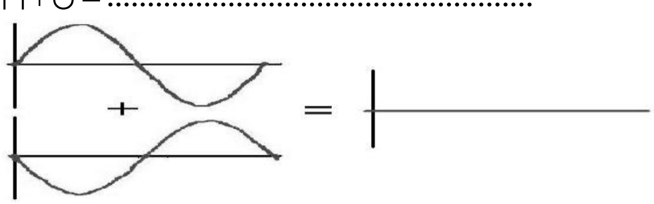


For Light, constructive Interference would give **increased brightness.**
For sound, constructive Interference would give **increased loudness.**

(b) Destructive interference

This occurs when the waves have a displacement in the opposite direction.

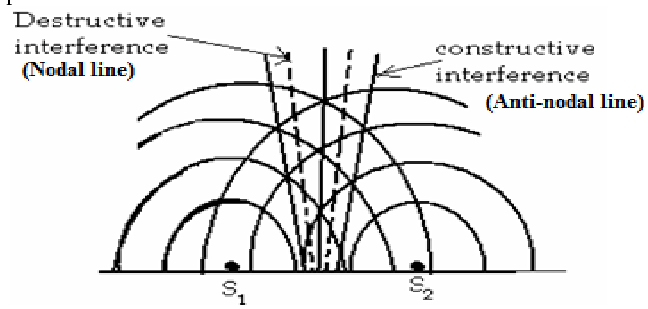
This occurs when waves add in a way that the amplitude of the resulting wave is smaller than the amplitudes of the component waves.
In a transverse wave, it occurs when the crest of one wave meets a trough of another wave resulting in either reduced amplitude or wave cancelling i.e.
If waves are out of phase, they cancel each other to give an area of zero resultant. This is called destructive interference. e.g.
∩+∪=..



For Light, destructive Interference would give **reduced brightness or darkness.**

For sound, destructive Interference would give **reduced loudness or no sound at all.**

Note:
The interference pattern caused by two sources placed close together – give nodal and anti-nodal lines that are spread widely. When the two sources are placed far apart, the nodal and anti-nodal lines are closer together making the pattern more difficult to see.



The waves from the two sources interfere;

- ✓ Constructively at points called antinodes and
- ✓ destructively at points callednodes

Anti-nodal linesare lines joining points of constructive interference.
Nodal lines are lines joining points of destructive interference. (*Where the waves cancel out*)

Note:
-When distance between the sources is reduced, points of maximum(Antinodal points) and zero disturbances (nodal points) are further apart.
- When the frequency of the source increases antinodal points come so close to each other. Nodal points too, become so close.

Applications of Interference.

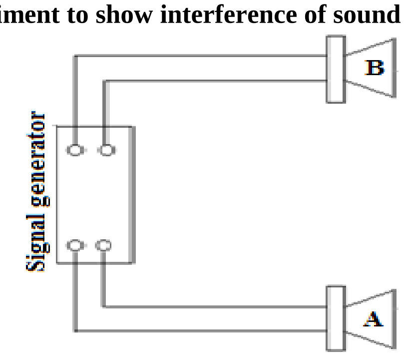
(i) Formation of stationary waves

Interference of sound waves travelling in opposite directions often leads to formation of stationary waves. Eg waves on vibrating strings, waves in open and closed pipes.

(ii) Formation of beats

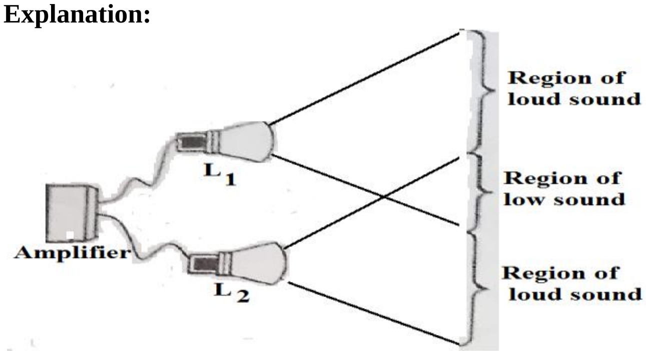
Interference of sound waves travelling in the same direction often leads to formation of beats.
When two sound waves from two different sources overlap, they produce regions of loud sound and regions of quiet sound. The regions of loud sound are said to undergo constructive interference while regions of quiet are said to undergo destructive interference.

An experiment to show interference of sound waves.



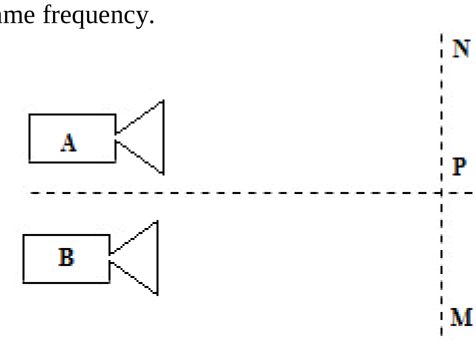
Two loud speakers A and B are connected to the same signal generator so that sound waves from each are in phase and are of the same frequency.
An observer moving in front of the loud along AB hears alternating **loud** and **soft** sounds as he moves along AB.

Explanation:



Interference of waves from A and B occurs and the loud and soft sounds correspond to **constructive** and **destructive** interferences respectively.
With the sound set at a lower frequency (long wave length) the interference pattern becomes widely spread.

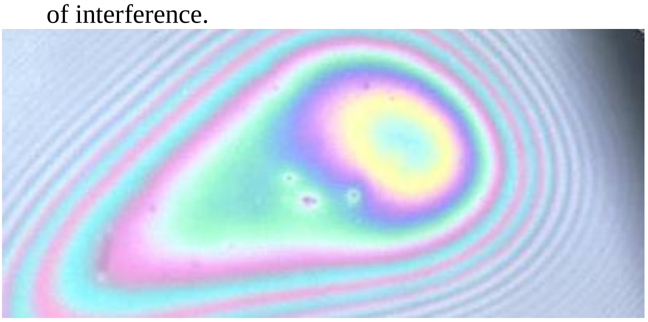
Question.
Two identical loudspeakers A and B are placed near each other as shown in the figure below. The speakersvibrate with same frequency.



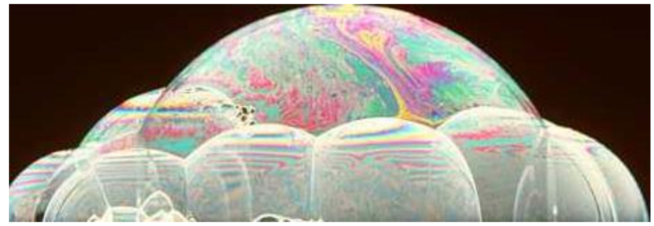
Explain what will be observed on a sound detector moved from Nto M.
The loudness of sound (amplitude) increases and decreases regularly due to interference of sound from the two speakers.

Applications of interference of light

(i) Light reflected at each surface of an extremely thin transparent film on a smooth surface can interfere. The ***rainbow colours of a film of oil on water*** are a result of interference.



(ii) The different ***colours that appear to streak the surface of soap bubbles*** correspond to different wavelengths of visible light interfering with each other at that point on the bubble's surface.



(a) With the aid of a diagram, describe how an interference patter (Interference fringes) can be produced in a ripple tank.

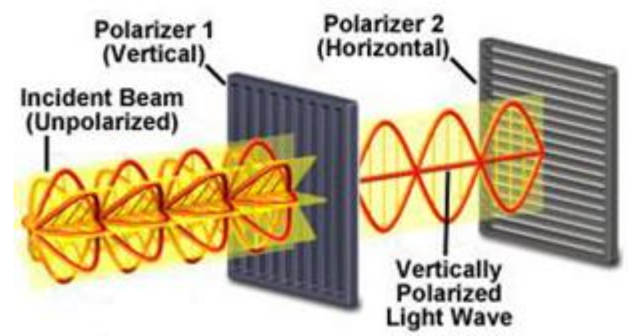
(b) What are the conditions necessary for interference to occur?

(c) Two identical sources are made to produce circular waves in a ripple tank. With the aid of a diagram explain how interference fringes may be obtained.

(d) With the aid of a diagram, describe an experiment to show interference of water waves.

(e) POLARISATION OF TRANSVERSE WAVES

Normally, light (and other electromagnetic waves) propagate in all directions. When the light is passed through a special filter, called a **polarizer**, it blocks light waves in all but allows it to pass in only one plane (direction), as shown in the following diagram:



It only occurs with transverse waves like electromagnetic waves, water waves.
Polarization: is the effect in which vibration are in only one defined plane.

SECTION A

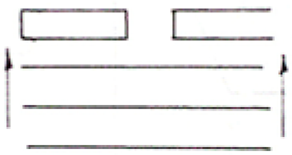
1. The supper position of two waves of the same frequency, speed and nearly the same amplitude is called:
A. interference B. stationary wave
C. Diffraction D. Polarization

2. Which of the following statements is true about the wave travelling from one medium to another?
(i) Its frequency and wave length change
(ii) Its frequency and velocity change
(iii) Its velocity and wave length change
(iv) Only the frequency remains unchanged
A. (i) only B. (i) and (ii) only

C. (i) and (iii) only D. (ii) and (iii) only

3. A longitudinal wave is one in which the
   A. direction of propagation is parallel to that of the vibration producing it.
   B. particles of the medium through which it travels move opposite to the direction of propagation.
   C. direction of propagation is perpendicular to that of the vibration producing it.
   D. particles of the medium through which it travels move together with it.

2. The diagram in the figure below shows parallel wave-fronts approaching a narrow gap.



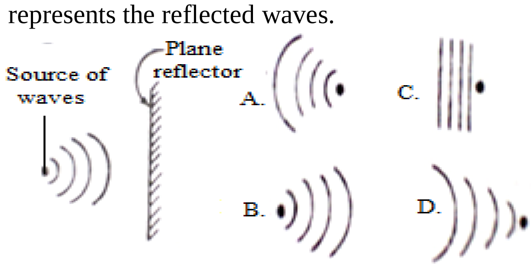
Waves passing through the gap are likely to under go

A. Reflection	C. refraction
B. diffraction	D. interference

3. Which of the following statements is true about the wave traveling from one medium to another.
(i) its frequency and wave length change.
(ii) its frequency and velocity change.
(iii) its velocity and wave length change.
(iv) only the frequency remains unchanged

A. (i) only	B. (i) and (ii) only
C. (i) and (iii) only	D. (iii) and (iv) only

4. The figure below shows circular waves incident on a plane reflector. Which of the following patterns represents the reflected waves.



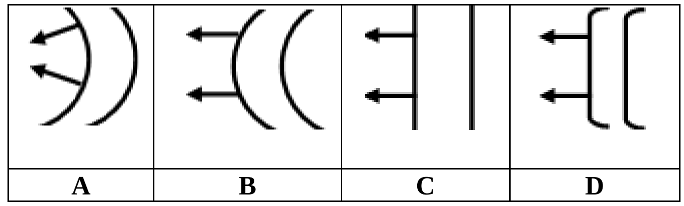
5. Which one of the following does not change when water waves travel through deep to shallow water.

A. frequency	C. amplitude
B. velocity	D. wave length

6. Which of the following statements are true about refraction of waves.
(i) the speed of waves changes.
(ii) the wave-length changes.
(iii) the direction of travel changes.
(iv) the frequency changes

A. (i) only	C. (i) and (iii) only
B. (ii) and (iv)	D. (i), (ii) and (iii) only

7. Which one of the following best describes the pattern of circular waves reflected from a concave reflector?



8. Which of the following change(s) when water waves travel from a deep to a shallow region.
(i) Velocity (ii) Amplitude
(ii) Wavelength (iv) Frequency

A. (i) only	B. (ii) and (iii) only
C. (i), (ii) and (iii) only	D. All

9. Which of the following properties of water waves is affected by a change in depth of the water?
(i) Direction (ii)Wave length
(iii) Velocity

A. (i) only	B (i) and (ii) only
C. (ii) and (iii) only	C. (i), (ii) and (iii)

10. The interaction where a wave hits an object and changes direction only is called?

a. reflection	b. refraction
c. diffraction	d. interference

11. The interaction that bends the wave due to a change in the speed of the wave is called?

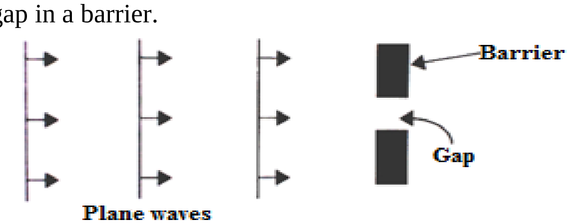
a. reflection	b. refraction
c. diffraction	d. interference

SECTION B

12. (a) (i) Describe how the speed of waves in a ripple tank can be decreased.
(ii) Explain the effect of decreasing the speed of the wave in (a) (i) above on the frequency.
(b) With the aid of sketch diagrams, explain the effect of size of a gap on diffraction of waves.

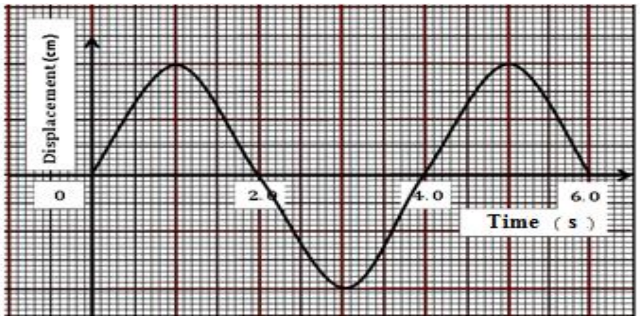
13. (a) With the aid of a diagram, explain the terms amplitude and wavelength as applied to wave motion.
(b) Derive an equation relating velocity, V, frequency, F and wave length of a wave.

14. (a) What is meant by **a standing wave**?
(b) The figurebelow shows plane waves approaching a gap in a barrier.



(i) Show the diagram, the appearance of the waves after the barrier.
(ii) What is the effect of reducing the size of the gap?

15. **(1997 PP1 No 46):** The diagram in the figure shows a section of a transverse wave of wave- length 4.0cm.



Find its:
(i) frequency (ii) amplitude (iii) velocity

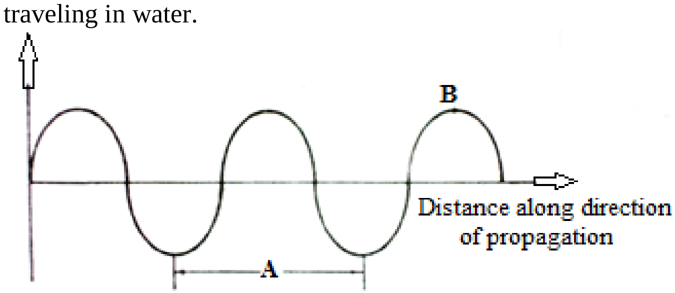
Also Check UNEB 2007 PP2 No.6(c) for a similar question.

21. The end Q of a rope is tied to a pole while the end P is moved up and down as shown in the figure below.

(a) Sketch the resultant wave pattern between P and Q
(b) (i) Name the type of wave produced in (a) above.
(ii) Name one musical instrument which produces this type of wave.

22. (a) Describe how a straight wave is produced in a ripple tank.
(b) State the conditions of the occurrence of destructive interference of waves.

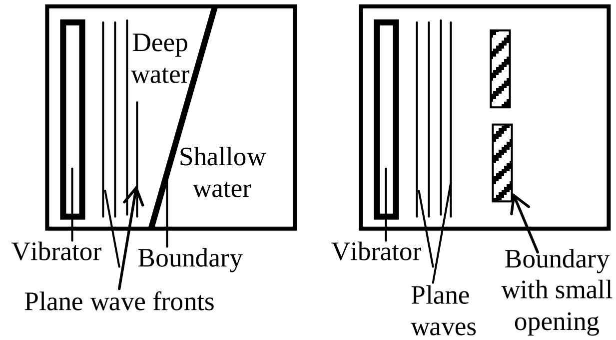
23. (a) What is a **transverse wave**?
(b) The diagram in figure below represents a wave traveling in water.



(i) Name the part labeled B .
(ii) If the distance represented by A is 20cm and the speed of the wave is 8.0 ms^{-1}, what is the frequency of the wave?

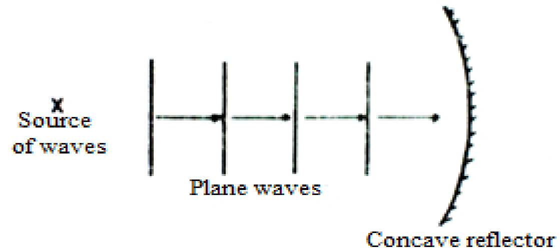
24. (a) Explain the difference between transverse and longitudinal waves. Give one example of each.

(b)The diagram in the figure below represents a plane view of horizontal ripple tanks set up to study characteristics of water waves.The vibrators were set up to produce plane waves.



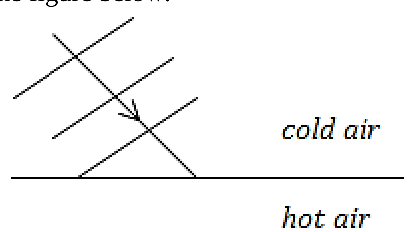
(i) Draw diagrams to show the wave patterns in each case.
(ii)Explain what happens to the plane waves in each case.

26. (a) The figure below shows waves propagating towards a concave reflector.



(i) Draw a diagram to show how the waves will be reflected.
(ii) If the velocity of the waves is 320ms^{-1} and the distance between two successive crests is 10cm, find the period of the waves.

(b) Straight water waves travel from cold air to hot air as shown in the figure below.



(i) Copy and complete the wave front pattern in the hot air.
(ii) Name the wave phenomenon shown by the wave.
(iii) Explain why the wave behaves the way you have drawn in the hot air.

27. A student observed the time interval between the lightning flash from adistant storm and the accompanying thunder as 4 beats of his pulse. If his pulserate is 72 beats per minute, determine the:
(i) time in seconds taken for him to hear the thunder from the instant he sees the flash.
(ii) distance of the storm from the observer.

SOUNDS WAVES

Sound is a form of energy that stimulates the sense of hearing. Sound is produced when particles of a medium are set into vibrations. Hence it is produced by vibrating objects. E.g. when a tuning fork is struck on a desk and dipped in water, the water is splashed showing that the prongs are vibrating or when a guitar string is struck.

Properties of sound waves

- Cannot travel in a vacuum because there is no material.
- Travels with a lower speed than light.
- Produced by vibrating particles of a medium.
- It is longitudinal and Cannot be polarized.

(a) SPECTRUM SOUND WAVES

Frequency	$0H_Z$ to $< 20Hz$	$20H_Z$ to $< 20{,}000Hz$	$< 20{,}000Hz$
Type of sound	Subsonic sound	Audible sound waves	Ultra sonic sound wave.

(i) Subsonic sound waves

These are not audible to human ear because of very low frequency of less than $20H_Z$.

(ii) Audible sound waves

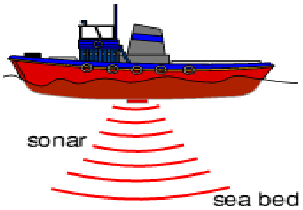
These are audible to human ear. This frequency ranges from $20H_Z$ - 20 KH_Z.

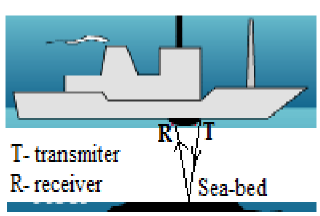
(iii) Ultra sonic sound waves

These are sound waves whose frequencies are above 20 KH_Z. They are not audible to human ears. They are audible to whales, Dolphins, bats etc.

Application of ultra sound waves

- Used in Sound Navigation and Ranging (**SONAR**) by bats in air, whales and dolphins in water to detect and locate obstacles. This is called **echo location**.
- Used in **ultrasonography** for viewing human organs like the liver, kidney, stomach, etc.
- Used in RADAR communication.
- Used by fishermen to catch fish
- Used in spectacles of blind to detect obstacles.
- Used to detect cracks and flaws in metal blocks.
- Used to measure the depth of seas and other bodies. In the echo-sounding system called a **fathometer**, ships use ultrasonic waves to measure the depth of the sea and to detect shoals of fish.





- Ultrasound can also be used in ultrasonic drills to cut holes of any shape or size in hard materials such as glass and steel.
- Jewellery, or more mundane objects such as street lamp covers, can be cleaned by immersion in a tank of solvent which has an ultrasonic vibrator in the base.

Example: 1

A fishing boat uses ultrasonic sound waves of frequency 3×10^8 Hz to detect fish directly below. Two echoes are received one after 0.1 seconds and the other after 0.12 seconds. If the first echo was from the shoal of a fish and the second from the sea bed which is 96m below the boat, calculate the:

(i) Speed of sound in sound in sound. (Ans: $1600\ ms^{-1}$)

(ii) Distance between the shoal of a fish and the boat. (Ans: 80 m)

(iii) Wave length of the sound waves. (Ans: 2×10^{-12} m)

(iv) A range of audible frequencies varies from 20Hz to 20KHz. If the speed of sound in air is $340ms^{-1}$, what is the corresponding range of wave lengths.

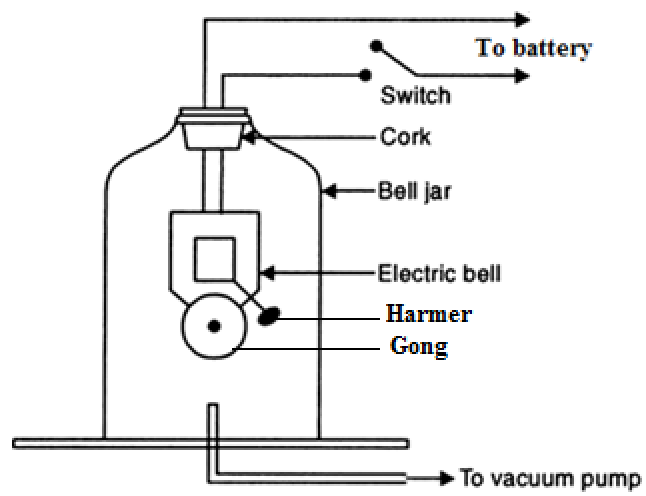
Example: 2

An echo-sounding equipment on a ship receives sound pulses reflected from the sea bed 0.02s after they were sent out from it. If the speed of sound in water is $1500ms^{-1}$, calculate the depth of water under the ship.[$d = 15$m]

(b) TRANSMISSION OF SOUND.

Sound requires a material medium for its transmission. It travels through liquid, solids and gases, travels better in solids and does not travel through vacuum.

Experiment to show that sounds cannot pass through a vacuum. (To show that sound requires a material medium for its transmission)



Procedures:

- Arrange the apparatus as in the diagram with air, in the bell jar.
- Switch on the electric bell, the hammer is seen striking the gong and sound is heard.
- Gently withdraw air from the jar by means of a vacuum pump to create a vacuum in the jar.

Observation:

- The sound produced begins to fade until it is heard no more yet the hammer is seen striking the gong.
- Gently allow air back into the jar, as the air returns, the sound is once again heard showing that sound cannot travel through vacuum.

Conclusion:

- Sound waves require a material medium for their transmission.

Note: The moon is sometimes referred to as a silent planet because no transmission of sound can occur due to lack of air (or any material medium).

Factors affecting the speed of sound in a medium.
The speed of sound depends on;

$$v \ \alpha \ \sqrt{\frac{T}{\rho}}$$

(i) **Medium of transmission**: Sound travels faster in solids slow in liquids and slowest in gases. This is because: The *particles in solids are very close together and they produce and transmit vibrations easily.*

$$V_{solids} > V_{liquids} > V_{gases}$$

(ii) **Density** of the medium: Speed of sound is slower in denser medium *since it requires more energy to make large molecules in a denser medium to vibrate*. Also sound travels faster in hot or warm air than in cold air because warm air is lighter than the cold one.

(iii) **Temperature:** Increase in temperature increases the speed of sound in the medium due to increased molecular vibrations.

(iv) **Wind:** Speed of sound is increased if sound travels in the same direction as wind. Speed of sound decreases if sound and wind are moving in opposite directions.

(v) **Humidity:** The higher the humidity, the higher the speed of sound. This is because the light water vapour molecules replace the oxygen or Nitrogen molecules.

At constant temperature, change in *frequency of the medium* and *pressure of air* do not affect speed of sound because, at constant temperature, the density of air is not affected by changes in pressure.

Some media and their corresponding speeds of sound

Medium		**Temp. (^{0}C)**	**Speed (ms^{-1})**
Gases	Oxygen	0	310
	Air	0	330
		20	340
Liquids	Ethanol	0	1160
	Mercury	0	1450
	Water	0	1500
		20	4800
Solids	Lead	0	1960
	Glass	0	5600
	Steel	0	5960
		20	16400

Some explanations

❖ If a person places his ear near the ground and another person taps along a metal which is some distance away the sound will be heard clearly than when standing since sound travels faster in solids than in gases.

❖ A sound made by a turning fork, sounds louder when placed on a table than when held in the hand. This is because a larger mass of air is set in vibration when vibrating on table there by increasing the sound.

Qn.1: *Explain why sound travels faster in solids than in liquids.*
Qn.2: *Sound waves of frequency 3.3 KHz travel in air. Find the wavelength (Take speed of sound in air = 330ms^{-1})*

- $V = f\lambda \Leftrightarrow \lambda = \frac{V}{f} = \frac{330}{3.3\times1000} = \frac{330}{3300} = 0.1 \text{ m}$

Example:
Two men stand a distance apart besides a long metal rail on a sill day. One man places his ear against the rail while the other gives the rail a sharp knock with a hammer. Two sounds separated by a time interval of 0.5s, are heard by the first man. If the speed of sound in air is 330ms^{-1}, and that in the metal rail is 5280ms^{-1}, find the distance between the men.

Solution:

$$t_1 - t_2 = 0.5$$

$$\frac{x}{330} - \frac{x}{5280} = 0.5$$

$$x = 176 \text{ m}$$

How sound waves travel through air

- ✓ *Sound waves are produced by the vibration of air particles. As air particles vibrate, the vibration, produce energy which is transferred to the next particles that also vibrate in the same direction as the sound wave.*
- ✓ *The next particles are also made to vibrate and in doing so, they transfer their energy to the neighbouring particles which also vibrate and the process continues.*

(c) ECHOES

An echo is a reflected sound.
Echoes are produced when sound moves to and fro from a reflecting surface e.g. a cliff wall. The time taken before an echo arrives depends on the distance away from the reflecting surface.

Conditions for the formation of Echoes

(i) The minimum distance between the source of sound and the reflecting body should be 17.2 metres.
(ii) The wavelength of sound should be less than the height of the reflecting body.
(iii) The intensity of sound should be sufficient so that it can be heard after reflection.

Note: When the obstacle is nearer the source of sound waves, echo joins the original sound. This makes the original sound appears to be prolonged. This effect is called ***reverberation*.**

REVERBERATION

Definition of Reverberation

Reverberation is the effect of the original sound being prolonged due to multiple reflections.

It can also be defined as the repetitive reflection of sound on surfaces.

Advantages of reverberation

In drama, reverberation is used in producing sound. Complete absence of reverberation makes speeches inaudible.

Disadvantages of reverberation

During speeches, there is a nuisance because the sound becomes unclear.

Prevention of reverberation

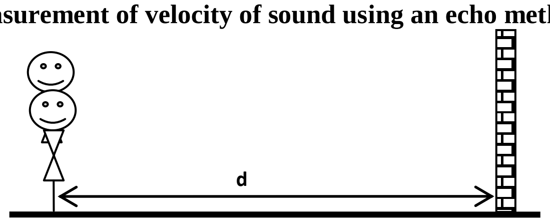
-The internal surfaces of a hall should be covered with soft sound absorbing material called acoustic materials such as cotton clothes and blankets. .

- Cushioning seats and Using carpets.

Why echoes are not heard in small rooms?

This is because the distance between the source and reflected sound is so small such that the incident sound mixes up with the reflected sound making it harder for the ear to differentiate between the two.

Measurement of velocity of sound using an echo method



- Two experimenters stand at a certain distance **d** from a tall reflecting surface
- One experimenter claps pieces of wood **n times**, while the other starts the stop clock when the first sound is heard and stops it when the last sound is heard.
- The time taken, t for the n claps is recorded and the speed of sound in air is calculated from;

$$\mathbf{Speed = \frac{2(distance)}{time} = \frac{2nd}{t}}$$

For an echo; Speed $= \frac{2(\text{distance })}{\text{time}} = \frac{2d}{\left(\frac{t}{n}\right)} = \frac{2nd}{t}$

Where **n** is the number of claps (or sounds) made.

Sources of errors in this experiment may be;

• wind, since it affects thespeed of sound in air

• temperaturechanges of the surroundingair

• timing errors, i.e. onemay not time well thetime of sending and receivingthe echo.

Example: 1

A girl stands 34m away from a reflecting wall. She makes sound and hears an echo after 0.2 seconds. Find the velocity of sound.

$$\text{Speed} = \frac{2(\text{distance})}{\text{time}}$$

$$V = \frac{2d}{t} = \frac{2 \times 34}{0.2} = 340 \text{ ms}^{-1}$$

Example: 2

A person standing 99m from a tall building claps his hands and hears an echo after 0.6 seconds. Calculate the velocity of sound in air.

$$\text{Speed} = \frac{2(\text{distance})}{\text{time}}$$

$$V = \frac{2d}{t} = \frac{2 \times 99}{0.6} = 330 \text{ ms}^{-1}$$

Example: 3

A bullet was fired and an echo from a cliff was heard 8 seconds later. If the velocity of sound is 340m/s, how far was the gun from the cliff?

$$\text{Speed} = \frac{2(\text{distance})}{\text{time}}$$

$$V = \frac{2d}{t} \Leftrightarrow 340 = \frac{2d}{8} \Leftrightarrow 2d = 340 \times 8 \Leftrightarrow d = 1360 \text{ m}$$

Example: 4

A student is standing between two walls. He hears the first echo after 2 seconds and then another after a further 3 seconds. If the velocity of sound is 330m/s, find the distance between the walls.

$V = \frac{2d_1}{t_1}$ $330 = \frac{2d_1}{2} \Rightarrow 2d_1 = 660$ $d_1 = 330$ m	$V = \frac{2d_2}{t_2}$ $330 = \frac{2d_2}{5} \Rightarrow 2d_2 = 1650$ $d_2 = 825$ m
$d = d_1 + d_2$ $d = 330 + 825$ $d = 1155$m	

Example: 5

A man is standing midway between two cliffs. He claps his hands and hears an echo after 3 seconds. Find the distance between the two cliffs.(Velocity of sound = 330m/s)

$V = \frac{2d_1}{t_1}$ $330 = \frac{2d_1}{3} \Rightarrow 2d_1 = 990$ $d_1 = 495$ m	Since the man is mid way between the cliffs, $d_2 = d_1 = 495$m $d = d_1 + d_2$ $d = 495 + 495$ $d = 990$m

Example: 6

A student made 50 claps in one minute. If the velocity of sound is 330s, find the distance between the student and the wall.

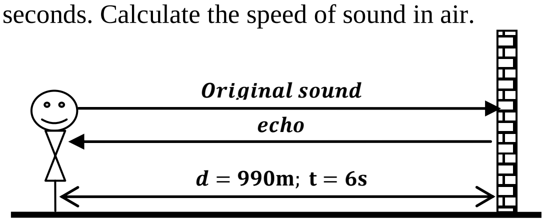
$$\text{Speed} = \frac{2n(\text{distance})}{\text{time}}$$

$$V = \frac{2nd}{t}$$

$$330 = \frac{2 \times 50 \times d}{60} \Leftrightarrow 100d = 330 \times 60$$

$$d = 198$$

1. A boy stands at a distance of 990m from a tall building and makes a loud sound. He hears the echo after 6 seconds. Calculate the speed of sound in air.



$$V = \frac{2d}{t} = \frac{2 \times 990}{6} = 330 \text{ ms}^{-1}$$

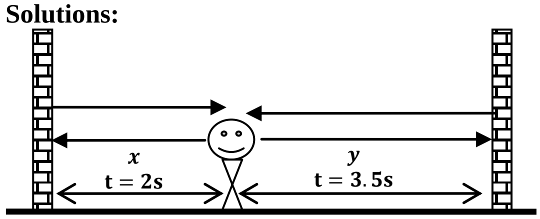
2. A sound wave of frequency 200Hz is produced 300m away from a high wall. If the echo is received after 2 seconds. Find the wave length of sound wave.

$$V = \frac{2d}{t} = \frac{2 \times 300}{2} = 300 \text{ ms}^{-1}$$

$$V = f\lambda \Leftrightarrow 300 = 200\lambda \Leftrightarrow \lambda = \frac{300}{200} = 1.5 \text{ m}$$

3. A man stands between two cliffs and fires a bullet. He hears the 1st echo after 2seconds and the second echo after 3 ½ seconds. Calculate the distance between two cliffs and speed of sound in air = 330ms^{-1}.

Solutions:



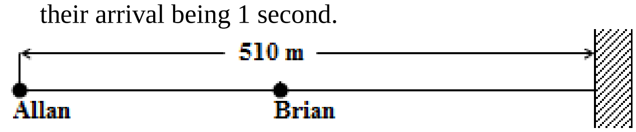
Case I	Case II
$V = \frac{2x}{t_1}$ $330 = \frac{2x}{2}$ $\Rightarrow 2x = 2 \times 330$ $x = 330$ m	$V = \frac{2x}{t_1}$ $330 = \frac{2y}{3.5}$ $\Rightarrow 2y = 3.5 \times 330$ $y = 577.5$ m
Distance between the cliffs, $d = x + y$ $d = x + y$ $d = 330 + 577.7$ $d = 907.5$ m	

4. Reverberation in a building can be reduced by
(i) using a soft carpet (ii) painting the walls
(iii) use of soft ceiling material.
A. (i) and (ii) only B. (ii) and (iii) only
B. (i) and (iii) only D. (i) (ii) and (iii) only

5. A man standing some distance from a vertical wall beats a drum. He hears the echo after 2s. Calculate the distance between the man and the wall. (speed of sound in air = 330ms^{-1})
A. 82.5m B. 165.0m
C. 330.0m D. 660.0m

6. A sound wave of frequency 250Hz is produced 350m away from a high wall. If an echo is received after 2s, the wavelength of the sound wave is
A. 1.4m B.1.2m C. 0.83m D. 0.6m

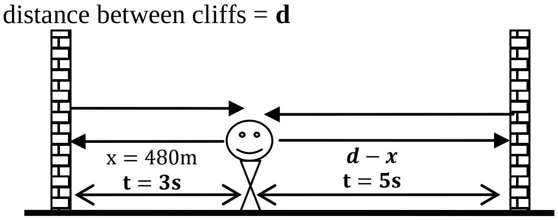
7. In the figure below boy A (Allan), clapped his hands once and Brian heard two claps; the interval between their arrival being 1 second.



Calculate the distance between the boys (speed of sound in air = 330 ms^{-1})
A: 255m B: 330m **C: 345m** D: 510m

8. A student, standing between two vertical cliffs and 480m from the nearest cliff shouted. She heard the 1st echo after 3 seconds and the second echo 2 seconds later. Calculate;
(i) The velocity of sound in air.
(ii) The distance between the cliff.

Solutions:
Let distance between cliffs = **d**



Case I	Case II
$V = \frac{2x}{t_1}$ $V = \frac{2 \times 480}{3}$ $\Rightarrow 3V = 960$ $V = 320 \text{ ms}^{-1}$	$V = \frac{2(d - x)}{t_2}$ $320 = \frac{2(d - 480)}{5}$ $2(d - 480) = 5 \times 320$ $d - 480 = 800$ $d = 1280$ m

Questions

1. A boy standing 100m from the foot of a high wall claps his hands and the echo reaches him 0.5s after. Calculate the speed of sound in air.

2. A sound wave is produced 600m away a high wall. If an echo is received after 4 seconds. Find the frequency of sound wave length is 2m.

3. A sound wave of frequency 250Hz is produced 120m away from a high wall. Calculate;
(i) The wavelength of the sound wave

(ii) The time taken for the sound wave to travel to the wall and back to the source and speed of sound in air = $330ms^{-1}$.

4. A man standing between two vertical walls and 170m from the nearest wall shouted. He heard the 1^{st} echo after 4s and the 2^{nd} echo 2 seconds later. Find the distance between the walls.

5. A boy standing 150m from a high cliff claps his hands and hears an echo. If the velocity of sound in air is $320ms^{-1}$. Find the time taken for the sound to travel to the wall and back to the source.

6. A man stands at a distance of 340m from a high cliff and produces sound. He hears the sound Again after 2 seconds. Calculate the speed of sound.

7. A child stands between 2 cliffs and makes sound. If it hears the 1^{st} echo after 1.5 seconds and the 2^{nd} echo after 2.0 seconds. Find the distance between the 2 cliffs. (speed of sound in air = $320ms^{-1}$).

8. A man sees the flash from a gun fired 1020m away and then hears a bang. How long does the bang take to reach him? [**Ans: 330x1020 s**].

9. The echo sounder on a boat sends down the sea, a pulse and receives its echo 0.3 seconds later. Find the depth of the sea. (speed of sound in water is $1445ms^{-1}$) [**Ans: 216.8m**].

10. A girl at point A clapped her hands once and a boy at B heard two claps in an interval of 1 second between the two sounds. Find the distance AB. [**Ans: 330m**].

11. A girl stands 160m away from a high wall and claps her hands at a steady rate so that each clap coincides with the echo of the one before.
(i) If she makes 60claps per minute, what is the speed of the sound.
(ii) If she then moves 40m closer to the wall, she finds that the clapping rate has to change to 80 claps per minute. What is the speed of the sound in this case.
(iii) Explain what this tells us about the speed of sound in air at the same temperature.

12. Two people X and Y stand in a straight line at distances of 330m and 660m respectively from a high wall. Find the time interval taken for X to hear the first and second sounds when Y makes a loud sound. [**Ans: 2.0 s**].

<u>Questions</u>:

1. (a) Outline four properties of electromagnetic waves.
(b) Distinguish between:
(i) Sound waves and light waves.
(ii) Sound waves and water waves.

2. A man standing midway between two cliffs makes a sound. He hears the first echo after 3s. Calculate the distance between the two cliffs (Velocity of sound in air = $330ms^{-1}$)

MUSICAL / SOUND NOTES

A musical note or a **tone** is a single sound of a definite pitch and quality made by a musical instrument or voice.

Music: This is an organized sound produced by regular vibrations.

Noise: This is a disorganized sound produced by irregular vibrations.

<u>Characteristics of musical notes or x-teristics of sound</u>

(i) Pitch

This is the perceived frequency a sound note. It depends on the <u>frequency</u> of sound produced, the higher the frequency the higher the pitch.

✓ ***Musical Interval:***

This is the ratio of the frequencies of two notes

Name of musical note	Tone ratio
Octave tone	2:1
Minor tone	5:4
Major tone	9:8
Semi tone	16:5

✓ ***Octave:***

This is the span of notes between one pitch and another that it is twice or a half its frequency.

Note: Two notes with fundamental frequencies in a ratio of any power of two (e.g half, twice, four times e.t.c) will sound similar. Because of that, all notes with these kinds of relations can be grouped under the same pitch class.

Note: In calculations involving octave use the formula;

$$\frac{f_2}{f_1} = \left(\frac{2}{1}\right)^n$$

Where, f_2 = Higher frequency, f_1 = Lower frequency
n = Number of octaves above or below f_1

Example: 1

Find the frequency of a note four octave above a note of frequency 20Hz.

Solution: $f_1 = 20Hz, n = 2\ (above);\ f_2 = ?$
$\frac{f_2}{f_1} = \left(\frac{2}{1}\right)^n \Rightarrow \frac{f_2}{20} = \left(\frac{2}{1}\right)^2 \Rightarrow f_2 = 2^2 \times 20 = 80Hz$

Example: 2

Find the frequency of a note of four octaves below a note of frequency 512Hz.

Solution: $f_2 = 512Hz, n = 4\ (below);\ f_1 = ?$
$\frac{f_2}{f_1} = \left(\frac{2}{1}\right)^n \Rightarrow \frac{512}{f_1} = \left(\frac{2}{1}\right)^4 \Rightarrow f_1 = 2^4 \times 20 = 32Hz$

(ii) Loudness

This is the amount of sound energy (Degree of sound volume) that enters the ear per second. It depends on the amplitude of sound waves and sensitivity of the ear.

- <u>Amplitude</u>; This is the measure of energy transmitted by the wave. The bigger the amplitude, the more energy transmitted by the wave and the louder sounder sound produced.

- Sensitivity of the ear.

If the ear is sensitive, then soft sound will be loud enough to be detected and yet it will not be detected by the ear which is insensitive.

(iii) Timber (Quality)

This is the characteristic of a note which allows the ear to distinguish sounds of the same pitch and loudness. It depends on the number of overtones produced, the more the number of overtones, the richer and the sweeter the music and therefore the better the quality of sound from the instrument.

A violin for example, has more and stronger higher overtones than a piano.

Common terms used in sound

(i) Fundamental note:

- Is a note with the lowest audible frequency.
- It is the note produced at the first position of resonance.
- The frequency of the lowest audible sound is called the *fundamental frequency*.

(ii) Overtones:

- Is a note whose frequency is higher than the fundamental frequency.

Uses of overtones:

-Determining the overall quality of sound.

-Describing sound systems in pipes or plucked strings.

Pure and impure musical notes.

Pure notes refer to a sound without overtones. It is very boring and only produced by a tuning fork.

Impure notes refer to a sound with overtones. It is sweet to the ear and produced by all musical instruments.

(iii) Harmonics:

Is a note whose frequency is an integral multiple of the fundamental frequency.

Beats

A beat refers to the periodic rise and fall in the amplitude of the resultant note.

$$f_{beat} = |f_2 - f_1|$$

Questions:

1. In sound amplitude is closely related to what?

a. pitch b. loudness
c. speed d. length

2. What interactions would cause noise?

a. reflection b. refraction
c. diffraction d. interference

3. Which of the following explains why sound travels faster in solids than in gases.

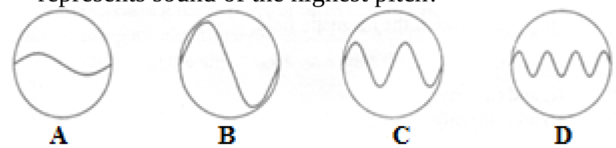
A. Solids don't allow waves to be diffracted.
B. Solids reflect sound better than gases.
C. Molecules in solids are closely packed together than in gases.
D. Molecules in gases vibrate too rapidly to transmit sound.

4. Loudness of a musical note depends on:

1. Pitch. 2. Frequency. 3. Velocity. 4. Amplitude.

A. 1, 2 and 3 only. B. 2 and 4 only.
C. 1 and 3 only. D. 4 only.

5. Which one of the following wave patterns on a CRO represents sound of the highest pitch?



6. The following affect the frequency of a vibrating string except:

A. length of the string
B. Temperature of the medium
C. Tension in the string
D. Thickness of the string

7. What is a wave? What do waves transmit? What is the difference between transverse and compression (longitudinal) waves? (answer is in your notes).

8. What happens to the wavelength of a sound wave as the pitch increases? (remember, pitch is how we detect the frequency of the wave).

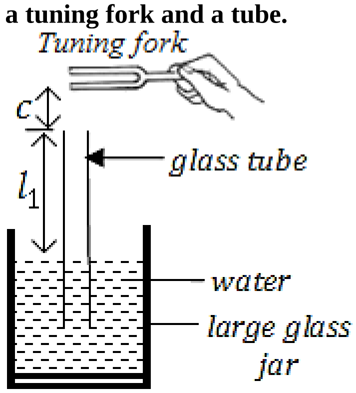
RESONANCE

Resonance *is the effect produced when a body is set to vibrate with its own natural frequency by another nearby body vibrating at the same frequency.*

The final amplitude of the resonating system builds up to a much greater value than that of the driving system.

An experiment to demonstrate Resonance:

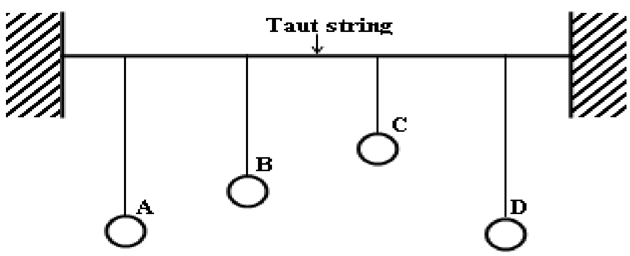
(i) Using a tuning fork and a tube.



- ❖ Water is poured in a beaker or any large glass jar and a tall glass tube dipped into the water.
- ❖ A vibrating tuning fork is held just above the glass tube and the tube moved up and down until a loud sound is heard.
- ❖ The air inside the tube is set into resonance by the tuning fork. At this point, the frequency of the tuning fork is equal to the natural frequency of the vibrating air.

(ii) using a coupled pendulum and tubes.

Procedures:



- ✓ Hang four pendulum bobs on the same taut string such that pendulum, A has variable length while B, C and D have different fixed lengths.
- ✓ Set pendulum A to the same length as D and make it swing and observe the mode of swinging of the pendulums.
- ✓ Set pendulum A to the same length as B and make it swing and observe the mode of swinging of the pendulums.

Observation:

- ✓ When length of **A** is equal to length of **D**, bobs B and C vibrate with smaller amplitudes while **D** swings with larger amplitudes.
- ✓ When length of **A** is equal to length of **B**, the motion of A will be transferred to B in greater amplitude and B will start to swing with appreciable amplitude while C and D will jiggle a little but they will not swing appreciably.

Examples of resonance.

(i) Tuning a radio changes the frequency of the radio waves until it is exactly the same as the frequency of the waves at transmitting station.
(ii) If a heavy vehicle is passing by a house, windows shake.
(iii) In cars, drumming sound is made due to resonance between the car's body and the engine vibrations.

Common consequences of resonance:

(i) A playground swing can be made to swing high by someone pushing in time with the free swing.
(ii) Soldiers need to break a step when crossing a bridge.
(iii) Vibrations of the sounding box of a violin.
(iv) A column of air in a tube resonates to a particular note.
(v) A diver on a spring board builds up the amplitude of oscillation of the body by bouncing on it at its natural frequency.
(vi) Singers who can produce very high frequency notes can cause wineglasses to break when the notes have the same frequency as the natural frequency of the glass. [Opera singers]

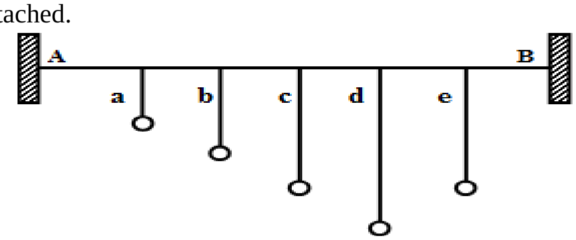
Applications of Resonance:

- In determining the speed of sound in air using a tuning fork and the resonance tube.
- In tuning strings of a musical instrument e.g a guitar and tuning electrical circuits which include indicators.

Dangers of Resonance

- Causes bridges to collapse as soldiers match across them. This can be prevented by stopping the matching.
- Causes buildings to collapse due to earthquake.
- Chimneys can also collapse due to strong resonance.

UNEB 2018 PP2 Qn: The figure below shows a stretched wire AB to which pendulums of length ***a, b, c, d*** and ***e*** are attached.



(i) Which pendulums will have different natural frequencies. amplitude (02 marks)
a, b, c, d or a, b, d, e.

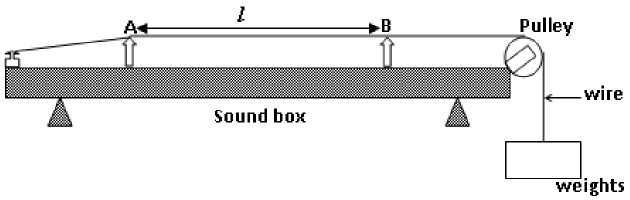
(ii) Which pendulums will have the same natural frequencies. (01 marks)
c and e

(iii) If pendulum, ***e*** is pulled to one side and released to oscillate freely, explain what happens to both ***c*** and ***e*** after some time. (03 marks)
The amplitude of c starts to increase while the that of e decreases, as e transfers energy to c.
Eventually, e comes to rest and c oscillates with almost the same amplitude as e had originally.
The process is reversed and the amplitude of e increases as that of c decreases to zero and so on.

(a) VIBRATION IN STRINGS

Many musical instruments use stretched strings to produce sound. A string can be made to vibrate plucking it like in a guitar or in a harp putting it in pianos. Different instruments produce sounds of different qualities even if they are of the same note.

Factors affecting the frequency of the stretched string.
These can be demonstrated by an instrument called **sonometer** as shown below



A. = Fixed bridge; B.= Movable bridge

(a) Length

For a given tension of the string, the length of the string is varied by moving the movable bridge, B between A and the pulley. By moving bridge B, higher frequency are obtained for a short length AB and lower frequency for a long length. The relation can be expressed as ;

$$f \propto \frac{1}{l} \Rightarrow fl = k \Rightarrow \boldsymbol{f_1 l_1 = f_2 l_2}$$

(b) Tension

Adding weights or removing them from its ends at load R the tension in the sonometer wire, T is noted. It will be noted that the higher the tension, the higher the frequency of the note produced.

$$f \propto \sqrt{T} \Rightarrow \frac{f}{\sqrt{T}} = k \Rightarrow \frac{\boldsymbol{f_1}}{\boldsymbol{f_2}} = \sqrt{\frac{\boldsymbol{T_1}}{\boldsymbol{T_2}}}$$

(c) Mass per unit length (μ) or Thickness

Keeping length (l) and tension (t) constant, the frequency of sound produced depends on the mass per unit length of the string. Heavy strings produce low frequency sounds. This is seen in instruments such as guitar, base strings are thicker than solo strings. If the tension and length are kept constant, the frequency of sound is inversely proportional to the mass of the strings thus a thin short and taut string produces high frequency sound.

$$f \propto \frac{1}{\sqrt{\mu}} \Rightarrow f\sqrt{\mu} = k \Rightarrow \boldsymbol{f_1\sqrt{\mu_1} = f_2\sqrt{\mu_2}}$$

Where, $\mu = mass\ per\ unit\ length = \frac{mass}{lengt\ h}$

<u>The three factors can be combined into a single formula to give the expression for frequency of a stretched string (wire) as:</u>

$$\boldsymbol{f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}}$$

Where, ***l*** is the length in m, **T** is the tension in N and μ is mass per unit length in kgm^{-1}

Example: 1

A musical note has frequency of $420H_z$ and length (l), if the length of the string is reduced by $\frac{1}{2}$, find the new frequency.

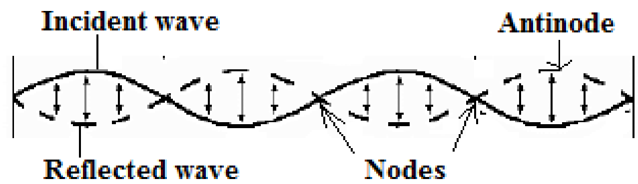
Solution: $f_1 = 420Hz,\ l_2 = \frac{1}{2}l_1,\ \ f_2 = ?$
$f_1 l_1 = f_2 l_2 \Leftrightarrow 420 \times l_1 = f_2\left(\frac{1}{2}l_1\right)$ $f_2 = 840$ Hz

Vibrating strings

The ways in which a string vibrates are called **harmonics**. The sound is produced when notes are performed at both ends of a stationary wave.

Modes of vibration

The ends of a stretched string are fixed and therefore the ends of the string must be the displacement nodes.
If the string is plucked, a **stationary wave** is formed.

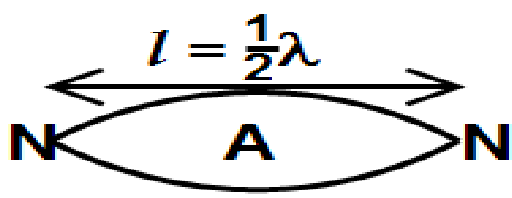


Stationary Waves In Strings:

(i) First Position of resonance (fundamental note)

1st harmonic vibration

The simplest mode of vibration is obtained when the string is plucked at half way its length.



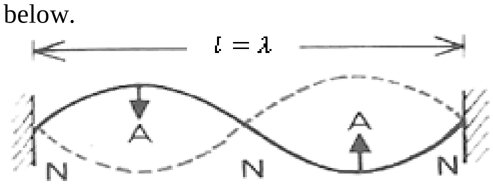
The wave formed in this case is the simplest form of vibration and is called the ***fundamental note***. The frequency at which it vibrates is called the fundamental frequency. If ***f*** is the frequency (Fundamental frequency). Then:

$$f_1 = \frac{v}{\lambda_1}, \quad But\ \lambda = 2l \ \Leftrightarrow \ f = \frac{v}{2l}$$

Where ***v*** is the speed of the wave.

(ii) ***Second Position of resonance (first Overtone).***

Th second mode of vibration is obtained when the string is plucked quarter way from one end, the wave formed is shown below.

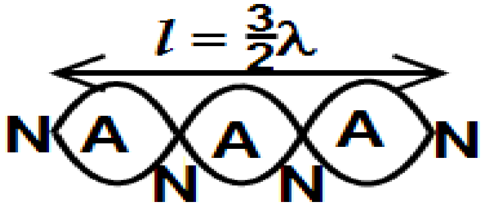


If $\boldsymbol{f_2}$ is the frequency of the wave, then;

$$f_2 = \frac{v}{\lambda_2} \Leftrightarrow f_2 = \frac{v}{l} \Leftrightarrow f_2 = 2\left(\frac{v}{2l}\right) \Leftrightarrow f_2 = \boldsymbol{2f}_1$$

Thus, it is also called the **second harmonic.**

(iii) ***Third Position of resonance (2^{nd}overstone)***



$$f_3 = \frac{v}{\lambda_3} \Leftrightarrow f_3 = \frac{v}{\left(\frac{2l}{3}\right)} \Leftrightarrow f_3 = 3\left(\frac{v}{2l}\right) \Leftrightarrow f_3 = \mathbf{3f_1}$$

Thus, it is also called the **third harmonic.**
Therefore in a stretched string all the harmonics are possible and their frequencies are; $\boldsymbol{f_1}$, $\boldsymbol{2f_1}$, $\boldsymbol{3f_1}$ etc. hence **both even** and **odd harmonics** are obtained.

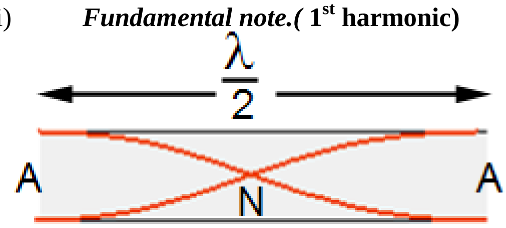
(b) VIBRATIONS OF AIR IN PIPES.
When a wave of a particular wave length and frequency is set into a closed pipe, reflection of the wave occurs at the bottom of the pipe. The reflected wave will interfere with the incidence when the length of the wave is adjacent so that a node is reflected at the reflected surface, a standing wave is produced.
The air column is now forced to vibrate at the same frequency as that of the source of the wave which is a natural frequency of the air column.

1. *Open pipes*

These are Pipes which are open at both ends.
In open pipes, standing waves resulting into resonance are created when the incident waves are reflected by the air molecules at the other end. Possible ways in which waves travel are shown below:
In open pipes, the sound nodes are produced when antinodes are formed at both ends.

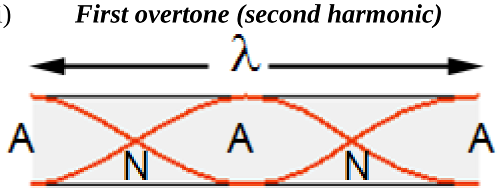
Open pipes boundary conditions:
Antinodes are at both ends.
If we consider an open pipe of length, ***l***, the allowed oscillation modes or standing wave patterns are:-

(i) ***Fundamental note.(* 1st harmonic)**



$$\text{Fundamental frequency; } \boldsymbol{f_1} = \frac{\boldsymbol{v}}{\boldsymbol{\lambda_1}} = \frac{\boldsymbol{v}}{\boldsymbol{2l}}$$

(ii) ***First overtone (second harmonic)***



$$f_2 = \frac{v}{\lambda_2} = \frac{v}{l} = 2\left(\frac{v}{2l}\right) = \mathbf{2f_1}$$

Hence the 2nd Harmonic

Thus frequencies for notes produced by open pipes are $f_1, 2f_1, 3f_1, 4f_1$............

So an open pipe can produces both odd and even harmonics. Therefore, open pipes produce a richer note than that from a similar closed pipe, due to the extra harmonics.

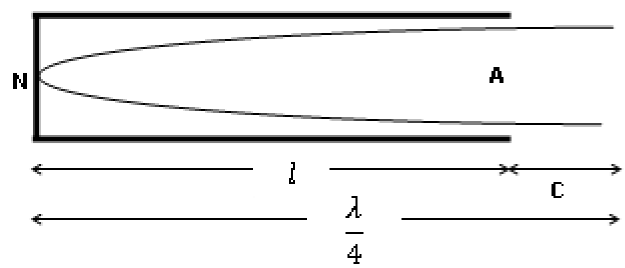
In general;

- For a **closed pipe:** $\boldsymbol{f_n = n\left(\frac{v}{4l}\right) = nf_1}$, Where, **n** = 1, 3, 5, 7………
- For an **open pipe:** ;$\boldsymbol{f_n = n\left(\frac{v}{2l}\right) = nf_1}$, Where, **n** = 1, 2, 3, 4………

End correction
Then, at the open end of the pipe is free to move and hence the vibration at this end of the sounding pipe extend a little into the air outside.

An antinode of the stationary wave due to any note is in practice a distance, c from the open end. The distance, c is known as the end correction.

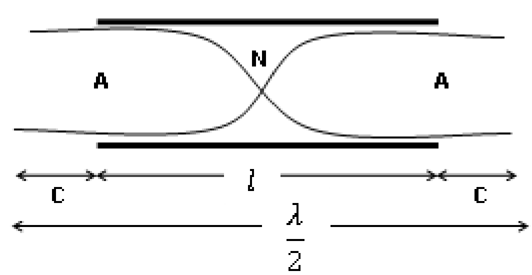
For the closed pipe;-
Fundamental mode



$$\frac{\lambda_1}{4} = l + c \Leftrightarrow \lambda_1 = 4(l + c)$$
$$f_1 = \frac{v}{\lambda_1} = \frac{v}{4(l + c)}$$

$$\boldsymbol{Fundamental\ frequency, f_1 = \frac{v}{4(l + c)}}$$

For open pipe;-
Fundamental mode,



$$\frac{\lambda_1}{2} = l + 2c \Leftrightarrow \lambda_1 = 4(l + 2c)$$
$$f_1 = \frac{v}{\lambda_1} = \frac{v}{2(l + 2c)}$$

$$Fundamental\ frequency, f_1 = \frac{v}{2(l+2c)}$$

Open pipes are preferred to closed pipes because they give both odd and even harmonics hence they produce better quality sound of more overtones than that of closed pipes.

2. ***Closed pipes.***

This consist essentially of a metal pipes closed at one end and open at the other.

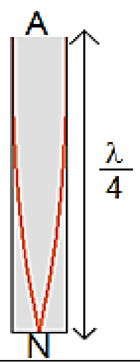
Closed pipes boundary conditions.

At the closed end, there is a displacement **node** while at the open end here is displacement **antinode**.

If we consider a closed pipe of length, ***l***, the allowed oscillation modes or standing wave patterns are:-

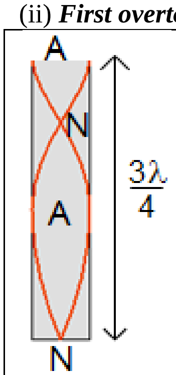
Fundamental or lowest audible frequency (f_1) is obtained when the simplest stationary wave form is obtained.

(i) ***Fundamental note***



Fundamental frequency ; $\boldsymbol{f_1 = \frac{v}{\lambda_1} = \frac{v}{4l}}$

(ii) ***First overtone*** (3rd harmonic)



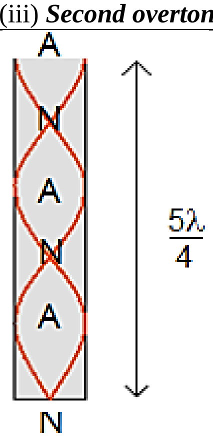
Frequency of first overtone $\boldsymbol{f_2}$ is given by;

$$f_2 = \frac{v}{\lambda_2} \Leftrightarrow f_2 = \frac{v}{\left(4l/3\right)}$$

$$\Leftrightarrow f_2 = 3\left(\frac{v}{4l}\right) \Leftrightarrow f_2 = \boldsymbol{3f_1}$$

Hence the **3rd** Harmonic

(iii) ***Second overtone*** (5th harmonic)



The frequency of the second overtone is given by:

$$f_3 = \frac{v}{\lambda_3} \Leftrightarrow f_3 = \frac{v}{\left(4l/5\right)}$$

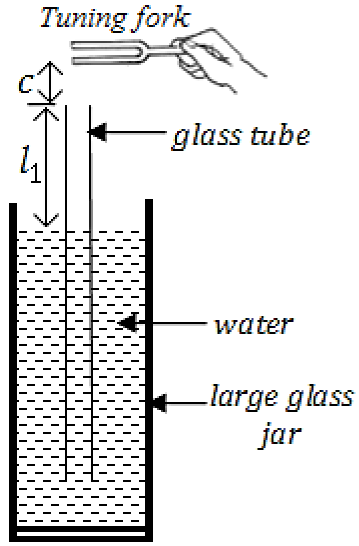
$$\Leftrightarrow f_3 = 5\left(\frac{v}{4l}\right) \Leftrightarrow f_3 = \boldsymbol{5f_1}$$

Hence the **5rd** Harmonic

The frequencies obtained with a closed pipe are: $\boldsymbol{f_1}$, $\boldsymbol{3f_1}$, $\boldsymbol{5f_1}$, $\boldsymbol{7f_1}$, $\boldsymbol{9f_1}$, etc i.e. only odd harmonics' are obtainable. Because of the presence of only odd harmonics, closed pipes are not as rich as open pipes.

In closed pipes, nodes are formed at closed ends and antinodes at open end.

Determination of velocity of sound in air by Resonance method.



C = End correction, l_1, l_2 = Length of air column.

- A **vibrating tuning fork** is held just above the resonance tube.
- The resonance tube is gently lowered until the 1st resonance (loud sound) is heard.
- The length l_1 of the vibrating air column at which the loud sound is heard is noted.

  $l_1 + c = \frac{1}{4}\lambda$……………………………………. (i)
- The resonance tube is raised until the 2nd resonance (loud sound) occurs.
- The length l_2 at which it occurs is measured and noted.

  $l_2 + c = \frac{3}{4}\lambda$……………………………….......... (ii)
- Subtract equation (i) from (ii) to eliminate c

  $(l_2 - l_1) + (c-c) = \frac{3}{4}\lambda - \frac{1}{4}\lambda$

  $l_2 - l_1 = \frac{1}{2}\lambda$

  $2(l_2 - l_1) = \lambda$
- Hence the speed or velocity of sound in air is determined from the expression. $V = f\lambda$.

  $$\boldsymbol{V = 2f(l_2 - l_1)}$$

Note: The reader should take care to use a **vibrating tuning fork** and just a tuning fork, when describing this experiment.

Example: 1.

In an experiment to determine the velocity of sound in air using a resonance tube, the following results were obtained:

- Length of 1st resonance = 16.1cm
- Length of 2nd resonance = 51.1cm
- Frequency of tuning fork = 480 H_z

.

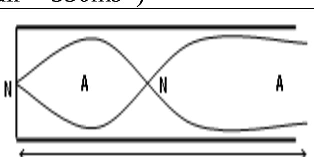
(i) Calculate the wave length of sound produced. $\lambda = 2(l_2 - l_2)$ $\lambda = 2(51.1 - 16.1)$ $\lambda = 70$ cm	(ii) The end correction of the resonance tube. $l_1 + C = \frac{1}{4}\lambda$ $16.1 + C = \frac{1}{4} \times 70$ $C = 17.5 - 16.1$ $C = 14$ cm
(iii)The velocity sound in air. $V = 2f(l_2 - l_1)$ $V = 2 \times 480\left(\frac{51.1}{100} - \frac{16.1}{100}\right)$ $V = 336\text{ms}^{-1}$	

Example: 2.
A glass tube open at the top is held vertically and filled with water. A tuning fork vibrating at 264 Hz is held above the tube and water is allowed to flow out slowly .The first resonance occurs when the water level is 31.5cm from the top while the 2nd resonance occurs when the water level is 96.3cm from the top. Find the;-

Solution:

(i) Speed of sound in the air column. $V = 2f(l_2 - l_1)$ $V = 2 \times 264\left(\frac{96.3}{100} - \frac{31.5}{100}\right)$ $V = 342.144\text{ms}^{-1}$	(ii) End correction. $\lambda = 2(l_2 - l_2)$ $\lambda = 2\left(\frac{96.3}{100} - \frac{31.5}{100}\right)$ $\lambda = 1.296$ m $l_1 + C = \frac{1}{4}\lambda$ $0.315 + C = \frac{1}{4} \times 1.296$ $C = 0.324 - 0.315$ $C = 0.009$ m

Example: 3.
The frequency of the third harmonic in a closed pipe is 280 Hz. Find the length of the air column. (Speed of sound in air = 330ms^{-1})

 $l = \frac{3\lambda_1}{4}$ $\lambda = \frac{4l}{3}$ From; $v = f\lambda$ $330 = 280 \times \frac{4l}{3}$ $3 \times 330 = 280 \times 4l$ $990 = 1120l$ $l = 0.884$	**Alternatively;** For a closed pipe, the possible frequencies are; **f_1, $3f_1$, $5f_1$…..;** where $f_1 = \left(\begin{matrix} frequency\ of\ the \\ fundamental\ note \end{matrix}\right)$ But frequency of third harmonic = $3f_1 = 280$Hz**.** **Thus;** $3f_1 = 280$ $f_1 = 93.33\ Hz$ $f_1 = \frac{v}{4l} \Leftrightarrow 93.33 = \frac{330}{4l}$
	$l = 0.884$ m

Example : 4.
The frequency of the 4th overtone in an open pipe is 900Hz when the length of the air column is 0.4m. Find the
(i) Frequency of the fundamental note
(ii) Speed of sound in air.

Solution:

(i)Frequency of the fundamental note **For an open pipe, the possible frequencies are; f_1, $2f_1$, $3f_1$, $4f_1$, $5f_1$…..; where** $f_1 = \left(\begin{matrix}\text{frequency of the} \\ \text{fundamental note}\end{matrix}\right)$ $f_1 = \frac{v}{2l}$ **But frequency of 4th overtone = $5f_1 = 900$Hz.**	**Thus;** $5f_1 = 900$ $f_1 = 180$ Hz (ii) Speed of sound in air. $f_1 = \frac{v}{2l}$ $180 = \frac{v}{2l}$ $v = 2 \times 0.4 \times 180$ $v = 144\text{ms}^{-1}$

EXERCISE:

1. The frequency of the 3rd overtone (4th harmonic) produced by an open pipe is 840H$_z$. Given that the velocity of sound in air is 330ms^{-1}, calculate;
   (i) Length of the pipe. (**Ans: 0.785 m**)
   (ii) Fundamental frequency. (**Ans: 210 Hz**)

2. A pipe closed at one end has a length of 10cm, if the velocity of sound is 340ms^{-1}; calculate the frequency of the fundamental note.

3. A tuning fork produces resonance in a tube at a length of 15.0cm and also at a length of 40.0cm. Find the frequency of the tuning fork.

4. (a) A tuning fork of 256Hz was used to produce resonance in a closed pipe. The first resonance position was at 22cm and the 2nd resonance position was at 97cm. Find the speed of the sound waves.
   (b) An open tube produced harmonics of fundamental frequency 245Hz, what is the frequency of the 2nd harmonics.

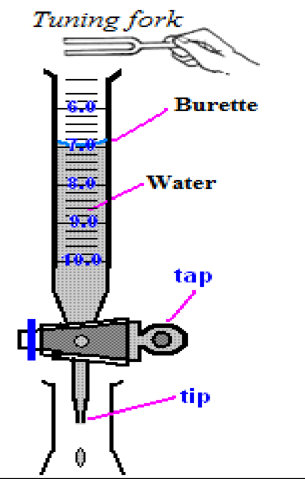
5. A tuning fork of frequency 256 Hz was used to produce resonance in a a tube of length 32.5cm and also in one of length 95.0cm. Calculate the speed of sound in the air column. [320ms^{-1}]

6. A tuning fork of frequency 512Hz is held over a resonance tube of length 80cm. The first position of resonance is 16.3 cm from the top of the tube and the second position of resonance is 49.5cm. Find the speed of sound in air. Why is it better to use a frequency of 512Hz rather than one of 256Hz? [340ms^{-1}]

7. A train blows its whistle as it enters a 50-metre long tunnel. What is the time delay at theother end of the tunnel between hearing the sound of the train's whistle through the rails and through the air? Assume that the

speed of sound in air and through steel is 342 m/s and 1560 m/s respectively.
delay = time taken by sound to travel through air – time taken by sound to travel through rails.
=> (50 m/330 m/s) – (50 m/1560 m/s) => t = 0.12 s.

8. **UNEB 2015 PP1 Section B.**



A sounding tuning fork held above the tube as shown on the left produces the first loud sound when the air colum in the tube is 31 cm above the water surface.
(Take speed of sound in air to be $320 ms^{-1}$).
(a)Find the frequency of the tuning fork.

(b)Explain why northing is heard than 31 cm.

9. A long tube is partially immersed in water and a tuning fork of frequency 425Hz is sounded and held above it. If the tube is gradually raised, find the length of air column when resonance first occurs. (Neglect the end correction, speed of sound in air). (**Ans: 0.2 m**).

10. (a) Whale-watchers use the reflection of ultrasound waves to identify the presence of whales inthe vicinity of their boats. If the safe distance from a whale is 100 m, what is the measured time delay between the emitted and reflected signal from the whale at a depth of 100 m? Assume that the speed of sound in water is 1560 m/s.
(a) time = 2 x distance/speed of sound
=> t = 2 x 2 m/330 m/s. => t = 4/330 => t = 0.012 s.

(b) Orchestras tune to concert pitch, A, at 440 Hz. What is the wavelength of the instruments
playing at this frequency if the speed of sound is 330 m/s?
(b) $\lambda = v/f \Rightarrow \lambda = 330\ m/s / 440\ Hz \Rightarrow \lambda = 0.75\ m$

(c) Suggest two applications of the echo-sounding principle.*radar; electronic tape-measure.*

SECTION A

1. The frequency of the third harmonic in a closed pipe is 280 Hz. Find the length of the air column. (Speed of sound in air = $330ms^{-1}$)
A. 93.3m B.0.884m C.0.164 m D. 88.4m.

2. Resonance is the phenomenon that occurs when a body is:
A. set to vibrate at some frequency by another nearby body vibrating at its natural frequency.
B. set to vibrate with its natural frequency by another nearby body vibrating at the same frequency.
C. set to vibrate at its lowest possible frequency.
D. set to vibrate at a frequency higher than its natural frequency.

3. The frequency of the 3[rd] overtone produced by an open pipe is $840H_z$. Given that the velocity of sound in air is $330ms^{-1}$, calculate the length of the pipe.
A. 210m B.0.21m C. 0.785m D. 785m

4. A long tube is partially immersed in water and a tuning fork of frequency 425Hz is sounded and held above it. If the tube is gradually raised, find the length of air column when resonance first occurs. (Neglect the end correction, speed of sound in air).
A. 20m B.0.2m C. 0.02m D. 0.002m

5. A vibrator produces a sound wave that travels 900m in 3s. If the wavelength of the wave is 10m, find the frequency of the vibrator.
A. 30Hz B. 270Hz C. 300Hz D. 3000Hz

6. A man standing in front of a tall wall makes a loud sound and hears the echo after one and half a sec. How far is he from the wall if the velocity of the sound in air is 330m/s?
A.110m B.247.5m C.440m D.990m

7. The number of vibrations a wave makes in 1s is the
A. Frequency B. period
C. Wave length D. amplitudes

8. Which of the following are longitudinal waves?
A. water waves B. sound waves
C. light waves D. radio waves

9. Points on a stationary wave which are permanently at rest are called
A. crests B. trough
C. nodes D. anti-nodes

10. Sound is produced by a source vibrating at a frequency of 50Hz. Given that speed is 330ms-1 in air its wavelength is
A. 0.15m B. 6.6m C. 380m D. 16500m

11. The velocity of sound in air at a constant pressure, A
A. increases with loudness
B. decreases with loudness
C. increases with temperature
D. decreases with temperature

12. A man sees the flash from a gun fired 1020m away and then later he has a bang. How long does the bang take to reach him. (Take speed of sound as $340ms^{-1}$)
A. $\frac{1020}{340\times10}$ s B. $\frac{340}{1020}$ s

C. $\frac{1020}{340}$ s D. (340x1020) s

13. The effect produced when many echoes merge into one prolonged sound is known as:
A. noise. B. harmonics.
C. reverberation . D. pitch.

14. What occurs when a body is made to vibrate with its natural frequency due to external vibration?
A. Echo B. Refraction
C. Resonance D. Reverberation

15. A man standing 85 m from a tall wall fires a gun and hears the echo from the wall after 0.5 s. calculate the speed of sound in air.
A. 340ms^{-1} B. 170 ms^{-1} C. 85 ms^{-1} D. 43 ms^{-1}

16. A boy standing 150 m from a vertical cliff claps his hands and hears an echo 0.85 seconds later. Find the speed of sound in air.
A. 128 m s^{-1} B.176 m s^{-1}
C. 255 m s^{-1} D. 353 m s^{-1}

17. In a sound wave the particles of the medium
A. are stationary.
B. move along with the wave.
C. vibrate in the same direction as the wave.
D. vibrate at right angles to the direction of the wave.

18. Which of the following statements are true about sound waves?
(i) they are longitudinal (ii) they are transverse
(iii) they are produced by vibrations
(iv) they can travel through empty space
A.(ii) and (iv) only B.(i) and (iii) only
C.(i), (ii) and (iii) only D.(ii), (iii) and (iv) only

19. A girl stands in between two tall cliffs and claps her hands. She hears the first echo after 1s and the second echo after 2s. If the speed of the sound is 300ms-1, the distance between cliffs is:
A. 300m B. 450m C. 900m D. 1200m.

20. Sound waves :
A. Do not pass through a vacuum
B. Travel through solids at a lower speed than air.
C. Do not travel through liquids.
D. Travel at ahigher speed in air.

21. Which of the following statements is true?
A. light waves, radio waves and sound waves will travel through a vacuum.
B. light waves and radio waves will travel through a vacuum, sound waves will not.
C. light waves and sound waves will travel through a vacuum, radio waves will not.
D. sound waves and radio waves will travel through a vacuum, light waves will not.

22. Sound travels much greater through;
A. steel B. water C. wood D. nitrogen gas

23. An echo is produced as a result of sound waves being
A. absorbed by objects B. transmitted by objects
C. deflected by objects
D. bent around corners by objects

24. The particles of the medium through which a longitudinal wave travels:
A. vibrate parallel to the direction of the propagation of the wave
B. vibrate perpendicular to the direction of the propagation of the wave
C. move along with the wave
D. move in the opposite direction to the wave.

25. A girl standing 300m away from a high vertical wall makes a loud sound of frequency 600Hz. Calculate the wave length of the sound wave if the girl hears the echo after 2s.
A. 0.2m B. 2.5m C. 5m D. 10m

26. In forced vibrations, resonance occurs when the forcing
A. Frequency is equal to the natural wavelength
B. velocity is equal to the natural velocity
C. frequency is equal to the natural frequency
D. frequency exceeds the natural frequency.

SECTION B

27. (a) What is meant by **sound**?
(b) Describe an experiment to show that sound waves require a material medium for transmission.

(c) Explain briefly the following:
(i) a dog is more able than a human being to detect the presence of a thief tip-toeing at night.
(ii) An approaching train can easily be detected by human ears placed close to the rails.

28. A sound of frequency 250Hz is produced 120m away from a high wall. Calculate the:
(i) Wave - length,
(ii) Time it takes the sound wave to travel to and from the wall. (Speed of sound in air = 330ms^{-1})

29. (a) What is an **echo**?
(b) State any two factors which determine the frequency of a note produced when a guitar string vibrates.
(c) Give two reasons why sound is louder at night than during the day.

30. An echo sounding equipment on a ship receives sound pulses from the sea bed 0.02 after they were sent out from it. If the speed of sound in water is 1500ms^{-1}, calculate the depth of water under the ship.

31. (a) A long open tube is partially immersed in water and a tuning fork of frequency 425Hz is sounded and held above it. If the tube is gradually raised, find the length of the air column when resonance first occurs. (Neglect the end correction, Speed of sound in air = 340ms^{-1})

(b) State three difference between **sound** and **light** waves.
(c) (i) Explain how stationery waves are formed.
(ii) State three main characteristics of stationary waves.

32. (a) Two identical sources are made to produce circular waves in a ripple tank. With the aid of a diagram, explain how interference fringes may be obtained.
(b) (i) Describe an experiment to measure the speed of sound in air.

(ii) State any two likely sources of error in the experiment.

(c) Describe an experiment to determine how frequency of a vibrating string depends on the length of the string.

33. (a) The velocity and frequency of sound in air at a certain time were 320ms^{-1} and 200Hz respectively. At a later time, the air temperature changed and the velocity of sound in air was found to be 340ms^{-1}. determine the change in wavelength of the sound.

(b) List three differences between sound waves and radio waves.

(c) A girl stands at a distance of 600m from a high cliff and blows a whistle. She hears the sound of the whistle again after 4 seconds. Calculate the speed of the sound.

34. (a) A girl at a distance of 165m from a high wall, clapped her hands once but heard two claps.

(i) Explain why the girl heard two claps.

(ii) Find how long it took her to hear the second clap. (The speed of sound on air is 330ms^{-1}).

(b) Give one practical application in which the principal in (a) above is used.

35. (a) Explain each of the following observations:

(i) Sound from a distant source is louder at night than during day.

(ii) an observer can hear sound from a source which is behind a building

(b) Describe an experiment to show interference of sound waves.

36. (a) What is meant by **reverberation**?

(b) How does complete absence of reverberation affect speech in a concert hall?

(c) A girl produces sound waves near a series of regularly spaced reflecting surfaces. If the reflected are 15cm apart and the velocity of sound in air is 330ms^{-1}, calculate the frequency of the echo.

(d) Explain why echoes are not heard in small rooms.

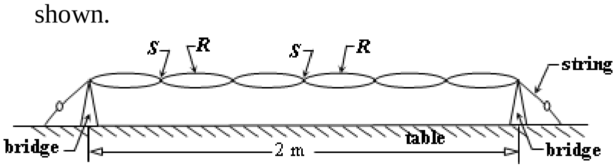
37. (a) An echo sounder on a boat sends down a pulse through the water and receive its echo 0.9 s later. If the velocity of sound in the water is 1450ms^{-1}, calculate the water depth.

(b) Identify two differences between **water** and **sound** waves.

(c) Define the terms **frequency** and **wavelength** as applied to sound.

(d) Describe an experiment to demonstrate resonance in sound.

38. The Figure below shows a string stretched between two bridges. When it is plucked at some point it vibrates as shown.



(i) Name the points marked *R* and *S*. (*01 mark*)

(ii) Calculate the wavelength of the wave in the string. (*02 marks*)

39. A man stands between two cliffs and makes a loud sound. He hears the first echo after one second and a second echo after a further one second. Find the distance between the cliffs.

40. Explain the following:

(i) Sound is fainter on a high mountain than at sea level.

(ii) The inside of a loud speaker box is covered is with a cotton material.

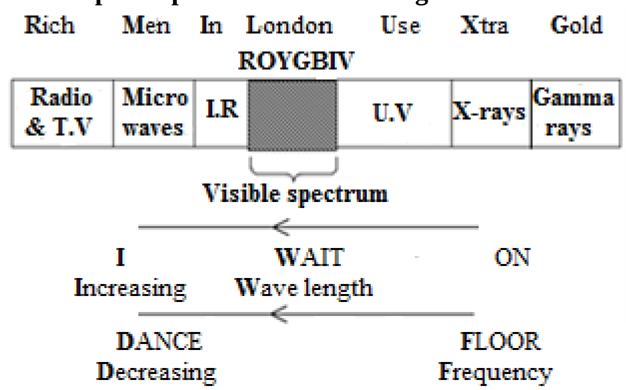
ELECTROMAGNETIC WAVES:

These are waves that don't require a material medium for their propagation. Electromagnetic waves travel in a vacuum.

They are waves produced by a disturbance in form of a varying electric or magnetic fields of high frequency.

Examples include: radio and T.V waves, micro waves, infra red, vissible light, Ultraviolet, X-rays, Gamma rays.

The complete Spectrum of electromagnetic waves



Properties of electromagnetic waves

- They are transverse waves.
- They can travel through vacuum.
- They travel at a speed of light (3.0×10^8 ms^{-1}).
- They can be reflected, refracted, diffracted, undergo interference and polarization.
- They can be emitted and absorbed by matter.
- They posses energy.

Effects of electromagnetic waves on meter

Wave band and its Origin or source	Uses or applications and Danger
Gamma rays -Energy changes in modes of atoms -Radioactive substance -Cosmic radiations	**Uses: -** Harden rubber solutions and thicken lubricate oil. -Used to sterilize medical instruments. **Danger:** -They destroy body tissues if exposed for a long time.
X- rays -Electrons hitting a metal target.	**Uses:** -Used in industries to detect leakages in pipes and in hospitals to detect fractures of

-X – ray tube. -Destroys body tissues if exposed for a long time.	bones. -Used to check for hidden weapons at the air port.
Ultra- violet radiations. -Fairly high energy changes in atoms. -Very hot bodies, Electron discharge Through gases e.g mercury vapour. -Causes sun burn -Causes blindness.	**Uses:** -Causes metals to give off electrons by the process called photoelectric emission. -Causes fluorescent lamp to give off visible light. -Causes teeth, finger nails, clothes washed in detergents to fluoresce. -Detection of forged bank notes -Used in Purification of water.
Visible light -Energy changes in electron structure of atoms. -Lamps, flames etc **-**Too much can damage the retina.	**Uses:** -Enables us to see. -Used in photosynthesis. -Changes the apparent colour of an object, Used in optical fibres, Photography,etc. -Makes objects appear bent due to refraction.
Infrared radiation -Low energy changes in electrons of atoms. - All hot bodies (I.R can be detected by our bodies because of their heating effects)	**Uses:** -Causes the body temperature of an object to rise. -It is a source of vitamin D. -Used in remote controls. -Used in the treatment of muscular complaints. –I.R devices such as those used during World War II enable sharpshooters to see their targets in total visual darkness.
Microwaves.	**Uses:** -Used in satellite communication. E.g with mobile phone signals. -Used in weather forecasting. -Used in cooking in ovens.
Radio and T.V waves. -High frequency Oscillating electric current. Very low energy changes in electronic structures of atoms. -Radio transmission aerials.	**Uses:** -Induces voltage on a conductor and it enables its presence to be detected. -Used for transmitting satellite signals. -Broadcasting radio and TV signals. -Radars- For military operation, Speed guns and Speed cameras.

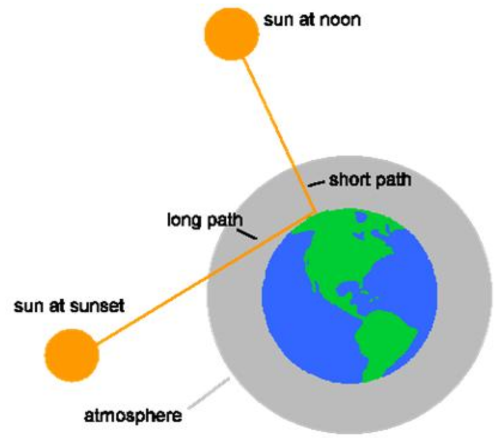
Detectors of the bands of the electromagnetic spectrum.

Wave band	Detector
Gamma rays	Geiger muller tube and scaler
X-rays	Photographic plates, ionization chambers
Ultra-violet radiations	Fluolescent paint, Photographic plates, Photo cells, Photo electric devices.
Visible light	Photographic plates, Photo cells, Human eye.
Infra red radiation (Heat radiation)	Blackened thermometer, Thermopiles, Photo diodes, e.t.c.
Micro waves	Diode probe, Aerials connected to tuned circuits
TV and radio waves	Aerials , T.V and Radio set circuits.

Effect of long and short wave lengths of visible light.

(a) Red Sun rise and sun set versus Long wavelength:

Waves of long wavelength are less scattered than waves of short wavelength. This explains why the sun appears red when rising or setting.



- <u>At sunset, because the angle of the sun is much lower</u>, the light must pass through much more of the atmosphere before we see it. By the time the light gets to our eyes, all of the colours are removed by scattering except for the extreme red end of the spectrum, which is why the sun appears red when it sets.

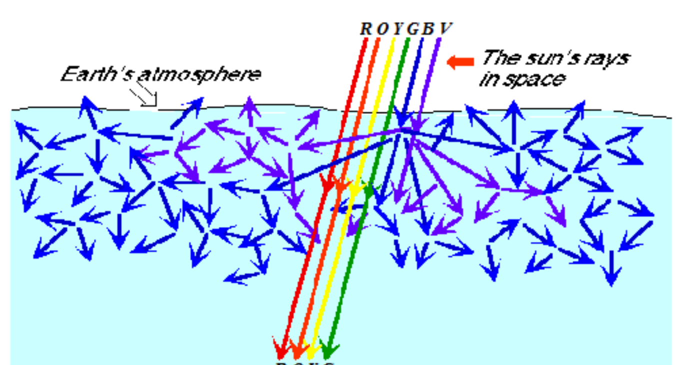
  Explanation: At sun rise or sun set, the light rays from the sun travel through greater thickness of earth's atmosphere. So the longer wavelength passes through.

(b) The blue sky versus Short wave length light:

Why the sky appears blue on a clear clouds day.

Waves of short wavelength are highly scattered. This explains why the sky appears blue, since the primary colour, blue has the shortest wavelength in the spectrum.

- **Note:** Beyond the atmosphere, the sky appears black and the astronauts are able to see the stars and the moon.



- Sunlight consists of many colours of different wavelengths (frequencies), extending from violet to red for visible light and it travels in a straight line in space as long as northing disturbs it.

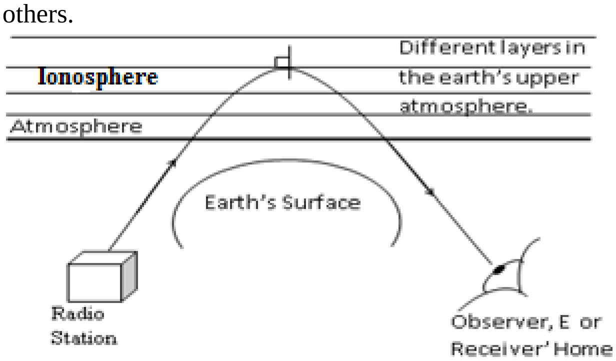
- When it passes through the atmosphere (dust, gas-molecules, water droplets e.t.c.) what happens to it depends on the wave length and the size of the particles it hits.
- When it hits large particles (e.g. dust & water droplets), it is reflected in a different direction. it still contains all the colours hence it is still white.
- when it hits small particles (e.g. gas molecules) small than the visible light, some of it is absorbed & after a while it radiates / scatters.
- The higher frequency (short wavelength) Blues are absorbed more hence are more scattered than the low frequency (high wavelength) red. (Amount scattered $\propto \frac{1}{\lambda^4}$) this is Rey leigh scattering.
- The absorbed blue light is radiated in different directions. It gets scattered all around the sky hence the blue appearance of the sky.

NOTE: This is also why the sun appears yellow during the day the combination of red, orange, yellow and green light appears yellow to us.

Water vapour molecules are much larger—ranging in size from 2–5 microns. For these larger particles, the probability of scattering is approximately the same for all wavelengths, which is why clouds appear white.

(c) Transmission of radio waves (or electro-magnetic waves)

Electromagnetic waves all travel at the same speed of light (3.0×10^8 ms^{-1}) and cannot be felt easily. Examples of electromagnetic waves are light, TV waves, radio waves, microwaves, infrared radiations, x-rays, gamma rays and others.



Radio waves are electromagnetic waves containing electric and magnetic fields and are refracted just like light.

Radio waves are produced at a certain point on earth by a <u>transmitter</u> in all directions.

Radio waves from a radio station on the earth's surface are beamed (or <u>directed) towards the ionosphere</u> (Region of ionized gases at very high altitudes).

<u>As the optical density of the ionosphere decreases with the height, the waves are gradually refracted away from the normal until such a height when the waves are totally internally reflected.</u>

Hence they are received by a receiver on the other side of the earth.

Ionosphere *is a certain layer at a given height above the earth surface that contains ions (usually electrons) produced by the radiations from the sun*.

It is due to the presence of the ionosphere that enables radio waves to be reflected to the other part of the earth.

This mode of communication (*Terrestrial Communication*) is still used today in the short wave (SW) and medium wave (MW) transmission bands (**not FM**). With the modern technology, artificial satellites are used to transmit most of the electromagnetic waves.

<u>SECTION A</u>

1. Which of the following can be detected by an ordinary antenna?

A. Microwaves B. Infrared rays
C. Ultra violent rays D. Gamma rays

2. Which of the following are transverse waves only?

A. Radio, sound, ultra-violet.
B. ultra-violet, x-rays, water waves.
C. Infrared, gamma rays, sound wave.
D. Sound waves, ultra-violet, x-rays.

3. A radio station broadcasts at a frequency of 95 MHz. How far will this signal travel in 2.0 ms?

A. 95 km B. 190 km
C. 210 km D. 600 km

4. If a light signal and a radio signal were transmitted simultaneously from a nearby star, the first signal to reach the Earth would be:

A. the radio signal. B. the light signal.
C. they would reach Earth at the same time.
D. None of them reaches the earth.

5. The fact that you can get sunburned while submerged in water is evidence that water,

a. absorbs infrared light. b. transmits infrared light.
c. absorbs ultraviolet light. d. transmits ultraviolet light

6. The worst thing you can do for the health of a green-leafed plant is to illuminate it with only,

a. red light. b. green light.
c. blue light. d. all are equally naughty.
e. none of these.

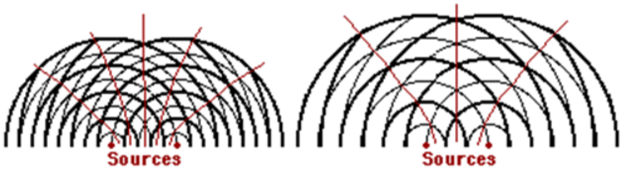
7. **Sunsets are red** because **the lower frequencies of light,**

A. are scattered by larger particles in the atmosphere.
B. are refracted by larger particles in the atmosphere.
C. are reflected by clouds and relatively large particles in the atmosphere.
D. survive being scattered in the atmosphere.

8. Diffraction is more pronounced through relatively

a. small openings. b. large openings.
c. same for each.

9. Use the figure below to answer question 9.

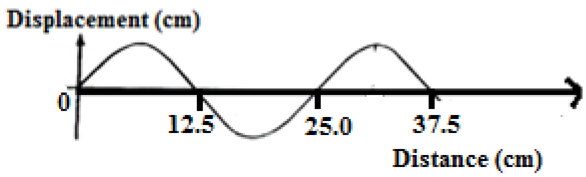


Interference is a property of
a. light waves. b. sound waves.
c. water waves. d. all of these.

10. Which of the following are not electromagnetic waves?
A. X-rays B. radar waves
C. Microwaves D. Sound waves

11. Which of the following radiations has the longest wave-length?
A. Gamma rays C. Radio waves
B. visible light D. X-rays

12. The frequency of the electromagnetic wave represented in the figure below is (velocity of light is 3.0 $x10^8ms^{-1}$)



A. $3x5x10^8/4x25$Hz B. $3x100x10^8/25$Hz
C. $12.5x100/3x10^8$Hz D. $3x100x10^8/37.5$Hz

13. The components of electromagnetic spectrum have
(i) the same velocity
(ii) different wavelength
(iii) different frequencies
(iv) the same refractive index for a given media
A. (ii) only B. (i) and (iii) only
C. (i), (ii) and (iii) only D. All

14. Which of the following shows the order in increasing wave length of the members of the electro-magnetic spectrum.
A. Ultra-violet, X-ray, radio waves, infra-red.
B. radio waves, infra-red, X-rays, Ultra-violet.
C. X-rays, ultra-violet, infra-red, radio waves.
D. Gamma rays, ultra-violet, radio waves, radio waves

15. X-rays are**.**
A. electrons of high velocity.
B. particles of negative charge .
C. neutrons of high velocity .
D. electromagnetic waves.

<u>SECTION B</u>

1. a) List 4 properties of electromagnetic waves
b) State two properties of electromagnetic radiation

2. (a) state two similarities between water waves and electromagnetic waves.
(b) Describe a simple method of detecting ultra violet radiations.

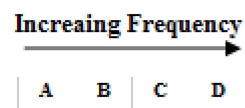
3. A radio station broad casts at a frequency of 200 kHz and the wave length of its signal is 1500m. Calculate the;
(i) Speed of the radio waves. [3.0×10^8].
(ii) Wave length of another station that broad casts at a frequency of 250 Hz. [$\lambda = 1.2 \times 10^6$ m.].

4. An F.M radio, broad casts at a frequency of 88.8MHz. What is the wave length of the signal? [$\lambda = 3.4$m]

5. A radio station broadcasts on 49m band.
(i) What is meant by the above statement?
(ii) Calculate the frequency of the broadcast.
(iii) Explain how radio waves are transmitted
(ii) Explain what happens to the plane waves in each case.

6. A vibrator in a ripple tank vibrates at 5Hz. If the distance between 10 successive crests is 37.8cm, calculate:
(i) the wavelength of the wave
(ii) the velocity of the waves

7. The figure below shows part of the electromagnetic spectrum consisting of gamma rays, radio waves, infrared and visible light.



(a) Identify the bands to which the radiations A, B, C and D belong?
(b) State one application of the radiation in
(i) B and A (ii) C and D

4. **UNEB 1995:** A radio station broad casts on 49 metres band. (i) State the meaning of of the statement
-The the wave wavelengthof the waves produced is 49m.

(ii) What is the frequency of the transmitters.
- $V = f\lambda \Leftrightarrow f = \frac{V}{\lambda} = \frac{3\times10^8}{49} = 6.12 \times 10^6$ Hz

5. Explain why the sky appears red during sunset and sunrise.
The wavelength of red colour is greater than that of any other colour. During the sunrise and sunset, red light travels through greater thickness of earth's atmosphere and is seen most than any other colour.

6. Name the electromagnetic radiation which
(i) Cause sensation of heat **(I.R)**
(ii) Passes through thin sheets of lead **(Gamma rays)**
(iii) Is used in satellite communication **(Radio waves)**
(iv) Is used for remote controls of a television receiver **(I.R)**

7. Complete the chart by matching the following vocabulary term with its definition, matching the variable and writing in an appropriate equation and unit.

Term and variable	Definition	Unit	
			a. A measure how high the crest of a wave or how low

frequency			the trough of a wave is. (determined by how much energy the wave is transmitting; how big, bright or loud it is)
Medium			b. The distance of one wave cycle.
Wave Length			c. The number of wave cycles per unit time (wavesper second)
Velocity			d. the time of one wave cycle. (time per wave)
Period			e. the material through which a wave moves; made of particles/molecules/atoms.
Amplitude			f. The speed of a wave, how quickly a wave travels a distance.

8. Brian sits in a boat in the ocean (he is fishing). He notices that his boat is moving up and down as the waves pass. It takes 6 seconds for his boat to move all the way down and back up again. He estimates that the distance between the wave crests is about 15 m. Are these transverse or compression waves? What is the period of the waves? How fast are the waves moving? How long will it take for a wave to get from Brian to the shore, which is 175 m away? Ans: look in notes for kind of wave; T = 6 s; v = 2.5 m/s; t = 70 s

9. Radar waves with a 0.034 m wavelength are sent out from a transmitter with a speed of 3 x 108 m/s. What is their frequency? Are they sound waves or electromagnetic waves? Ans: 8.82 x 109 Hz, use the speed of the wave to determine your answer.

10. A 2.5 Hz wave has a wavelength of 0.6 m. What is its speed? Ans: 1.5 m/s

11. What is the period of a wave with a crest-to-crest distance of 10 m and a frequency of 20 Hz? What is its speed? Ans: 0.05s, 200 m/s.

12. Water waves in a tank are 10 cm long. If they pass a point at the rate of 3.75 waves/sec, What is their speed? What is their period? Ans: 0.375 m/s; 0.27 s.

13. Pam and Denise are watching fireworks that are exploding 518 m above their heads. They see a beautiful firework, and hear the boom of the firework 1.5 seconds later. Why does this occur? How fast are the sound waves moving? The explosion has a frequency of 158 Hz. What is the wavelength of the explosion? *Ans: Look up the speed of sound and the speed of light. 345.3 m/s m/s; 2.2 m.*

14. Lighting flashes and you hear the thunderclap 3 sec later. How far away did the lightning strike if velocity of sound is 340 m/s? ***Ans: 1020 m***.

15. For light and sound, what do frequency and amplitude represent? (how would we detect them?)

16. What do x-rays, microwaves and radio waves all have in common? (use notes and reference table)

5. ELECTROSTATICS

ELCTROSTATICS

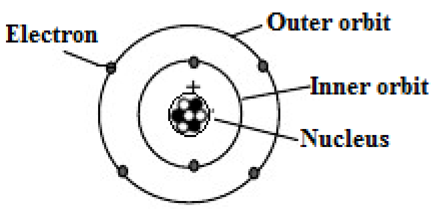
Electrostatics refers to the study of charges at rest.
To understand the nature of charge, it is necessary to know the structure of an atom.

Structure of an atom
An atom is the smallest electrically neutral indivisible particle of an element which can take part in a chemical reaction.

The atom consists of three particles, namely

Particle	Charge	Location
(i) Neutron	No charge	In the nucleus of the atom
(ii) Proton	Positive (+)	In the nucleus of the atom
(iii) Electron	Negative (+)	Outside the nucleus of the atom

The electrons are negatively charged while protons are positively charged. The two types of charges however are of the same magnitude in a neutral atom.



In a neutral atom, the number of negative charges is equal to the number of positive charges and the atom is said to be electrically neutral. Therefore, electrostatics is the study of static electricity because the charges which constitute it are stationary.

Conductors and insulators
A conductor is a material in which the electrons are loosely bound to the nucleus of its atoms. The loosely bound electrons are known as **conduction electrons.**
Hence a conductor is a material which allows charge to flow through it. The flow of these electrons constitutes current flow.
Conduction occurs when electrons transfer charges as they move from one part to another.

Examples: all metals, graphite, acids, bases and salt solutions are conductors.

An insulator is a material in which the electrons are strongly bound to the nucleus of its atoms. It has no conduction electrons because its electrons are strongly bound by the nuclear attractive forces.

Hence a insulator is a material which does not allows charge to flow through it.

Examples: rubber, dry wood, glass, plastic, ebonite, fur, polythene, sugar solutions etc.

Charge: Is the quantity of electricity flowing at any given time. Its S.I unit is a **Coulomb**, (**C**). Charges are produced by friction between insulators.

Note: A body (Conductor or Insulator) can lose or gain electrons.
- Loss of electrons leaves the body with a positive charge.
- Gain of electrons leaves the body with a negative charge.

Differences between conductors and insulators

Conductors	Insulators
- Electrons easily move - Electrons loosely held -The charge acquired is not fixed. (i.e. charge acquired is flexible).	- Electrons hardly move - Electrons tightly held -Charge acquired is fixed

Electrification
This is the process of producing electric charges which are either positive or negative.

Methods of producing Electric charges.
(i) By friction or rubbing or electron transfer (good for insulators and non conductors).
(ii) By conduction/contact (good for conductors).
(iii) By induction (conductors).

(i) Electrification by friction
- Two uncharged bodies (insulators) are rubbed together. Electrons are transferred from the body to the other.
- The body which looses electrons becomes positively charged and that which gains electrons becomes negatively charged.

Acquire positive charge	Acquire negative charge
-Glass, Fur, Cellulose	-Silk, Ebonite (hard rubber), Polythene

Explanation of charging by friction
All insulators do not have electrons arranged in the same way i.e. some insulators have electrons held to them fairly loosely e.g. in glass electrons are held fairly loose compared to silk.

When glass is rubbed with silk, glass tends to lose electrons faster than silk. This results in electrons being lost from atoms of glass at the same time being carried by silk.
The lost electrons from glass are carried by atoms of silk, so glass becomes positively charged and silk becomes negatively charged.

Note: *Electro-static experiments require dry conditions, hence polythene and cellulose are preferred for charge production since they are not affected by dump conditions. Dump air is a better conductor of electricity than dry air. Hence it causes easy leakage of charges.*

NOTE: The production of charge by rubbing is due to electrons being transferred (lost) from materials where they are less held by the nucleus to the other materials where they are tightly held by the nucleus.

Production of charges by friction is used to explain the following:

(i) A plastic comb used in hair attracts pieces of paper.
(ii) Sparks are heard when a plastic comb is use in dry hair.
(iii) Some pieces of cloth get stuck on glass windows when the windows are cleaned with dry a cloth.

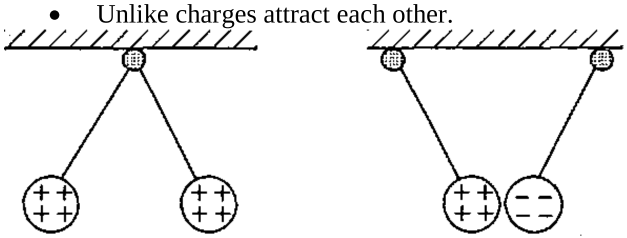
Question: 1 Explain why a dressing table mirror may become more dusty when rubbed with a dry cloth on a worm day.

Answer: *When the mirror is rubbed with a dry duster, there is a buildup of positive charges on the glass. This causes nearby dust particles to get charged negatively. Since un like charges attract, dust particles are attracted to the mirror and stick to it.*

Question: 2 Explain why dust particles gather up on a television screen.
Answer: *In a T.V, the picture is produced by a beam of electrons hitting the inside of the screen. Hence there is a buildup of negative charges on the inside of the screen. This attracts the dust particles which stick to the screen.*

Law of Electrostatics

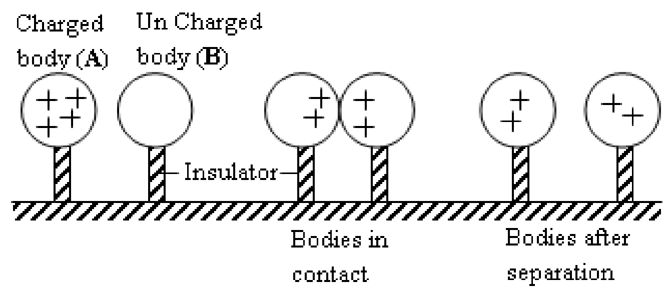
- Like charges repel each other.
- Unlike charges attract each other.



NOTE: However, attraction between a charged body and any other body DOES NOT necessarily mean that the other body is of opposite charge.
Thus the only SURE / TRUE test for presence of charge on a body is **repulsion.**

Explanation of attraction between a charged body and an uncharged body
When a negatively charged body is brought near a conductor, induced charges are produced on the conductor.
The negative charges on the conductor are repelled by the negative charge on the rod.
Consequently, the part of the conductor near the rod becomes positively charged and the far end becomes negatively charged.
Because the positive charge on the conductor is nearer the negatively charged rod than the negative charge on the conductor, the attraction between the positive charge and negatively charged rod is greater than the repulsion between the negative charge and the negatively charged rod.
The net force between the rod and the conductor is therefore an attraction. Therefore because of this fact, the only SURE/ TRUE test for presence of charge on a body is **repulsion.**

Electrification by conduction i.e Contact method
(By sharing excess electrons)



- Support the uncharged conductor on an insulated stand.
- Put a positively charged rod in contact with the conductor.
- Because of mutual repulsion between the positive charges in the rod, some of them are converted or transferred to the conductor.
- When the conductor is removed from the rod, it is found to be positively charged.

NOTE:

❖ The negative charges (electrons) migrate from the un charged body to the charged body until the positive charge on both of them is the same.
❖ Sphere B acquires a positive charge because it has lost electrons while sphere A is still positive but it is left with less positive charges.

❖ The insulated stand prevents flow of charge away from the conductor.
❖ To charge the conductor negatively, a negative rod is used.

Electrification by induction (By Electrostatic induction)
Electrostatic Induction is the acquisition of charges in an un charged conductor from a charged body placed near it but not in contact with it.
It can briefly be defined as the production of tempolary charges on a conductor due to its closeness to a charge.

Facts about charging a conductor by induction.

❖ Bringing a charging rod near the conductor to be charged.

A charged body is brought near one end of the conductor to be charged without touching it.
It induces charges on the conductor. That is electrons are either repelled or attracted to one end.

❖ Earthing the side of the conductor remote to the charging rod in presence of the charging rod.

The other side of the conductor is earthed to allow inflow or out flow of electrons from or to the earth.

❖ <u>Breaking the earth connection in presence of the charging rod.</u>

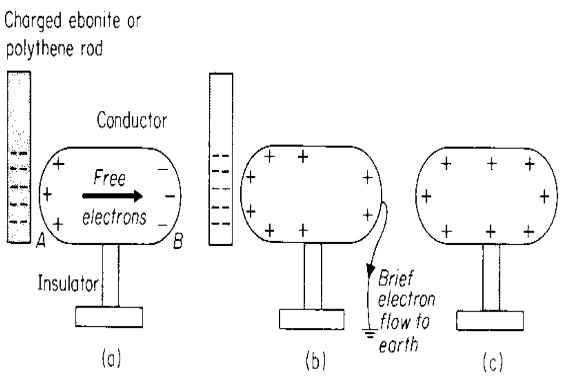
While the charged body is still in position, the earth line disconnected.

❖ <u>Removing the charging rod</u>

The charged body is the removed and the net charge distributes its self all over the conductor.

Note: The charge obtained is always opposite to that of the charging body.

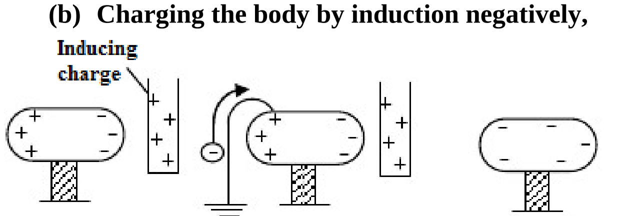
(a) Charging the body positively.



Procedure:

- Bring a negatively charged rod near the conductor placed on an insulated stand. The positive and negative charges separate as shown in (a)
- In presence of the charged rod, earth the conductor by momentarily touching it at the side furthest from the charging rod with a finger. Electrons flow from it to the earth as shown in (b).
- In presence of the charged rod, disconnect the earth line and then remove the charged rod.
- The conductor is found to be positively charged.

(b) Charging the body by induction negatively,



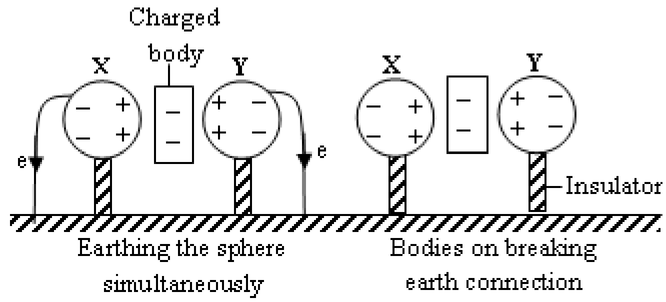
(a) **(b) Electrons flow from earth** **(c) Conductor remains negatively charged**

Procedure:

- Bring a positively charged rod near the conductor placed on an insulated stand. The positive and negative charges separate as shown in (a)
- In presence of the charged rod, earth the conductor by momentarily touching it at the side furthest from the charging rod with a finger. Electrons flow to it from the earth as shown in (b).
- In presence of the charged rod, disconnect the earth line and then remove the charged rod.
- The conductor is found to be negatively charged.

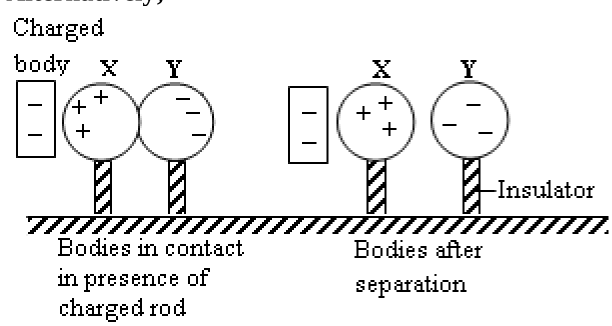
Charging two bodies simultaneously:

(i) Such that they acquire an opposite charge.



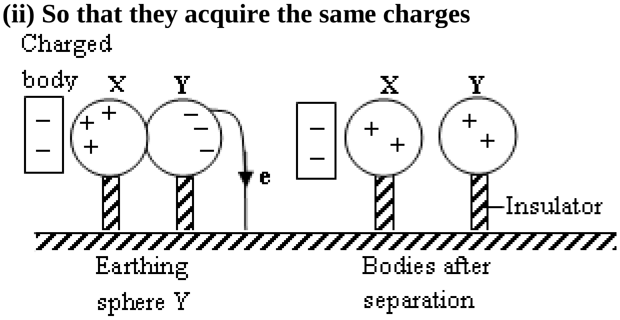
- Two identical metal X and Y are supported by insulating stands.
- A negatively charged rod is placed between the two metal spheres.
- Positive charges in each sphere are attracted towards the negatively charged rod and negative charges (electrons) are repelled to the side remote to the charging rod.
- In presence of the charging rod, both conductors are earthed at the same time by touching the sides remote to the charging rod.
- On earthling the sphere, electrons flow to the ground. When the earth is disconnected, the radial spheres are left with positive charge.
- When the charging rod is withdrawn, the positive charge on the spheres distributes themselves over the entire surface of the sphere.

Alternatively;



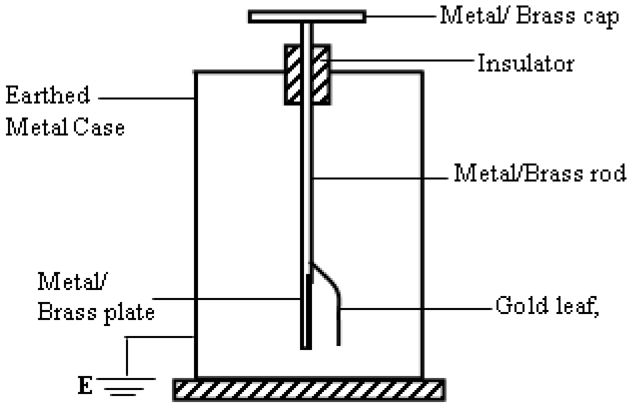
- Support two uncharged bodies, X and Y on an insulated stand and then place them in contact as shown in (a)
- Bring a positively charged rod near the two bodies, positive and negative charges separate as in (b).
- Separate, X from Y in presence of the inducing charge.
- Remove the inducing charge, X will be negatively charged and Y will be positively charged.

(ii) So that they acquire the same charges



To charge the two spheres simultaneously such that they acquire the same charge, Sphere Y (one remote to the charging rod) is earthed by touching it in presence of the charging rod.

The gold leaf electroscope



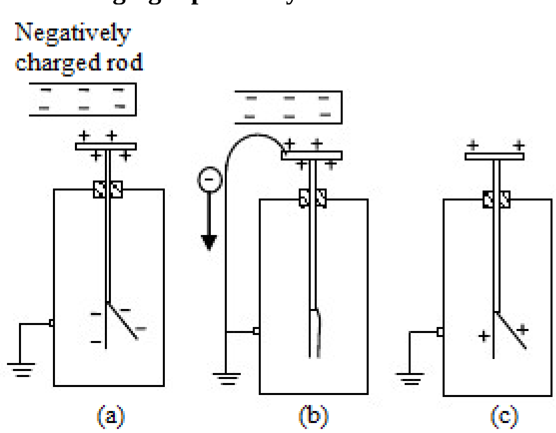
- It consists of a brass cap and brass plate connected by a brass rod.
- A gold leaf is fixed together with a brass plate with a brass.
- The brass plate, gold leaf and part of brass rod are put inside a metallic box which is enclosed with glass windows.

Mode of action

- When a charged body is brought **near with the cap** of the electroscope, the cap will acquire an **opposite charge** to that on the body by induction.
- The charge on the body will repel all charges similar to it down to the metal rod, to the plate and the leaf.
- Due to presence of like charges on the plate and gold leaf, the gold leaf diverges as it is repelled by the plate.
- Leaf divergence implies that the body brought near or in contact with the cap carries a charge.

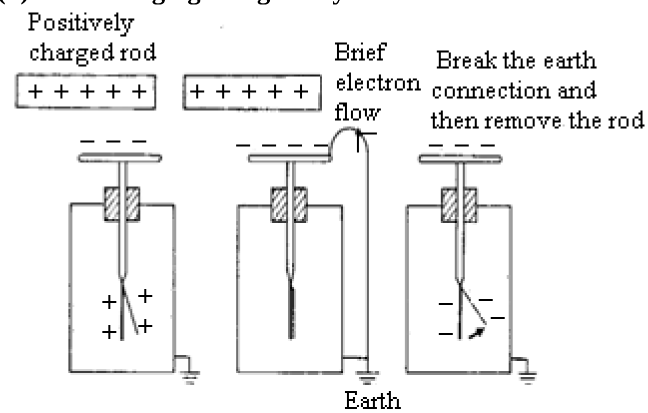
Note:
If the body is placed in **contact** with the cap of the electroscope, the cap, metal plate and the gold leaf will acquire a **similar** charge to that on the body.

Charging a gold leaf electroscope by induction.
(i) Charging it positively



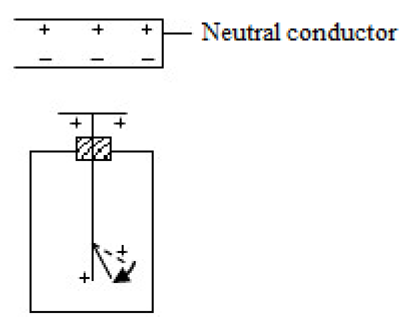
- Bring a negatively charged rod near the cap of the gold leaf electroscope.*Positive charges are attracted to the cap and negative charges are repelled to the plate and gold leaf.*
- The leaf diverges due to repulsion of the same number of charges on the plates.
- Earth the gold leaf electroscope in presence of a negatively charged rod.*Electrons on the plate and leaf flow to the earth.*
- The leaf collapses due to the sudden charge leakage.
- Remove the negatively charged rod, positive charges on the cap spread out to the rod and leaf therefore the leaf diverges againand the gold leaf is said to be positively charged.

(ii) Charging it negatively.



- Get an uncharged gold leaf of electroscope.
- Bring the positively charged rod near the gold leaf cap.
- Negative charges are attracted to the cap and positive charges are repelled to leaf and glass plate.
- Earth the gold leaf electroscope in presence of a positively charged rod.
- Negative charges flow from the earth to neutralize positive charges on plate and leaf.
- The leaf collapses.
- Remove the positively charged rod, negative charges on the cap spread out on the leaf plate, therefore, the leaf diverges and a gold leaf therefore becomes negatively charged.

Effects of Bringing a Neutral Conductor near the Cap of a Charged Electroscope.



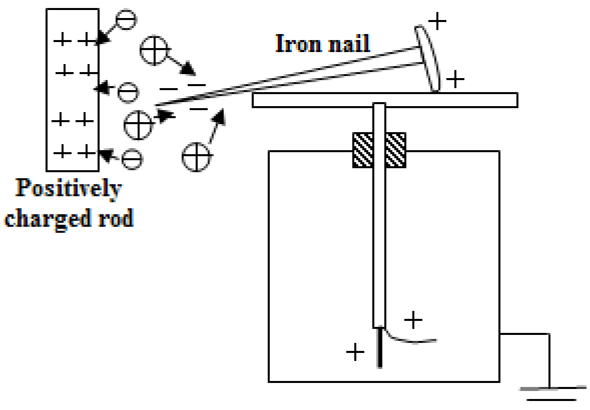
Suppose the electroscope is positively charged. When a neutral conductor is brought near the cap, electrostatic

induction occurs in the conductor so that the side near the cap acquires a negative charge.
This repels some electrons from the cap to the metal plate and the leaf, thus reducing the positive charge there. This results in reduction of the divergence of the leaf.

As the conductor is lowered further the divergence of the leaf decreases until it is zero. Now, all the positive charge on the plate and cap is completely neutralized.

Lowering the conductor beyond this point makes the leaf to begin diverging again. This is because some negative charge begins existing on the plate and leaf causing repulsion again.

Induction and Contact

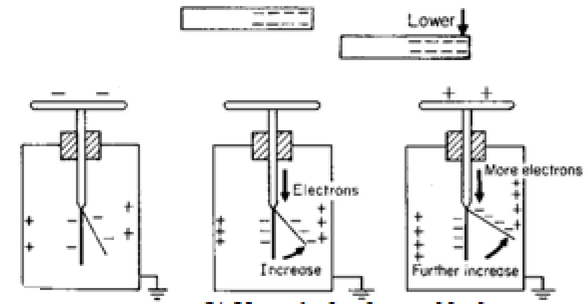


The positively charged rod induces a negative charge at the sharp end of the pin and a positive charge at its opposite end as well as the brass plate and leaf of the GLE.
Point action then takes place at the sharp end of the pin, leading to ionization of the air around it.
The negative ions are attracted to the positively charged rod and neutralize it.
The positively charged ions are attracted to the sharp point and GLE causing leaf divergence. The GLE becomes positively charged.

Uses of a Gold leaf Electroscope
(a) Un charged or neutral G.L.E
1. <u>To detect the presence of charge on a body.</u>
Bring the body under test near the cap of a **neutral G.L.E**.
If the leaf deflects, then the body has got a charge.
However, if the leaf remains un deflected, then the body is neutral (has no net charge).

2. <u>To compare and measure potentials.</u>
Two bodies which are similarly charged are brought in contact with the cap of a G.L.E one after the other.
The divergences in the two cases are noted and compared.
The body which causes more divergence is at a higher potential.

(a) Charged G.L.E (+vely or –vely charged G.L.E)
3. <u>To test the nature or sign of charge on a body.</u>



(a) Negatively charged G.L.E **(b) Negatively charged body near the cap of +vely charged G.L.E**

Bring the body under test near the cap of a **charged G.L.E.**
If the leaf diverges further, then the body has a charge similar to that on the G.L.E.

However, if the leaf collapses, then the body is either neutral or it carries a charge opposite to that on the G.L.E.

In this case, we cannot conclude. But the G.L.E is discharged by touching its cap with a finger and then given a charge opposite to the one it had previously and the experiment is repeated.
If still the leaf collapses, then the body is neutral.

NOTE: *An **increase in leaf divergence** is the **only sure test for the sign of charge** on a body.*
*Increase in leaf divergence occurs when the **test charge** and the **charge on the gold leaf electroscope** are the **same.***

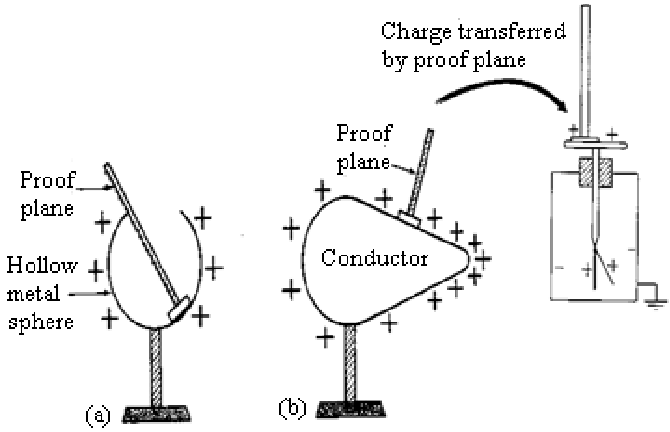
4. <u>To classify conductors and insulators.</u>
Bring the body under test in contact with the cap of **a charged G.L.E.**
- ✓ If the leaf collapses suddenly or instantly, then the body is a good conductor.
- ✓ If the leaf remains un changed, then the body is a good insulator.
- ✓ If the leaf collapses gradually or slowly, then the body is either a poor conductor or a poor insulator. The leaf collapses due to charge leakage.

Distribution of charge on a conductor.
Surface density is the quantity of charge per unit area of the surface of a conductor.

- ❖ The distribution of surface density depends on the shape of the conductor.
- ❖ It is investigated using a gold leaf electroscope and a proof plane (a small metal disc with a handle made of insulator).
- ❖ The surface conductor is touched using a proof plane. The proof plane is then transferred to an electroscope by allowing it to touch the cap of the G.L.E.
- ❖ The angle of leaf divergence is noted and it gives a rough measure of the charge transferred and hence the magnitude of surface density at that point.

Experimental results show that:
(i) Charge density is greatest at the most curved point.
(ii) Charge always resides on the outside of a hollow conductor.

(a) Hollow conductor

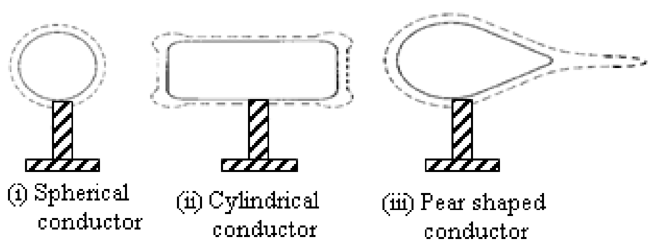


When the proof plane is placed on the outside surface of a charged hollow conductor, charge is transferred to the uncharged G.L.E, the leaf diverges as shown in (a). This proves that charge was present on the outside of the surface. When the proof plane is placed on the inside of a charged conductor is transferred to the uncharged G.L.E, the leaf does not diverge as in (b) therefore, charge resides on the outside surface of the hollow charged conductor.

(b) Curved bodies

A curve with a big curvature has a small radius and a curve with small curvature has big radius therefore, curvature is inversely proportional to radius. A straight line has no curvature.

Surface charged density is directly proportional to the curvature. Therefore a small curvature has small charge density. Surface charge density is the ratio of charge to the surface area.

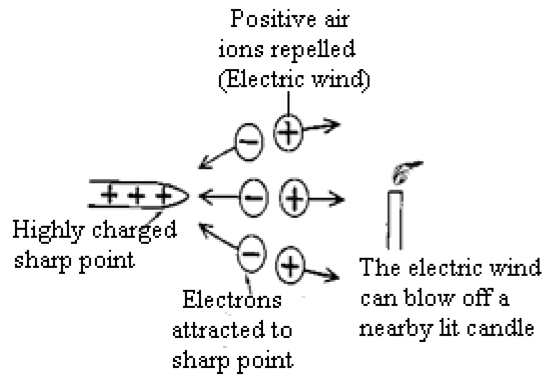


<u>Action of points</u>

This refers to the effect produced when a charged sharp point strongly repels ions of the same kind. These ions then collide with the air molecules knocking off electrons out of them (i.e they cause ionization of air molecules).

This results in a stream of air containing ions (called electric wind) to move away from the sharp the point.

Charge concentrates at sharp points. This creates a very strong electrostatic field at charged points which ionizes the surrounding air molecules producing positive and negative ions. Ions which are of the same charge as that on the sharp points are repelled away forming **an electric wind** which may blow a candle flame as shown in the diagram below and ions of opposite charge are collected to the points.



Therefore, a charged sharp point acts as;

(i) Spray off' of its own charge in form of electric wind.

(ii) Collector of unlike charges.

The spraying off and collecting of charges by the sharp points is known as **<u>corona discharge</u>** (action of points.)

Note: ***An electrically charged body gets discharged when held above a flame, because the hot gases in the flame are ionized***

Application of action of points (corona discharge)

- Used in a lightening conductor.
- Used in electrostatics generators.
- Electrostatic photocopying machines.
- Air crafts are discharged after landing before passengers are allowed. Air crafts get electrified but charge remains on the outer surface.

Lightening

A lightening is a gigantic (very large) discharge between clouds and the earth, or between the charges in the atmosphere and the earth.

A lightening conductor:

Lightening conductor is a single component in a lightening protection system used to safe guard tall building from being destroyed by lightening.

It provides a safe and easy passage of charge to the earth hence safe guarding the building.

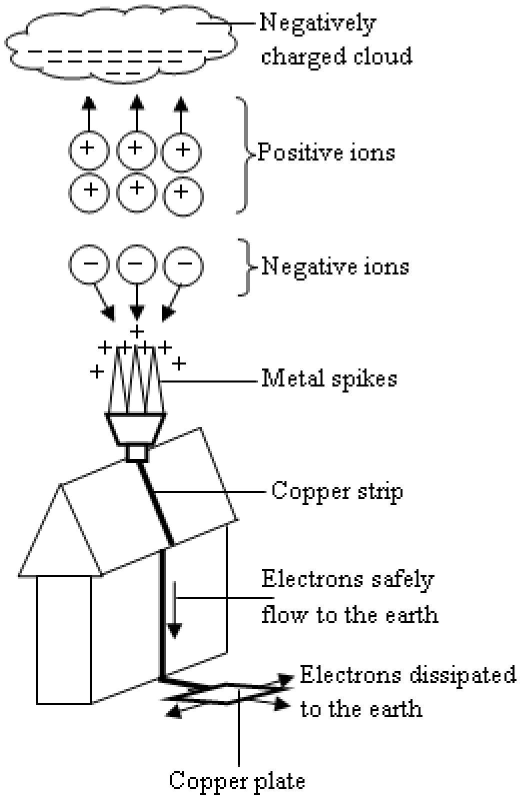
A lightening conductor is made up of:

(i) **Spikes** placed high up on a tall building**.**

(ii) **copper strip** which is fixed to the ground and on the walls of the tall building ending with several

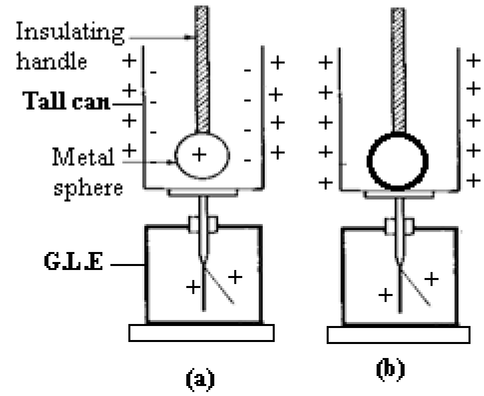
(iii) **Copper plate** buried under the grounded

How it works



- Charging the clouds negatively by friction: A moving cloud becomes negatively charged by friction.
- Induction: Once it approaches the lightening conductor, it induces a large opposite charge on the spikes and a negative charge on the copper plate. The negative charge (electrons) on the plate is immediately lost to the earth.
- Action of point leading to ionization and neutralization: A high charge density on the conductor ionizes the air molecules surrounding the spikes producing negative and positive ions.
  Discharging the negative ions:
  The negative ions are attracted to the spikes and become discharged by giving up their electrons. These electrons pass down the conductor and escape to the earth.
  Discharging the negative ions: At the same time, positive ions are repelled upwards as an electric wind. These neutralize (discharge) some of the negative charges on the cloud.
- Conduction: The excess negative charges on the clouds can also be easily and harmlessly conducted to the earth through a copper strip since it provides a path with very low resistance.
  In this way, the lightening conductor safe guards a tall building from being struck by lightning.

Faraday's Ice pail experiment



PART I
Procedures:
- ❖ Place an un charged metal can on an uncharged G.L.E.
- ❖ Suspend a positively charged metal sphere and lower it into the pail, without touching the pail as shown in diagram (a).
- ❖ Move the charged metal sphere about inside the can and then remove the metal sphere completely.

Observation:

Action	Observation
On lowering the metal sphere	G,L,E diverges
On moving the metal sphere about	No observable change
On complete removal of the metal sphere	Leaf returns to its original shape.

PART I
Procedures continued:
- ❖ Lower the metal sphere again into the metal can, this time allow the sphere to touch the bottom of the can as shown in diagram (b).
- ❖ Test the charge on the sphere using another G.L.E.

Observation:

Action	Observation
On touching the metal can	G,L,E remains diverged
On testing the metal sphere with another G.L.E	The sphere is found to have lost all the charge

Conclusions from Faradays' experiment.
- ✓ A charged metal object suspended inside a neutral metal container induces an **equal but opposite charge** on the inside of the container.
- ✓ When the charged sphere touches the inside of the container, the induced charge exactly neutralizes the excess charge on the sphere.
- ✓ When a charged body is suspended within a metal container, an equal charge of the same sign is forced to the outside of the container.

Electric fields
This is a region around the charged body where electric forces are experienced. Electric fields may be represented by field lines.
Field lines are lines drawn in an electric field such that their directions at any point give a direction of electric field at that point. The direction of any field at any given point is

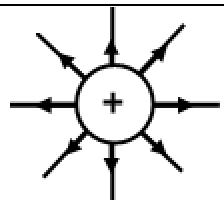
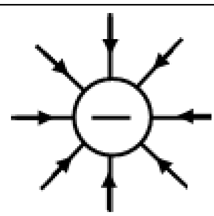
the direction of the forces on a small positive charge placed at that point.

Properties of electric field lines

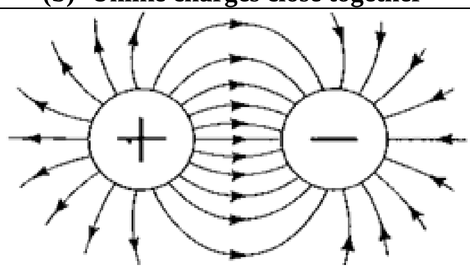
- They begin and end on equal quantities of charge.
- They are in a state of tension which causes them to shorten.
- They repel one another side ways.

Field patterns

(a) Isolated charges

(i) Isolated positive charge	(ii)Isolated negative charge
 Field lines point away from the charge.	 Field lines point towards the negative charge.

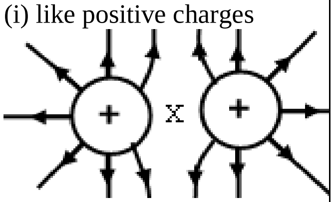
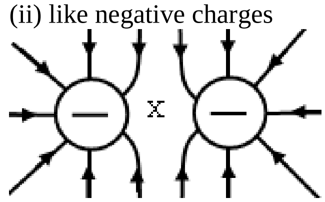
(b) Unlike charges close together



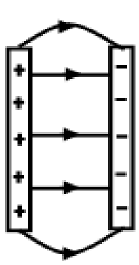
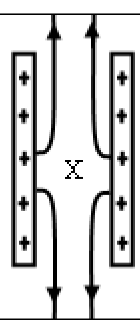
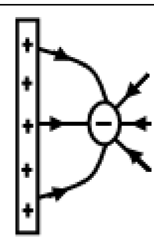
The lines of force connect from positive charge to negative charge.

(c) Like charges close together

The field lines repel side ways.

(i) like positive charges	(ii) like negative charges
	

(d) Two charged plates/ a charged plate and a point charge

EXERCISE:

SECTION A

1. A charged conductor usually loses charge gradually by a process called;

A. induction B. insulation

C. conduction D leakage

2. The result of rubbing a glass rod with silk and separating them is;

A. a negative charge on the rod and an equal positive charge on the silk.

B. equal amounts of negative charge on both

C. a positive charge on the rod and an equal negative charge on the silk.

D. no charge on both the rod and the silk.

3. A metal rod gains a positive charge when rubbed with fabric. The fabric acquires

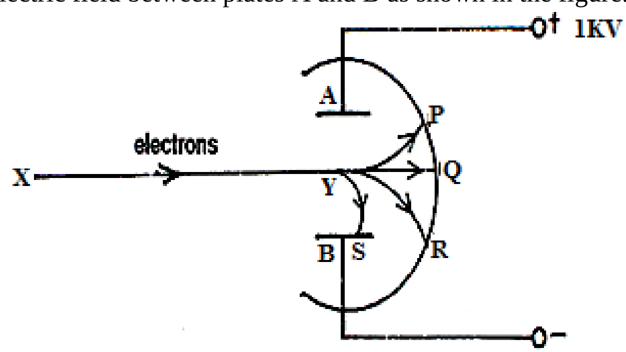
A. No charge.

B. A negative charge equal to that of the rod.

C. Appositive charge equal to that on the rod

D. A positive charge greater than that on the rod.

4. In the diagram below, an electron beam XY enters an electric field between plates A and B as shown in the figure.



Which one is the possible route of movement of the electrons?

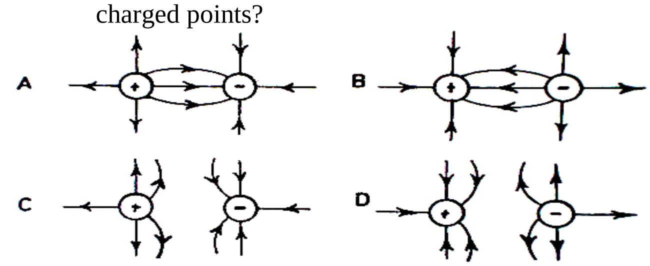
A YS B. YR

C. YQ D. YP

5. When a rod is brought close to the cap of a negatively charged gold leaf electroscope and its leaf diverges, it shows that the rod is

A. Negatively charged
B. positively charged
C. neutral
D. partially charged.

6. Which one of the following diagrams represents the correct electric field pattern for two oppositely charged points?



7. The laws of electrostatic induction states that

A. like poles repel and unlike poles attract
B. like poles attract and unlike poles repel
C. like charges repel and unlike charges attract
D. like charges attract and unlike charges repel.

8. Which one of the following actions will cause the leaf of a negatively charged electroscope to fall?

(i) Bringing a positively charged rod near the cap.
(ii) Bringing a negatively charged rod near the cap.
(iii) Connecting the can to the earth.
A. (i) and (ii) only B. (i) and (iii) only
C. (ii) and (iii) only D. (i), (ii) and (iii)

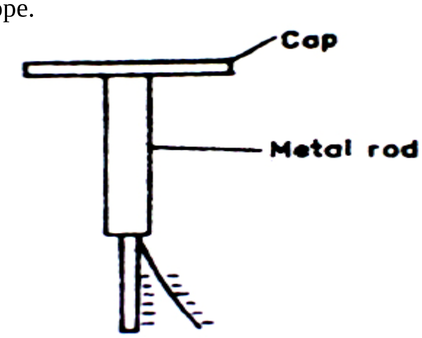
9. When polythene and wool are rubbed against each other and then separated, they acquire;
A. no charge.
B. equal amount of same type of charge.
C. equal and opposite charges.
D. both acquire positive and negative charges.

10. A body can only be confirmed to be electrically charged when:
A. another charged body attracts it.
B. it does not affect the leaf of a charged electroscope.
C. it is repelled by another charged body.
D. it is found to have less protons than electrons.

11. It is recommended that buildings should have earthed conductors in order to:
A. reduce heat intensity on hot days
B. remove excess electrons from the building
C. stabilise the current electricity to the building
D. provide more charges to electrical appliances in the building.

12. It is easier to charge insulators than conductors because;
A. the insulators don't allow the charge to flow away but the conductors allow the charge to flow away
B. the conductor retain the charge by conduction but the insulators release it to the atmosphere
C. it is impossible to charge conductors under any condition
D. insulators just receive the charge from the atmosphere without being rubbed.

13. The diagram below shows a part of the gold leaf electroscope.



What will happen to the leaf if a positively charged rod is brought near the cap of electroscope? It will
A. increase in deflection
B. remain in the same position
C. reduce in deflection
D. break off from the plate.

14. Which of the following statements is true about a good insulator?
A. it acquires electric charge when rubbed with suitable materials
B. all its electrons are loosely bound to its atoms
C. electric charge easily flows on its surface
D. some of its electrons are free to move about.

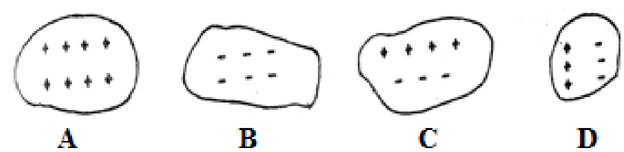
15. An electroscope becomes negatively charged when it
A. loses electrons B. gains protons
C. gains electrons D. loses proton

16. An insulating rod that can be charged positively rubbing with a piece of fabric is rubbed with fabric and left in contact for a long time and then separated. What will you expect each of them to have?
A. no charge
B. equal number of opposite charges
C. more positive charge on the rod than on the fabric .
D. more negative charge on the fabric than on the rod

17. When a plastic rod is brought near a charged electroscope, the gold leaf is seen to diverge more. The possible charges on the rod and the electroscope are.

	Electroscope	**Plastic rod**
A	Positive	Negative
B	Negative	Positive
C	Negative	Negative
D	Positive	Un charged

18. Which one of the following shows the correct distribution of electric charges generated in clouds due to violent movements within the thunder clouds?



19. Which of the following statements are true
(i) protons and neutrons are found in the nucleus of an atom
(ii) electrons and beta particles are the same
(iii) protons and electrons occur in equal numbers in all neutral atoms
(iv) alpha particles and beta particles are both positively charged.
A. (i), (ii) and (iii)
B. (i) and (iii) only
C. (ii) and (iv) only
D. (iv) only

20. The leaf of a charged electroscope gradually collapses with time due to
A. leakage to the surroundings
B. surrounding magnetic field
C. pressure variations in the surroundings
D. similar charges from the surroundings

21. It is easier to charge insulators than conductors because
A. Insulators don't allow charge to flow away but conductors allow it to flow away
B. The conductors retain the charge by conduction but insulators release it to the atmosphere
C. It is impossible to charge conductors under any condition

D. Insulators just receive the charge from the atmosphere without being rubbed

22. A charged electroscope loses its charge when a flame is brought near its cap because
A. point action takes place at the cap
B. the flame blows the charges off the cap
C. Charges of opposite sign from the flame are attracted onto the cap
D. The flame ionizes nearly air molecules and those of opposite sign are attracted on the cap

23. When a positively charged body is brought near the cap of a negatively charged electroscope, the golf leaf
A. Remains unchanged
B. Decreases in divergence
C. Increases in divergence
D. Gains a negative charge.

24. When a rod is brought near the cap of a negatively charged gold leaf electroscope and the leaf diverges further, it shows that the rod is;
A. Positively charged
B. Negatively charged
C. Neutral
D. Partially charged

25. The leaf of a charged electroscope gradually collapses with time due to;
A. leakage of charge to the surrounding
B. Surrounding magnetic field
C. Pressure variation in the surroundings
D. similar charges from the surroundings

26. An insulating rod that can be charged positively, by rubbing with a piece of fabric is rubbed with fabric and left in contact for a long time the separated. What would you expect each one of them to have?
A. No charge
B. Equal number of opposite charges
C. More positive charge on the rod than the fabric
D. More negative charge on fabric than on the rod

SECTION B

1989 Qn. 60
(a) Sketch the electric field patterns for the following;
(i) Two negative charges close to each other
(ii) A positively charged conducting sphere
(iii) Two oppositely charged parallel plates

(b) Explain the following observations;
(i) The leaves of a positively charged gold leaf electroscope fall when the cap is touched.
(ii) When a positively charged conductor is lowered in an ice pail placed on the cap of an uncharged electroscope, the leaves diverge. When the conductor touches the inside of the pail, the divergence of the leaves is not altered.

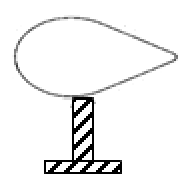
(c) Explain how a lightening conductor safe guards a house against lightening.

1990 Qn.8
(a) Draw a well labeled diagram of a gold leaf electroscope.
(b) Describe an experiment to test the charge on a charged body using a gold leaf electroscope.
(c) Draw electric field patterns for;
(i) Two positively charged bodies at a small distance apart.
(ii) An isolated negative charge.

1991 Qn.7
(a) State the law of electrostatics.
(b) Describe how two identical metal balls may be charged positively and simultaneously by induction.
(c) (i) Explain what happens when a negatively charged rod is brought near the cap of an uncharged electroscope and slowly taken away.
(ii) Briefly explain how an electroscope can be used to test whether a material is a conductor or an insulator.
(d) What precautions should be taken when carrying out experiments in electrostatics?

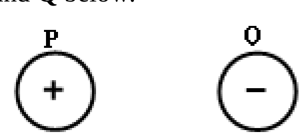
1994 Qn.7
(a) Explain why a pen rubbed with a piece of cloth attracts pieces of paper.
(b) A positively charged metallic ball is held above a hollow conductor resting on the cap of a gold leaf electroscope.
(c) Explain what happens to the leaf of the electroscope as the ball is lowered into the hollow conductor.

1998 Qn.10
(a) Explain what happens to an insulator when it is rubbed with another insulator of different material?
(b) The figure below shows a conductor supported on an electrical insulator. The conductor is given some positive charge.



Show how the charge is distributed on the conductor.

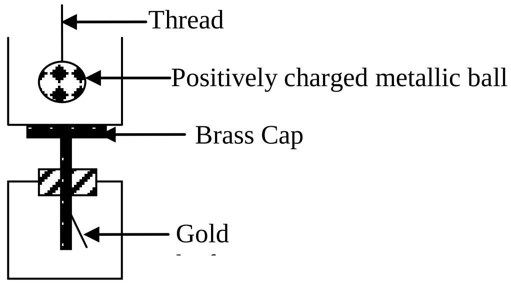
(c) Sketch the electrical field pattern due to two unlike charges **P** and **Q** below.



2005 Qn.4
(a) Describe how you would use a gold leaf electroscope to determine the sign of a charge on a given charged body.
(b) Explain how an insulator gets charged by rubbing.
(c) Sketch the electric field pattern between a charged point and a metal plate.

10. (a) Explain why a pen rubbed with a piece of cloth attracts pieces of paper.

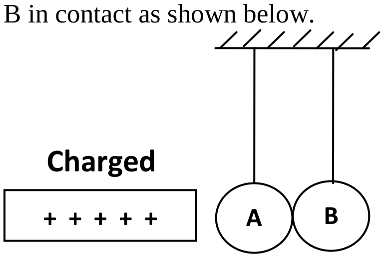
(b) A positively charged metallic ball is held above a hollow conductor resting on the cape of a gold leaf electroscope as shown in the figure below.



(i) Explain what happens to the leaf of the electroscope as the ball is lowered into the conductor.

(ii) Briefly explain how gold leaf electroscope can be charged negatively by induction.

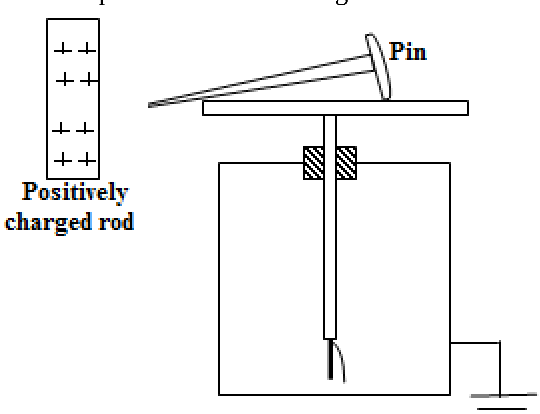
11. (a) Distinguish between a **conductor** and an **insulator.**
(b) A positively charged rod is brought near spheres A and B in contact as shown below.



i) Show the charges on the spheres.
ii) Describe how the spheres can be given a permanent charge.

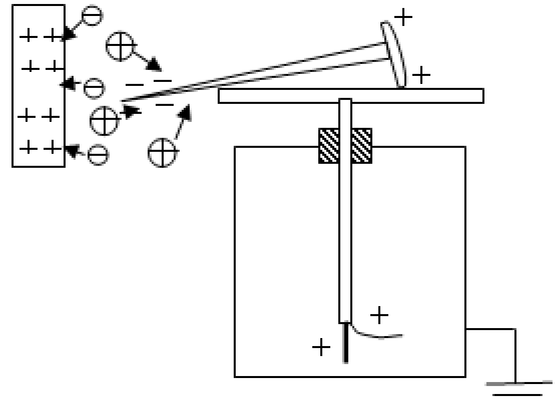
12. (a) Explain why it is not advisable to touch the copper strip of a lightening conductor when it is raining.
(b) Why is it difficult to perform experiments in electrostatics under damp conditions?

13.A sharp pin is placed on the cap of the gold leaf electroscope as shown in the diagram below.



A positively charged rod is held next to the sharp end of the pin. Draw the diagram and use it to explain what happens to the electroscope and the charged rod. (04 marks)

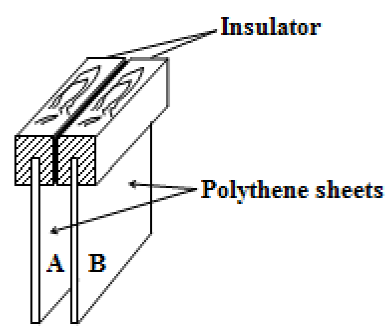
Solution



The positively charged rod induces a negative charge at the sharp end of the pin and a positive charge at its opposite end as well as the brass plate and leaf of the GLE.
Point action then takes place at the sharp end of the pin, leading to ionization of the air around it.
The negative ions are attracted to the positively charged rod and neutralize it.
The positively charged ions are attracted to the sharp point and GLE causing leaf divergence. The GLE becomes positively charged.

14. A piece of dry nylon thread was rubbed against a polythene rod and placed near a gold leaf electroscope, it produced a deflection yet a similar piece of moistened thread tested in the same way did not produce a deflection. Explain this observation.

15. (a) Describe how a gold leaf electroscope can be positively charged by electrostatic induction.
(b) Two polythene sheets A and B are both positively charged with equal amounts of charge. One end of each polythene sheet is fixed into an insulator and the two sheets brought near each other as shown in the figure beow.



(i) Describe and explain what happens.
(ii) Describe and explain what happens if an earthed sheet of metal is inserted between the polythene sheets without touching them.

(d) Explain how thunder is produced during a rainstorm

6.	ELECTRICITY

ELECTIC CELLS OR BATTERIES

A cell is a device which directly changes chemical energy to electrical energy.

Types of electric cells

a) Primary cells, these are cells which cannot be recharged and their chemical reaction which produces electrical energy cannot be reversed e.g the simple cells, dry cells

b) Secondary cells, these are cells that can be recharged and the chemical reaction that produces electricity can be reversed by passing the current thru the opposite direction.

(a) Primary cells

These are cells which produce electricity from an irreversible chemical reaction.
They cannot be recharged by passing a current through them from another source and their chemical reaction which produces electrical energy cannot be reversed

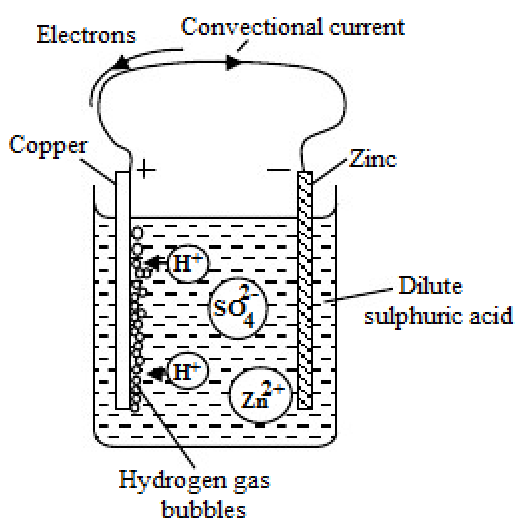
Examples of primary cells;

(i) Simple cells (Voltaic cells)
(ii) Leclanche' cell (Dry cell and Wet cell)

(i) Simple cells (Voltaic cells)

A simple cell is made up of two electrodes and an electrolyte. A more reactive metal becomes the cathode while the less reactive metal becomes the anode.
It commonly consists of a copper rod (Positive electrode) and the zinc rod (Negative electrode) dipped into dilute sulphuric acid (Electrolyte). The electrodes are connected by pieces of conducting wires.

In a simple cell, the cathode is Zn, the Anode is copper and the electrolyte is dilute H_2SO_4.



Mechanism of the simple cells

A simple cell gets its energy from the chemical reaction between Zn and H_2SO_4 (aq) i.e.

$$\mathbf{Zn(s) + H_2SO_4(aq) \longrightarrow ZnSO_4(aq) + H_2}$$

Electrons flow the negative plate zinc to the positive plate copper while current flows from the positive to negative plate.

At the cathode

When the circuit is complete, the zinc rod slowly dissolves and goes into electrolyte as zinc ions Zn^{2+}, according to the equation;

$$\mathbf{Zn(s) \rightarrow Zn^{2+}(aq) + 2\bar{e}}$$

At the anode

The electrons travel through the external circuit and arrive at the copper electrode, where they are picked up by the hydrogen ions from the acid to form hydrogen gas according to the equation:

$$\mathbf{2H^{+}(aq) + 2\bar{e} \rightarrow H_2(g)}$$

- ❖ Thus bubbles of a colourless gas (hydrogen) are seen at the copper plate.
- ❖ The reaction generates an electric current.

DEFECTS OF A SIMPLE CELL

Defect	How to minimize
1. Polarization: This is the formation of hydrogen bubbles on the copper plate. The hydrogen given off insulates the anode from the electrolyte. This reduces the voltage of the cell.	-Use of a depolarizing agent like potassium dichromate,(K_2,Cr_2O_7) or manganese dioxide (MnO_4), which oxides hydrogen to form water. -Brushing the copper plate occasionally.
2. Local action: This is due to some reaction between the impurities in Zinc and the acid resulting into the formation of hydrogen bubbles on the zinc plate. The hydrogen bubbles insulate zinc from the electrolyte.	-Rubbing clean Zinc with mercury (amalgamating zinc).This prevents contact of the impurities with the electrolyte) -Cleaning Zinc with conc. H_2SO_4.

NOTE: A simple cell stops working after a short time because of polarization and local action.

(ii) Leclanche' cells

- ❖ Dry Leclanche' cell (Portable, electrolyte cant pour out, faster depolarizing action & can maintain high steady current for some period of time)

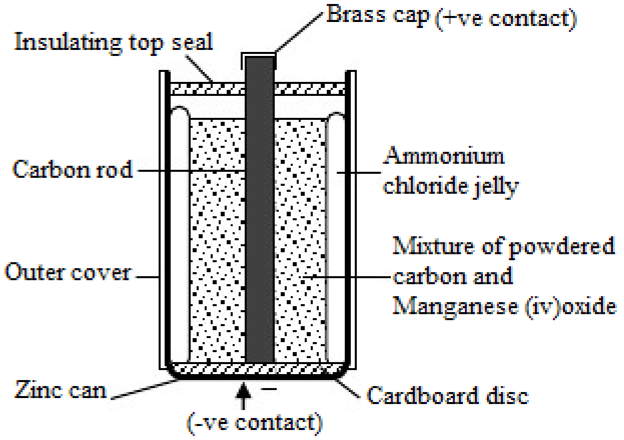
- ❖ Wet Leclanche' cell (Bulky and electrolyte can easily pour out, slow depolarizing action & cannot maintain high steady current which lights).

Here polarization and local action are avoided

- Manganese (iv) oxide is in place to act as a depolarizing agent to oxidize hydrogen to water. Thus preventing polarization.

- The carbon powder reduces the internal resistance of the cell and increases the conducting surface area.

❖ **Diagram of a dry Leclanche' cell**



Carbon is the anode and Zinc is the cathode. The electrolyte is ammonium chloride jelly. The chemical reaction between zinc and ammonium chloride is the source of electrical energy is a dry cell and therefore e.m.f is up.

$Zn\ (s) + 2NH_4Cl\ (aq) \longrightarrow ZnCl_2 + 2NH_3 + H_2\ (g)$

The e.m.f produced goes on to fall due to polarization and local action. These are the defects of a dry cell.

Polarization

The formation of Hydrogen bubbles at the carbon rod.

Its prevention

The manganese IV oxide around the carbon rod acts as a depolarizing agent which oxides hydrogen to water.

Note: 1. Even if the cell is not working (giving out e.m.f) e.m.f reduces because of local action.

2. Memorized the parts as named from the most inside part using the acronym **CaMAZIB.**

PART	FUNCTION
Carbon rod	Its the positive plate
Manganese (iv) oxide	Its the oxidizing agent
Powdered Carbon	Reduces internal resistance
Ammonium chloride	Its the electrolyte
Zinc can	Container of all the parts inside. Its also the negative plate
Insulating top seal	Prevents drying up of the jelly
Brass cap	Prevents mechanical wear of the carbon rod
Card board disc	Prevents contact between the carbonrod and the zinc can

(b) Secondary cells (Accumulators) (or storage cells)

Secondary cells are cells that can't be recharged by passing a current through them from another source once they stop working or reduce on the amount of current being supplied. Current is produced as a result of a reversible chemical change taking place within the cell.

Use of accumulators

-To start (ignition) of cars and other locomotives and to provide light to motor cars.
-Used in factories to run machines

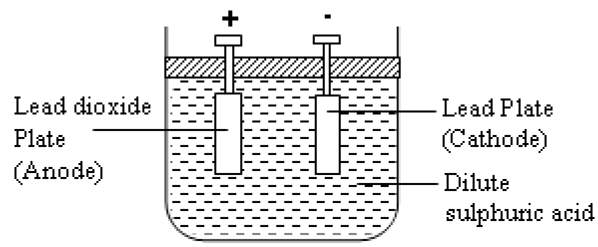
Examples of secondary cells (Accumulators)

There are two types of accumulators.

(i) Lead acid accumulator
(ii) Alkaline accumulator (e.g Nickel – cadmium cell; **NiCd** cell, Nickel – iron cell **; NiFe** cell)

(i) Lead acid accumulators

A Lead acidstorage battery consists of cells connected in series. Each cell consists of a **lead plate** (negative electrode), **lead dioxide** (or lead (iv) oxide) (positive electrode), and **dilutesulphuric acid** as the electrolyte.
When the accumulator is fully charged, the **relative density of the acid** is about **1.25** and the e.m.f of each pair is **2.2V.**



The cathode is lead, the anode is lead dioxide and the electrolyte is dilute sulphuric acid.
When it is working both electrodes gradually change to lead sulphate while the acid becomes more dilute and its relative density decreases.

Mechanism of an accumulator.

When in use, the negative lead electrode dissociates into free electrons and positive lead (ii) ions.

$$\mathbf{Pb(s) \rightarrow Pb^{2+}(aq) + 2\bar{e}}$$

The electrons travel through the external circuit while the lead (ii) ions combine with the sulphate ions in the electrolyte to form lead (ii) sulphate.

$$\mathbf{Pb^{2+}(aq) + SO_4{}^{2+}(aq) \rightarrow PbSO_4(aq)}$$

When the electrons re-enter the cell at the positive lead dioxide electrode, a chemical reaction occurs. The lead dioxide combines with the hydrogen ions in the electrolyte and the electrons to form water, releasing lead (ii) ions into the electrolyte to form additional lead (ii) sulphate.

$$\mathbf{PbO(s) + 2\,H^+(aq) + 2\bar{e} \rightarrow H_2O(\mathit{l}) + Pb^{2+}(aq)}$$

Care and maintenance of lead –acid accumulator

Dos	DONTs
(i) The battery should be charged regularly.	(v) Cells should not be left uncharged for a long time.
(ii) The liquid level should be maintained using distilled water before charging it to ensure that electrodes are not exposed.	(vi) When charging, avoid nearby flames because O_2 and H_2 are given off during the process i.e. O_2 is from anode and H_2 from cathode. The mixture of these gases is highly explosive.
(iii) Cells should be charged if the R.D. reduces to 1.18 R.D. can be	(vii) Avoid **shorting** the

checked using a hydrometer. (iv) Wipe the accumulator tops when dirty, because moisture and dirt can lead to short circuits. -	terminal i.e. you should not directly connect the terminals with a low resistance wire or metal because when shortened too much current is taken away from the cell. (viii) Avoid overcharging and over discharging. (ix) Avoid the addition of acid except where spillage has occurred.

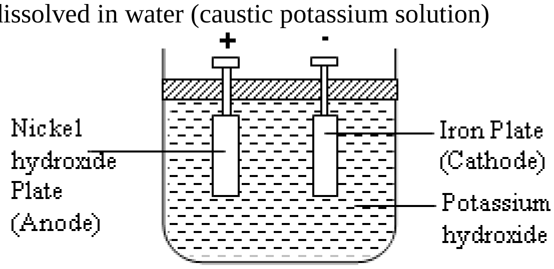
(ii) Alkaline cells

❖ **Nickel – cadmium (NiCd cells)**

Anode is the Nickel –hydroxide and cathode is cadmium

❖ **Nickel – Iron (NiFe Cells)**

Anode is Nickel hydroxide and cathode is iron.
In both cases, the electrolyte is potassium hydroxide dissolved in water (caustic potassium solution)



Uses

- Used in battery driven vehicles
- Used for emergency lighting

Advantages of alkaline cells over Lead-acid cells or accumulators

Alkaline Accumulators	Lead-acid accumulators
(i) Require no special maintenance.	(i) Require special maintenance
(ii) May be left uncharged for a long time without being damaged. They can be out of use for a long time	(ii) They get damaged if left un charged for a long time.
(iii) Are less heavy. (iv) Are long lasting.	(iii) Are heavy. (iv) Are not long lasting.
(v) They provide large currents without being damaged.	(v) They provide low currents.
(vi) Are suitable for supplying steady current for a long time.	
(vii) Can with stand over charging.	Can be damaged by over charging.

Disadvantages of the alkaline cells over the lead acid cells.

❖ Alkaline cells are expensive compared to lead acid cells.
❖ Alkaline cells have a low e.m.f and a higher internal resistance.
❖ Cadmium compounds are poisonous
❖ They do not properly store charge.

Capacity of an accumulator

This is the amount of electricity which an accumulator can store. It's measured in ampere hours (Ah)

$$\textbf{Capacity} = \textbf{current (A) x time (h)}$$
$$\textbf{Capacity} = \textbf{It}$$

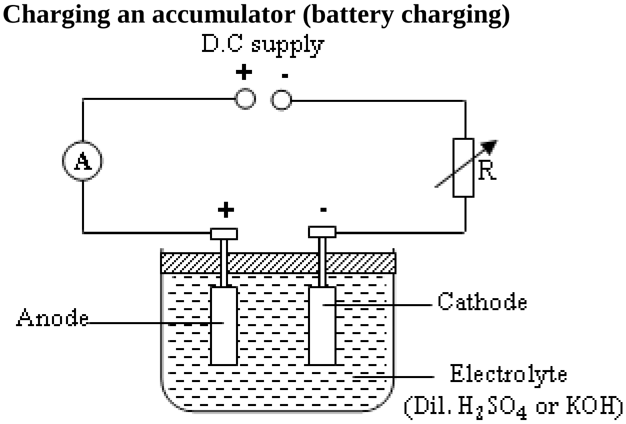
Example:

How long wills a cell marked 80Ah supply a current of 4.5A before it is exhausted.

Solution:

$$\text{Capacity} = \text{current (A) x time (h)}$$
$$\text{Capacity} = \text{It}$$
$$80 = 4.5 \times t$$
$$t = 17.8 \text{ Hours}$$

Charging an accumulator (battery charging)



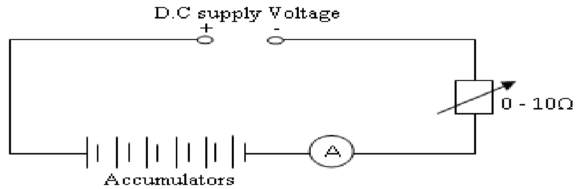
An accumulator is recharged by passing a current through it from a D.C supply in the opposite direction to the current it supplies.
Positive of the D.C. supply is connected to the positive of the accumulator while negative terminal of the D.C. supply is connected to the negative of the accumulator.
The acid becomes more concentrated during charging and R.D. of the acid increases.
The Rheostat varies resistance to make the current adjustable.
The ammeter measures the charging current which becomes low as the accumulator is charged and restored to usable condition. This is due to the rise in the e.m.f of the accumulators.
When chemicals have been restored to their original condition, hydrogen gas is given off (gassing process) and the cell is said to be fully charged.

Note;

❖ When an accumulator (battery) is being charged, electrical energy charges to chemical energy.
❖ When a battery (an accumulator) is being used (supplying current), chemical energy changes to electrical energy.

❖ Direct current is used during the charging process because alternating current would charge the accumulator in the first half cycle and then discharge it in the next half cycle.

Question:
Six accumulators each of e.m.f 2V and each of internal resistance 0.1Ω as shown below;



(i) Explain why its necessary to include a rheostat in the circuit.
(ii) Explain why direct current is used in the charging process.
(iii) What will the ammeter read if the Rheostat is set at 5.4Ω. (I = 2A)
(iv) Find the rate at which electrical energy is converted to chemical energy in (ii) above. (P = 2 4W).

Differences between primary cells and secondary cells.

Primary Cell	**Secondary Cell**
-Cannot be recharged once it stops working	-Can be recharged when they stop working.
-Current is produced as a result of irreversible chemical change.	-Current is produced as a result of reversible chemical change.
-Provide a lower e.m.f -Works for a shorter time -Higher internal resistance	-Provide a hiigher e.m.f -Works for a longer time. -Lowe internal resistance

Exercise:
1.

1995 Q.28	1998 Q.33	1998 Q.39	2002 Q.15

2. Which of the following statement(s) is or are true?
(i) Regular charging
(ii) Maintaining the level of acid by topping it up with distilled water.
(iii) Avoid over discharging
(iv) Avoid shorting the terminals.
A: (i), (ii) and (iii) only. B: (i) and (iii) only.
C: (i), (iii) and (iv) only. D: all

3. 1993 Qn.6
(a) (i) Draw a diagram to show the structure of a simple cell.
(ii) Give one defect of a simple cell and state how it is minimized.
(b) Explain how a lead acid accumulator can be recharged when it has run down.

4. 1994 Qn.4
(a) List four different sources of e.m.f
(b) State two advantages of a secondary cell over a primary cell.

5. 1995 Qn.6
(a) Explain why a current does not flow between the electrodes in dilute sulphuric acid until a certain value of p.d is exceeded.

6. 1996 Qn.10
(a) State two advantages of nickel iron accumulator over a lead acid accumulator.
(b) Name the gases evolved during the charging of the lead acid accumulator.
(c) Why a dry cell is called a primary cell?

CURRENT ELECTRICITY

Electricity is the flow of charged particles such as electrons and ions.
Electricity has various forms which include static electricity and current electricity. Static electricity is discussed in Electrostatics and current electricity will be discussed majorly now.

Electric current is the rate of flow of charge. OR It is the rate of flow of electrically charged particles.

Steady current is the constant rate of flow of charge.
It's measured in **amperes** represented by A. 1 A = 1 CS^{-1}.

An ampere is a current when the rate of flow of charge is one coulomb per second.
Qn. What type of quantity is current?

SOURCE OF ELECTRIC ENERGY
It has various sources which include among others;-

(i) Chemical energy (Electrochemical cells). Its also known as potential or stored energy and releasing. It always requires combustion of burning of coal, natural gas etc.

(ii) Thermal energy (Thermopile). Heat means thermo/ it can produce electrical energy when /after combustion of fossil fuels and biomass.

(iii) Mechanical Energy (Electric generators). This is energy in motion e.g. moving water, moving wind etc as they turn the turbines.

(iv) Nuclear energy (Nuclear reactors). Its energy in the bonds inside atoms and molecules during its release it can emit radioactive and thermal energy as well. Its normally produced in nuclear reactors

(v) Solar energy. (Solar cells). This is energy from the sun which can be captured by photovoltaic cells and then a source of electrical energy.

There could be other sources of energy but generally, the above are the major sources.

Common electrical /appliances we use in Uganda include.
- Electrical lamps
- Electric kettles

- Electric plates (cookers)
- Electric flat irons

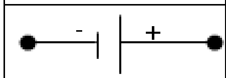
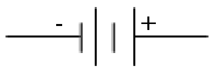
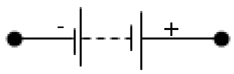
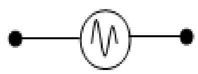
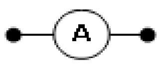
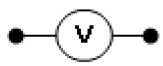
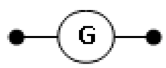
N.B. *Electrical appliances can be defined as devices used to simplify worker but use electricity as a form of energy*.

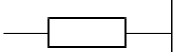
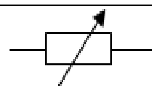
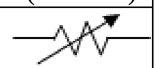
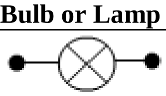
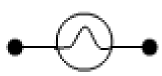
ELECTRIC CIRCUITS AND SYMBOLS

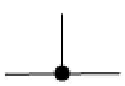
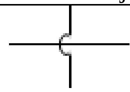
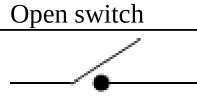
Symbols

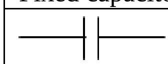
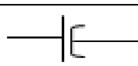
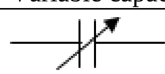
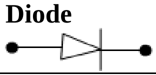
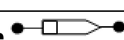
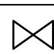
Electric symbols are symbols used in electricity during the circuits to draw them schematically and represent electrical and electronic components.

They include;

D.C source		**A.C source**
A cell	Battery	Alternating current (a.c)
	 or 	 or 
Meters		
Ammeter	Voltmeter	Galvanometer
		

Resistors			
Fixed resistor		Variable resistor (Rheostat)	
			
Bulb or Lamp			
			

Wires		
Connected wires	Wires not joined	Open switch
		

Capacitors			
Fixed capacitor		Variable capacitor	
			
Others			
Diode 		**Fuse**  or 	

There are very many symbols but these are the mostly used electrical symbols.

Terms used;

(i) Charge, Q; Is the quantity of electricity that passes a given point in a conductor at a given time.

The S.I unit of charge is a coulomb. **A coulomb** is the quantity of electric charge that passes a given point in a conductor when a steady current of 1A flows in one second.

(ii) Current, (I); Is the rate of flow of charge. i.e. $I = \frac{Q}{t}$.

The S.I unit of current is an **ampere**. An ampere is a current flowing in a circuit when a charge of one coulomb passes any point in the circuit in one second.

$\mathbf{1A = 1Cs^{-1}}$

Example 1: UNEB 2008 Qn.32

A current of 6A amperes flows for two hours in a circuit. Calculate the quantity of electricity that flows in this time.

Solution:

Given: $I = 6A, t = 2hrs$ $= 2 \times 60 \times 60 = 7200s.$ $Q = ?$	$\mathbf{Q = It}$ $Q = 6 \times 7200$ $Q = 43200\ C$

Example 2: UNEB 2007 Qn.48 (b)

A charge of 180C flows through a lamp for two minutes. Find the electric current flowing through the lamp.

Solution:

Given: $Q = 180\ C, t = 2minutes$ $= 2 \times 60 = 120s.$ $Q = ?$	$\mathbf{Q = It}$ $180 = I \times 120$ $I = 1.5\ C$

(iii) Potential difference (P.d); Is the work done in transferring one coulomb of charge from one point to another in a circuit.

It can also be defined as the electrical energy changed into other forms of energy when 1 coulomb of charge passes from one point to another in a circuit.

Whenever current flows, it does so because the electric potential at two points are different. If the two points are at the same potential, no current flows between them. $P.d = \frac{W}{Q}$

The S.I unit is a volt. A **volt** is the potential difference between two points in circuit in which, 1J of work is done in transferring 1C of charge from one point to another.

$\mathbf{1V = 1JC^{-1}}$

(iv) Electromotive force, (e.m.f): Is the work done in transferring one coulomb of charge around a complete circuit in which a battery is connected.

It is the p.d across a cell in an open circuit.

<u>Sources of electrical e.m.f.</u>

(i). Electric cell: This converts chemical energy to electrical energy.
(ii). Generators: These convert mechanical energy to electrical energy.
(iii). Thermo couple: This converts thermal energy (or heat energy) to electrical energy.
(iv). Piezo-electric effect (Crystal pick ups)
(v). Photo electric effect (solar cells)

(v) Electrical Resistance, (R): Is the opposition to the flow of current in a conductor. $R = \frac{V}{I}$.

The S.I unit of resistance is an ohm (Ω). **An ohm** is the resistance of a conductor through which a current of one ampere flows when a p.d across it is one volt.

(vi) Internal resistance of a cell, r:

Internal resistance of a cell is the opposition to the flow of current within the cell.

(vii) Open circuit: where current is not being supplied to an external circuit.
(viii) Closed circuit: Where the cell is supplying current to an external circuit.

1. E.m.f:- Is the work done to move a charge of IC through a circuit including a source (cell) i.e. the p.d. when the cell is not supplying current to an external circuit.

2. Terminal p.d. The work done to move a charge of IC through a circuit across the terminals of a battery i.e. it's the p.d when current is being delivered to an external circuit.

NB. Thevalue of the terminal p.d. is always less than e.m.f because of the opposition to the flow of current inside the cell.
Internal resistance: Is the opposition to the flow of current within the cell.

$$\text{E.m.f} = \text{Terminal pd.} + \begin{pmatrix} \text{p.d across the internal} \\ \text{resistance, r} \end{pmatrix}.$$

$$E = VR + Vr$$
$$\mathbf{E = IR + Ir}$$

Factors affecting resistance of a conductor.
The resistance of a conductor is independent of the P.d, V and the current I through the conductor but it depends on physical factors like; length, cross sectional area and temperature.

Factor	Effect on resistance
(i) Length, l $R \propto l$	Increasing the length increases the resistance of the conductor. This is because increase in length increases the number of collisions electrons have to make with atoms as they travel through the conductor. This reduces the drift velocity of the free electrons and hence increases the resistance of the conductor.
(ii) Cross sectional area, A $R \propto \frac{1}{A}$	When there is an increase in the cross sectional area of the conductor, the number of free electrons that drift along the conductor also increases. This means that there is an increase in the number of electrons passing a given point along the conductor per second, thus an increase in current Consequently, this reduces the resistance of the conductor.
(iii)Temperature, T $R \propto T$	When there is an increase in the temperature of the conductor, the atoms vibrate with greater amplitude and frequency about their mean positions. The velocity of the free electrons increases which increases their kinetic energy. Consequently, the number of collisions between the free electrons and the atoms increases. This leads to a decrease in the drift velocity of the electrons. This means that there is a decrease in the number of electrons passing a given point along the conductor per second, thus a decrease in current Consequently, this increases the resistance of the conductor.
(iv) Nature of the substance.	Good conductors like metals have low resistance while poor conductors (insulators) have very high resistance.

Note: Supper conductors are materials whose resistance vanishes when they are cooled to a temperature near -273^0C.

Combining the first two factors at constant temperature, we get:

$$R \propto \frac{l}{A} \Leftrightarrow \boldsymbol{R = \rho \frac{l}{A}}$$

Where, ρ is a constant which depends on the nature of the conductor. It is called the Resistivity of the conductor.
Thus thick and short conductors have lower resistances compared to thin and long conductors.

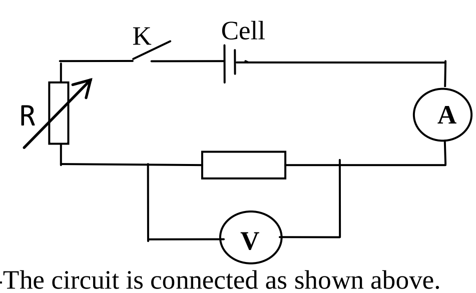
Resistivity, $\boldsymbol{\rho}$:
Is the electrical resistance across the opposite faces of a cube of 1m length.
The S.I unit of resistivity is an ohm metre,(Ωm).

Conductivity, $\boldsymbol{\sigma}$:
Is the reciprocal of electrical resistivity.

$$\boldsymbol{\sigma = \frac{1}{\rho}}$$

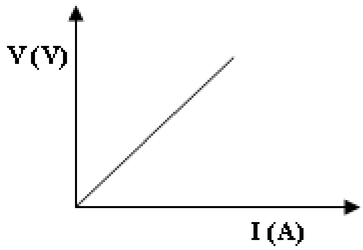
OHMS LAW:
It states that the current through an ohmic conductor is directly proportional to the P.d across it provided the physical conditions remain constant.

Experiment to verify Ohms law;



-The circuit is connected as shown above.
-Switch, K is closed, and a current, I flows through the circuit.
-Read and record the ammeter reading and the corresponding voltmeter reading.
-The rheostat is adjusted to obtain several values of V and I.

-Plot a graph of V against I



-It is a straight line graph through the origin, implying that V is directly proportional to I which verifies Ohm's law.
.

Note: In case the experiment requires resistance, then the slope of the graph is the resistance.
From the graph; $\mathbf{Slope, R = \frac{V}{I} = \tan\theta}$.
Whereθ is the angle between the line and the horizontal.

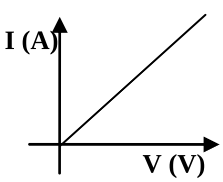
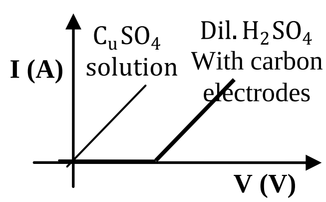
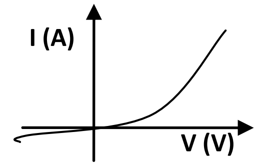
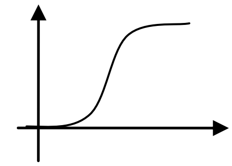
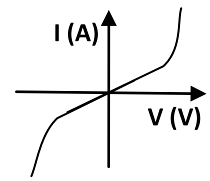
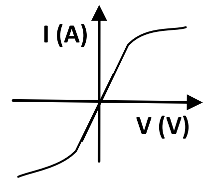
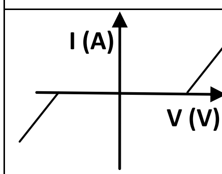
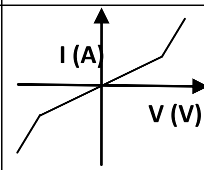
Limitations of ohm's law

- ✓ It only applies when the physical conditions of a conductor are constant e.g. temperature, length of a conductor, cross section area e.t.c.
- ✓ It doesn't apply to semi conductors e.g. diodes and electrolytes

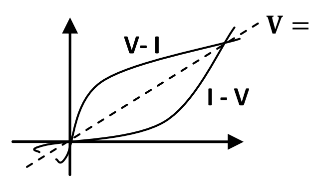
Ohmic and non- ohmic conductors

- Ohmic conductors are conductors which obey ohm's law. E.g. Metals.
- Non Ohmic conductors are conductors which do not obey ohm's law e.g. filament lamps, in diodes, neon gas tubes.

The graphs of current against voltage for different conductors.

(i) **Ohmic conductor** (Pure metal)	**(ii) Electrolytes**
 The straight line passes through the origin. The conductor closely obeys Ohm's law.	 Conductions in electrodes and electrolytes are both ohmic. For some electrodes conduction begins after the voltage has reached a certain value,
(iii) Semi Conductor diode A diode allows current to flow in only one direction $R = 0\ \Omega$ in foward bias $R = \infty\ \Omega$ in reverse bias	**(iv)Thermionic diode (diode valve)**
 There is a slow rise in the current and it is nearly Ohmic.	 The graph is fairly Ohmic. At saturation, the current becomes constant.
(v) Thermister And carbon resistor	**(vi) Filament bulb**
 The resistance of a thermister decreases as temperature increases. A fall in resistance causes current to increase more rapidly.	 At low currents, the graph is a straight line. As current increases, more heat is produced and temperature increases which increases the resistance of the filament wire.
(v) Acid water	**(vi) Neon gas**
 Dilute H_2SO_4 With platinum electrodes	

Note: The Shape of the I-V and V-I graphs are basically the reflection of about the $\mathbf{V = I}$ line.



For the filament lamp,
As temperature increases, the resistance also increases.
The graph is not a straight line. i.e, it does not obey ohms law.
As more current flows in the lamp, the metal filament gets hotter.
The metal atoms in the filament vibrate faster and further from their positions. This results in an increase in the collision with the travelling electrons, hindering their flow and causing more resistance. This is shown by the flattening out of the graph as the current increases indicating that resistance increases.

For the Thermister,
As temperature increases, the resistance also decreases.
The graph is the reverse of that of the filament lamp.

As more current flows in thermister, the graph gets steeper. It conducts more current when heated.
As the temperature increases, it makes available more free electrons to carry current.
As the current increases, the thermister gets hotter releasing more electrons resulting in a reduction in resistance.

ELECTRIC CIRCUITS

An electric circuit can be defined as a combination or a connection of electric appliances represented by electric symbols for a particular purpose.

(a) Open and closed circuits
A circuit can be open (incomplete) or closed (completed).
An **open circuit** is circuit in which electrons are not continuously flowing.
A **closed circuit** is a circuit which is complete and having electrons continuously flowing.

(b) A short Circuit: is a connection between two points which provides a path of very low resistancein an electric circuit. This causes excessive currents to flow through the connections, resulting in fires.

Parallel and series electric circuits' connection
In connections, we must either connect in series or in parallel.

Some examples
1. A current of 4A flows through an electric kettle when the p.d. across it is 8V. Find the resistance.
2. What voltage is needed to make a current of 0.4A flow through when the appliance has resistance of 20Ω?

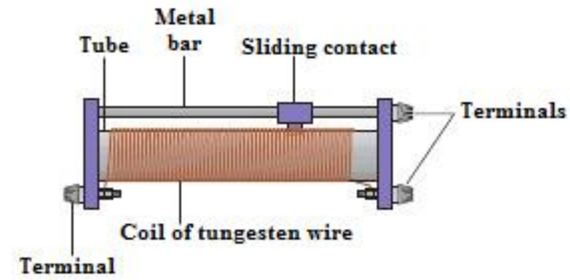
Questions
1. Give the unit and its symbol for
   (a) Current
   (b) Charge
2. What instrument is used to measure current.
3. A charge of 4C flows through an ammeter in 1s. What reading will the ammeter show? If the same charge flowed through the ammeter in 2s. What would the current be?
4. (a) Draw a circuit diagram to show two cells connected in series with a switch and two bulbs.

(b) Draw a 2nd circuit diagram with the same components, but with a switch and two bulbs in Parallel with each other.

Qn. Determine resistance from the information given.

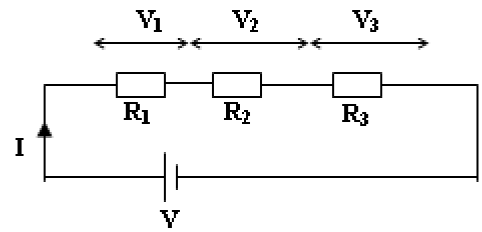
p. d (V)	1.05	1.40	1.80	2.20	2.40
I (A)	0.15	0.20	0.25	0.30	0.34

RESISTANCE
It can be defined as the opposition to the flow of current through a conductor. A resistor is a conductor which opposes the flow of current through it.
There are two types of resisiters
(i) Fixed resistor
(ii) Variable resistor (Rheostat)



The unit of resistance is an ohm (Ω)
An **ohm** is the resistance of the conductor when a current of 1 A is flowing and a p.d. of 1 V is across its ends.

Resistor Net works
(i) Series arrangement of resistors
Resistors are said to be in series when they are connected end to end so that the same amount of current is the same.
The positive of one load is connected to the negative of another load.



In series
(i) Same current flows through each resistor.
(ii) P.d across each resistor is different
(iii) Total p.d V = sum of p.d across each resistor.

Thus: $V = V_1 + V_2 + V_3$

Using Ohm's law, $V_1 = IR_1$, $V_2 = IR_2$ and $V_3 = IR_3$

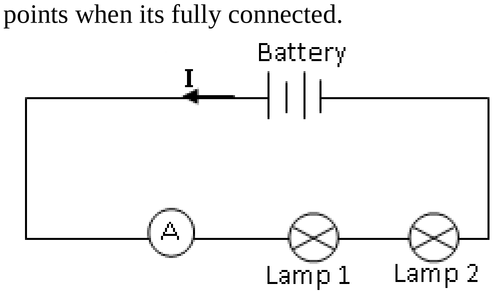
$$V = IR_1 + IR_2 + IR_3$$
$$V = I(R_1 + R_2 + R_3)$$

If **R** is the resistance of a single resistor representing the three resistors, then V=IR.

$$IR = I(R_1 + R_2 + R_3)$$

$$\mathbf{R = R_1 + R_2 + R_3}$$

Series circuits
The current is the same at all points around a series circuit connections i.e. from the source (battery/cell) up to all points when its fully connected.

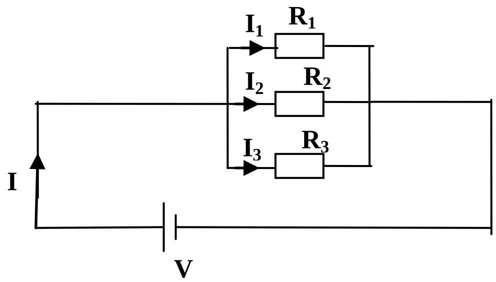


Which is a series connection and current being measured in series.

(ii) **Parallel arrangement of resistors**

Resistors are said to be in parallel if they are connected such that they branch from a single point (known as a **node**) and join up again.

The positive of one load is connected to the positive of another load.



For parallel

(i) P.d across each resistor is the same.

(ii) The main current flowing splits and therefore, the current through each resistor is different

(iii) Total current, I is equal to sum of the current through each resistor. Thus: $I = I_1 + I_2 + I_3$.

Using Ohm's law, $V_1 = \frac{V}{R_1}; V_2 = \frac{V}{R_2}$ and $V_3 = \frac{V}{R_3}$

$$I = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$I = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

If **R** is the resistance of a single resistor representing the three resistors, then: $\mathbf{I = \frac{V}{R}}$.

$$\frac{V}{R}. = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

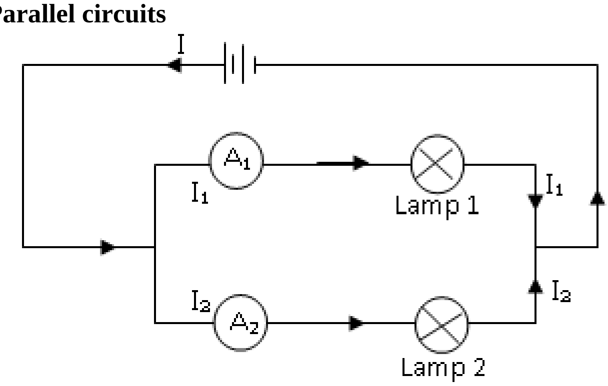
$$\mathbf{\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

Note: For only two resistors in parallel, the effective resistance can be obtained as follows:

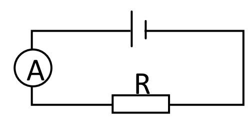
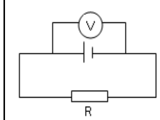
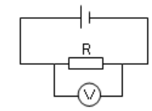
$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \Leftrightarrow \frac{1}{R} = \frac{R_2 + R_1}{R_1R_2} \Leftrightarrow \mathbf{R = \frac{R_1R_2}{R_2 + R_1}}$$

$$\mathbf{R} = \frac{\textbf{Product of the two resistances}}{\textbf{Sum of the two resistances}}$$

Parallel circuits



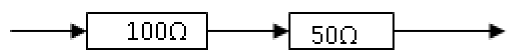
Ammeters are for measuring the current in a parallel circuit. It's characteristic in parallel connections to derive current whenever it reaches the parallel arms of the circuit. But current later recombines to form the original current again before it returns to the cell.

Ammeter	**Voltmeter**
-A device used to measure current -It has a very low resistance -Always placed in the path of current, i.e in series 	-A device used to measure potential different -It has a very high resistance -Connects across the path of the conductor whose p.d. is to be determined, i.e in parallel.  

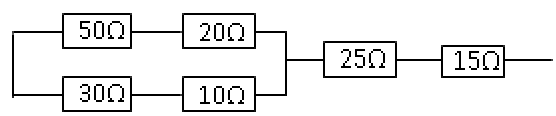
Examples:

1. Show that for two resistors in parallel, the effective resistance $R = \frac{R_1R_2}{R_1 + R_2}$

2. What is the total resistance of the resistors below;

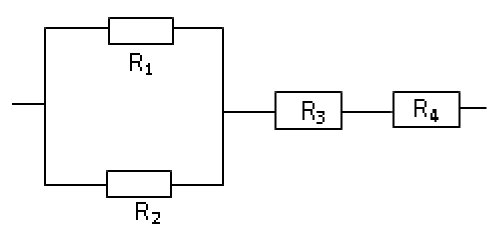


3. What is the effective resistance of the circuit below?



More combinations:

It's very possible to have series and parallel connections combined and in this case, we apply both principles within a given circuit.



If the effective is R

Let the effective of R_1 and R_2 be R_p

$$\frac{1}{R_p}. = \frac{1}{R_1} + \frac{1}{R_2} = \frac{R_1 + R_2}{R_1R_2} \Leftrightarrow R_p = \frac{R_1R_2}{R_1 + R_2}$$

Let the effective of R_3 and R_4 be R_s

$$R_s = R_3 + R_4$$

Thus the effective resistance R is given by:

$R = R_p + R_s$

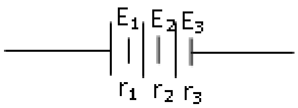
$$R = \frac{R_1R_2}{R_1 + R_2} + R_3 + R_4$$

Voltage and connections

Voltages or e.m.f's can also be connected in series or parallel.

(i) Cells in series

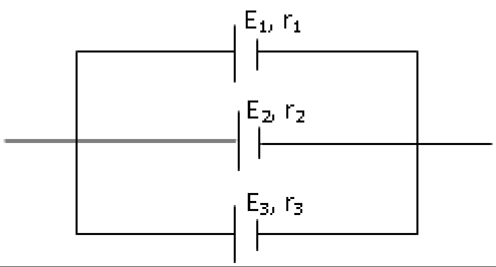
In this case, we sum all the individual e.m.f's to obtain the total e.m.f's:



Effective e.m.f, E	Effective resistance, r
$\mathbf{E = E_1 + E_2 + E_3}$	$\mathbf{r = r_1 + r_2 + r_3}$

(ii) Cells in parallel

For the case of parallel connection of e.m.f. they have the same e.m.f.

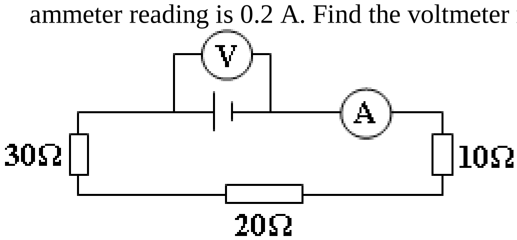


Effective e.m.f, E	Effective resistance, r
$\mathbf{E = E_1 = E_2 = E_3}$	$\mathbf{\frac{1}{r} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}}$

EXAMPLES

1. What would happen to the current passing through a resistor of unknown resistance if the potential difference across it were increased from 3 V to 6 V?

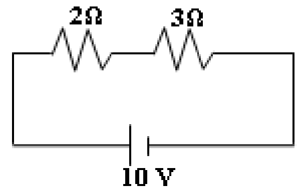
2. (1991 Qn. 35). In the circuit diagram below, the ammeter reading is 0.2 A. Find the voltmeter reading.



Let R_1=10Ω, R_2=20Ω, R_3=30Ω, I=0.2A, V=?	
First determine the effective resistance, R	Now that we know I and R, let us use Ohms law; **V=IR**
$R = R_1 + R_2 + R_3$ $R = 10 + 20 + 30$ $R = 60\Omega$	$V = IR$ $V = 0.2 \times 60$ $V = 12$ V.

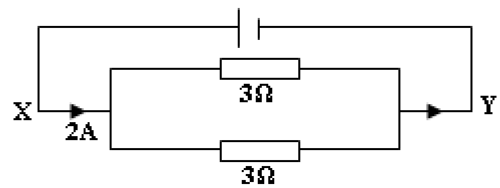
3. **(1997 Qn. 35).** Two coils of wire of resistance 2Ω and 3Ω are connected in series with a 10 V battery of negligible internal resistance. Find the current through the 2Ω resistor. [**Ans: 2A**]

Solution:



Let R_1=10Ω, R_2=20Ω, R_3=30Ω, I=0.2A, V=?	
First determine the effective resistance, R	Now that we know V and R, let us use Ohms law; **V=IR**
$R = R_1 + R_2$ $R = 2 + 3$ $R = 5\Omega$	$V = IR$ $10 = I \times 5$ $5I = 10$ $I = 2$ A

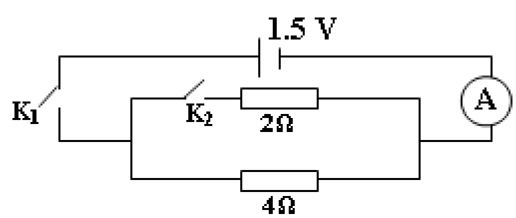
4. **(1993 Qn. 15).** A current of 2A in flows in a circuit in which two resistors each of resistance 3Ω are connected as shown in the figure below. Calculate the P.d across XY.



Solution:

Let R_1= 3Ω, R_2= 3Ω, I= 2A, V=?	
First determine the effective resistance, R	Now that we know I and R, let us use Ohms law; **V=IR**
$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$ $\frac{1}{R} = \frac{1}{3} + \frac{1}{3} = \frac{2}{3}$ $R = \frac{3}{2}\Omega = 1.5\Omega$	$V = IR$ $V = 2 \times 1.5$ $V = 3$ V.

5. **(2007 Qn. 3).** What will be the reading of the ammeter in the figure below if switch $\mathbf{K_2}$is**;**



(i) Open and $\mathbf{K_1}$ is closed

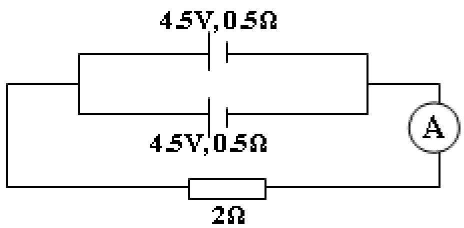
(ii) Closed and $\mathbf{K_1}$ is closed**.**

Solution:

(i) When K_2 is open and K_1 closed, current flows through the 4Ω only. Let R= 4Ω, V=1.5 V, I=?	
First determine the effective resistance, R	Now that we know I and R, let us use Ohms law; **V=IR**
$R = 4\Omega$	$V = IR$ $1.5 = I \times 4$ $I = 0.375$ A

(ii) When K_2 is closed and K_1 closed, current divides into the 2Ω and 4Ω. Let R_1= 2Ω, R_2= 4Ω, V=1.5 V, I=?	
First determine the effective resistance, R	Now that we know I and R, let us use Ohms law; **V=IR**
$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$ $\frac{1}{R} = \frac{1}{2} + \frac{1}{4} = \frac{3}{4}$ $R = \frac{4}{3}\Omega = 1.33\Omega$	$V = IR$ $1.5 = I \times \frac{4}{3}$ $I = 1.125$ A

6. **(2008 Qn. 28).** The figure below shows two cells each of e.m.f 4.5 V and internal resistance 0.5Ω, connected to a 2Ω resistor.

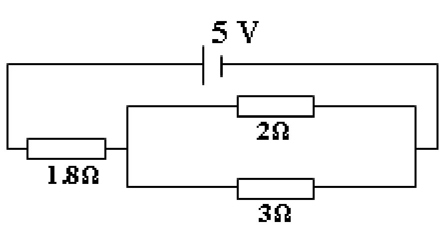


What is the ammeter reading?

Solution:

Let r_1= 0.5Ω, r_2= 0.5Ω, R_3= 2Ω V= 4.5V (Voltages in parallel; E_1=E_2=V), I=?	
First determine the effective resistance, Rp of the resistors in parallel. $\frac{1}{r} = \frac{1}{r_1} + \frac{1}{r_2}$ $\frac{1}{R} = \frac{1}{0.5} + \frac{1}{0.5} = \frac{4}{1}$ $R = \frac{1}{4}\Omega = 0.25\Omega$	This resistance Rp is now in series with the 2Ω resistor. Thus the effective resistance, R is; $R = R_P + R_3$ $R = 0.25 + 2$ $R = 2.25\Omega$ Now that we know I and R, let us use Ohms law; $V = IR$ $4.5 = I \times 2.25$ $I = 2$ A.

7. **(1994 Qn. 4).** The diagram below shows three resistors, 1.8Ω, and 2.0 Ω and 3Ω resistor.



Calculate the; (i) Effective resistance of the circuit
(ii) Current through the circuit.
(iii) P.d across the 2Ω resistor
(iv) Current through the 3Ω resistor.

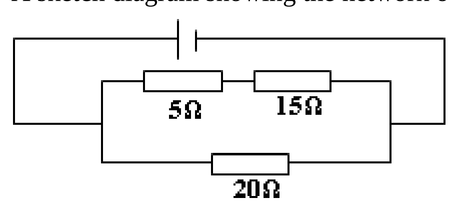
Solution:

(i) Effective resistance of the circuit   The 2Ω and 3Ω are in parallel. Their effective resistance is in series with the 1.8Ω resistor.   Thus the effective resistance R is given by: $R = R_p + R_s$ $R = \frac{R_1 R_2}{R_1 + R_2} + R_3$ $R = \frac{2 \times 3}{2 + 3} + 1.8 \Leftrightarrow R = \frac{6}{5} + 1.8 \Leftrightarrow R = 1.2 + 1.8$ $R = 3\Omega$
(ii) Current through the circuit.   From Ohms law; **V=IR.** $V = IR$ $5 = I \times 3$ $I = \frac{5}{3} = 1.67$ A
(iii) P.d across the 2Ω resistor   P.d across the 2Ω resistor is equal to the P.d across the 3Ω which is equal to the P.d across the parallel combination.   Thus from Ohms law; **V=IR.** $V_P = IR_P$ $V_P = \frac{5}{3} \times 1.2$ $V_P = 2$ V   Thus the P.d across the 2Ω resistor is 2V.
(iv) Current through the 3Ω resistor.   Let the 3Ω resistor = R_1; Then; $V_1 = I_1 R_1$; In this case, $V_1 = V_P = 1.2$ V $1.2 = I_1 \times 3$ $I_1 = 0.4$ A   Thus the current through the 3Ω resistor is 0.4A.

8. **(2001 Qn. 31**). Find the effective resistance when two resistors of 5Ω and 15Ω joined in series are placed in parallel with a 20Ω resistor.

Solution:

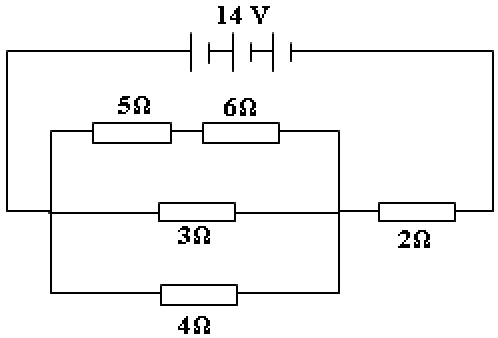
Let R_1= 5Ω, R_2= 15Ω, R_3= 20Ω,
A sketch diagram showing the network of resistors.



First determine the effective resistance, $\mathbf{R_s}$ for the resistors in series.	Now $\mathbf{R_s}$ is in parallel with the $\mathbf{R_3}$**= 20Ω.** Thus the effective resistance in the circuit is;
$R_s = R_1 + R_2$ $R_s = 5 + 15$ $R_s = 20\Omega$	$R = \frac{R_s R_3}{R_s + R_3}$

	$R = \frac{20 \times 20}{20 + 20} = \frac{400}{40}$ $R = 10\Omega$

9. In the figure below, find the ;



(i) Effective resistance in the circuit.
(ii) Current through the circuit.
(iii) P.d across the 2Ω resistor.
(iv) P.d across the 6Ω resistor.

Solution:

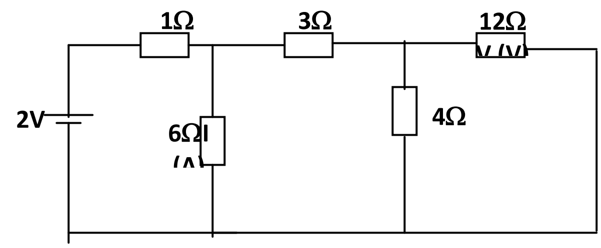
Let R_1= 5Ω, R_2= 6Ω, R_3= 3Ω, R_4= 4Ω, R_5= 2Ω, **(i) Effective resistance in the circuit.**	
First determine the effective resistance, $\mathbf{R_s}$ for the 5Ω and 6Ω resistors in series. $R_s = R_1 + R_2$ $R_s = 5 + 6$ $R_s = 11\Omega$ Now $\mathbf{R_s}$ is in parallel with the **3Ω.** and **4Ω** resistors. Thus the effective resistance in parallel is; $\frac{1}{R_p} = \frac{1}{R_s} + \frac{1}{R_3} + \frac{1}{R_4}$ $\frac{1}{R_p} = \frac{1}{11} + \frac{1}{3} + \frac{1}{4}$ $\frac{1}{R_p} = \frac{12 + 44 + 33}{132} = \frac{89}{132}$ $\frac{1}{R_p} = \frac{12 + 44 + 33}{132} = \frac{89}{132}$ $R_p = \frac{132}{89}\Omega = 0.674\Omega$	Now $\mathbf{R_p}$ is in series with the **2Ω** resistor. Thus the effective resistance in the circuit is; $R = R_P + R_5$ $R = 0.674 + 2$ $R = 2.674\Omega$ **(ii) Current through the circuit.** From Ohms law; **V=IR.** $V = IR$ $14 = I \times 2.674$ $2.674I = 14$ $I = 5.236$ A **(iii) P.d across the 2Ω resistor.** From Ohms law; **V=IR.** $V = IR$ $V = 5.236 \times 2$ $V = 10.472$ V
(iv) P.d across the 6Ω resistor. The P.d across $R_s(5\Omega \text{ and } 6\Omega)$ is equal to the p.d across the 3Ω and is also equal to the p.d across the 4Ω resistor. This is because, R_s, 3Ω and 4Ωare in parallel.	
P.d across the parallel combination: From Ohms law; **V=IR.** $V_P = I_P R_P$ $V_P = 5.236 \times 0.674$ $V_P = 3.529$ Current through $R_s(5\Omega \text{ and } 6\Omega)$ resistors. From Ohms law; **V=IR.** $V_P = I_s R_s$ $3.529 = I_s \times 11$ $11I_s = 3.529$ $I_s = 0.321$ A	Then the P.d across the 6Ω resistor is obtained as follows; From Ohms law; **V=IR.** $V = I_s R$ $V = 0.321 \times 6$ $V = 1.925$ V

Example 10.

A dry cell of e.m.f, E and internal resistance, r drives a current of 0.25A through a resistor of 5.5Ω. When the resistance is changed to 4.5Ω, the current becomes 0.3Ω. Determine the:

(i) Internal resistance of the cell. (**Ans: r = 0.5Ω**)
(ii) E.m.f of the cell. (**Ans: E = 1.5V**)

Example: 8



4 Ωand 12Ω resistors are parallel, their effective resistance is:

$$R_1 = \frac{4 \times 12}{4 + 12} = 3\Omega$$

R_1 and 3Ω resistors are in series, their effective resistance is

$$R_2 = R_1 + 3 = 3 + 3 = 6\Omega$$

R_2 and 6Ω resistors are in parallel, their effective resistance is:

$$R_3 = \frac{6 \times 6}{6 + 6} = 3\Omega$$

R_3 and 1Ω resistors are in series, their effective resistance is

$$R = R_3 + 1 = 3 + 1 = 4\Omega$$

Hence effective resistance of the whole circuit is R = 4Ω

Current flowing is:

$$I = \frac{V}{R} = \frac{2}{4} = 0.5A$$

Example:9

A cell is joined in series with a resistor of 2Ω and a current of 0.25A flows through it. When a second resistor of 2Ω is connected in parallel with the first, the current through the cell increases to 0.3A. Calculate the e.m.f and internal resistance of the cell.

Solution:

Case I

I=0.25A, R=2Ω, E=?, r=?

$E = I(R + r)$

$E = 0.25(2 + r)$

$E = 0.5 + 0.25r \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(i)$

Case II

I= 0.3A, $R_2 = \frac{RR}{R+R} = \frac{R^2}{2R} = \frac{2^2}{2(2)} = 1\Omega$, E=?, r=?

$E = I(R_2 + r)$

$E = 0.3(1 + r)$

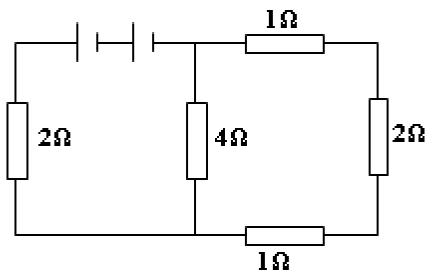
$E = 0.3 + 0.3r \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(ii)$

Solving equations (i) and (ii) simultaneously, we get;

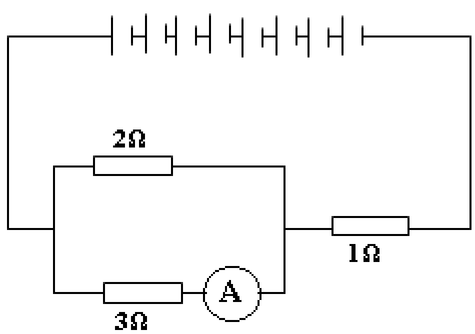
$\underline{E = 1.5V, \text{and } r = 4\Omega}$

EXERCISE:

1. Calculate the effective resistance of the circuit below. [**Ans: 4Ω**]



2. Eight identical cells each of e.m.f 1.5 and internal resistance 0.1Ω are connected in a circuit as shown bellow.

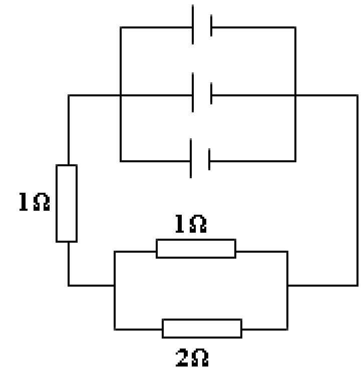


Calculate the;

(i). Current in the circuit.[Ans: 4A]

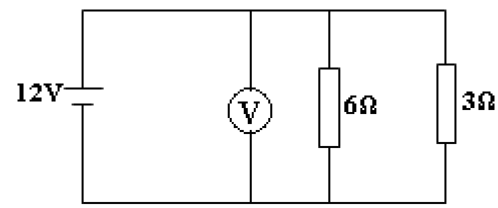
(ii). Ammeter reading, A. [Ans: 1.6 A]

3. Three identical cells each of e.m.f 1.5V and internal resistance 0.1Ω are connected as shown bellow.



Calculate the current in the circuit. [Ans: 0.88A]

4. (1997 Qn. 30). A battery of e.m.f 12V is connected across two resistors of 6Ω and 3Ω as shown below.



Calculate the current through the resistors.

5. UNEB 2014 PP2 No. 6:

(a) A lamp is marked 240V, 60W. Explain what this means.

(b) (i) Use a diagram to show how three identical cells, each of e.m.f 1.5 V and internal resistance 0.1Ω, can be arranged to give minimum e.m.f.

(ii) Calculate the current flowing in the circuit in (b) (i) above, if two resistors of resistance 4Ω and 5Ω are in series in the circuit.**(Ans: I = 0.166A)**

6. See UNEB Paper1

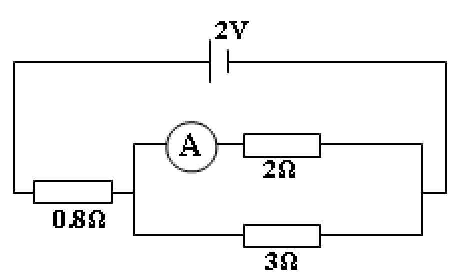
Section A:

1987 Qn.29	1989 Qn.32	1992 Qn.8	1994 Qn.4
1998 Qn.35	2000 Qn.37	2006 Qn.38	2008 Qn.36
1992 Qn.15	1989 Qn.11	1991 Qn.28	1994 Qn.24
1995 Qn.29	1998 Qn.37	2004 Qn.6	2007 Qn.12
1994 Qn.32			

Section B:

2002 Qn.50	1994 Qn.5	1997 Qn.8	1998 Qn.8
2000 Qn.9	2002 Qn.7		

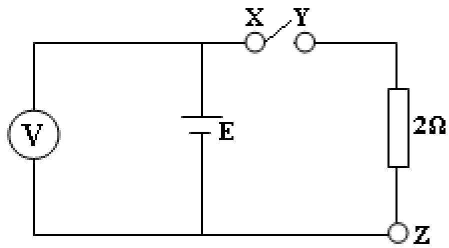
(1989 Qn. 7). (b) A battery of e.m.f 2.0 V and of negligible internal resistance is connected as shown below.



Find the reading of the ammeter, A.

(c) A battery of e.m.f 12 V and internal resistance 1Ω is connected for three minutes and two seconds across a heating coil of resistance 11Ω immersed in a liquid of mass 0.2 kg and specific heat capacity of $2.0 \times 10^3 Jkg^{-1}K^{-1}$. Find the rise in temperature of the liquid. Clearly state any assumptions made.

(1989 Qn. 7). (b) A cell of e.m.f, E and internal resistance 1.0 Ω is connected in series with a 2Ω resistor as shown bellow.



The voltmeter reads 1.5V when the switch is open.

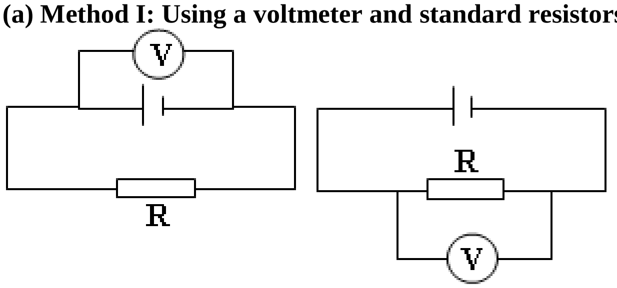
(i). Find the value of E.

(ii). What will be the voltmeter's reading when the switch is closed?

(iii). What will be the voltmeter's reading when X is connected to Z? Give a reason for your answer.

An experiment to obtain internal resistance of a cell.

(a) Method I: Using a voltmeter and standard resistors.



-A high resistance voltmeter is connected across the terminals of the cell, we take the reading which is the E.m.f., **E** of the cell.

-A standard resistor is connected to the cell terminals and the voltmeter reading is taken again which is **V**.

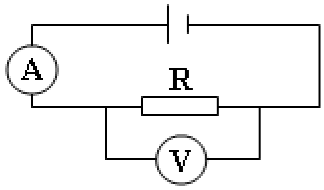
-Calculate the internal resistance of the cell, **r** from;

$$\mathbf{r = \frac{R(E-V)}{V}}$$

-Repeat the procedure using other resistors of different resistances.

-Finally take the mean value of internal resistance.

(b) Method II: Using a voltmeter, Ammeter and standard resistors.



-A high resistance voltmeter is connected across the terminals of the cell, we take the reading which is the E.m.f., **E** of the cell.

-A standard resistor is connected in series with the cell terminals and the voltmeter connected across it as shown above.

-Read and record the voltmeter reading, **V** and the corresponding ammeter reading, **I**.

-Calculate the internal resistance of the cell, **r** from;

$$\mathbf{r = \frac{E-V}{I}}$$

-Repeat the procedure using other resistors of different resistances.

-Finally take the mean value of internal resistance

Derivation: Find the total resistance using R and r and them apply ohm's law $\text{Total resistance} = R + r$ $E = I \times \text{Total restance}$ $E = I(R + r)$ $E = IR + Ir \dots\dots\dots\dots (i)$	For the resistor alone; $V = IR \dots\dots\dots\dots\dots\dots (ii)$ Subtracting equation (ii) from equation (i) , we get; $E - V = Ir$ Making r the subject of the formula gives; $\mathbf{r = \frac{E-V}{I}}$
Note: The expression $\mathbf{E - V}$is called **lost volt** and it is defined as the voltage wasted in overcoming the internal resistance of a cell.	
Alternatively: From; $V = IR$, $I = \frac{V}{R}$ Substituting for current, I in the equation for r above, gives;	$r = \frac{E-V}{\left(\frac{V}{R}\right)}$ $\mathbf{r = \frac{R(E-V)}{V}}$

Example:

1. A very high resistance voltmeter is connected across a battery and it reads 4.5V. When a resistor of 10 Ω is connected across the battery, the voltmeter reading drops to 4.2V. Calculate the internal resistance of the cell and the current through the circuit.

ELECTRICAL ENERGY AND POWER

The advantage of electric energy is the ease with which it may be transferred to light, heat and other forms of energy. Because of this, it can be used in many types of equipment like refrigerators, cookers, lamps, e.t.c.

When electricity passes thru an appliance, it develops and produces some heat which may depend on any of the following;

- Resistance of the conductor
- The amount of current flowing
- The time for which the current has been flowing

Work done by an electric current.

When a charge moves through a resistance wire, the work done becomes the electrical energy which changes to heat energy.

$$\mathbf{\text{Work done} = \text{Voltage} \times \text{Charge}}$$
$$\mathbf{W = V \times Q}$$

From the definition of current, $Q = It$: Thus;

$W = V \times It$

$$\mathbf{W = VIt} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ (\mathbf{i})$$

But from Ohm's law, $V = IR$: Thus;

$W = IR \times It$

$$\mathbf{W = I^2Rt} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (\mathbf{ii})$$

$$\mathbf{W = \frac{V^2t}{R}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (\mathbf{iii})$$

Electrical Power

Power is the rate of doing work or it's the rate of energy transfer.

$$\text{Power} = \frac{\text{Work done}}{\text{Time taken}} = \frac{\text{Energy transfered}}{\text{Time taken}}$$

$$\text{Power, } P = \frac{IVt}{t} = IV \Leftrightarrow \mathbf{P = IV = I^2R = \frac{V^2}{R}}$$

Note: Why a wire heats up when a current is passed through it.

The wire has some resistance, R. Thus when a current, I passes through it, some of the electrical energy from the electric source is wasted in doing work against this resistance (opposition to the flow of current in this wire).
This enegy ($\boldsymbol{I^2Rt}$) is converted to heat energy in the wire which makes the wire heat up.

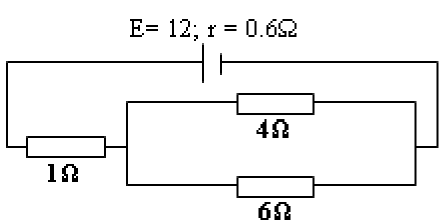
Examples

2. An electrical flat iron of rated 240V, 1500W. calculate the;
   (i) The current through the flat iron.
   (ii) The resistance of the flat iron
   (iii) The energy consumed in $1\frac{1}{2}$ hours.

Solution:

P = 1500W; V = 120V, I = ?	
(i) the current through the flat iron. $\mathbf{P = IV}$ $1500 = I \times 240$ $240I = 1500$ $I = 6.25$ A	(ii) The resistance of the flat iron $\mathbf{P = \frac{V^2}{R}}$ $1500 = \frac{(240)^2}{R}$ $1500R = 57600$ $R = 38.4\ \Omega$
(iii) The energy consumed in $1\frac{1}{2}$ hours: $\mathbf{E = Pt}$ $E = 1500 \times (1.5 \times 60 \times 60)$ $E = 8{,}100{,}000J$	**One can use;** $\mathbf{E = IVt}$, **or** $\mathbf{E = \frac{V^2}{R}}$

3. In the diagram, below, a 12V battery of internal resistance 0.6Ω is connected to the 3 resistors. A, B, C.



Find the:
(i) Current in each resistor.
(ii) Power dissipated in the 4Ω resistor.

Solution:

R=0.6Ω; E= 12V, I = ?	
<u>Effective resistance of the circuit</u> The 2Ω and 3Ω are in parallel. Their effective resistance is in series with the 1.8Ω resistor. Thus the effective resistance R is given by: $R = R_p + R_s$ $R = \frac{R_1R_2}{R_1 + R_2} + R_3 + r$ $R = \frac{4 \times 6}{4 + 6} + 1 + 0.6$ $R = \frac{24}{10} + 1 + 0.6$ $R = 2.4 + 1 + 0.6$ $R = 4\Omega$	**(i) Current through the circuit.** From Ohms law; **V=IR.** $V = IR$ $12 = I \times 4$ $I = \frac{12}{4} = 3$ A Thus current through the 1Ω resistor is 3 A. P.d across the parallel combination, 4Ω and 6Ω resistors. From Ohms law; **V=IR.** $V_P = IR_P$ $V_P = 3 \times 2.4$ $V_P = 7.2$ V Thus the P.d across the 4Ω and 6Ω resistors is 7.2V.
Current through the Ω resistor. From Ohms law; **V=IR.** $V_1 = I_1R_1$ $7.2 = I_1 \times 4$ $4\,I_1 = 7.2$ $I_1 = 1.8$ A	**Current through the 6Ω resistor.** From Ohms law; **V=IR.** $V_2 = I_2R_2$ $7.2 = I_2 \times 6$ $6\,I_2 = 7.2$ $I_2 = 1.2$ A Alternatively: $I_2 = I - I_1$ $I_2 = 3 - 1.8$ $I_2 = 1.2$ A
(ii) Power dissipated in the 4Ω resistor. $P = I^2R$ $P = (1.8)^2 \times 4$ $P = 3{,}24 \times 4$ $P = 12.96$ W	**One can use;** $\mathbf{P = IV}$, **or** $\mathbf{P = \frac{V^2}{R}}$

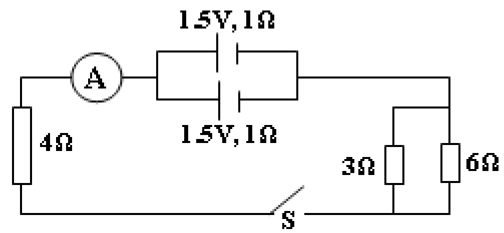
4. **(1992 Qn. 6).** An electrical appliance is rated 240V, 60W. (a) What do you understand by this statement?
(b) Calculate the current flowing through and the resistance of the appliance when operated at the rated values above. [0.25A, 960Ω respectively]

Solution:

(a) 240V, 60W means that the appliance supplies or consumes 60 joules of electrical energy in one second when connected to a 240V mains supply.
(b) V=240V, P=60W, I=?

(**i**) From: $P = IV$ $60 = I \times 240$ $240I = 60$ $I = 0.25A$	(**ii**) From: $P = \frac{V^2}{R}$ $P = \frac{V^2}{R}$ $60 = \frac{(240)^2}{R}$ $60R = 57600$ $R = 960\Omega$

5. **(1990 Qn. 3).** (c) In the diagram below, two batteries of e.m.f 1.5V and internal resistance of 1Ω each are connected to a network of resistors in a circuit which includes a switch, S.



(i). What will be the reading on the ammeter when switch S is closed? [Ans: 0.23A]

(ii). What is the power developed in the 4Ω resistor when S is closed? [Ans: 0.21 W]

Solution:

R_1= 4Ω; R_2= 3Ω; R_3= 6Ω; V_1= 1.5V; V_2= 1.5V; r_1= 1Ω; r_2= 1Ω;	
Effective resistance of the circuit For the two cells in parallel. $r = \frac{r_1 r_2}{r_1 + r_2} = \frac{1 \times 1}{1+1} = 0.5\Omega$ For the two standard resistors in parallel. $R_P = \frac{R_1 R_2}{R_1 + R_2} = \frac{3 \times 6}{3+6}$ $= 2\Omega$ Thus effective resistance is; $R = R_p + R_s + r$ $R = 0.5 + 2 + 4$ $R = 6.5\ \Omega$	**(i) Current through the ammeter.** From Ohms law; **V=IR.** $V = IR$ $1.5 = I \times 6.5$ $6.5I = 1.5$ $I = 0.23\ A$ **(ii) power developed in the 4Ω resistor when S is closed?** From Ohms law; **V=IR.** $P = I^2R$ $P = (0.23)^2 \times 4$ $P = 0.0529 \times 4$ $P = 0.21\ W$

Exercise:

1. An electric appliance is rated 200V, 0.05kW. Calculate the;
(i) Current through the appliance.[0.25A]
(ii) Resistance of the appliance.
(iii) Time it will take to transfer energy of 10,000J.[200 seconds]

2. Appliance A allows 3A of current to go through it when connected to a 200 V supply while appliance B has a resistance of 40Ω when connected to the same supply. Which of the two appliances heats up first and why?

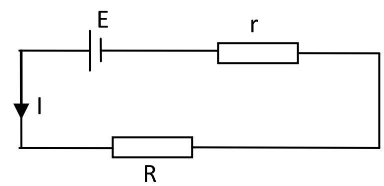
3. see UNEB

Section A			
1997 Qn. 37	1989 Qn. 8	2007 Qn. 4	2003 Qn. 38
1988 Qn. 10	1991 Qn. 15	1998 Qn. 35	1999 Qn. 36
2006 Qn. 36			

Example: 5

A battery of un known e.m.f and internal resistance is connected in series with a load of resistance, R ohms. If a very high resistance voltmeter is connected across the load reads 3.2V and the power is dissipated in the battery is 0.032W and efficiency of the circuit is 80%. Find the:
(i) Current flowing
(ii) Internal resistance of the battery.
(iii) Load resistance, R
(iv) E.m.f of the battery.

Solution:

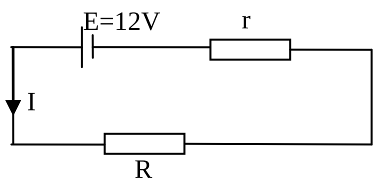


Total resistance, $= R + r$ From the circuit formula; $I = \frac{E}{R+r}$ ……………….(i) Power dissipated in the battery; $P = I^2r = 0.032$ ……… (ii) From Ohm's law; the terminal p.d is; $V = IR = 3.2$ ………… (iii) Efficiency, $= \frac{P.out}{P.in} \times 100$ $\frac{80}{100} = \frac{I^2R}{ER}$ $0.8 = \frac{I^2R}{I^2(R+r)}$ $R = 0.8(R+r)$ $R = 4r$	From equation (iii) $I(4r) = 3.2$ ……….… (iv) Equation (ii) ÷ (iv) $\frac{I^2r}{4Ir} = \frac{0.032}{3.2}$ $I = 0.04\ A$ From equation (ii) $(0.04)^2 r = 0.032$ $r = 20\Omega$ $R = 4r$ $R = 4(20) = 80\Omega$ From equation (ii) $E = I(R + r)$ $E = 0.04(40 + 20)$ $E = 4\ V$

Example:6

A battery of e.m.f 12V and un known internal resistance is connected in series with a load resistance, R reads 11.4V and the power dissipated in the battery is 0.653W. Find the:
(i) Current flowing.
(ii) Internal resistance of the battery.
(iii) Load resistance, R.
(v) Efficiency of the circuit.

Solution:



From Ohm's law; the terminal p.d is;
$V = IR = 11.4 \ldots\ldots\ldots\ldots (i)$

P.d across the internal resistance is lost volts (Ir). From;
$E = I(R + r) \Leftrightarrow Ir = E - IR$
$Ir = 12 - 11.4$
$Ir = 0.6 \ldots\ldots\ldots\ldots\ldots\ldots (ii)$

Power dissipated in the battery;
$P = I^2r = 0.653 \ldots\ldots (iii)$
Equation (iii) ÷ (ii)
$\frac{I^2r}{Ir} = \frac{0.653}{0.6}$
$\underline{\underline{I = 1.088\text{ A}}}$

From equation (iii)
$(1.088)^2 r = 0.653$
$\underline{\underline{r = 0.55\Omega}}$

From equation (i)
$IR = 11.4$
$(1.088)R = 11.4$
$\underline{\underline{R = 10.48\Omega}}$

$\text{Efficiency}, = \frac{\text{Power output}}{\text{Power input}} \times 100\%$

$= \frac{I^2R}{ER} \times 100\%$

$= \frac{(1.088)^2(10.48)}{12(1.088)} \times 100\%$
$= 95\%$

Note: The potential difference of a battery falls to less than its EMF when connected in a circuit**.** This happens because some of the energy is wasted within the battery leaving less potential difference to drive current through the circuit.

COMMERCIAL ELECTRIC ENERGY

All electric appliances are connected in parallel so that each is at the same voltage.
All electric appliances are marked showing the power rating in watts (W) and the voltage in volts (V).
The power of an appliance indicates the amount of electrical energy it supplies or the amount of work it does per second.

For example: A heater marked **240V, 1000W**, *means that the heat consumes 1000J of electrical energy every second when connected to 240V.*

Commercial Unit of electric energy.
There are always charges for electricity consumed that the electricity board gives for us for payment and they use our meters to estimate the energy consumed.
The energy consumed is measured in **kWh** which is an abbreviation for **kilowatt hour**.
The commercial unit of electrical energy is a kilowatt-hour, (kWh) since a watt second is very small.

A kilowatt hour is the electrical energy used by a rate of working of 1000 watts for 1 hour.
It is the quantity of electrical energy converted into other forms of energy by a device of power 1000watts in one hour.
1 watt = 1 joule per second
1 kWh = 1000x1hr
= 1000 x 60 x 60 x 60 joules.
1 kWh = 3,600,000J = 3.6 MJ

Cost of electric energy calculation

$$\begin{bmatrix}\textbf{Number of units used}\\ \text{(Energy consumed)}\end{bmatrix} = \begin{bmatrix}\textbf{Power}\\ \text{(in kW)}\end{bmatrix} \times \begin{bmatrix}\textbf{Time}\\ \text{(in hours)}\end{bmatrix}$$

$$\textbf{Total cost} = \begin{bmatrix}\textbf{Number of units}\\ \textbf{used}\\ \left(\begin{matrix}\text{Energy consumed}\\ \text{in kWh}\end{matrix}\right)\end{bmatrix} \times \begin{bmatrix}\textbf{Rate per}\\ \textbf{unit}\end{bmatrix}$$

The **rate per unit** is the **cost per unit** of electrical energy consumed. Thus the cost of using an appliance is given by;

$$\textbf{Total Cost} = \begin{bmatrix}\textbf{Power}\\ \text{(in kW)}\end{bmatrix} \times \begin{bmatrix}\textbf{Time}\\ \text{(in hours)}\end{bmatrix} \times \begin{bmatrix}\textbf{Cost per}\\ \textbf{unit}\end{bmatrix}$$

Examples;

1. **(1995 Qn. 33).** Four bulbs each rated at 75W operate for 120 hours. If the cost of electricity is sh.100 per unit, find the total cost of electricity used.

Solution:

Number of bulbs = 4;
Power rating for each bulb = 75W
Total Power rating for 4 bulb = $4 \times 75\text{W} = 300\text{W}$
$= \frac{300}{1000}$ kW
$= \mathbf{0.3\ kW}$

Total Time = 120 Hours
Cost per unit = sh. 100

$$\text{Total Cost} = \begin{bmatrix}\text{Power}\\ \text{(in kW)}\end{bmatrix} \times \begin{bmatrix}\text{Time}\\ \text{(in hours)}\end{bmatrix} \times \begin{bmatrix}\text{Cost per}\\ \text{unit}\end{bmatrix}$$

$\text{Total Cost} = [0.3\text{ kW}] \times [120\text{ hrs}] \times [\text{sh. }100]$

$\text{Total Cost} = \text{sh. }3600$

2. An electric immersion heater is rated at 3000W, 240V. Calculate the;
   (i) Current and resistance of the heating element.
   (ii) Total number of electric units it consumes in $1\frac{1}{2}$ hours.
   (iii) Cost per unit if sh. 9000 is paid after using it for 3hours everyday for ten days.

Solution:

(i) V= 240V, P =3000W, I=?, R = ?

From: $P = IV$
$3000 = I \times 240$
$240I = 3000$
$I = 12.5\text{A}$

From: $P = \frac{V^2}{R}$
$P = \frac{V^2}{R}$
$3000 = \frac{(240)^2}{R}$
$3000R = 57600$
$R = 19.2\Omega$

(ii)

Total Power $= 3000W$ $= \frac{3000}{1000}$ kW $= \mathbf{3\ kW}$	Total Time $= 1\frac{1}{2}$ hours $= \frac{3}{2}$ hours $= \mathbf{1.5\ hours}$

$$\begin{bmatrix}\text{Number of units used}\\ \text{(Energy consumed)}\end{bmatrix} = \begin{bmatrix}\text{Power}\\ \text{(in kW)}\end{bmatrix} \times \begin{bmatrix}\text{Time}\\ \text{(in hours)}\end{bmatrix}$$

Number of units used (Energy consumed) $= 3 \times 1.5$

Number of units used (Energy consumed) $= 4.5$ kWh $= 4.5$ Units

(iii)

Total Power $= 3000W$ $= \frac{3000}{1000}$ kW $= 3$ kW	Total Time $= 3 \times 10$ hours $= 30$ hours

Let the cost per unit be y

$$\text{Total Cost} = \begin{bmatrix}\text{Power}\\ \text{(in kW)}\end{bmatrix} \times \begin{bmatrix}\text{Time}\\ \text{(in hours)}\end{bmatrix} \times \begin{bmatrix}\text{Cost per}\\ \text{unit}\end{bmatrix}$$

$9000 = 3 \times 30 \times y$
$9000 = 90y$
$y = \text{sh}.100$

3. Mr. Bagira uses 3 kettles of 800W each, a flat iron of 1000W, 3 bulbs of 60W each and 4 bulbs of 75W each. If they are used for 3 hours every day for 30 days and that one unit of electricity costs sh. 200, find the total cost of running the appliances.

Solution:

Kettles	**Flat irons**	**60W Bulbs**	**75W Bulbs**
$P = 3 \times 800$ $P = 2400$ W $= \frac{2400}{1000}$ kW $= 2.4$ kW	$P = 1 \times 1000$ $P = 1000$ W $= \frac{1000}{1000}$ kW $= 1$ kW	$P = 3 \times 60$ $P = 180$ W $= \frac{180}{1000}$ kW $= 0.18$ kW	$P = 4 \times 750$ $P = 300$ W $= \frac{300}{1000}$ kW $= 0.3$ kW

Total power $= (2.4 + 1 + 0.18 + 0.3)$ kWh $= 3.88$ kWh

Total time $= (3 \times 30)$ hours $= 90$ hours.

$$\text{Total Cost} = \begin{bmatrix}\text{Power}\\ \text{(in kW)}\end{bmatrix} \times \begin{bmatrix}\text{Time}\\ \text{(in hours)}\end{bmatrix} \times \begin{bmatrix}\text{Cost per}\\ \text{unit}\end{bmatrix}$$

Total Cost $= [3.88\ \text{kW}] \times [90\ \text{hrs}] \times [\text{sh}.200]$

Total Cost $= \text{sh}.69840$

4. Find the cost of running five 60 W lamps and 4 100 W lamps for 8 hours if the electric energy costs shs. 5.0 per unit. **[Shs.28**]

5. A house has one 100 W bulb, two 75 W bulbs and 5 40 W bulbs. Find the cost of having all lamps switched on for 2 hours every day for 30 days at a cost of shs. 30 per unit. [**Shs. 810**].

6. An immersion heater works on a potential difference of 250V and the current flowing through the coil of the heater is 12A. If it is being used in a house every day for 2.5 hours, calculate the

(i) Electrical energy consumed in a day.
(**Ans: E = 27,000,000 J**) or (**Ans: E = 7.5 KWh**)

(ii) Electrical bill for 30days if electricity costs shs. 300 per unit. (**Ans: Cost = shs. 67500**)

7. See UNEB

Section A			
2002 Qn. 36	1999 Qn. 40	2003 Qn. 37	2006 Qn. 28
2007 Qn. 14			
Section B			
1992 Qn. 2	1997 Qn. 8	2008 Qn. 4	

GENERATION AND TRANSMISSION OF ELECTRICITY

(a) Generation of electricity

Electricity is generated at power stations or power plants by using one of the following;

- ❖ Coal, Nuclear reactions, Falling water, e.t.c.

(b) Transmission of electricity

- ❖ The electricity generated at the power station is then stepped up to higher voltage using step up transformers for long distance transmission.

- ❖ *Electricity is transmitted at high voltages to reduce power loss through heating effect in the transmission cables.*
  Transmission cables are made thick to reduce its resistance hence minimizing power loss through the $\boldsymbol{I^2R}$ *− mechanism.*

- ❖ The electricity is then stepped down using step down transformers in phases. That is, it is first stepped down to heavy factories, industries, cities, towns, and finally to homes.

- ❖ The transmission can either be over head or underground. In some developed countries, the grid system is used
  The grid system is a system where different power stations are inter connected or networked so that in case there is power failure in one power station or when one station is stopped for maintenance work, the other stations continue to supply the power.

(c) House wiring.

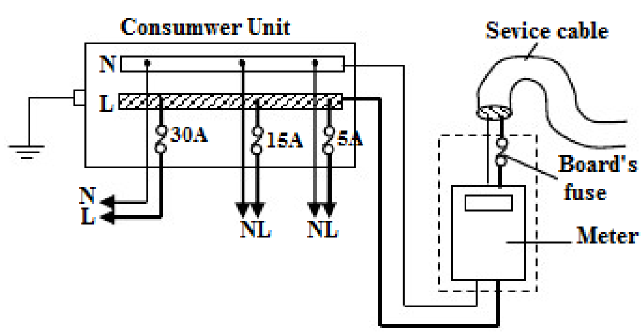
Domestic electric installation

Power is connected in a house by thick cables from the pole called <u>mains</u> to the fuse box {meter box}, then main switch and to the distribution box. Here, power is directed to electrical equipments. Each circuit has its own fuse which is connected to a live wire.
The main switch board (distribution box) breaks both wires when in OFF position and is therefore called a **double pole switch.** It completely cuts off the supply in the house.

In supply cable:
Power enters the house through the supply cable from the electric pole from which two insulated wires, the live and the neutral come from. They are distinguished by colour i.e;

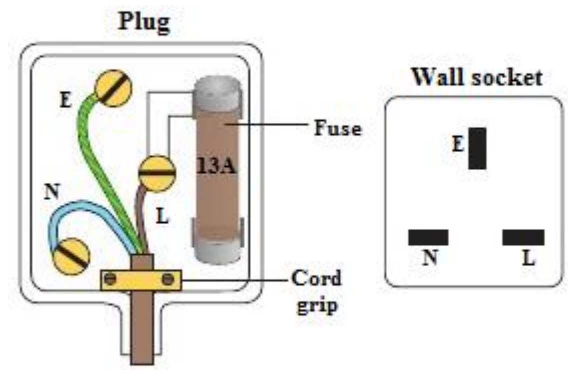
Type of wire	Colour
(i) Live wire	Red or Brown
(ii) Neutral wire	Blue or Black
(iii) Earth wire	Yellow or Green or Yellow with green stripes

The earth wire is usually earthed and is therefore at zero potential while the live wire is at a potential of 240V for the case of Uganda.
The electricity being supplied is alternating and it therefore alternates from positive to negative in a single cycle.

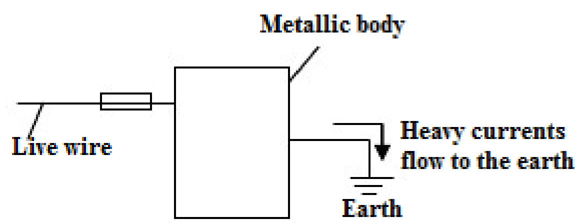


Switches, Sockets and Plugs

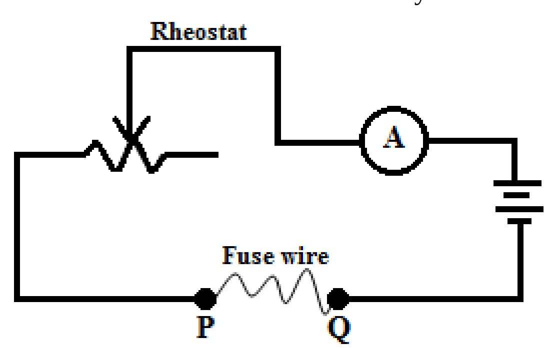
Electric system	Connection
(i) Switches	❖ Control the flow of current ❖ Connected to the live wire to prevent the appliance from being live when switched off. Thus they are called single pole switches.
(ii) Fuses	❖ It is a thin wire of low melting point which melts when the current exceeds a required value so as to break the circuit. ❖ It must be connected to the live wire. ❖ The rating value of a fuse should be **slightly above** the value of the current required by the device
(iii) Sockets	❖ These are power points usually put on the walls. ❖ They have 3 holes leading to the live wire L, neutral wire N and earth wire E.
(iv) Plugs	❖ These are points which connect or tap power from the socket to the appliance. ❖ It has 3 pins that fit into the 3 holes in the socket. The pins are marked with L, N and E for live, neutral and earth wires respectively.



Importance of Earthing
The purpose of earthing is to offer protection against earth-leakage currents. The earth connection provides an extremely low-resistance path for such a current.
Take an example of an appliance A, in the diagram, having a metallic body.



Question: UNEB 2008 PP2 No. 4
A student set up the circuit in the figure below to determine the maximum current which can be taken by a fuse wire.



(a) Describe briefly how this circuit can be used to determine the maximum current.

- Starting with the rheostart at its maximum length, the ammeter reading is noted.
- The length of the rheostat is then gradually reduced and each time, the ammeter reading is noted.
- The process is continued until the fuse wire melts. The reading of the ammeter for which the fuse melts gives the maximum current which can be taken in by that fuse.

(b) **Explain what would happen if:**
(i) Two strands of the fuse wire were connected in parallel across P and Q.

The effective resistance of the two strands of fuse wire in parallel will be half the original resistance of the one fuse wire.
As a result, great amount of current flows before the new fuse melts. The ammeter reading for the maximum current will therefore be greater than before.

(ii) The length of the fuse wire was doubled.
The resistance of the new longer wire will be twice that of the original wire.
As a result, less amount of current flows before the new fuse melts. The ammeter reading for the maximum current will therefore be gless than before.

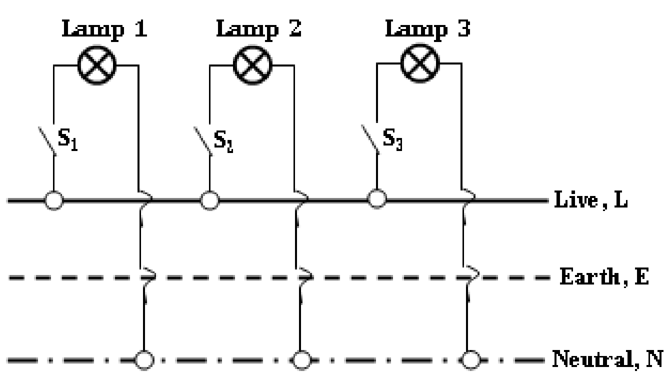
(c) An electric fire alarm, a lamp and electric drill rated at 2000W, 100W, and 300W respectively are connected in parallel across a 240V mains. Find the:
(i) power taken from the mains.

$$P = 2000 + 100 + 300$$
$$P = 2400\text{ W}$$

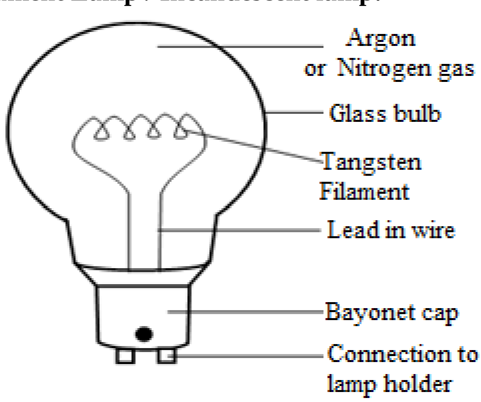
(ii) Current supplied by the mains. (**Ans:** $\mathbf{I = 10\ A}$)
(iii) Cost of running these appliances for 12 hours if one unit of electricity costs Shs. 200. (**Ans:** $\mathbf{Cost = Shs. 5760}$)

Connection of appliances
Electrical appliances are usually connected in parallel with the mains so that;
(i) They receive full main potential difference.
(ii) When one circuit is faulty or switched off, the other circuits remain working.

(a) Light circuits
All lamps in house wiring are connected in parallel with the switch on the live wire to the lamp.



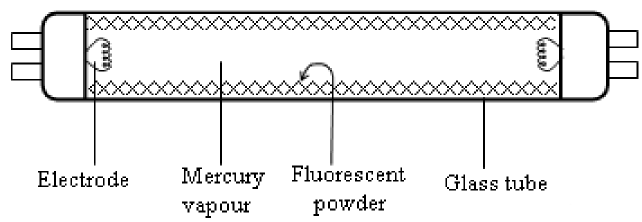
(i) Filament Lamp / Incandescent lamp:



-When switched on, the coiled tungsten filament is heated, it becomes white hot and emits light.
-The higher the temperature of the filament, the greater the electrical energy changed to light.

Note:
- The filament is made out of tungsten, because tungsten has a higher melting point. Hence it can't easily melt when white hot.
- The filament is coiled in order to reduce space occupied and hence reduce the rate of heat loss by convection currents in the gas.
- The glass bulb is filled with an inert gas at low pressure, to prevent evaporation of tungsten and increase the operating temperature. Otherwise it would condense on the bulb and blacken it.

(ii) Fluorescent lamps/ Tubes/ Discharge lamp.



-When switched on, the mercury vapour emits ultra-violet radiations.
-The radiations strike the fluorescent powder (e.g Zinc sulphide, **ZnS**) and the tube glows emitting light.

Differences between a filament lamp and a fluorescent lamp

Filament lamp	Fluorescent lamp
-Not long lasting	-Long lasting
-Cheaper	-Expensive
-Emit light by heating the filament in the bulb.	-Emit light by sending an electrical discharge through an ionized gas.
-Have high operating temperatures.	-Have low operating temperatures.
-Can easily be disposed off since the inert gasses are not poisonous.	-Care should be taken when disposing them off, since mercury vapour is poisonous.
-High energy/ power consumption, hence high energy costs.	-Low energy/ power consumption, hence low energy costs.

Qn. With the aid of diagrams, describe how a filament lamp and a fluorescent/discharge lamp work.

(b) Socket ring mains.
The sockets on the ring main circuit are connected in parallel so that they receive full main potential difference.
The use of a **ring** of wire reduces the thickness of wire which has to be used.
Both ends of the loop are connected to the fuse box.
The current, I flowing is normally 12 amperes. Thus the fuse used should be just above 12 A.

Choosing an ideal fuse for the appliance

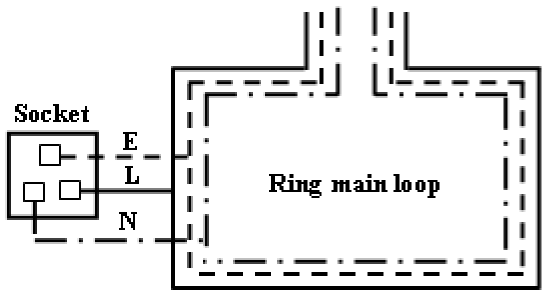
The ideal fuse to be used should have a maximum rating which is a little higher than the normal current expected.

Example:
Suggest an appropriate fuse value to be used for a 3kW appliance when used on a 240V main supply.

P = 3kW=3000 W; V = 240 V

$$P = IV$$
$$3000 = I \times 240$$
$$240I = 3000$$
$$I = 12.5A$$

Thus the appropriate fuse should be slightly higher than 12.5A



Safety precautions in a house

- Electric cables must be properly insulated
- Keep hands dry whenever dealing with electric supply
- In case of an electric shock, switch off the main switch immediately
- Before a fuse is replaced check the fault in the circuit which caused the problem and make sure it's rectified.

Sources of e.m.f
They are;
- Cells. These change energy to electric energy
- Batteries/accumulators. Also convert chemical energy to electrical energy
- D.C and A.C. generators
- Photo cells, they convert light energy to electrical
- Thermo couples. They convert heat energy to electrical energy.

EXERCISE:

1. (1989 Qn. 17). How many lamps marked 75W, 240V could light normally when connected in parallel having a 5A fuse.
A: 1 B: 3 C: 16 D: 26

2. (1990 Qn.39). Very high voltages are used when distributing electric power from the power station because;
A: Some electric equipment require very high voltages
B: Currents are lower, so energy losses are smaller
C: Very high voltages are generated at the power stations
D: There is less likely hood of the transmission lines being struck by lightning.

3. (1991 Qn.7). An electric toaster plate rating is 220-240V, 750W. The fuse is:
A: 1 A B: 3 A C: 5 A D: 13 A

4. (2000 Qn. 31). For safety in a house, a fuse and a switch are connected to:

	Fuse	Switch
A	Live wire	Neutral wire
B	Neutral wire	Earth wire
C	Live wire	Live wire
D	Earth wire	Neutral wire

5. (1999 Qn. 39). Which of the following statements are true about electric wiring?
(i) The fuse is always connected into the live wire leading to the circuit.
(ii) The fuse is always connected into the Neutral wire leading to the circuit.
(iii) When a fault develops in a circuit, it is the neutral which has to be disconnected.
A: (i) only B: (iii) only
C: (i) and (iii) only D: (i), (ii) and (ii).

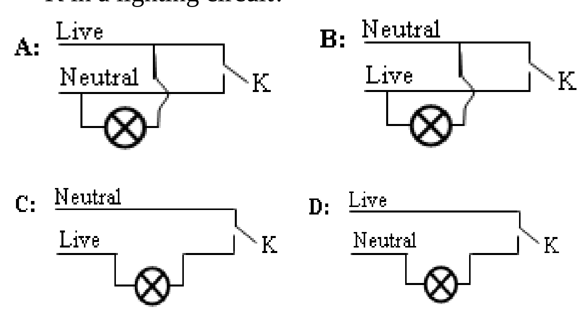
6. The electrical device used to control the amount of electric current is:
A. ammeter B. rheostat
C. voltmeter D. galvanometer

7. (2002 Qn. 18). The device which disconnects the mains when there is a sudden increase in voltage is;
A: Fuse B: Switch
C: Earth wire D: Circuit breaker

8. (1992 Qn. 2). In a house wiring system, all connections to the power points are in parallel so as to:
A: Supply the same current.
B: Operate at the same voltage.
C: Minimize the cost of electricity
B: Consume the same amount of energy.

9. (2008 Qn. 17). The possible energy transfer in an electric bulb is;
A: Light energy to heat energy.
B: Heat energy to electrical energy.
C: Electrical energy to light energy.
D: Light energy to electrical energy.

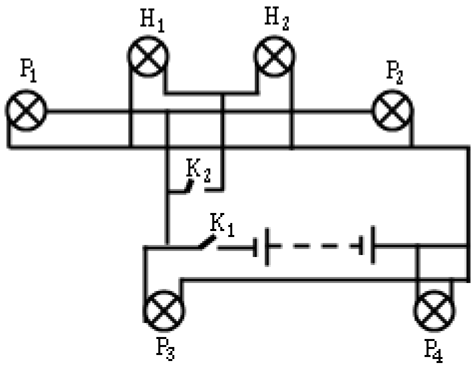
10. (1993 Qn. 33). Which of the following circuit diagrams shows the correct positions for the lamp and the switch K in a lighting circuit?



11. (1991 Qn. 7).

SECTION B

11. (1991 Qn.3). The figure below shows a circuit diagram of a part of a wiring system of a car. H_1 and H_2 are headlamps and P_1, P_2, P_3 and P_4 are parking lamps.



(a) How can;
  (i) All the lamps be switched on?
  (ii) Both headlamps be switched off without affecting the parking lamps.

(b) State what happens to the lamps if P1 is broken when all the lamps are on. Give a reason for your answer.

12. (2000 Qn.8). (a) Describe the structure and action of a fluorescent tube.
(b) Give **one** advantage of a fluorescent tube over a filament lamp.
(c) Describe the functions of;
  (i) A fuse.
  (ii) An earth wire

(d) Describe briefly how power is transmitted from a power station to a home.

(e) Find the cost of running two 60W lamps for 20 hours if the cost of each unit is sh.40.

Example:1
A battery of e.m.f 18V and internal resistance of 3Ω is connected to a resistor of resistance 8Ω. Calculate the:
  (i). Power generated[29.45W]
  (ii). Efficiency[72.7%]

Example:2
Two cells each having an e.m.f of 1.5V and internal resistance 1Ω are connected to resistance of 4Ω. Calculate the current in this resistance if the cells are in:
  (i). Parallel [0.33A]
  (ii). Series [0.5A]

Example:3
A battery of e.m.f 2V and internal resistance of 1Ω is connected in series to a battery of e.m.f 4V and internal resistance of 3Ω so that they assist each. A resistor of 8Ω is joined to this arrangement. Calculate the current flowing:[I = 0.5A].

Example:4
A d.c source of e.m.f 16V and negligible internal resistance is connected in series with two resistors of 400Ω and RΩ respectively. When the voltmeter is connected across the 400Ω resistor, it reads 4.0V, while it reads 6.0V when connected across the RΩ resistor. Find the;
  (i). Resistance of the voltmeter [$R_v = 400\Omega$].
  (ii). Value of R [$R = 600\Omega$].

Example:5
(a) Two bulbs are connected in series in a circuit and a current of 3 A is passed through it. How much current would pass through each bulb? How would the potential differenceacross both the bulbs be determined?
The power of the battery would be shared by the two components leaving the first component with less power than previously.

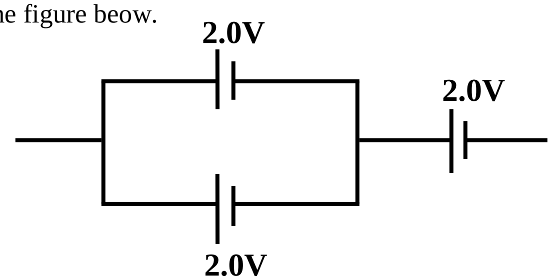
(b) What would happen to the current passing through a resistor of unknown resistance if thepotential difference across it were increased from 3 V to 6 V?

(c) If the P.d across both the bulbs is the same and they are connected in parallel, how much current would pass through each bulb if a total current of 8A were passed through the circuit?

(d) What is the purpose of earthling? Why are some appliances not earthed?

(e) The P.d across a resistance wire is 12V. Find the quantity of electric charge flowing through the wire to generate 1.68KJ of heat energy in one second.(UNEB 2018)

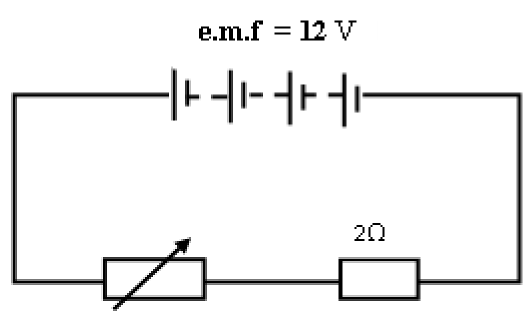
Example:7
Three cells each of 2.0 V are arranged as shown in the figure beow.



Find the total electromotive force in the circuit.

A. 2.0 V   C. 4.0 V
B. 6. 0 V   D. 8. 0 V

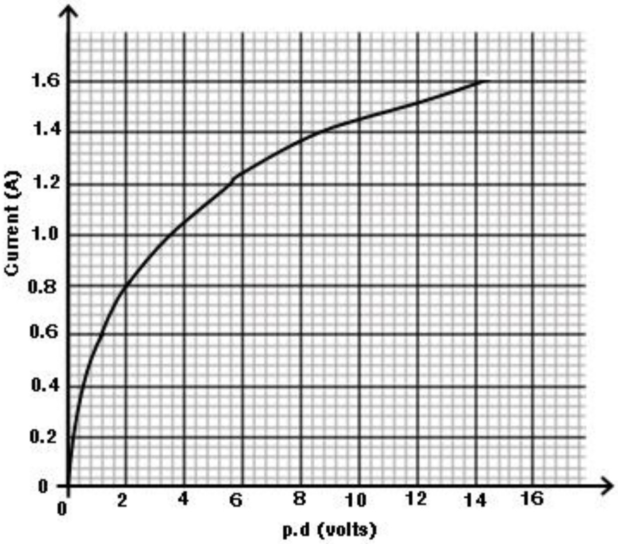
Example:8
The figure below shows a potential divider circuit. The e.m.f of the cell is 12V and it has negligible internal resistance.



(a) What happens to the potential difference across the 2 Ω resistor as the resistance of the variable resistor is increased?

(b) When the variable resistor is set at 4Ω, what is current is the 2 Ω resistor?

8. (a)The graph below shows the variation of current through a tungsten filament with a p.d across it.



(i) Draw a suitable circuit diagram to show how the results in the graph can be obtained.
(ii) State what happens to the resistance of the filament as current increases.
(iii) Using the graph, determine the resistance of the filament when the current is 0.7 A

(b) An electric heater of resistance 40 Ω is connected to a 240 V mains. How long will it take to raise the temperature of 4 kg of water from 40 ^{0}C to 100 ^{0}C.

(c) With the aid of a labeled diagram, explain how a dry cell works.

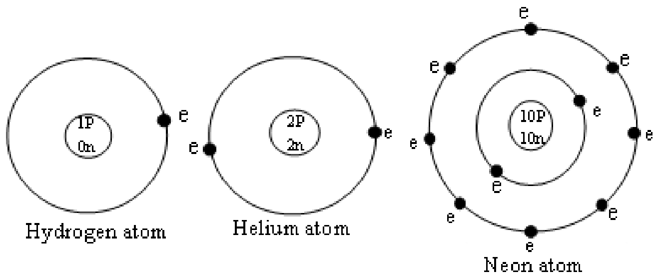
7. MODERN PHYSICS

STRUCTURE OF AN ATOM
(a) The atom

An atom is defined as the smallest electrically neutral particle of an element that can take part in a chemical reaction.
An atom consists of 3sub atomic particles namely -:

- Proton , Neutrons and Electrons.

It is made up of the central part called **nucleus** around which **electrons** rotate in **orbit** or shells or energy levels. The protons and neutrons lie within the nucleus and these particles are sometimes referred to as nuclei particles or **nucleons**.



Name of particle	Symbol	change	Location
Protons	1_H	$+1$	In the nucleus
Neutrons	0_n	0	In the nucleus
Electrons	-1_e	-1	Outside nucleus

The nucleus is positively charged

The atom of an element is represented in a chemical equation using a chemical symbol as shown below.

$$^{A}_{Z}X$$

Where, X is the chemical symbol of the element, A is the mass number and Z is the atomic number.
An atom with specified number of protons and neutrons (or specified A and Z) is called a **nuclide**.

(b) Atomic number and mass number

(i) Atomic number (Z)

This is the number of protons in the nucleus of an atom.

(ii) Atomic mass (A)

This is the sum of protons and neutrons in a nucleus of an atom. It is sometimes called **Mass number or nucleon number.**

The atomic number, **Z**, mass number, **A** and the number of neutrons, **n** are related by the expression:

$$\textbf{Atomic mass} = \textbf{Atomic number} + \textbf{No. of nucleons}$$
$$\mathbf{A = Z + n}$$

(c) Isotopes

These are atoms of the same element having the same atomic numbers but different mass numbers.
Thus Isotopes of an element have;
(i) The same number of protons and electrons.
(ii) Different number of neutrons.

Examples of Isotopes:

Element	Isotopes
Carbon	-Carbon-12 ($^{12}_{6}\mathbf{C}$); Carbon-13 ($^{13}_{6}\mathbf{C}$); Carbon-14 ($^{14}_{6}\mathbf{C}$)
Chlorine	-Chlorine-35 ($^{35}_{17}\mathbf{Cl}$); Chlorine-35 ($^{37}_{17}\mathbf{Cl}$);
Uranium	-Uranium-35 ($^{236}_{92}\mathbf{U}$); Uranium-35 ($^{232}_{92}\mathbf{U}$)

Isotropy is the existence of atoms of the same element with the same atomic number, but different mass number.

Question:
Describe the composition of the following nuclides.
(i) $^{228}_{88}\mathbf{Ra}$ **(ii)** $^{210}_{82}\mathbf{Pb}$ **(iii)** $^{335}_{92}\mathbf{U}$

Exercise:

1. (1991 Qn. 18): $^{120}_{80}\mathbf{X}$ is a symbol for a nuclide whose number of neutrons is:
A. 40 B. 80 C. 120 D. 200

2. (1990 Qn. 7): The table below shows the numbers of the respective particles constituting atoms of elements P,Q, R and S.

Element	Neutrons	Protons	Electrons
P	0	1	1
Q	2	1	1
R	2	2	2
S	2	3	3

The isotopes are
A. P and Q C. Q and R
B. C. R and S D. Q and S

3. (1990 Qn. 11): The copper atom $^{63}_{29}\mathbf{Cu}$ has

	Electrons	Protons	Neutrons
A	29	29	34
B	34	34	29
C	34	29	29
D	34	39	34

4. (1991 Qn. 8): If X is an isotope of Y, then the
A. Atomic mass of X is equal to that of Y
B. Atomic mass is equal to the atomic number of Y
C. Atomic number of X is equal to that of Y
D. Atomic number of X is equal to the atomic mass of Y

5. (1994 Qn. 9): An atom has mass number 88 neutrons and atomic number 38. Which of the following statements are correct about the atom;
(i) It has 38 protons and 50 neutrons
(ii) It has 38 protons and 38 electrons
(iii) It has 50 protons and 38 neutrons
A. (i) and (ii) C. (ii) and (iii)
B. C. (i) and (iii) D. (i), (ii) and (iii)

6. (1995 Qn. 18): Isotopes are nuclides with the same number of;
A. Protons but different but different number of electrons
B. Protons but different number of neutrons
C. Neutrons but different number of protons
D. Electrons but the same number of protons

7. (2004 Qn. 22): The table below shows the structure of four atoms P,Q, R and S

Elements	Neutrons	Protons	Electrons
P	6	6	6

Q	8	6	6
R	2	2	2
S	2	3	3

A. P and Q   C. Q and R
B. P and S   D. P and R

8. (2004 Qn. 32): An atom contains 3 electrons, 3 protons and 4 neutrons. Its' nucleon number is?
A. 3   B. 4   C. 6   D. 7

9. (2006 Qn. 21): A Nickel nuclide, $^{60}_{28}\mathbf{Ni}$ contains
A. 28 protons and 28 neutrons
B. 32 electrons and 28 neutrons
C. 28 protons and 32 neutrons
D. 28 electrons and 32 protons

10. $^{236}_{92}\mathbf{X}$ and $^{232}_{92}\mathbf{X}$ are isotopes of an element. Find the number of neutrons in the nucleus of $^{232}_{Z}\mathbf{X}$.
A. 144   B. 140   C. 92   D. 4

11. An isotope of nuclide, $^{35}_{17}\mathbf{X}$, has
A. 18 protons and 17 neutrons
B. 17 electrons and 18 neutrons
C. 17 protons and 20 neutrons
D. 18 protons and 18 neutrons

12. (a) What is the difference between atomic number and mass number?
(b) What is meant by;
(i) Mass number?
(ii) Atomic number?

PHOTOELECTRIC AND THERMIONIC EMISSIONS

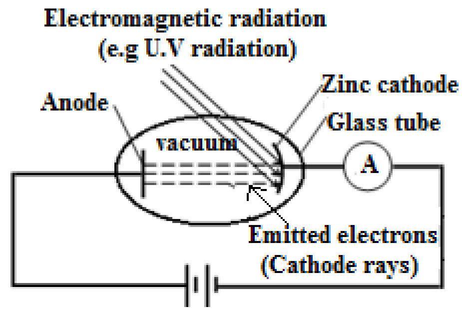
(a) Photoelectric Emission:

Photo electric emission is the ejection of electrons from a certain metal surface e.g zinc plate, when electromagnetic radiation of sufficient frequency falls on it.
It normally occurs in phototubes or photoelectric cells.

Phototube or Photoelectric cell

✓ A photoelectric cell consists of a cathode coated with a photo sensitive material and an anode. These are enclosed in a vacuum glass tube.

✓ The glass tube is evacuated in order to avoid collision of the ejected electrons with the air or gas molecules. This would otherwise lead to low currents.



Electromagnetic radiations (eg Ultra violet radiation) are directed onto the cathode and supplies sufficient energy that causes the liberation of electrons.
The electrons are then attracted by the anode. and produce current in the circuit hence the ammeter deflects.

Note: The flow of electrons to the anode completes the circuit and hence an electric current flows which causes the ammeter to deflect.

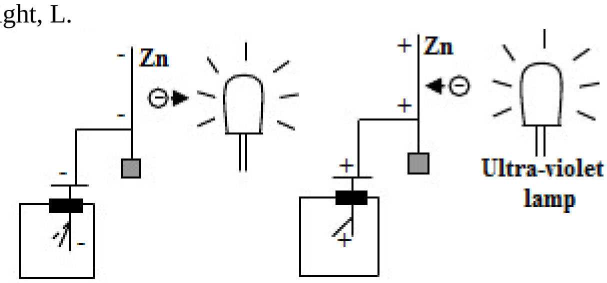
❖ The magnitude of the current produced is proportional to the intensity of the incident radiation.
❖ If gas is introduced into the tube, current decreases slowly because gas particles collide with electrons hence reducing the number of electrons reaching the anode.

Conditions for photoelectric effect to take place.

❖ Nature of the metal.
❖ Frequency of the incident electromagnetic radiation. It should be noted that electrons are not emitted until a certain frequency called Threshold frequency is reached.

The following observations can be explained by the photoelectric effect.

A zinc plate is first cleaned with emery paper, supported on an insulator and connected to the cap of a gold leaf electroscope. The zinc plate is given a positive charge by induction. In a dark room the plate is exposed to ultra-violet light, L.



(i) Zinc plate positively charged   (ii) Zinc plate negatively charged

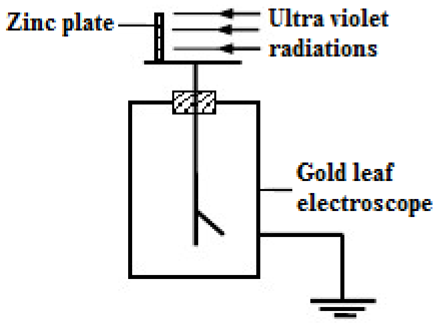
The divergence of the leaf is observed to remain the same.

The experiment is repeated when the zinc plate is negatively charged. This time the leaf slowly collapses. (See fig (ii) above)

Explanation:

When the zinc plate is positively charged the photoelectrons emitted are attracted to the plate. So the charge on the plate remains the same – No change in divergence.
With the zinc plate negativelycharged, the photoelectrons are repelled away. So the plate loses charge and the leaf collapses.

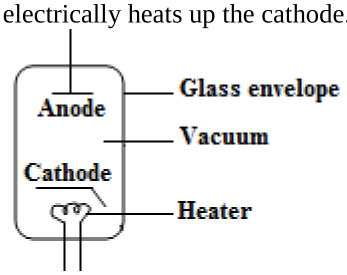
Question:
Ultra violet radiations is incident on a clean zinc plate resting on the cap of a charged gold leaf electroscope as shown in the figure below.



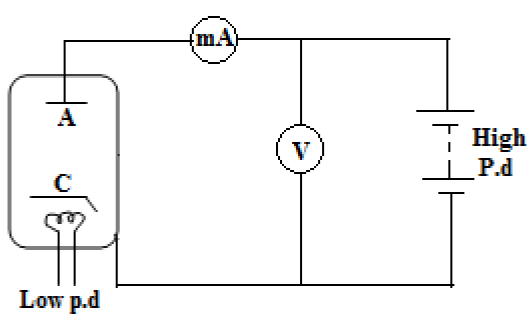
Explain what is observed if:
(i) the gold leaf electroscope is positively charged.
(ii) radio waves is used instead of ultra violet radiations.

(b) Thermionic Emission:
This is the process by which electrons are emitted from metal surface by heating. The steams of electrons are transmitted or travel in a straight line and these steams are called cathode rays.

The thermionic diode.
It consists of a:
Vacuum to prevent electrons from colliding with air molecules.
Cathode which is heated and emits electrons thermionically.
Heater which electrically heats up the cathode.



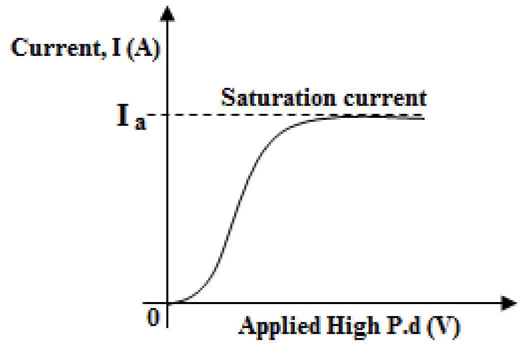
Action of a thermionic diode



The cathode, C is heated, and emits electrons by thermionic emission. When no voltage is applied across the anode and cathode, the emitted electrons stay around the cathode.

If anode A is positive with respect to the cathode C, electrons from the ***space charge*** are attracted to the anode and this causes a current to flow through the circuit.

The number of electrons emitted from the cathode depends on the voltage across the anode and cathode. Thus the higher this p.d is, the higher the temperature and more electrons are emitted and hence the higher the current in the circuit.
When the voltage increases, the current until its maximum value, $\mathbf{I_a}$ where any increase in voltage will not increase the current. This maximum value is called ***saturation current***.

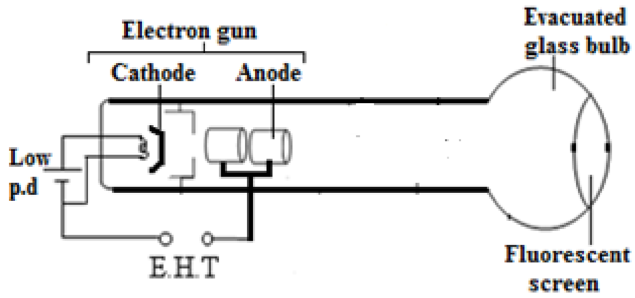


1. CATHODE RAYS:
Cathode rays are steams of fast moving electrons.

The Cathode ray tube.
Cathode rays are produced in an electronic vacuum tube called cathode ray tube (C.R.T).
C.R.Ts use a focused beam of electrons from a thermionic cathode, deflected by electric field (for C.R.O) or magnetic field (for T.V CRT) to crate a spot on the Fluorescent screen.
The screen is coated with a fluorescent material called phosphor(normally compounds of zinc, cadmium, magnesium and silicon) which emits light when bombarded with electrons.
The screen is usually coated with a layer of alluminium or graphite to:
(i) Act as a heat sink and prevent phosphor from burning.
(ii) Avoid build up of charges which would slow down the electrons and limit the brightness of the spot.
(iii) Scatter the light produced and hence increase brightness.
(iv) Trap stray electrons emitted from the screen and makes the potential in that region uniform.

The spot can be made to move fast, and its intensity varied so that it can be used for drawing graphics and to provide fixed or moving (television) images.

Production of Cathode rays:



The cathode is heated by a low P.d applied across the filament.
The cathode then emits electrons by thermionic emission. The emitted electrons are attracted towards the anodes, and then accelerated by a high p.d (E.H.T) applied between the filament and the anode so that they move with a very high speed to constitute the cathode rays.
On hitting the phosphor coated screen, electrons give up all their kinetic energy and the screen fluoresce (glows).

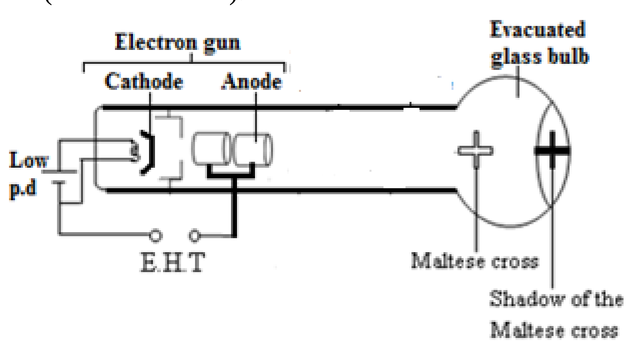
Other methods by which cathode rays are produced are;

- Photoelectric emission
- Applying a high p.d
- By natural radioactive nucleus which emit beta particles.

Properties of cathode rays

- They travel in a straight line
- They carry a negative charge.
- They are deflected by an electric field towards the positive plate, since they are negatively charged.
- They are deflected by a magnetic field. In the magnetic field; the direction of deflection is determined using Fleming's left hand rule. But remember, the direction of flow of current is opposite to that of electrons.
- They ionize air and gas molecules.
- They cause fluorescence to some substance e.g zinc sulphide.
- They darken photographic film.
- They posses kinetic energy and momentum
- They produce X-rays when stopped by matter.

Experiment to show that cathode rays travel in straight line (Thermionic tube).

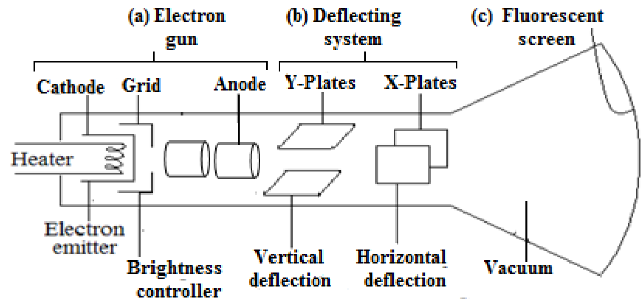


Cathode rays are incident towards the Maltese cross.
A shadow of the cross is formed on the fluorescent screen.
The formation of the shadow verifies that cathode rays travels in a straight line.

Applications of Cathode rays

The thermionic emission and cathode rays are utilized in cathode ray oscilloscope (C.R.O), X – ray tube, Image tube of a Tv, Electron microscope, etc.

THE CATHODE RAY OSCILLOSCOPE (C.R.O)
The C.R.O consists of three main components.



Electrons are produced by thermionic emission by the hot filament and accelerated to a certain speed by the High voltage, the Extra High Tension (E.H.T).
The moving electrons are deflected, by the electric fields between the deflection plates.
When the elections hit the screen, the fluorescent material on it emits visible light which enables one to see the electron beam as a bright spot.

(a) The electron gun:
This consists of the following parts
(i) The cathode: It is used to emit electrons.
(ii) The control grid: It is connected to low voltage supply and is used to control the number of electrons passing through it towards the anode.
(iii) The anode: the anode is used to accelerate the electrons and also focus the electrons into a fine beam.

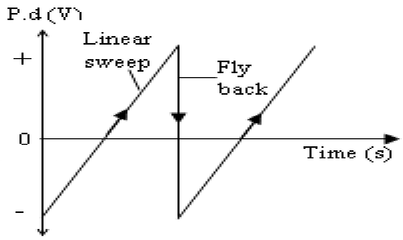
Note: Since the grid controls the number of electrons moving towards the anode. It consequently controls the brightness of the spot on the screen.

(b) Deflecting system:
This consists of the X- and Y- plates. They are used to deflect the electron beam horizontally and vertically respectively.

The X- plates are connected with the C.R.O to a special type of circuit called the time base circuit.

Time base switch: This is connected to the X – plate and is used to move the bright spot on the screen horizontally.

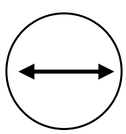
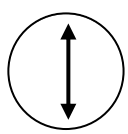
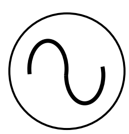
The Time Base or sweep generator
This is a special electrical circuit which generates a "saw tooth" voltage (i.e. a voltage p.d that rises steadily to a certain value and falls rapidly to zero.)
This p.d (time base) is connected to X-plates and causes the spot of electron beam to move across the screen from left to right, This is called a **linear sweep**.
The spot returns to the left before it starts the next sweep. This is called **fly-back.** The time for the fly back is negligible.



Note: During the fly back, the control grid is automatically made more negative thereby suppressing the brightness of the spot.

(c) Fluorescent Screen:
This is where the electron beam is focused to form a bright spot.
The coating on the screen converts kinetic energy into light energy and produce a bright spot when the electron beam is focused on it.

Action of a C.R.O
(a) A.C out put on the screen of a C.R.O
Connecting a signal in form of alternating current (a.c) voltage across the plates has the following traces on the screen of a C.R.O.

(i) Time base off. X-plate a.c signal only.	(ii) Time base off. Y-plate a.c signal only	(iii) Time base on,. X and Y-plate a.c signals combined
		
Horizontal line at the centre	Vertical line at the centre	Sinusoidal wave

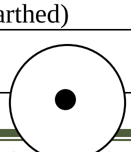
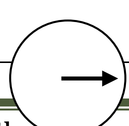
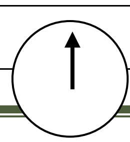
(i) When time base (x- plate) is switched on and there is no signal on the y-plate , the spot is deflected horizontally . The horizontal line is observed at the centre of the C.R.O...

(ii) When alternating current (a.c) is applied to the y- plate and time base (x – plate) is off , the spot is deflected vertically. The vertical line observed at the centre of the C.R.O.

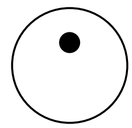
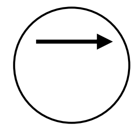
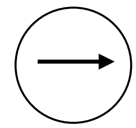
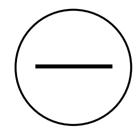
(iii) When a.c is applied on the y-plate and x- plate is on ,a wave form is observed on the screen.

When time base is switched off , and no signal to the y- plate , a spot is only observed.

(b) D.C out put on the screen of a C.R.O
Connecting a signal in form of direct current (d.c) voltage across the plates has the following traces on the screen of a C.R.O.

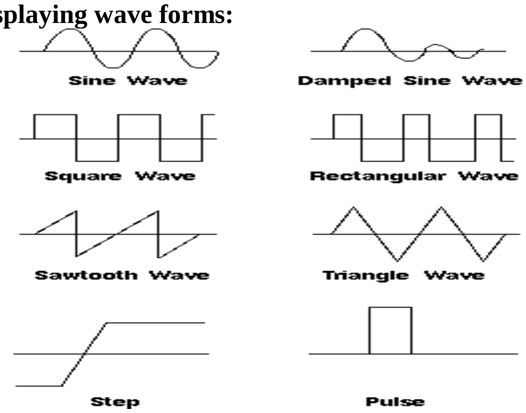
(i) Time base off. No signal on the plates.(Both plates earthed)	(ii) Time base off. X-plate signal only	(iii) Time base off. Y-plate signal only
		
Spot at the centre	One direction horizontal line from the centre	One direction vertical line from the centre

Note:

(i) Time base off. d.c signal on the Y-plates	(ii) Time base on, d.c signal on the Y-plates	(iii) Time base on. d.c signal on the X-plates
		
Spot deflected vertically through a distance, **d** from the centre	One direction horizontal line	One direction vertical line
With the **time base switched on**, and the **Y- plates earthed (off),** the electron spot moves very fast across the screen and it appears like a straight horizontal line.		

Uses of a C.R O
(i) Measurement of a.c and d,c voltage
(ii) Measurement of frequency
(iii) Measurement of phase difference
(iv) Displaying pictures in TV sets.
(v) Displaying wave forms.

Displaying wave forms:



Measurement of p.d
A C.R.O can be used as voltmeter because the spot is deflected depending on the p.d between the plates

Method
- Connect a cell 1.5V to the y-plate and adjust the grid control until the trace indicating the p.d is 1cm above 0 so that every 1cm deflection represents a p.d of 1.5V.
- Get unknown p.d and connect it to y-plate and then compare the deflection by counting the number of of cm deflected. This means that we can measure unknown p.d.

Measuring d.c. Potential Difference

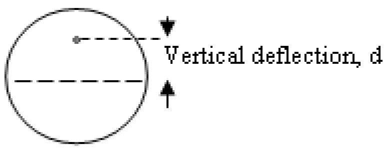
- switch off the time-base.
- a spot will be seen on the c.r.o. screen. Adjust the grid control (Y- gain control) until the trace indicating the p.d is 1cm above 0 so that every 1cm deflection represents a p.d of 1.5V
- d.c. to be measured is applied to the Y-plates.
- spot will either be deflected upwards or downwards.
- Deflection of the spot is proportional to the d.c. voltage applied. Then compare the deflection by counting the number of cm deflected. This means that we can measure unknown p.d.

Measuring d.c. Potential Difference

In this case, the voltage gain or the Y-sensitivity is set at a suitable value. Then the p.d to be measured is connected to the Y-plates and the time base is switched off.

The vertical deflection is measured and the direct voltage is got from:

$$\mathbf{V_{dc}} = \left[\frac{\textbf{Voltage gain}}{\textbf{(or Y − sensitivity)}}\right] \times \textbf{Vertical deflection}$$



If the Y-gain control is set at 2 volts/division And the vertical deflection, y, is 1.5 divisions

Then d.c. voltage

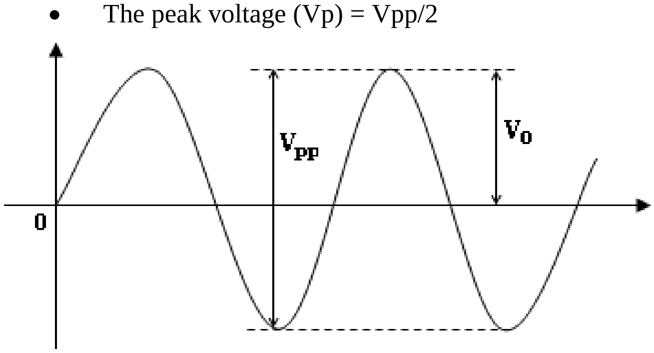
$$= 1.5 \times 2$$
$$= 3.0\,V$$

Measuring a.c. voltage

- switch off the time-base
- a spot will be seen on the c.r.o. screen.
- a.c. to be measured is applied to the Y-plates.
- spot will move up and down along the vertical axis at the same frequency as the alternating voltage.
- The spot moves to the top when the voltage increases to its maximum (positive)
- The spot moves to the bottom when the voltage decreases to its lowest (negative) .

When the frequency is high.

- The spot will move so fast that a vertical line is seen on the screen.
- Length of the vertical line gives the peak-to-peak voltage (Vpp) applied to the Y-plate.
- The peak voltage (Vp) = Vpp/2



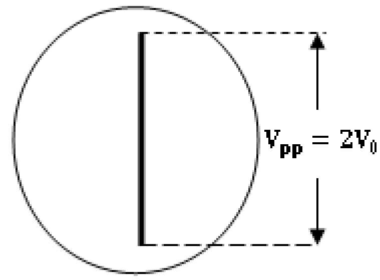
For a.c voltage

The length l of the vertical trace is measured and

$$V_{pp} = \left[\frac{\text{Voltage gain}}{\text{(or Y − sensitivity)}}\right] \times \text{Vertical deflection}$$

Where$\mathbf{V_{pp}}$ is the peak to peak voltage. The maximum voltage (amplitude,V_0) is given by $\mathbf{V_0} = \frac{\mathbf{V_{pp}}}{\mathbf{2}}$ and the actual voltage at root mean square (r.m.s) is given by

$$\mathbf{V_{r.m.s}} = \frac{\mathbf{V_0}}{\sqrt{\mathbf{2}}}$$



Example: 1

A CRO with Y-sensitivity (voltage gain) of $8Vcm^{-1}$ has its Y-plates connected (with the time base turned off) to:

(a) A d.c accumulator delivering 16 V,

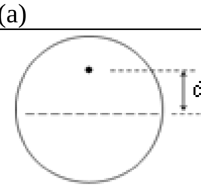
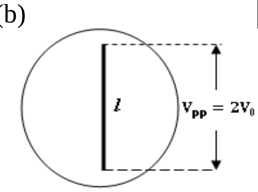
(b) An a.c voltage delivering 16 V at root mean square.

(i) Determine the deflection of the spot in (a) above and the length of a vertical line in (b) above.

(ii) Explain with a diagram what will happen if the plates are connected with time base on to a voltage in (b) above.

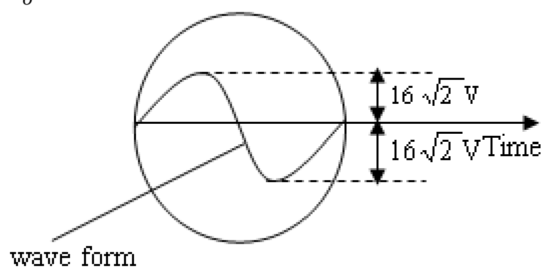
Solution

(a)

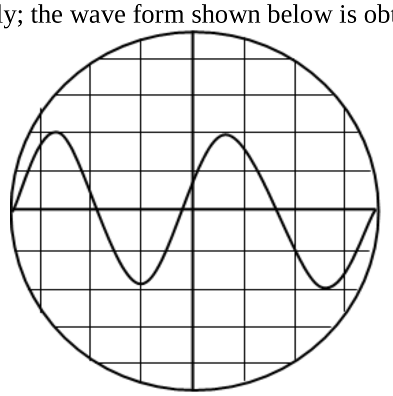
	Given: $V_{dc} = 16$ V $\left[\frac{\text{Voltage gain}}{\text{(or Y sensitivity)}}\right] = 8\text{V cm}^{-1}$
Then from; $V_{dc} = \left[\frac{Voltage\ gain}{(\ or\ Y - sensitivity)}\right] \times Vertical\ deflection$ $16 = 8 \times d$ $d = 2$ cm The spot will be deflected by 2 cm from the zero line.	
(b) 	$V_{r.m.s} = 16$V $\left[\frac{\text{Voltage gain}}{\text{(or Y sensitivity)}}\right] = 8\text{V cm}^{-1}$
$V_{r.m.s} = \frac{V_0}{\sqrt{2}} \Rightarrow 16 = \frac{V_0}{\sqrt{2}} \Rightarrow V_0 = 16\sqrt{2}$ V $V_{pp} = \left[\frac{Voltage\ gain}{(\ or\ Y - sensitivity)}\right] \times Vertical\ deflection$ $2 \times 16\sqrt{2} = 8 \times l$	

$$\boldsymbol{l} = 4\sqrt{2}\ \text{cm}$$

(ii) If the time base is on and Y-plates connected then we shall obtain the wave from below with a peak value $V_o = 16\sqrt{2}$ V



Example: 2
A C.R.O with time base switch on is connected across a power supply; the wave form shown below is obtained.



Distance between each line is 1cm

(i) Identify the type of voltage generated from the power source. **Alternating current voltage.**

(ii) Find the amplitude of voltage generated if voltage gain is 5V per cm.

Solution:

$$\left[\begin{matrix}\text{Voltage gain}\\ (\text{ or Y} - \text{sensitivity})\end{matrix}\right] = 5\text{V cm}^{-1}$$

From the graph, Amplidude = 2 cm

$$V_0 = \left[\begin{matrix}\text{Voltage gain}\\ (\text{ or Y} - \text{sensitivity})\end{matrix}\right] \times \text{Amplitude}$$
$$V_0 = 5 \times 2$$
$$V_0 = 10\ \text{V}$$

(iii) Calculate the frequency of power source if the time base setting on the C.R.O is 5 X $10^{-3}$$\text{scm}^{-1}$.

Solution:

$$\left[\begin{matrix}\text{Time sensitivity,}\\ (\text{Time base setting})\end{matrix}\right] = 5.0 \times 10^{-3}\ \text{scm}^{-1}$$

From the graph, Length for 2 cycles = 8cm
Time, t for 2 cycles =?

Time, t for 2 cycles

$$\text{Time, t} = \left[\begin{matrix}\text{Time sensitivity,}\\ (\text{Time base setting})\end{matrix}\right] \times \text{Legnth on time axis}$$
$$\text{Time, t} = (5.0 \times 10^{-3}) \times 8$$
$$\text{Time, t} = 0.04\ \text{s}$$

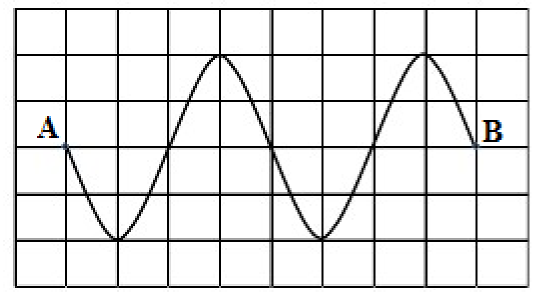
Time, T for 1 cycles (Period time, T)

$$\text{Time, T} = \frac{\text{t}}{\text{No. of cycles}} = \frac{0.04\ \text{s}}{2} = 0.02\ \text{s}$$

Frequency;

$$\text{Frequency, f} = \frac{1}{\text{T}} = \frac{1}{0.02} = 50\ \text{Hz}$$

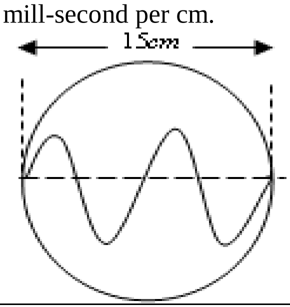
Trial Question:
A cathode oscilloscope CRO with time base switched on is connected across a power supply. The wave form shown in figure below is obtained.



The distance between each line as 1cm.

(i) Identify the type of voltage generated by the power supply.
(ii) Find the amplitude of the voltage generated if the voltage gain is 5Vcm^{-1}.
(iii) Calculate the frequency of the power source, l the time base setting on the C.R.O is 5 X $10^{-3}\text{scm}^{-1.}$

Example: 3
Determine the frequency of the signal below, if the time base is set at 10 mill-second per cm.



2 cycles occupy	= 15 cm
1 cycle occupies	= 15/2 = 7.5 cm

$$\text{Period time, T} = \left(\begin{matrix}\text{Legnth}\\ \text{for 1 cycle}\end{matrix}\right) \times (\text{Time base setting})$$
$$\text{Period time, T} = 7.5 \times 10\ \text{ms cm}^{-1}$$
$$\text{Period time, T} = 75\ \text{ms}$$
$$\text{Period time, T} = 75\ \times 10^{-3}\text{s}$$

Frequency;

$$\text{Frequency, f} = \frac{1}{\text{T}} = \frac{1}{75\ \times 10^{-3}} = 13.33\ \text{Hz}$$

Note
If the CRO has no calibrated time base setting, when the unknown frequency f_2 of the signal is determined from the relation

$$\text{Since, f} \propto \frac{1}{\text{d}} \Rightarrow \mathbf{f_1 d_1 = f_2 d_2}$$

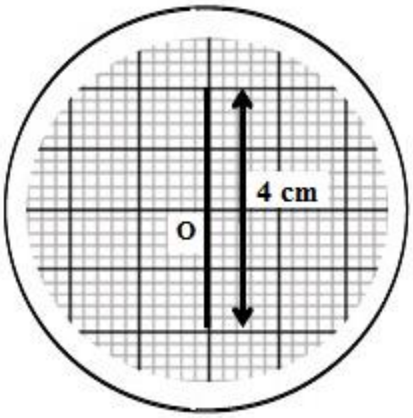
Where

d_1 – horizontal distance occupied by signal 1 for one cycle

d_2 – horizontal distance occupied by signal 2 for one cycle

f_1 – known frequency of signal at same time base setting.

Example:
The Figure below shows the appearance of the screen of the cathode ray oscilloscope when an a.c. voltage is connected across the Y-plate. A vertical trace of length 4 cm is formed.



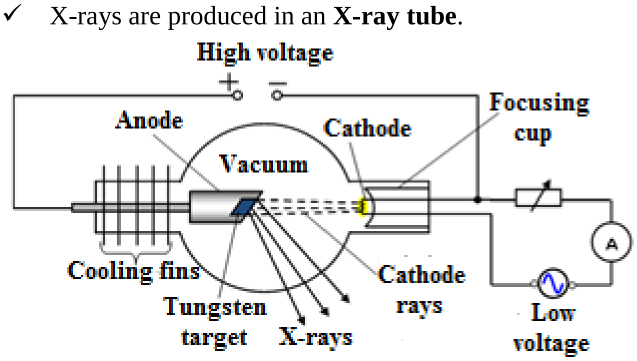
If the Y-gain is set at 5 V cm -1, find the peak voltage of the a.c. voltage.

Advantages of a C.R.O over an ammeter and voltmeter
(i) It has infinite resistance and therefore draws very little current from the circuit.
(ii) It can be used to measure both **a.c** and **d.c** voltages.
(iii) It has instantaneous response.
(iv) It has no coil that can burn out.

2. X – RAYS

These are electromagnetic radiations of short wave length. They are produced when fast moving electrons are suddenly stopped by a metal target.
The process involved in the production of X-rays is the inverse of Photoelectric emission.

Production of X-Rays
✓ X-rays are produced in an **X-ray tube**.



✓ The cathode is heated to emit electrons by **thermionic emission** using **a low voltage** supply.
✓ A **high p.d** is applied across the anode to accelerate the electrons (**cathode rays**) towards the anode.
✓ When the cathode rays strike the metal target, about 99% of their kinetic energy is converted to heat energy and 1% is converted to X- rays.

Energy Changes in the X-ray tube.

Electrical energy → Heat enegy in the filament → K.E of electrons → E/m energy

Note:
(i) The x – ray tube is **evacuated** to prevent fast moving electrons from being hindered by friction due to **air resistance.**
(ii) The heat generated is conducted away through the copper anode to the **cooling fins**, or by use of a circulating liquid, oil or water through the **hollow anode.**
(iii) The curvature of the cathode helps to focus the electrons onto the anode.
(iv) The target is made of tungsten because tungsten has a very high melting point (33800 ^{o}C).
(v) The lead shield is used to absorb stray X-rays hence preventing exposure of X-rays to un wanted regions.

Intensity of X-rays:
Intensity of X-rays refers to the number of X-rays produced.
- The intensity of X-rays increases when the filament current or heating current (the low P.d) is increased. This is because when the filament current is increased, the number of electrons hitting the target increases.
- The intensity also increases with the applied voltage across the tube since the applied voltage increases the energy with which the electrons hit the target hence increasing energy for X-ray photons.

Penetrating Power (Strength or Quality) of X-rays:
- The penetrating quality of X-Rays increases with the applied voltage across the tube
- X-rays of low frequency or low penetrating power are called **soft X-rays** and are produced when a low voltage is applied across the tube.
- If the applied voltage is high, X-rays (**hard X-rays**) of high frequency are produced.
- The penetrating power of X-rays is independent of the filament current.

Types of x – rays
(i) **Soft x –rays** are X-rays of low penetrating power i.e low frequency and long wave length produced when a low accelerating p.d is applied across the x-ray tube.
Use: *They are used in Radiography, to photograph diseased parts of a body, e.g a fracture in a bone.*

(ii) **Hard x –rays** are X-rays of high penetrating power i.e high frequency and short wave length produced when a high accelerating p.d is applied across the x-ray tube.
Use: *They are used in Radiotheraphy, e.g in treatment of cancer.*

Properties of x- rays

- They can penetrate matter (the penetration increases with the frequency and its minimum in materials of high density e.g. lead.).
- They travel in straight lines at the speed of light.
- They are not deflected by both electric and magnetic fields since they are not charged.
- They can ionise a gas increasing its conductivity.
- They affect a photographic plate or film.
- They cause some substances to fluoresce e.g. Zinc sulphide.
- They are electromagnetic radiations of short wave length.
- They can produce photo electric emission.
- They undergo refraction, reflection and diffraction.

Health hazards of X-rays

Frequent exposure to X-rays can lead to dangers like;

- They destroy cells especially hard x- rays.
- Cause gene mutation or genetic change.
- Cause damage of eye sight and blood.
- Cause cancer eg Leukemia (cancer of the blood)
- Produce deep seated skin burns.

Safety Precautions

- Avoid unnecessary exposure to x –rays.
- Keep exposure time as short as possible.
- The x- ray beam should only be restricted to parts of the body being investigated.
- Soft X-rays should be used on human tissues.
- Workers dealing with x-rays should wear shielding jackets with a layer of lead.
- Exposure should be avoided for unborn babies and very young children.

Uses of X-rays

a) **Medicine (Hospital Use)**

- X-ray photographs are used to investigate bone fractures. This is because they travel in a straight line , have a high penetrating power (so they can pass through fresh but not bones
- Detecting lung tuberculosis..
- Used to locate swallowed metal objects.
- Used to detect internal ulcers along a digestive track
- Used to treat cancer especially when it hasn't spread by radiotherapy i.e very hard x-rays are directed to the cancer cells so that the latter are destroyed.
- Used to sterilize medical equipments.
- Used in studying the structure of DNA.

How an X-ray is used to locate broken parts of a bone .

Bones are composed of much denser material than flesh hence if x- rays are passed thru the body , they are absorbed by the bones onto a photographic plate which produces a shadow of the photograph the bone that is studied to locate the broken part.

b) **Industrial use**

- Used to detect cracks in car engines and pipes.
- Used to detect defects motor car tyres
- Used to locate internal imperfections in welded joints e.g pipes , boilers storage tanks e.t.c.
- Used to detect cracks in building.
- Used to harden rubber.

c) **X-ray crystallography**

- Used to determine inter – atomic spacing in the crystal. This done by using X-ray diffraction.

d) **Security:**

- X-rays are used to check luggage for potentially dangerous weapons and smuggled items at airports and custom security check point.

Differences between cathode rays and x-rays

Cathode rays	**X-rays**
Negatively charged	Have no charge
Travel at low speed	Travel at high speed
Low penetrating power	High penetrating power
Deflected by both Magnetic and electric fields	Not deflected since they have no charge.

EXERCISE:

1. Thermionic emission may occur when
   A. Fast moving electrons hit a metal
   B. A metal is given heat energy
   C. Metal receives light energy.
   D. A substance undergoes radioactive decay

2. Which one of the following will affect the number of electrons emitted in a thermionic tube?
   (i) The p.d between anode and cathode
   (ii) The pressure of the filament
   (iii) The current flowing in the filament circuit
   A. (i) and (ii) only C. (i) and (iii) only
   B. (ii) and (iii) only D. (iii) only

3. What is the process by which electrons are emitted from a hot filament?
   A. Radioactivity
   B. Nuclear reaction
   C. Thermionic emission
   D. Thermo-electric effect

4. Which one of the following are properties of cathode rays?
   (i) They travel in straight lines
   (ii) They can penetrate a thick sheet of paper
   (iii) They darken a photographic plate
   (iv) They are deflected by a magnetic field

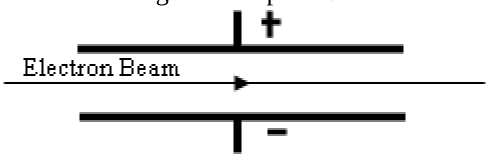
   A. (i), (iii) and (iv) only C. (i), (ii) and (iv) only
   B. (i), (ii) and (iii) only D. (iv) only

5. The phenomenon by which electrons are released from a metal surface when radiation falls on it is known as
   A. Radioactivity C. Photoelectric effect
   B. Thermionic emission D. Reflection

6. Streams of electrons moving at high speed are called?
   A. X-rays C. Gamma rays
   B. Cathode rays D. Alpha particles

7. The process by which electrons are emitted from the surface of a metal by application of heat is known as
   A. Photoelectric emission
   B. Electromagnetic emission
   C. Thermionic emission
   D. Heat emission

8. Fig below shows a beam of electrons incident mid way between two charged metal plates.

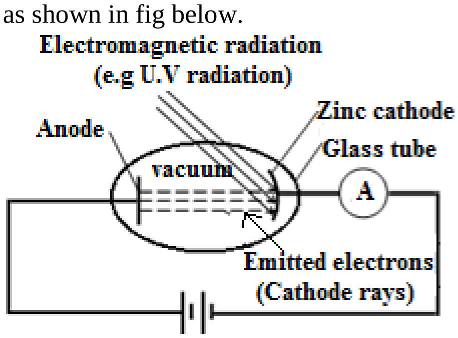


Which one of the following is correct? The beam
   A. Is deflected towards the positive plate
   B. Is deflected towards the negative plate
   C. Moves perpendicular to the plates
   D. Passes through the plates undetected.

9. The particles that are emitted from a hot metal surface are called:
   A. Electrons C. Neutrons
   B. Protons D. Alpha

10. Cathode rays are;
   A. Electromagnetic waves
   B. Streams of X-rays
   C. Protons emitted by a hot cathode
   D. Streams of electrons moving at high speed

11. A Zinc cathode was enclosed in an evacuated glass tube as shown in fig below.



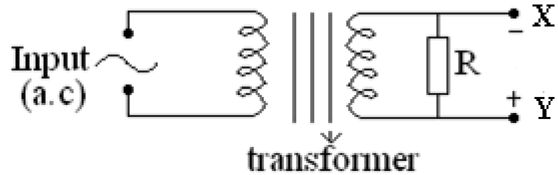
When the cathode was irradiated with ultra violet radiation, the ammeter gave a reading
   (i) Explain why the ammeter gave a reading.
   (ii) A gas was gradually introduced into the glass tube. Explain what happened.

12. (a) What is meant by the following?
   (i) Thermionic emission.
   (ii) Photoelectric effect

(b) State the conditions necessary for photoelectric effect to occur.

(c) With the aid of a diagram, describe how cathode rays are produced by thermionic emission.

13.

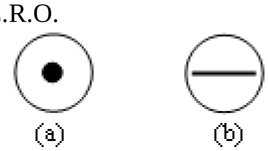


The wave form obtained when X and Y are connected to a cathode ray oscilloscope is:

A. B. C. D.

14. A sinusoidal wave is observed on a cathode ray oscilloscope, when;
   A. A cell is connected to the Y- plates with time base off.
   B. A low frequency alternating voltage is connected to the Y-plates with time base on.
   C. A high frequency alternating voltage is connected to the Y-plates with time base on.
   D. A cell is connected to the Y- plates with the time base on.

15. The figure below, (a) shows a spot of light on the screen of a C.R.O.

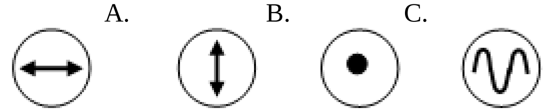


The spot can be turned into a horizontal straight line shown in (b), by;
   A. Switching off the time base.
   B. Switching on the time base.
   C. Making one of the plates positive.
   D. Connecting the a.c voltage to the Y- plates

16. The cathode ray oscilloscope may be used to;
   (i) Measure energy.
   (ii) Measure potential difference.
   (iii) Display wave forms.
   A. (i) only. C. (ii) and (iii) only.
   B. (i) and (ii) only. D. (i), (ii) and (iii).

17. Which of the following represent the appearance on the screen of a cathode ray oscilloscope when a d.c voltage is connected across the Y- plates with the time base switched on?

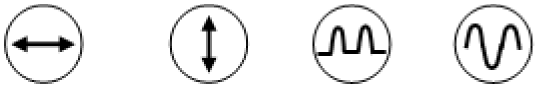
A. B. C. D.



18. The brightness on the screen of a T.V is determined by;
   A. Darkness in the room.
   B. Size of the screen.
   C. Number of electrons reaching the screen.
   D. Direction of the aerial.

19. Which one of the following sketches represents the appearance the wave form observed in a C.R.O connected across an a.c supply when the time base of the C.R.O is on?

A. B. C. D.

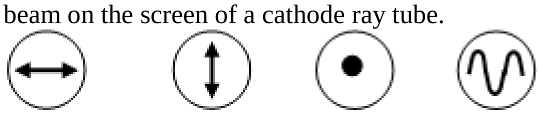


20. The brightness of the spot on a C.R.O screen is controlled by;
A. X – Plates. C. Grid.
B. Anode. D. Cathode.

21. The X and Y – plates in a cathode ray oscilloscope make up the:
A. Electron gun. C. Deflection system
B. Focusing system. D. Accelerating system.

22. (a) (i) Draw a well labeled diagram of a cathode ray oscilloscope. (C.R.O).
(ii) State one function of each part you have labeled in (i) above.

(b) The diagrams below show the traces of a cathode ray beam on the screen of a cathode ray tube.



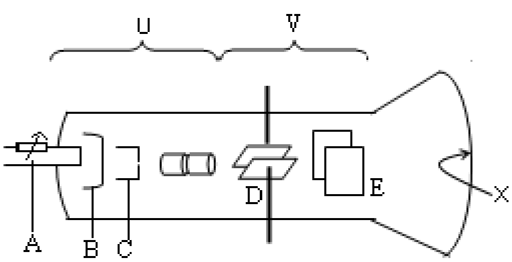
Explain how each one may be obtained.

(c) Give two uses of a C.R.O.

23. The diagram below shows the main parts of a cathode ray oscilloscope (C.R.O).

24. The following are some of the uses of X – rays except;
A. Detection of flaws in a material.
B. Detection of affected tissues in living organisms.
C. Destruction of cancer cells.
D. Preservation of cereals.

25. The figure below shows a cathode ray oscilloscope.



(a) Name the parts labeled; A, B, C, D, E, U, V and X.
(i) Explain why the C.R.O is evacuated.
(ii) Describe briefly the principle of operation of a C.R.O.
(iii) Describe how a bright spot is formed on the screen.
(b) Using diagrams, show what is observed when on the screen of the C.R.O when;
(i) The CRO is switched on and no signal is applied to the Y - plates.
(ii) The time base is switched on and no signal is applied to the Y - plates.
(iii) An alternating signal is applied to the Y- plates while the time- box is switched off.
(c) Give two applications of a cathode ray oscilloscope.

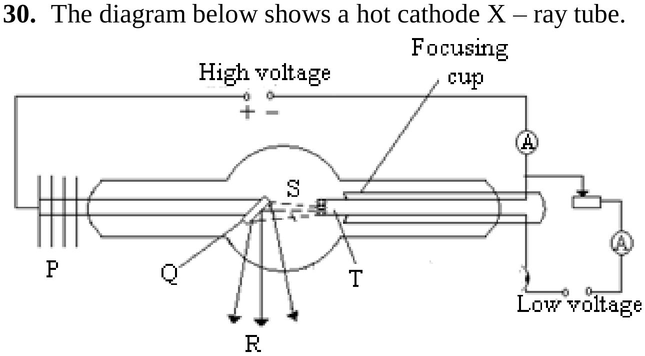
26. Which of the following is the correct sequence of the energy conversions in an X – ray tube?
A. Electrical energy → Heat energy → K. E → Electro magnrtic energy
B. Heat energy → Electrical energy → K. E → Electro magnrtic energy
C. Electrical energy → Heat energy → Electro magnrtic energy → K. E
D. K. E energy → Electrical energy → Heat energy → Electro magnrtic energy

27. Which of the following is true about X – rays?
(i) Cause photographic emissions.
(ii) Deflected by an electric field.
(iii) Ionize matter
(iv) Not deflected by a magnetic field.
A. (i), (ii) and (iii). C. (ii) and (iv).
B. (i) and (ii). D. (i), (iii) and (iv).

28. The difference between X – rays and ultra – violet rays is that X – rays have;
(i) Greater velocity. (iii) Lower frequency.
(ii) Shorter wavelength. (iv) More energy.
A. (i), (ii) and (iii). C. (i) and (ii).
B. (ii) and (iv). D. (i), (iii) and (iv).

29. The difference between soft and hard X – rays is that;
A. Hard X- rays travel faster than soft X – rays.
B. Hard X – rays penetrate more than the soft X–rays.
C. Hard X – rays less dangerous than the soft X–rays.
D. Soft X – rays are produced at high potential differences.

30. The diagram below shows a hot cathode X – ray tube.



(a) Name the parts labeled P, Q, R, S and T.
(b) What is the purpose of the;
(i) Low voltage.
(ii) High voltage
(c) State two applications of X – rays .
(d) Explain why part Q must be cooled.

31. (a) What are X – rays?
(b) With the aid of a labeled diagram, describe the structure and mode of operation of an X – ray tube.
(c) Explain how each of the following can be increased in an X – ray tube:
(i) Intensity of the X – rays.

(ii) Penetrating power of the X – rays.

(d) Give two biological uses of X – rays.
(e) State any four ways in which X – rays are similar to gamma rays.

RADIOCTIVITY

Radioactivity is the spontaneous disintegration of heavy unstable nucleus to form stable nucleus accompanied by release of radiations. The S.I unit of activity is a Becquerel **(Bq).**

Activity is the number of disintegrations (or break down emissions) per second.

$$Activity, A = \frac{Number\ of\ distintegrations}{Time\ taken} = \frac{N}{t}$$

The radiations emitted are:
Alpha particles (**α**), beta particle (**β**) or gamma radiations (**γ**). Elements that emit radiations spontaneously are said to be radioactive elements.
Radioactivity is considered as a random process because you can not tell which atoms of a molecule will disintegrate at a particular instant.

Properties of Radiations emitted

(a) Alpha particle

An alpha particle is a helium nucleus which is positively charged i.e. $^{4}_{2}\mathbf{H}$.

Properties

- It is positively charged with a charge of $+2$.
- It has a low penetrating power because of its relatively large mass and due to this; it can be stopped or absorbed by a thin sheet of paper.
- It can be deflected by both electric and magnetic fields because of its charge and it is deflected towards a negative plate.
- It has a high ionising power due to its high charge or great charge.
- It has a low range in air.

Note: When un stable nuclei emits an alpha particle, the mass number reduces by 4 and atomic number reduces by 2.
When a nuclide decays by release of an alpha particle, it loses two protons and two neutrons. This can be expressed as below:

$$^{A}_{Z}X \longrightarrow\ ^{A-4}_{Z-2}Y +\ ^{4}_{2}He$$

Parent nuclide — Daughter nuclide — alpha particle

Example

(i) Uranium decays by emitting alpha particles to become thorium;

$$^{238}_{92}U \longrightarrow\ ^{206}_{82}Th +\ ^{4}_{2}He$$

(ii) Polonium – 210 undergoes alpha decay to become lead – 206;

$$^{210}_{84}Po \longrightarrow\ ^{206}_{82}Pb +\ ^{4}_{2}He$$

Question:
1. A radioactive substance $^{238}_{92}\mathbf{X}$ undergoes decay and emits an alpha particle to form nuclide Y. Write an equation for the process.
2. A radioactive substance $^{238}_{92}\mathbf{X}$ undergoes decay and emits two alpha particles to form nuclide Y. Write a balanced equation for the process.

(b) A beta particle

A beta particle is a high energy electron i.e. $^{-1}_{0}\mathbf{e}$.

Properties

- It is negatively charged with a charge of -1.
- It has a low ionising power because of its low charge (-1).
- It has a higher penetrating power because of its low mass and due to this; it can be stopped or absorbed by an alluminium foil (a few cm).
- It can also be deflected by both electric and magnetic fields at a higher angle and it is deflected towards a positive plate.
- It has a high range in air.

Note:
When a radioactive nuclei decays by emitting a beta particles. Its mass number is not affected but the atomic number increases by one.

When an element decays by emitting a beta particle, it loses an electron. This results from the decay of a neutron to a proton:

$$^{1}_{0}n \longrightarrow\ ^{1}_{1}P +\ ^{0}_{-1}\beta$$

neutron — proton — beta particle

Beta decay can be expressed as:

$$^{A}_{Z}X \longrightarrow\ ^{A}_{Z+1}Y +\ ^{0}_{-1}e$$

parent nuclide — daughter nuclide — beta particle

Example

Radioactive sodium undergoes beta decay to become magnesium. This can be written as:

$$^{24}_{11}Na \longrightarrow\ ^{24}_{12}Mg +\ ^{0}_{-1}e$$

Note: When a nuclide undergoes beta decay:
(i) Its atomic number increases by one.
(ii) Its atomic mass remains the same.

Questions:
1. An unstable nuclide $^{226}_{88}\mathbf{X}$decays to form a stable nuclei **Y** by emitting a beta particle.
(i) Write down an equation for the process.

(ii) How would nuclide X be affected if a beta particle was emitted instead of the alpha particle?
(iii) Compare the nature and properties of an alpha particle with those of a beta particle,

2. A radioactive nucleus $^{226}_{88}\mathbf{Ra}$ undergoes decay and emits two alpha particles and two beta particles to form nuclide **S**. State the atomic number and mass number of nuclide S.

3. (a) Consider the equation below.

$$^{210}_{82}X \xrightarrow{(i)} {}^{206}_{80}Y \xrightarrow{(ii)} {}^{206}_{81}Z$$

Name the particle emitted at each of the stages (i) and (ii).

(c) Gamma Rays

These are neutral electromagnetic radiations with the shortest wave length.

Properties

They are neutral (not charged) and therefore can not be deflected by both electric and magnetic fields.
They have the highest penetrating power because of their light mass and due to this they can be stopped or absorbed by a lead metal or shield which has the highest density.
They can also cause ionisation of a gas by knocking off electrons from the neutral atoms but this is by small amounts.
They have the highest possible range in air.

Question:

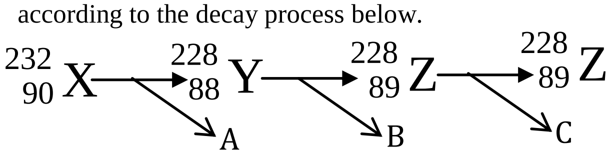
1. (a) Describe the composition of the $^{23}_{11}\mathbf{Na}$ atom.
(b) $^{60}_{27}\mathbf{Co}$ is a radioisotope of Cobalt which emits a beta particle and very high energy gamma rays to form an element Y. Write a balanced equation for the nuclear reaction.

$$^{60}_{27}Co \longrightarrow {}^{60}_{28}Y + {}^{0}_{-1}e + \gamma$$

2. A radioactive nuclide $^{230}_{90}\mathbf{X}$ emits 4 alpha particles, 2 beta particles and gamma radiations to turn into another nuclide, Y. Find the mass number and atomic number of Y.

3. A radioactive nuclide $^{235}_{92}\mathbf{X}$ emits 2 alpha particles and the resulting nuclide emits 3 beta particles and a nuclide P which emits gamma radiations.
(i) Determine the mass number and number of protons of P.
(ii) Write a balanced equation for the decay.

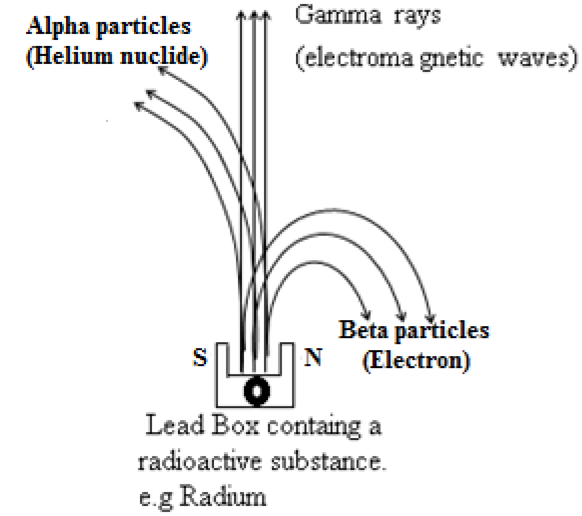
4. A radioactive nuclide $^{230}_{90}\mathbf{X}$decays to nuclide Z according to the decay process below.



(a) Identify the particles or radiations A, B and C.
(b) State two differences between radiations A and B.

Note: In a chemical reaction or equation,
(i) The total mass number on the left must be equal to the total mass number on the right hand side.
(ii) The total atomic number on the left must be equal to the total atomic number on the right hand side.

Deflection of Alpha, Beta and Gamma radiations in electric and magnetic fields (**Experiment to distinguish the radiations emitted by a radio active source**).

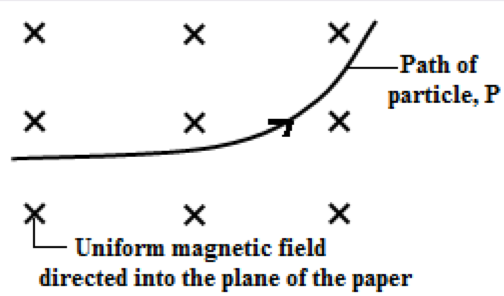


A radio active source is placed in a lead box and radiations emitted are subjected to a strong magnetic field at right angles to their direction.
It will be observed that some radiations are deflected in a similar way just like cathode rays, implying that they are negatively charged. These are beta particles. beta particles are deflected towards the North Pole just like cathode rays

Other radiations will be deflected **slightly** in a direction opposite to that of beta particles. This shows that they are heavier than Beta particles and carry a positive charge.
These are alpha particles. Alpha particles are deflected in a direction towards the South Pole.

The third type of radiation is not deflected at all.This shows that they carry no charge. These are gamma rays.

Question:
The figure below shows particle P emitted from a radio active sample of a rock, passing through a region of uniform magnetic field directed perpendicular into the paper.

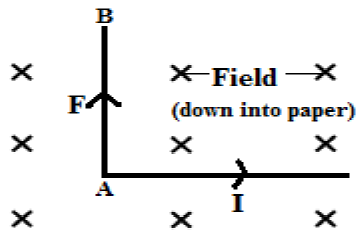


(i) Identify particle , P.

(ii) Describe the changes in the nuclear structure of element, **X** whose atomic and mass numbers are 88 and 226 respectively, which emits particle, P identified above.

Solution:

(i)



The direction of the field is into the paper. The direction of the thrust (force, F) on the particle is from A to B.
By Fleming's left-hand rule, the direction of the current must be from **left** to **right**.
Now the particle is moving in the same direction as the current, I. Therefore, the particle must be positively charged (i.e, an alpha particle, $\mathbf{H^{2+}}$). This is so because, by convention, current moves in the direction where positive charges would move.

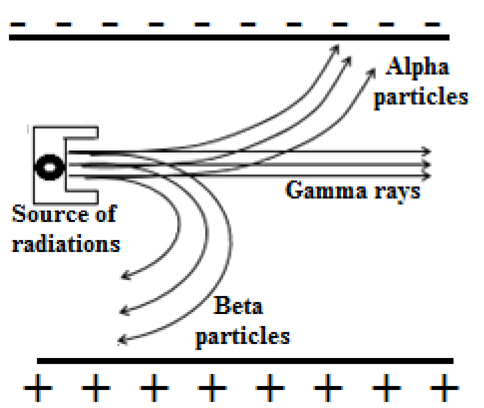
(ii). The phrase **'nuclear structure'** in the question refers to the composition of the nucleus which in turn implies number of protons and neutrons (which make up the nucleus).
Thus, number of protons in X = 88.
number of neutrons in X = 226 − 88 = 138

When X emits an alpha, particle:

$$^{226}_{88}\mathbf{X} \rightarrow {}^{222}_{86}\mathbf{Y} + {}^{4}_{2}\mathbf{He}$$

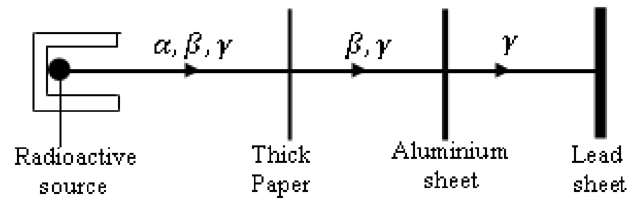
There fore the number of protons decreases fromm88 to 86 and the number of neutrons decreases from 138 to 136.

<u>Deflection of Alpha, Beta and Gamma radiations in electric field.</u>
If the radiations are subjected to an electric field, the paths below are seen.

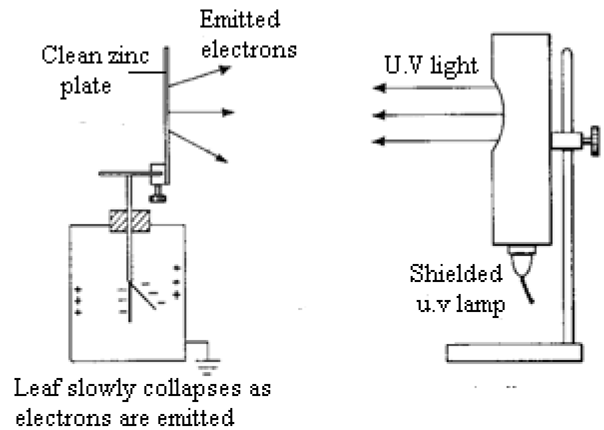


Alpha particles are deflected towards the negative plate since they are negatively charged, while beta particles are deflected towards the positive plate since they are negatively charge.
The gamma rays are not deflected in the electric field implying that they have no charge.

<u>Penetration Power of Alpha, Beta and Gamma radiations</u>



<u>Ionising effects of the radiations</u>
Ultra violent radiation is incident on a clean zinc plate resting on the cap of a charged G.L.E as shown below.



- When a radioactive source is brought near the cap of a charge G.L.E , the leaf falls , this show that the G.L.E has been discharged as a of the ionization of air around the cap.
- If the G.L.E is positively charged, negative ions or (electrons) from air attracted and the gold leaf falls and if is negatively charged, irons are attracted and leaf also falls.

Question:
Explain what is observed when;
(i) The G.L.E is positively charged.
(ii) Radio wave is used instead of ultra violent radiation.

Answer
(i) No further divergent of the leaf is observed because the ultra violent radiation eject electrons from the metal surface but the electrons are immediately attracted back hence no loss of charge.
(ii) Radio waves have low energy thus are unable to release electrons so there will be no effect on the leaf divergence of the electroscope.

Back ground radiation
These are radiations which are naturally existing even in the absence of radioactive source.

<u>Sources of back ground radiations:</u>
Natural back ground radiations
- Cosmic rays from ratiotions that reach earth from outer space eg from sun, stars etc..
- Rocks. Some rocks that give off radioactive Randon gas. From broken down Uranium.
- Animals, soils and plants.

Artificial back ground radiations
- Nuclear power stations accidents eg due to earth quake

- Nuclear weapons testing
- X-rays.

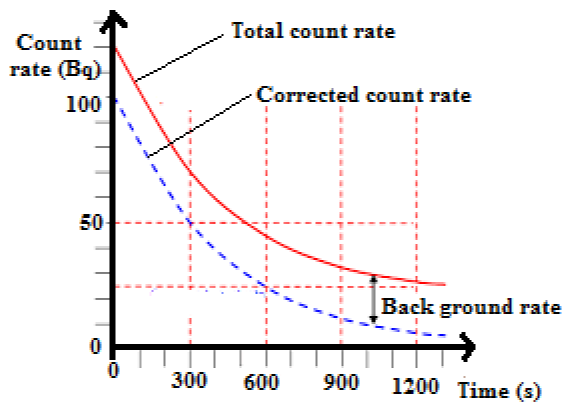
Back ground radiations can be found as follows,

- With no radioactive source in the room, a stop watch is started and the GM tube (with a counter) at the same time.
- After 60seconds, the GM tube is and counter is stopped and the number of counts in 60s recorded.
- Calculate the back ground activity in the room.
- The process is repeated several times and the average back ground activity calculated.

❖ The back ground count rate is subtracted from each measurement of the count rate from the radioactive source

❖ Thus the Actual count rate from the source (also known as the corrected count rate is calculated as follows.

$$\begin{pmatrix} \textit{Actual} \\ \textit{count rate} \end{pmatrix} = \begin{pmatrix} \textit{Observed} \\ \textit{count rate} \end{pmatrix} - \begin{pmatrix} \textit{Back ground} \\ \textit{count rate} \end{pmatrix}.$$



Example:1

Given that the back ground rate is 2 counts per minute and the Geiger Muller count rate is 25, determine the approximate number of radiations present.

$$\textbf{Actual Count rate} \quad = 25 - 2 = 23\ C\ min^{-1}$$

Example: 2

Comparisons of the Radiations

(a) Differences between alpha and beta particles.

Property	Radiation	
	Alpha particle	**Beta particle**
Charge	Positive	Negative
Nature	Helium particles which have lost the electrons	High energy electrons
Deflection in fields	Towards negative plate and south pole	Towards positive plate and north pole
Penetrating power	Low: Penetrate thin paper but stopped by thick ones.	High: Penetrate thick paper and thin alluminium foil but stopped by thick alluminium sheets.
Ionizing power	High (Most)	Moderate
Absorbed by	Thick sheets of paper	5mm of alluminium

(b) Differences between Gamma rays and X-rays

	Gamma rays	**X-rays**
(i) Wave Length	Shorter wave length than X-rays.	Longer wave length than gamma rays.
(ii) Origin	From nuclei of atoms as a result of radioactivity.	From cathode rays suddenly stopped by matter.

(c) Comparison of Alpha, Beta and Gamma radiations

Property	**Radiation**		
	Alpha particle	**Beta particle**	**Gamma rays**
Charge	Positive (+2)	Negative (-1)	No charge (0)
Nature	Helium particles which have lost the electrons	High energy electrons	High energy electromagn etic radiation.
Deflection in fields	Towards negative plate and south pole	Towards positive plate and north pole	Not deflected
Penetrating power	Least	Moderate	Most
Ionizing power	Most	Moderate	Least
Absorbed by	Thick sheets of paper	5mm of aluminium	Thick sheet of lead
Range in air	0.05m	3m	100m

Note:

(i) **Range** of radiation is the maximum distance covered by a radiation in air before it is totally absorbed.

(ii) **Ionisation** is the process of changing the neutral atoms of a gas into positive and negative ions.

(d) Similarities between alpha and beta particles.

- Both ionize gases.
- They both penetrate matter.
- They are both deflected by and magnetic fields.

Detectors of the radiations

These include:

(i) Ionisation chamber
(ii) Geiger Muller Tube (G.M tube)
(iii) Cloud chamber (both expansion type and diffusion cloud chamber)
(iv) Scintillation counter

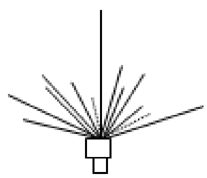
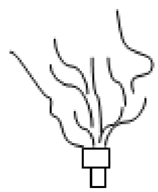
Cloud chamber tracks for the Alpha, Beta and Gamma radiations

When an ionising radiation from a radioactive source, enters the chamber the ions are produced.

Alcohol droplets in the cloud chamber will collect around these ions produced forming strings.

Using a strong illumination, the droplets can be photographed by using a camera.
The type of radiation depends on the thickness or length of the traces of ions formed.

Alpha particles produce, thick short, straight and continuous tracks, Beta particles produce longer but wavy tracks and Gamma rays have an irregular and faint tracks as shown below.

Alpha particle	Beta particle	Gamma rays
		
Short, straight and continuous tracks	Long and wavy tracks	Irregular and faint tracks

Dangers of radiations.

(i) Alpha particles;

Alpha particles are less dangerous unless the source enters the body.

(ii) Beta Particles and Gamma radiations:

These are very dangerous because they damage skin tissues and destroy body cells.
They cause:

(i) Radiation burns. (i.e. redness and sore on the skin).
(ii) Leukemia, (Blood cancer).
(iii) Sterility, (Inability to reproduce).
(iv) Blindness, (i.e. they damage the eye sight)
(v) Low body resistance to normal diseases, due to damage of blood corpuscles.
(vi) Mutation. (A harmful genetic change, that occurs during DNA replication and protein synthesis).

The effects of genetic mutations appear in the subsequent generations. E.g, a child may be born with one arm or both but when one is shorter than the other.

Safety precautions when dealing with radioactive sources

Radioactive sources should be handled with care. In that;

- They should be held with forceps or a pair of tongs and not with bare hands.
- Avoid eating, drinking or smoking where radioactive sources are in use.
- Radioactive sources must be kept in lead boxes when not in use.
- Wash hands thoroughly after exposing them to radioactive materials.
- Any cut on the body should be covered before dealing with radioactive sources.
- Operators should put on gloves and lead coats.
- During experiments with radioactive materials, the radiations should not be directed towards the people.

Applications of Radioactivity(Uses of alpha , beta ,and gamma rays)

The uses in various fields are based on the following

- Gauge control and fault finding: If a radioisotope is placed on one side of a moving sheet of material and a GM tube on the other, the count rate decreases if the thickness increases. Flows in a material can be detected in a similar way; the count-rate will increase where a flaw is present.
- Radioactive tracers: A small amount of a weak radioisotope is injected into the system and traced by a GM tube or other detectors.
- Radiotherapy: Gamma rays and Hard X-rays are used in the treatment of cancer.
- Radiography Soft X-rays are used to take photographs used in detecting breakages in bones.
- Sterilization: Gamma rays are used to sterilize medical and industrial instruments and foods.
- Archaeology: Living plants and animals take in radioactive carbon. When a tree dies, no fresh carbon is taken and the carbon starts to decay. By measuring the residual activity of carbon containing material such as wood, charcoal the age of archaeological remains can be estimated.

(a) **Industrial uses:**

They are used;

- ✓ in tracer techniques to investigate the flow of liquids in chemical plants. (Identifying oil leakages in oil pipe lies).
- ✓ in the automatic control of thickness or uniformity of industrial products. (e.g Cigarettes)
- ✓ In the study of wear and tear in machinery.
- ✓ To detect faults in thickness of metals sheets in welded joints. (gamma rays)
- ✓ in food preservations.
- ✓ to sterilize equipments in food industry
- ✓ to detect smoke
- ✓ in energy production: Nuclear reactors use radio isotopes to produce electricity.
- ✓ In nuetralising charges in industries. e.t.c.

(b) **Medical uses**

- ✓ Used to treat cancerous cells. (Radiotherapy).
- ✓ They are used to kill bacteria in food (x- rays).
- ✓ Used to sterilize medical surgical equipments.
- ✓ Locate broken bones
- ✓ Asses the amount of blood in a patient

(c) **Archeological uses**

- ✓ Used to determine the time that has elapsed since death of a certain organism occurred in a process called **carbon dating.**

(d) **Geology**

- ✓ They are used to determine the age of rocks.

(e) Biological uses

- ✓ Used to study the uptake of fertilizers by plants.
- ✓ Used to sterilize insects and hence eliminate pests that destroy crops.

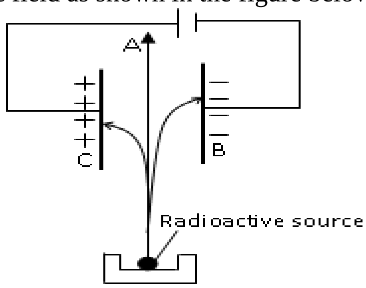
(f) Defense

✓ Nuclear reactions of fusion and fission are used in manufacture of weapons of mass destruction like nuclear and atomic bombs.

Exercise:

1. Which one of the following radiations has the listed properties?
(i) Long range in air.
(ii) Not deflected by magnetic and electric fields.
(iii) Cause very little ionization of air molecules.
A. Alpha. C. Gamma
B. Beta. D. X - rays.

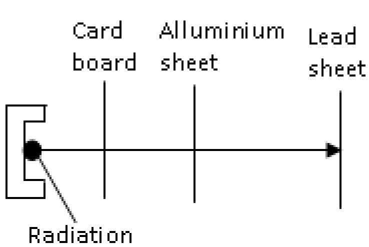
2. A radioactive source decays by emission of all the three radiation. The radiation enters normally into electric field as shown in the figure below.



(a) Which radiation is most likely to detect at;
(i) Position A. (ii) Position B. (iii) Position C.

(b) (i) What can you deduce about the charges of the radiation?
(ii) State two differences between radiation A and B.
(iii) What happens when the radioactive source is completely covered with an ordinary sheet of paper.
(iv) Draw diagrams to show the paths of the particles named in (d) above.

(c) A radioactive source that emits all the three radiations is placed in front of the cardboard aluminum and lead sheets as shown in the figure above. Name the radiations likely to be between the card board.



(i) Cardboard and aluminum sheet.
(ii) Aluminum and the lead sheets

(d) (i) Name any three precautions which must be undertaken by one working with ionizing radiation.
(ii) Give 2 uses of radioactivity.
(iii) Name two health hazards of radioactivity.

(e) Name one;
(i) Industrial use;
(ii) Biological use of radio activity.

HALF LIFE

Half life is the time taken for a radioactive substance to decay to half of its original mass (or nuclei).

Half life can be measured in any unit of time, e.g seconds, minutes, hours, days, weeks, months and years.
It is not affected by physical factors like temperature and pressure.

It is different for different nuclides as shown for some nuclides in the table below.

Radioactive element	Symbol	Half life	Radiations
Polonium – 218	$^{218}_{84}Po$	3.05 minutes	α
Thorium – 234	$^{234}_{90}Th$	24.10 days	β, γ
Uranium – 234	$^{234}_{92}U$	2.47×10^5 years	α, γ
Uranium – 238	$^{238}_{92}U$	4.51×10^9 years	α, γ

Note:

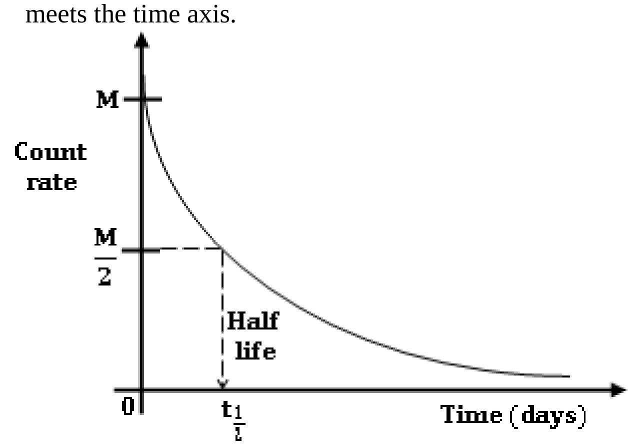
❖ These values are **not** to be memorized.
❖ The last two are called **Radioisotopes**. (Radioactive atoms of the same element with the same atomic number but different mass numbers).

Experiment to determine the half life of a radioactive nuclide.

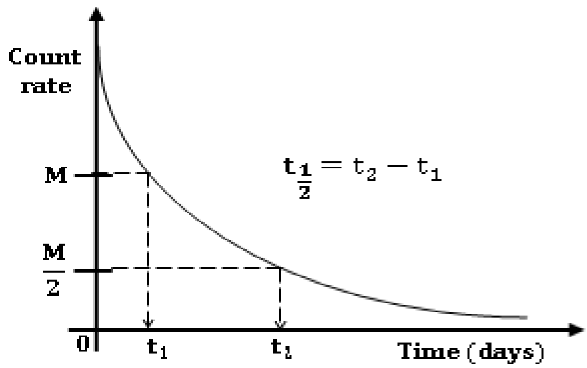
✓ Place the source of the radioactive nuclide into the ionization chamber or Geiger Muller tube.
✓ Note and record the count rate (Change in the intensity of radiations from the source with time).
✓ Plot a graph of intensity or number of nuclei remaining against time.
✓ Read off the half life from the graph.

How to read half life from the graph:

✓ Draw a horizontal line from half of the original amount (or count rate or original number of nuclei) to meet the curve.
✓ Draw a vertical line from the point on the curve to meet the time axis.
✓ Read the value of half life from where the vertical line meets the time axis.



In some cases, the original mass may not coincide with the zero (0) time.



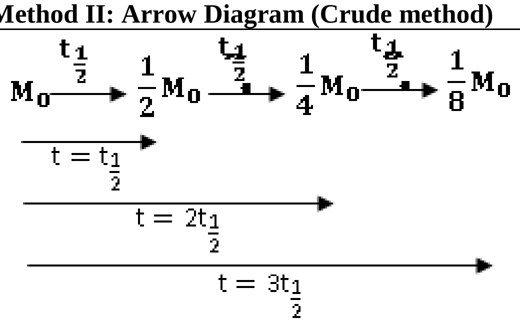
Calculations of Half life:

Method I: Using a table

Time Taken, t	Mass remaining, M_t	Mass Decayed $M_D = M_o - M_t$
0	M_0	0
$t_{\frac{1}{2}}$	$M_o\left(\frac{1}{2}\right)^1$	
$2t_{\frac{1}{2}}$	$M_o\left(\frac{1}{2}\right)^2$	
$3t_{\frac{1}{2}}$	$M_o\left(\frac{1}{2}\right)^3$	
-	-	
-	-	
$nt_{\frac{1}{2}}$	$M_o\left(\frac{1}{2}\right)^n$	

Where: $\mathbf{nt_{\frac{1}{2}} = t}$

Method II: Arrow Diagram (Crude method)



The total time taken for the required amount to decay, is given by; $\mathbf{t = nt_{\frac{1}{2}}}$

Where, $\mathbf{n}$ is the number of half livesin a time, $\mathbf{t}$

Method III: Using the formula

The mass remaining after a time t, M_t, when an original sample of mass M_o decays with a half- life of $t_{\frac{1}{2}}$ is given by;

$\mathbf{M_t = M_o\left(\frac{1}{2}\right)^n}$**: Where,** $\mathbf{n = \frac{t}{t_{\frac{1}{2}}}}$

Case I: Finding the half life when the final mass, M and time taken, t are given,.

- In this method, we continuously half the initial count rate or initial mass until the given count rate or final mass.
- Then we use the formula; $\mathbf{t = nt_{\frac{1}{2}}}$**.** Where, t is the time taken for the decal to half, $\mathbf{t_{\frac{1}{2}}}$ is the half life and n is the number of half lives.

Example 1:

(1994 Qn. 15): The count rate of a radioactive isotope falls from 600 counts per second to 75 counts per second in 75 minutes. Find the half life of the radio isotope.

Solution:

Method I: Using a table

$M_0 = 600\ Cs^{-1}$; $M_t = 75\ Cs^{-1}$; $t = 75s$

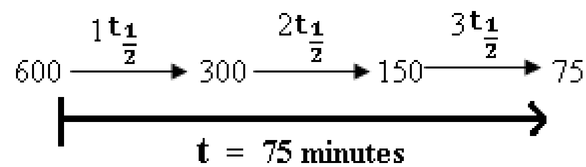
Count rate(Cs^{-1})	Number of half- lives, n
$M_0 =$ 600	0
300	1
150	2
$M_t =$ 75	3

Then from; $\mathbf{nt_{\frac{1}{2}} = t}$.

$3t_{\frac{1}{2}} = 75.$

$t_{\frac{1}{2}} = 25$ minutes

Method II: Arrow Diagram (Crude method)



Then from; $\mathbf{nt_{\frac{1}{2}} = t}$.

$3t_{\frac{1}{2}} = 75.$

$t_{\frac{1}{2}} = 25$ minutes

Method III: Using the formula

The mass remaining after a time t, M_t, when an original sample of mass M_o decays with a half- life of $t_{\frac{1}{2}}$ is given by;

$\mathbf{M_t = M_o\left(\frac{1}{2}\right)^n}$**: Where,** $\mathbf{n = \frac{t}{t_{\frac{1}{2}}}}$

$M_t = M_o\left(\frac{1}{2}\right)^n$:

$75 = 600\left(\frac{1}{2}\right)^n$:

$75 = 600(2^{-1})^n$

$$(2)^{-n} = \frac{75}{600}$$

$$2^{-n} = \frac{1}{8}$$

$$2^{-n} = 2^{-3}$$

$$-n = -3$$
$$n = 3$$

Alternatively; At the stage of;

$$2^{-n} = \frac{1}{8}$$

Introducing logarithms to base 10 on both sides;

$\log 2^{-n} = \log 0.125$

$-n\log 2 = \log 0.125$

$-n = \frac{\log 0.125}{\log 2}$

$-n = -3$

$n = 3$

Then from; $\mathbf{nt_{\frac{1}{2}} = t}$.

$3t_{\frac{1}{2}} = 75.$

$t_{\frac{1}{2}} = 25$ minutes

Example 2:

(1987 Qn. 6): After 18 hours, a sixteenth of the original mass of a radioactive isotope remained. What is the half life of the isotope.

Solution:

Method I: Using a table

Let the initial amount be N;

N =? ; $N_t = \frac{N}{16}$; t = 18 Hours

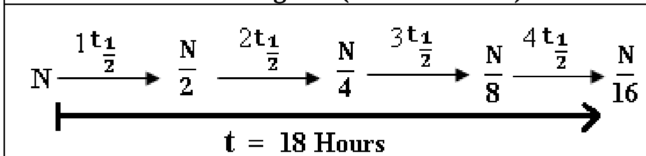
Mass	Number of half- lives, n
$M_0 = N$	0
$\frac{N}{2}$	$1\mathbf{t_{\frac{1}{2}}}$
$\frac{N}{4}$	$2\mathbf{t_{\frac{1}{2}}}$
$\frac{N}{8}$	$\mathbf{3t_{\frac{1}{2}}}$
$M_t = \frac{N}{16}$	$4\mathbf{t_{\frac{1}{2}}}$

Then from; $\mathbf{nt_{\frac{1}{2}} = t}$.

$4t_{\frac{1}{2}} = 18.$

$t_{\frac{1}{2}} = 4.5$ hours

Method II: Arrow Diagram (Crude method)



Then from; $\mathbf{nt_{\frac{1}{2}} = t}$.

$4t_{\frac{1}{2}} = 18.$

$t_{\frac{1}{2}} = 4.5$ hours

Method III: Using the formula

The mass remaining after a time t, M_t, when an original sample of mass M_o decays with a half- life of $t_{\frac{1}{2}}$ is given by;

$\mathbf{M_t = M_o\left(\frac{1}{2}\right)^n}$**: Where,** $\mathbf{n = \frac{t}{t_{\frac{1}{2}}}}$

$N_t = N\left(\frac{1}{2}\right)^n$:

$\frac{N}{16} = N\left(\frac{1}{2}\right)^n$:

$$\frac{1}{16} = \left(\frac{1}{2}\right)^n$$

$$2^{-n} = 2^{-4}$$

$$-n = -4$$
$$n = 4$$

Alternatively; At the stage of;

$$2^{-n} = \frac{1}{16}$$

Introducing logarithms to base 10 on both sides;

$\log 2^{-n} = \log 0.0625$

$-n\log 2 = \log 0.0625$

$-n = \frac{\log 0.0625}{\log 2}$

$-n = -4$

$n = 4$

Then from; $\mathbf{nt_{\frac{1}{2}} = t}$.

$4t_{\frac{1}{2}} = 18.$

$t_{\frac{1}{2}} = 4.5$ hours

Case II: Finding the mass left when half life and time taken are given

- ❖ Half the original mass continuously until we reach the time given.
- ❖ The mass that corresponds to the time given is the mass left.

Example 3:

(1994 Qn. 6): The half life of a radioactive element is 2 minutes. What fraction of the initial mass is left after 8 minutes?

Solution:

Method I: Using a table

Let the initial amount be N;

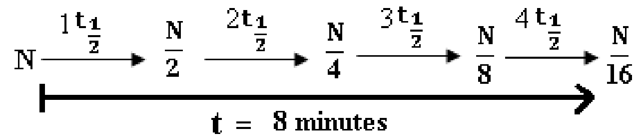
N =? ; $N_t = \frac{N}{16}$; $t_{\frac{1}{2}} = 2$ minutes; t = 8 minutes;

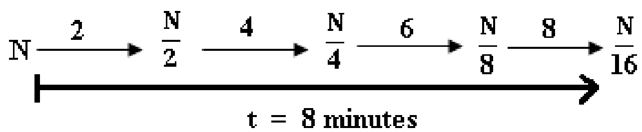
Mass	Number of half- lives, n	Time taken, t (minutes)
$M_0 = N$	0	0
$\frac{1}{2}N$	$1\mathbf{t_{\frac{1}{2}}}$	2
$\frac{1}{4}N$	$2\mathbf{t_{\frac{1}{2}}}$	4

$\frac{1}{8}N$	$3t_{\frac{1}{2}}$	6
$M_t = \frac{\mathbf{1}}{\mathbf{16}}N$	$4t_{\frac{1}{2}}$	**8**

From the table, the fraction left after 8 minutes $= \frac{1}{16}$

Method II: Arrow Diagram (Crude method)





From the above, the fraction left after 8 minutes $= \frac{1}{16}$

Method III: Using the formula

The mass remaining after a time t, M_t, when an original sample of mass M_o decays with a half- life of $t_{\frac{1}{2}}$ is given by;

$$\mathbf{M_t = M_o\left(\frac{1}{2}\right)^n : Where,\ n = \frac{t}{t_{\frac{1}{2}}}}$$

$$n = \frac{t}{t_{\frac{1}{2}}} = \frac{8}{2} = 4$$

$$N_t = N\left(\frac{1}{2}\right)^n:$$

$$N_t = N\left(\frac{1}{2}\right)^4:$$

$$\frac{N_t}{N} = \left(\frac{1}{2}\right)^4$$

$$\frac{N_t}{N} = \frac{1}{16}$$

Thus, the fraction left after 8 minutes $= \frac{1}{16}$

Example 4:

(1994 Qn. 6): The half life of Uranium is 24 days. Calculate the mass of Uranium that remains after 120 days if the initial mass is 64g.

Solution:

Method I: Using a table

Let the initial amount be N;

$M_0 = 64\ g$; $M_t = ?$; $t_{\frac{1}{2}} = 24$ days; $t = 120$ days;

Mass (g)	Number of half- lives, n	Time taken, t (days)
$M_0 = 64$	0	0
32	$1t_{\frac{1}{2}}$	24
16	$2t_{\frac{1}{2}}$	48
8	$3t_{\frac{1}{2}}$	72
4	$4t_{\frac{1}{2}}$	96
$M_t =$ **2**	$5t_{\frac{1}{2}}$	**120**

From the table, the mass left after 120 days $= \mathbf{2\ g}$

Method II: Arrow Diagram (Crude method)

Try using the crude method, you will still get themass left after 120 days $= \mathbf{2\ g}$

Method III: Using the formula

The mass remaining after a time t, M_t, when an original sample of mass M_o decays with a half- life of $t_{\frac{1}{2}}$ is given by;

$$\mathbf{M_t = M_o\left(\frac{1}{2}\right)^n : Where,\ n = \frac{t}{t_{\frac{1}{2}}}}$$

$$n = \frac{t}{t_{\frac{1}{2}}} = \frac{120}{24} = 5$$

$$N_t = N\left(\frac{1}{2}\right)^n:$$

$$N_t = 64 \times \left(\frac{1}{2}\right)^5:$$

$$N_t = 64 \times \frac{1}{32}$$

$$N_t = 2 \quad :$$

Thus, the mass left after 120 days = 2 g

Case III: Finding the mass decayed when half life and time taken are given

- ❖ Half the original mass continuously until we reach the time given.
- ❖ The mass that corresponds to the time given is the mass left.
- ❖ Find the mass decayed from the expression:

  Mass decayed = Original mass − Mass left

Where**:** Original mass = mass at a time t = 0.
Mass left = mass corresponding to the given time

Example 5:

(2001 Qn. 4) (e) : The half life of a radioactive substance is 24 days. Calculate the mass of the substance which has decayed after 72 days, if the original mass is 0.64g.

Solution:

Method I: Using a table

Let the initial amount be N;

$M_0 = 0.64\ g$; $M_t = ?$; $t_{\frac{1}{2}} = 24$ days; $t = 72$ days;

Mass (g)	Number of	Time

	half- lives, n	taken, t (days)
$M_0 = 0.64$	0	0
0.32	$1t_{\frac{1}{2}}$	24
0.16	$2t_{\frac{1}{2}}$	48
$M_t = 0.08$	$3t_{\frac{1}{2}}$	72

From the table, the mass left after 72 days = 0.08 g

Mass decayed = Original mass − Mass left

Mass decayed = 0.64 − 0.08

Mass decayed = **0.56 g**

Method II: Arrow Diagram (Crude method)

Try using the crude method, you will still get the mass left after 72 days = **0.08 g** andMass decayed = **0.56 g**

Method III: Using the formula

The mass remaining after a time t, M_t , when an original sample of mass $M_o$decays with a half- life of $t_{\frac{1}{2}}$ is given by;

$$\mathbf{M_t = M_o\left(\frac{1}{2}\right)^n} \textbf{: Where, } \mathbf{n = \frac{t}{t_{\frac{1}{2}}}}$$

$$n = \frac{t}{t_{\frac{1}{2}}} = \frac{72}{24} = 3$$

$$N_t = N\left(\frac{1}{2}\right)^n:$$

$$N_t = 0.64 \times \left(\frac{1}{2}\right)^3:$$

$$N_t = 0.64 \times \frac{1}{8}$$

$$N_t = 0.08 \quad :$$

Thus, the mass left after 72 days = 0.08 g

Mass decayed = Original mass − Mass left

Mass decayed = 0.64 − 0.08

Mass decayed = **0.56 g**

Example 6:

(2002 Qn. 23): The half life of a radio active substance is 10s. How long will it take for a mass of of 16g of the substance to reduce to 2g? **[Ans: t = 30s].**

Example 7:

(2008. Qn.8) (c): A radioactive element has a half life of 4 minutes. Given that the original count rate is 256 counts per minute,

(i) Find the time taken to reach a count rate of 16 counts per minute. **[Ans: t = 16 minutes]**

(ii) What fraction of the original number of atoms will be left by the time the count rate is 16 counts per minute?

[Ans: Fraction left $= \frac{1}{16}$**]**

Example 8:

(a) The table below shows results obtained in an experiment to determine the half life of a radioactive substance.

Count rate	250	175	76	38	25
Time (min.)	0	5	10	15	20

Draw a graph of count rate against time and use it to determine the half life of the radioactive substance.

(b) Explain why radioactive substances must be stored in thick lead containers.

(c) The nuclide $^{220}_{84}\mathbf{X}$ has a half life of 3000 years and decays to nuclide Y by emission of an alpha particle. and three beta particles

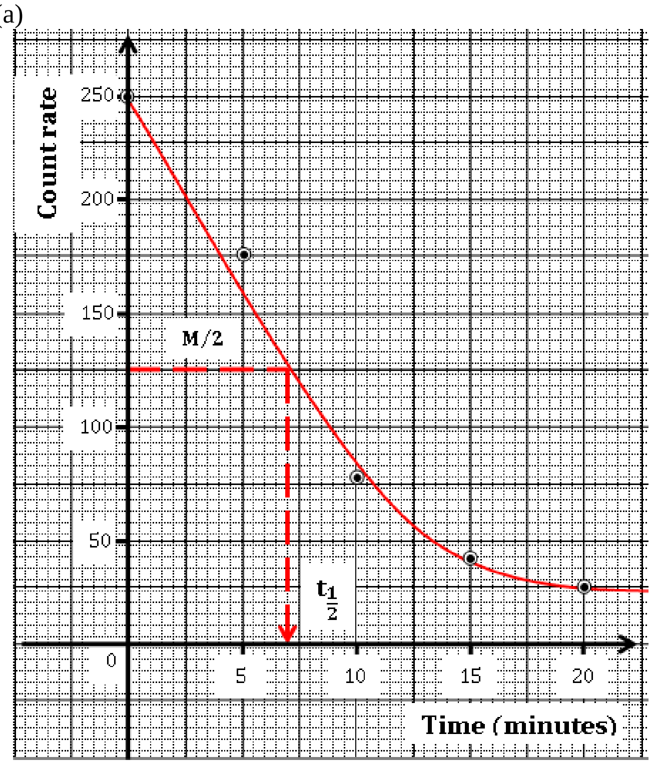
(i) State the meaning of the statement "Half- life of a nuclide is 3000 years."

(ii) Write a balanced equation for the decay process.

(iii) What percentage of the original sample of the nuclide, remains after three half lives.

Solution:

(a)



From the graph above, half life,

$$\mathbf{t_{\frac{1}{2}}} = 5 + 4(0.5)$$
$$= \mathbf{7minutes}$$

(b) Radioactive materials emit radiations, alpha, beta particles and gamma rays which are harmful to human life. Lead containers absorb these radiations and prevent them from coming into contact with people.

(c) (i) The element takes 3000 years to decay to half its original mass.

(ii)

$$^{220}_{84}X \longrightarrow {}^{216}_{85}Y + {}^{4}_{2}He + 3\,{}^{0}_{-1}e$$

(iii)

Method I: Using a table

%age mass	Number of half- lives
100	0
50	1
25	2
12.5	3

Therefore, 12.5% of the original mass will remain after 3 half lives.

Method II: Arrow Diagram (Crude method)

$$220 \xrightarrow{t_{\frac{1}{2}}} 110 \xrightarrow{t_{\frac{1}{2}}} 55 \xrightarrow{t_{\frac{1}{2}}} 27.5$$

Thus the percentage of the original sample that remains after 3 half lives is given by;

$$= \frac{\text{Mass left}}{\text{Original mass}} \times 100\%$$

$$= \frac{27.5}{220} \times 100 = 12.5\%$$

Method III: Using the formula

The mass remaining after a time t, M_t , when an original sample of mass M_o decays with a half- life of $t_{\frac{1}{2}}$ is given by;

$$\mathbf{M_t = M_o \left(\frac{1}{2}\right)^n : Where, \ n = \frac{t}{t_{\frac{1}{2}}}}$$

$M_t = M_o \left(\frac{1}{2}\right)^n$:

$M_t = 220 \left(\frac{1}{2}\right)^3$:

$M_t = 220 \times \frac{1}{8}$:

$M_t = 27.5$ g

Thus the percentage of the original sample that remains after 3 half lives is given by;

$= \frac{\text{Mass left}}{\text{Original mass}} \times 100\%$

$= \frac{27.5}{220} \times 100\%$

$= 12.5\%$

EXERCISE:

1. If a radioactive element of mass 32 decays to 2g in 96days .calculate the half life.

2. A certain radioactive substance takes 120years to decay from 2g to 0.125g. Find the half life.

3. The half life of substance is 5days. Find how long it takes for its mass to disintegrate from 64g to 2g.

4. A radioactive sample has a half life of 3×10^3 years. Find how long it takes for three quarters of the sample to decay.

5. The activity of a radioactive element with a half life of 30 days is 2400 counts per second. Find the activity of the element after 120 days.

6. The count rate from a radioactive source is 138 counts per minute when the back ground rate is 10 counts per minute. If the half life of the source is 6 days, find the count rate after 18 days. [**Ans:** 16 counts per minute]

7. A radioactive element has a half life of 4years .if after 24hours 0.15g remains calculate the initial mass of the radioactive material.

8. A certain mass of a radioactive material contains 2.7×10^{24} atoms, how many atoms decayed after 3200years if the half life of material is 1600years?
   [**Ans:** 2.025×10^{24} atoms]

9. (a) The activity of a radioactive source decreases from 4000 counts per minute to 250 counts per minute in 40 minutes. What is the half life of the source?

   (b) A carbon source initially contains 8×10^6 atoms. Calculate the time taken for 7.75×10^6 atoms to decay.

10. The table below shows the count rates of a certain radioactive material.

Count rate (s^{-1})	6400	5380	3810	2700	1910	1350
Time (min)	0	1	3	4	7	9

Plot a suitable graph and use it to find the half life of the material.

11. The following values obtained from the readings of a rate meter from a radioactive isotope of iodine

Time (min)	0	5	10	15	20
Count rate (min^{-1})	295	158	86	47	25

Plot a suitable graph and find the half life of the radioactive iodine.

12. The following figures were obtained from Geiger miller counter due to ignition if the sample of radon gas

Time (min)	0	102	155	….	300
Rate (min^{-1})	1600	…	200	100	50

(a) i) Plot a graph of count rate against time
 ii) determine the half life
 iii) Find the missing values

(b) (i) what is the count rate after 200 minutes
 (ii) after how many minutes is the count rate 1000 minutes.

13. The following figures were obtained from Geiger miler counter due to ignition of the sample of radon gas

Time (min)	0	102	155	208	300
Rate (min^{-1})	1600	1400	200	100	50

a) Plot a graph of count rate against time.
b) Determine the half life.
c) What is the count rate after 200 minutes?
d) After how many minutes is the count rate 1000 minutes?

NUCLEAR REACTIONS:

A nuclear reaction is a process in which energy is produced by either splitting a heavy nucleus or combining two lighter nuclei at high temperatures.

A nuclear reaction takes place in a nuclear reactor.

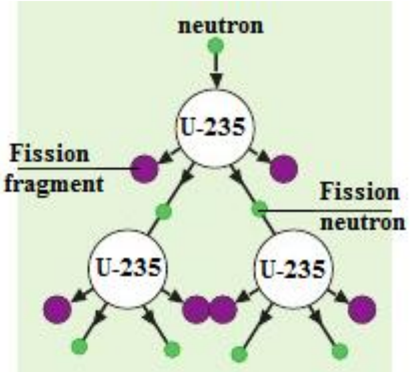
Types of nuclear reactions:

(i) Nuclear fission

This is the splitting of a heavy unstable nucleus into two lighter nuclei with the release of energy.
This process can be started by bombardment of a heavy nucleus with a fast moving neutron. The products of the process are two light atom and more neutrons which can make the process continue.
Note: *Neutrons are used in nuclear reactions because they have no charge. Thus they cannot be repelleled by the electrons around the nucleus or the protons inside the nucleus of the atom.*

Example:
When Uranium – 235 is bombarded with slow moving neutrons, Uranium – 236 is formed.
Uranium – 236 then under goes nuclear fission to form Barium, (Ba) and Krypton, (Kr) with the release of neutrons and energy according to the equation below.

$$\mathbf{{}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{236}_{92}U \rightarrow {}^{144}_{56}Ba + {}^{92}_{36}Kr + 2{}^{1}_{0}n + Energy}$$

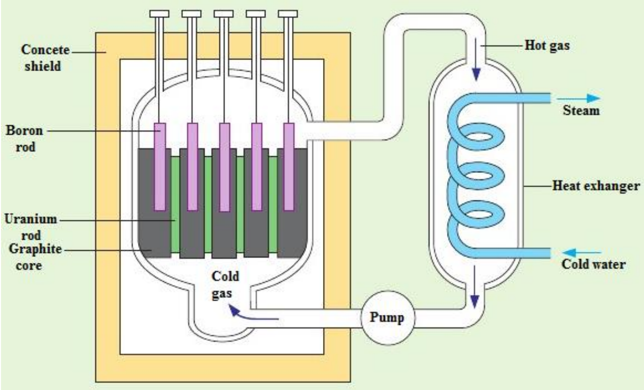


The energy released in a single nuclear fission reaction of a single Uranium atom is about **200 MeV.**

Conditions for nuclear fission to occur:
- ❖ Low temperatures.
- ❖ Fast moving neutrons

Application of nuclear fission:
- ❖ Used in making atomic bombs.
- ❖ Used to generate electricity.
- ❖ Used to generate heat energy on large scale.

Note: Nuclear reactors make use of controlled nuclear fission while **atomic bombs** make use of un controlled nuclear fission.



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(ii) **Nuclear fusion:**

This is the union (or combining) of two light nuclei at high temperatures to form a heavy nucleus with the release of energy.

Example:
When two Deuterium (Heavy hydrogen) nuclei combine at very high temperature (of about 10^8K), Helium – 3 and a neutron are produced accompanied by the release of energy according to the equation below.

$$\mathbf{{}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + {}^{1}_{0}n + Energy}$$

Reactions of this type occur in the in the sun and stars and are the source of the sun's or star's energy.

Conditions for nuclear fission to occur:
- ❖ Very high temperatures.
- ❖ The light nuclei should be at very high speed to over nuclear division.

Application of nuclear fission:
- ❖ Used to produce hydrogen.
- ❖ Used in making atomic bombs.
- ❖ Used to generate electricity.
- ❖ Used to generate heat energy on large scale.

Similarities between nuclear fission and nuclear fusion.
- ❖ In both nuclear reactions, nuclear energy is released which can be used to generate electricity, heat or in atomic bombs.
- ❖ Energy changes in a nuclear reactor:

$$\begin{pmatrix}\text{Nuclear}\\ \text{energy}\end{pmatrix} \rightarrow \begin{pmatrix}\text{Chemical}\\ \text{energy}\end{pmatrix} \rightarrow \begin{pmatrix}\text{Kinetic}\\ \text{energy}\end{pmatrix} \rightarrow \begin{pmatrix}\text{Electrical}\\ \text{energy}\end{pmatrix}$$

Differences between nuclear fission and nuclear fusion.

Nuclear fission	Nuclear fusion
Is the disintegration of a heavy nucleus into two lighter nuclei..	Is the combining of two lighter nuclei to form a heavy nucleus.
Requires low temperature.	Requires high temperatures
Requires slow neutrons for bombardment	Neutrons are not required. For fusion to occur
High energy is released	Lower energy is released
Results into 4 products	Results into 3 products

EXERCISE:

1. (a) What is meant by **radio activity**?
(b) The equation below shows a reaction which takes place in a nuclear reactor.
$${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{236}_{92}U \rightarrow {}^{141}_{x}Ba + {}^{y}_{36}Kr + 3{}^{1}_{0}n + \text{Energy}$$
(i) Name the reaction represented by the equation
(ii) Find the values of x and y.

2. **(1991 Qn. 1).** The process whereby the nuclei of alight elements combine to form a heavy nuclei is called?
A. Fission B. Fusion
C. Ionisation D. Radioactivity

3. **(1993 Qn. 22).** The process by which a heavy nucleus split to form lighter nuclei is called?
   A. Fission B. Fusion
   C. Ionisation D. Radioactivity

4. **(1994 Qn. 18).** $^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{144}_{56}\text{Ba} + ^{92}_{36}\text{Kr} + 2x$
The equation above represents a nuclear reaction. Identify ***x*.**
   A. Proton B. Neutron
   C. Alpha particle D. Beta particle

5. **(2000 Qn. 7).** In the atomic bomb, energy is produced by:
   A. Fission B. Fusion
   C. Thermionic emission D. Radioactivity

6. **(2001 Qn. 17).** When Uranium – 235 is bombarded with a neutron, it splits according to the equation;
$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{\text{M}}_{\text{N}}\mathbf{P} + ^{92}_{36}\text{Kr} + 3^{1}_{0}\text{n}$$

M and N on P represent;

	M	**N**
A	56	141
B	141	56
C	199	36
D	107	128

7. (a) (i) Distinguish between nuclear fission and nuclear fusion.
   (ii) two conditions necessary for each to occur.

(b) State **one** example where nuclear fusion occurs naturally.

(c) State **one** use of nuclear fission.

(d) The following nuclear reaction takes place when a neutron bombards a sulphur atom.
$$^{34}_{6}\mathbf{S} \quad + \quad ^{1}_{0}\mathbf{n} \quad \rightarrow \quad ^{a}_{b}\mathbf{Y}$$

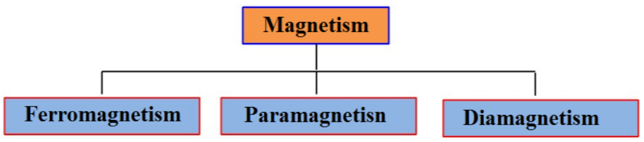
(i) Describe the composition of nuclide Y formed.
(ii) Nuclide Y decays by emission of an alpha particle and a gamma ray. Find the changes in mass and atomic number of the nuclide.

8. MAGNETISM AND ELECTROMAGNETISM

MAGNETISM

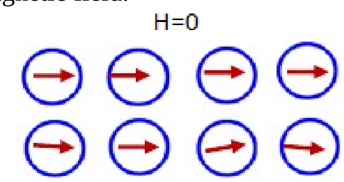
Magnetism is the force exerted by a magnetic field.
A **magnet** is a piece of metal that attracts other metals. It has two poles i.e. North Pole and South Pole.
A magnet is a substance which has the capacity of attracting and holding the other substance e.g iron, steel, -Nickel etc.

Examples of magnets include Lodestone magnet, which is a form of Iron (ii) oxide called magnetite which is a naturally occurring magnet.
It always points in north and south directions if it is freely suspended.
Depending on the existence and alignment of magnetic moments with or without application of magnetic field, three types of magnetism can be defined: *Diamagnetism, Paramagnetism* and *Ferromagnetism.*



Types of material	Definition and magnetic properties.	Examples
(a) Magnetic material	This is a material which has the property of being attracted or repelled by a magnet.	iron, cobalt, steel, nickel, gadolinium, dysprosium e.t.c.

Ferromagnetism is where atoms of a material have parallelaligned permanent magnetic moments inthe absence of an external magnetic field.

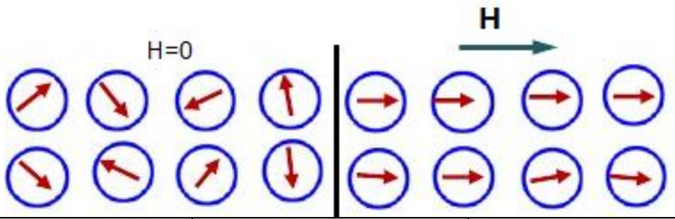


H is the magnetic field strength.

Ferro-magnetic materials	These are materials which are strongly attracted by a magnet. Their magnetic dipoles line up more readily. When placed in a magnetic field, they retain their magnetism after the external field is removed.	iron, cobalt, steel, nickel, gadolinium, dysprosium e.t.c.
(b)Non-magnetic materials	These are materials which are rarely attracted or repelled by amagnet. However, they also have some magnetic properties under certain conditions.	e.g. copper, brass, wood, plastic, wood, rubber, glass etc.

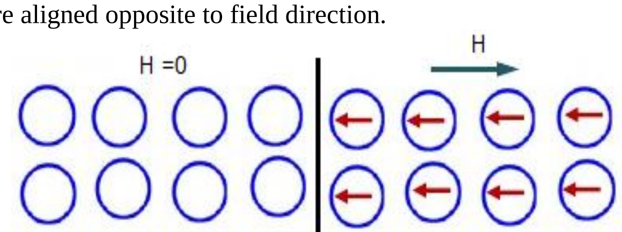
(i) Para magnetism is wherethe cancellation of magnetic moments between electron pairs is incomplete and hence magnetic moments exist without any external magnetic field. However, the magnetic moments are randomly aligned andhence no net magnetization without any external field.

When a magnetic field is applied all the dipole moments arealigned in the direction of the field.



Para-magnetic materials	***These are materials that are slightly or weakly or feebly attracted by a strong magnetic field.*** When a magnetic field is applied all the dipole moments are aligned in the direction of the field. They become more magnetic when they are very cold.	Aluminium, Na, Ca, Mg, K, Li, Wood, brass, copper, Tin, (Mainly transitional metals: e.g Mn, platinum, uranium). etc.

(ii) Diamagnetism is a weak form of magnetism which arises only when an external field is applied.
There is no magnetic dipoles in the absence of a magnetic field and when a magnetic field is applied the dipole moments are aligned opposite to field direction.



(i) Dia-magnetic materials	***These are materials that are weakly or feebly repelled by a strong magnetic field.*** When in a strong magnetic field, they become weakly magnetized in a direction opposite to the magnetizing field.	Copper, carbon, Zinc,, gold, Bismuth, Hydrogen, chlorine, Rare gases, Lead, mercury, Benzene,water e.t.c.

<u>**Note:**</u> Magnets strongly attract ferromagnetic materials, weakly attract paramagnetic materials and weakly repel diamagnetic materials.

HARD AND SOFT MAGNETIC MATERIALS

Hard magnetic materials.

These are ferro-magnetic materials which are not easily magnetized but retain their magnetism for a long period.

They can be produced by heating and sudden cooling.

E.g Carbon steel, Tungesten steel, AliNiCo (Al, Ni, Co) alloy, Chromium steel

Hard magnetic materials are used for making permanent magnets used in instruments like

- ✓ Electricity meter
- ✓ Radio loudspeaker
- ✓ Telephone receiver

Soft magnetic materials

These are ferro-magnetic materials which are easily magnetized but lose their magnetism easily.

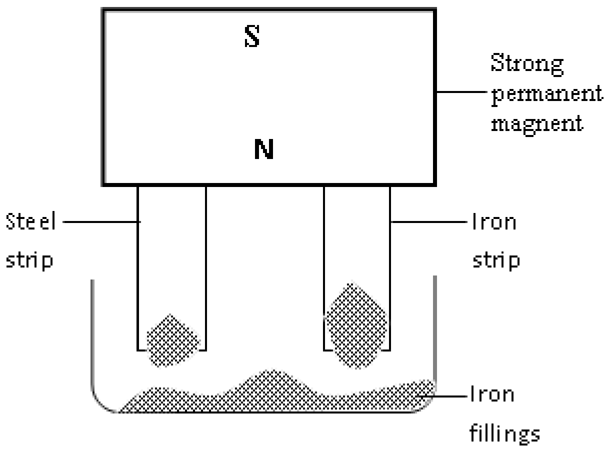
They can be produced by heating and slow cooling.

E.g iron, iron silicon alloys, ferrites, Garnets

Soft magnetic materials are used in

- Transformer
- Magnetic keepers
- Making of temporary magnets used in: electric bells, relays, electromagnets, dynamos, motor armatures, etc

Experiment to distinguish between hard and soft magnetic materials



Procedure

Two strips of iron and steel are attracted to a magnet as shownabove

The arrangement is then dipped in the iron fillings.

Observations:

(i) More iron fillings are attracted to the iron strip thanthe steel strip. This is because the induced magnetism in iron strip is stronger than that in steel. Iron is easily magnetized than steel.

(ii) On removing the permanent magnet almost all iron fillings on iron fall off and very few if any fall from steel.

This is because the induced magnetism in iron is temporary while induced magnetism in steel is permanent.

Conclusion

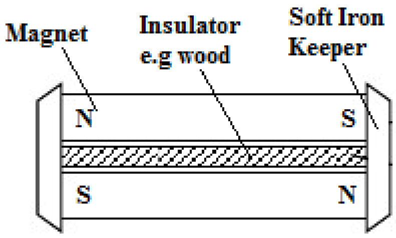
Iron is a soft magnetic material i.e temporarily magnetized while steel is permanently magnetized and thus hard magnetic material.

<u>Assignment:</u> give some differences between steel and iron as magnetic materials

Storing magnets

Magnets tend to become weaker with time due to repulsion of the free like poles of molecular magnets near the ends. This upsets the alignment of the atomic dipoles.

To prevent this self demagnetization of magnets, bar magnets are stored in pairs with un like poles put together and pieces of soft iron called <u>magnetic keepers</u> are placed at the end as shown below.



<u>Explanation</u>

How magnetic keepers are used to store magnets

- Magnetic keepers become induced magnets and their poles neutralize the poles of the bar magnets. In other words, the keepers and the bar magnets **form a closed loop with no free poles thus eliminating self demagnetization.**

Uses of magnets

- Used in industries to lift heavy loads
- Tapes and tape recorders use a special type of magnetic materials with very fine powder where each particle can be magnetized
- Used in electric motors and generators to rotate the wheels of a machine
- Used in a relay reed switch and as a circuit breakers
- Used in telephone receivers and loud speakers. etc

Polarity of a magnet

Polarity of a magnet refers to the points at the ends of a magnet that have opposite magnetic properties where the magnetic strength is more powerful. The points are called poles.

Magnets are never found as monopoles. (Single magnetic poles). Every magnet has two poles called North pole(N) and South pole (S).

The North Pole is the pole which is attracted to the geographic north and the South Pole is the pole which is attracted to the geographic south.

<u>Law of magnetism:</u>

It states that, unlike poles attract and like poles repel.

Note: The attraction or repulsion between two magnets depends on the strength of the magnets and the distance between them.

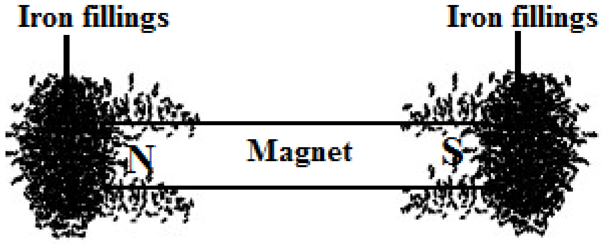
The further apart the magnets are, the less they attract or repel one another.

steel

<u>Properties of magnets</u>

- Magnets attract only certain materials.
- Magnets have two ends called magnetic poles. Its at these ends where the attractive forces are strongest.
- Magnets with two poles i.e. North Pole & South Pole when freely suspended come to rest in the north-south direction.
- Magnets have a basic law which states that unlike poles attract while like poles repel.

{Assn. Describe an experiment to show that attractive forces of a magnet are strongest at its ends}



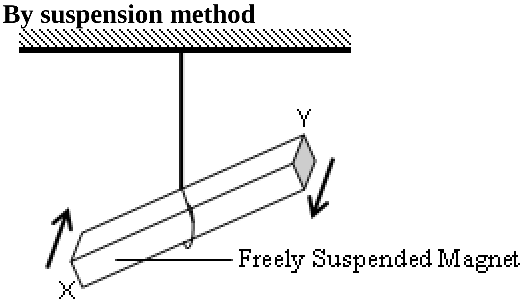
- This is shown by dipping a magnet into a container of iron fillings.
- Iron fillings are seen in large numbers at the magnetic poles than in the middle of the magnet.

{Assn, Describe an experiment to verify the law of magnetism}

{Assn. Describe an experiment to show that a freely suspended magnet comes to rest in the north-south direction}

Testing polarity [How to identify the pole of a magnet]

(a) By suspension method



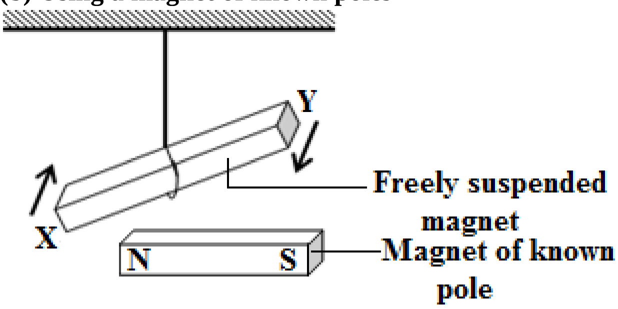
Procedures:

- ✓ Suspend a given un marked magnet with a help of a thread so that it can rotate freely.
- ✓ Wait until the magnet comes to rest.

Observation:
The magnet points in north-south direction.

Conclusion:
The end facing the geographic north is the North pole and the end facing the geographic south is the south pole.

(b) Using a magnet of known poles



Procedures:

- ✓ Suspend an iron bar and mark its ends X & Y
- ✓ Bring the N-pole of a magnet slowly towards the end X and after towards end Y. Note the observations in each case.

- ✓ **Repeat** the above procedures using the S- pole of a known pole magnet.

Observations

(i) Attraction: Probably due to attraction between unlike poles or due to attraction between a magnet and a magnetic material.
Therefore we cannot make a conclusion here.

(ii) Repulsion: It is due to like poles. If repulsion occurs, then the unknown pole is similar to the known pole of the magnet.
In this case we can make our conclusion of the unknown pole.

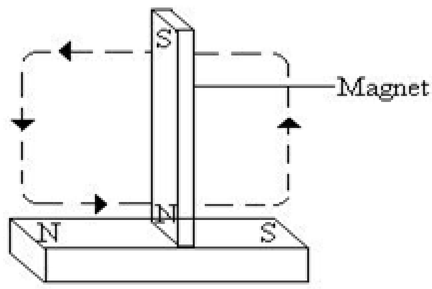
	North Pole	South Pole	Magnetic Substance
North Pole	**Repulsion**	Attraction	Attraction
South Pole	Attraction	**Repulsion**	Attraction
Magnetic Substances	Attraction	Attraction	No effect

Note: Repulsion is the only sure way of testing for the polarity of a magnet and not attraction because attraction occurs for both magnets and magnetic materials.

Methods of magnetizing a magnet

(i) Single touch/stroke method
(ii) Divided/double touch/stroke method.
(iii) Electrical method using direct current.
(iv) Induction method.
(v) Absolute method

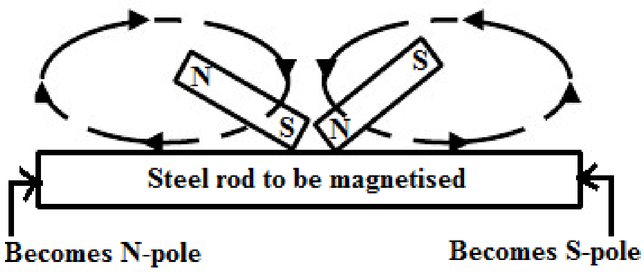
Single touch method



In this method, the steel bar is stroked from end to end several times in one direction with one pole of a permanent magnet.

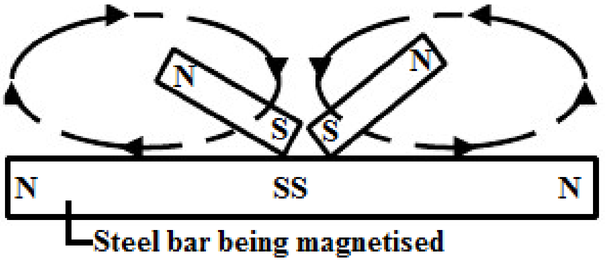
The polarity produced at the end of the bar is of the opposite kind to that of the stroking pole.

Double touch method



In this method, the steel bar is stroked several times from the centre outwards with unlike poles of the two permanent magnets.
After each stroke, the stroking pole should be raised higher and higher to avoid weakening of the induced magnetism in the steel bar.
The polarity produced at the end of the bar is also of the opposite kind to that of the stroking pole.

Consequent pole magnet.
Consequent poles of a magnet are double like poles both at the centre and at the ends.

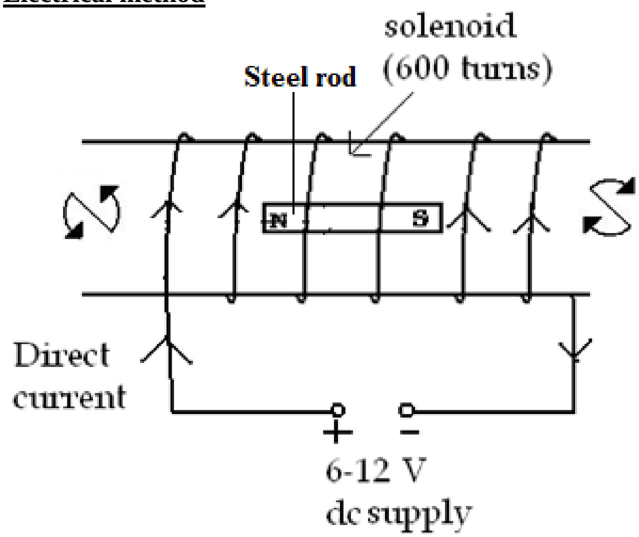


Consequent poles are obtained when a steel bar is double stroked using two like poles from the centre outwards as shown below.

If such a magnet is freely suspended in air, it does not come to rest.

Qn. (a) Whatis a consequent pole magnet?
(b) Briefly describe how a consequent pole magnet is made..

Electrical method



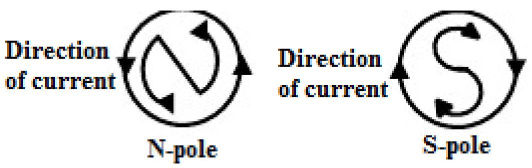
The material to be magnetized is inserted into a solenoid to which a steady d.c is connected to flow.

The current is switched on for a few minutes and then off. When the steel bar is removed, it is found to be magnetized.

The current flowing in the same direction makes the atomic magnets in the Domains to point in same direction.

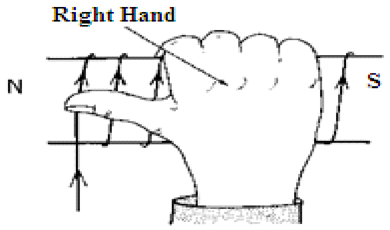
Determining the polarity of the magnet produced.
The polarity of the magnet produced depends on the direction of the current at the ends of the solenoid.
It can be established by using one of the following methods:

(i) Using the direction of flow of current.
Look at the ends of the solenoid;

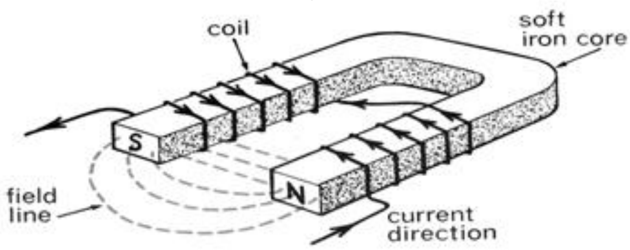


- If it is flowing in an anti-clockwise direction, then that will be the **North Pole.**
- If the current is flowing in a clockwise direction, that will be a **South Pole.**

(ii) Using the Right hand grip rule.
Grip the solenoid such that the fingers point in the direction of current in the solenoid. Then, the thumb points in the North pole.

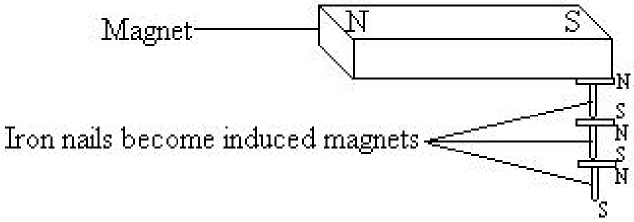


Note:
Similar procedure is used for magnetizing a U – shaped piece of steel shown below, by electrical method..

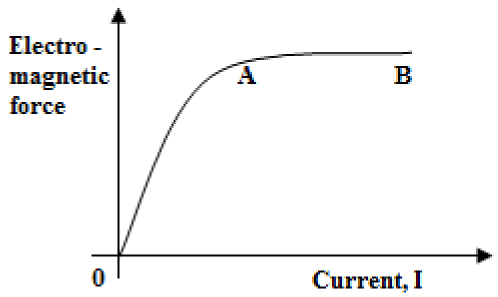


Absolute method.
In this method, the steel bar is heated to red hot, hammered and allowed to cool while facing in the north-south direction.

Induced magnetism
A piece of un-magnetized steel/iron becomes magnetized when its either near or in contact with a pole of a magnet. This is a process called induced magnetism or magnetization by magnetic induction. The end nearest to the pole of the magnet acquires an opposite pole.



A graph to show variation of electromagnetic force with current.



Explanation of the features of the graph.
Along OA: Increase in current, I increases the force of attraction between the electromagnet and the soft iron on the spring balance.
With the increasing current, I, the number of magnetic domains align in the same direction thereby increasing the force of attraction between the electromagnet and the

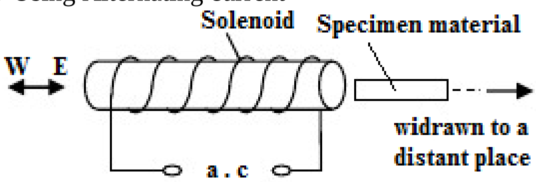
soft iron.

Along AB: The force of attraction remains constant inspite the increase in current. This is because all the domains in the soft iron have been aligned in the same direction. That is to say magnetic saturation has occurred in the soft iron.

❖ **Demagnetization**

It is the process by which a magnet loses its magnetism. i.e. the atomic magnets are now in a random arrangement and facing in different directions.

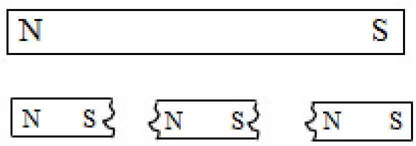
It can be demagnetized by:

Method	Explanation
(i) Hammering	The magnet is hammered while lying in the E-W direction.
(ii) Dropping	The magnet is dropped on a hard surface several times.
(iii) Heating	The magnet is heated until it becomes red hot and then allowed to cool while lying in the East-West direction.
(iv) Using Alternating current  -The magnet is placed in a solenoid whose ends are connected to an a.c supply. -It is then withdrawn from the solenoid slowly so that the changing magnetic flux destroys the order of alignment of the atomic magnets.	

Note: the demagnetized magnet should be removed in an East-West direction to avoid magnetization bythe earth field.

The domain theory of magnetism

A magnet is made up of small magnets lined up with their north poles pointing in the same direction; this is illustrated when the magnet is broken into two pieces intending to separate the North Pole and the South Pole as shown below.

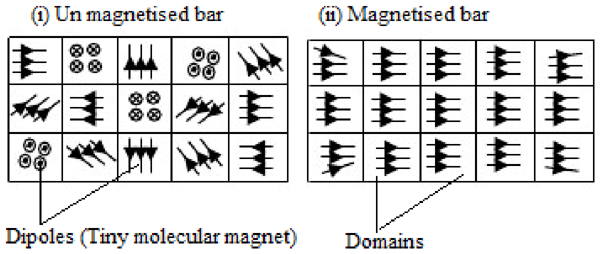


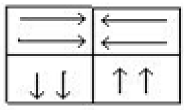
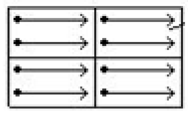
No matter how many times the magnet is broken, the small pieces will still be magnets. These atomic magnets are called magnetic di- poles.

In a magnetic substance e.g magnetized steel bar, there are a number of magnetized region called domains. Domains are a grip of atoms which are tied magnets called dipoles.

Domain theory states that in an un magnetized substance the dip holes in all domains are not aligned, so when the magnet is made, the domain are aligned in the same direction

Once they are all aligned, the substance can't be magnetized any further and it is said to be magnetically saturated.



Magnetic dipole (molecular magnet)	Magnetic material in un magnetized state	Magnetic material in magnetized state
		

QN. Explain in terms of the molecular theory how a steel bar gets magnetized and demagnetized.

When a magnet is stroked on the steel bar the magnet domain are forced to align in the direction of the magnetic field from the magnet. They do so and remain in that direction hence the bar gets magnetized.

However, when a magnet is heated strongly, dropped on a rough surface or alternating current passed through it, the domain is set to point in opposite directions which aren't north – south hence weakening the magnet. This is called demagnetization

Magnetic saturation:

When a magnetic material is magnetized, it reaches a point where it cannot be magnetized further. This is called **magnetic saturation.**

It is the limit beyond which the strength of a magnet can't be increased at constant temperature.

QN. Explain why increase in temperature destroys the magnetism of a magnet.

When a substance is heated, molecules vibrate with greater energy, these increased vibrations destroy alignment of tiny magnets in the domain and the magnetism is decrease.

MAGNETIC FIELDS

A magnetic Field is a region or space in which:

- A magnetic dipole (magnet) experiences a force.
- A current carrying conductor experiences a force or a moving charge experiences a force.
- An emf is induced in a moving conductor.

Magnetic flux.

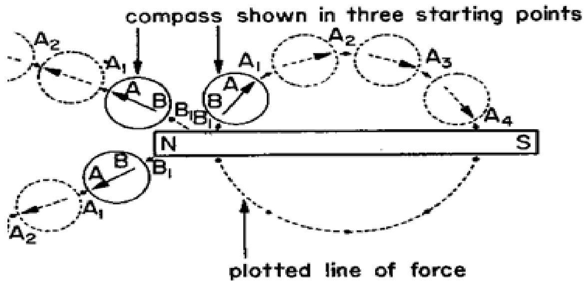
Magnetic flux is a group of magnetic field lines passing through a certain area.

Field lines are used to represent the direction and magnitude of the magnetic field. The strength of the magnetic field is proportional to the density of the field lines.

The direction o the magnetic field is represented by the magnetic field lines. The magnetic field lines are taken to pass through the magnet, emerging from the North Pole and returning via the South Pole. The lines are continuous and do not cross each other.

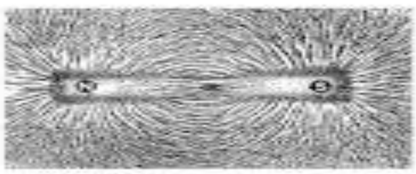
Magnetic lines of force do not intersect or touch and can pass through a non-magnetic substance.

Methods of locating magnetic flux
(i) Using a plotting compass.



- ❖ Place a magnet on a flat surface and then place a piece of paper on top of the magnet.
- ❖ Place a plotting compass near one pole of the magnet, note and mark the position of the North pole of the compass needle using a pencil dot.
- ❖ Move the compass needle onto the dot marked on the paper and make a second dot.
- ❖ Continue the process until you reach the south pole of the magnet.
- ❖ Join the dots to give a line of force and show the direction of the force using an arrow.
This method is slow but suitable for weak fields.

(ii) Using Iron fillings.

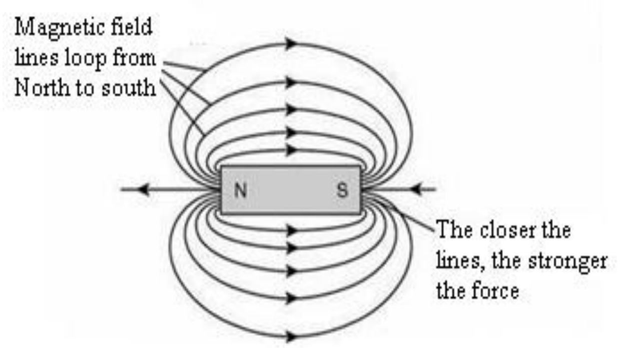


- ❖ Place a magnet on a flat surface and then place a piece of paper on top of the magnet.
- ❖ Sprinkle iron fillings all over the paper.
- ❖ Tap the paper gently.

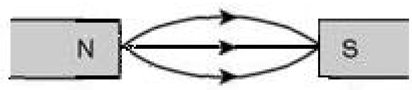
<u>Observation:</u> The iron fillings re-arrange themselves as shown above.
The method is quick but not suitable for weak magnetic fields.

<u>Magnetic flux patterns</u>

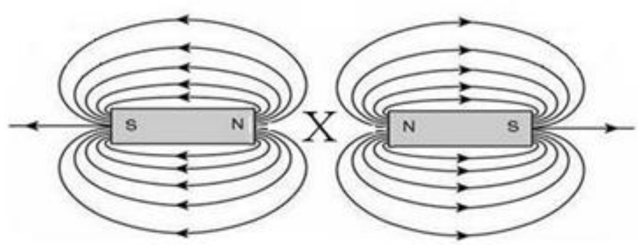
(a) Isolated bar magnet



(b) Unlike poles close together (attraction)

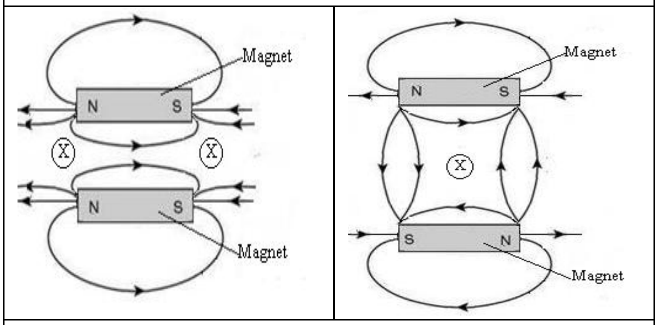


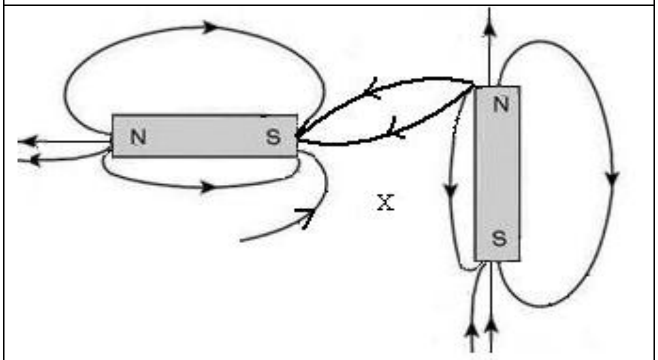
(b) Two like poles (repulsion)



<u>A neutral point in a magnetic fields</u>

A neutral point is a point in a magnetic field where the resultant magnetic field strength is zero (0). The opposing magnetic fields are of equal strength and therefore cancel out.





Magnetic shielding or screening
This is the creation of a magnetically neutral space or region in the neighbourhood of the magnetic field irrespective of the strength of the field.

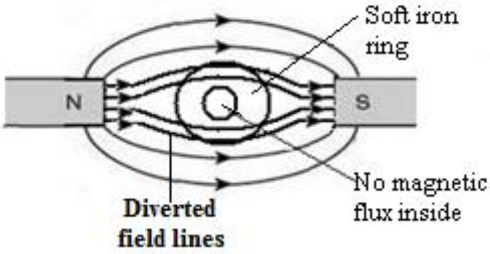
Iron has the ability of drawing and concentrating all the flux from its surroundings through itself. It is thus said to be more **permeable** to the magnetic flux than air.

Iron in form of a ring causes the lines of force to pass through its walls and no magnetic flux passes the surrounding ring.
The space inside the ring is said to be shielded or screened from magnetic flux.

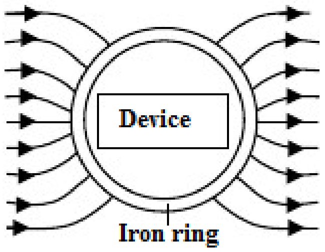
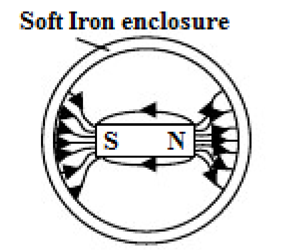
All lines of force incident on the ring induce magnetism into it. These create a neutral region inside the ring
Magnetic shielding can be applied

- In non digital watches
- In T.V tubes and cathode ray tubes
- In electron beams
-

They are used to shield them from external magnetic field by placing a strong iron cylinder along the neck of the tube.

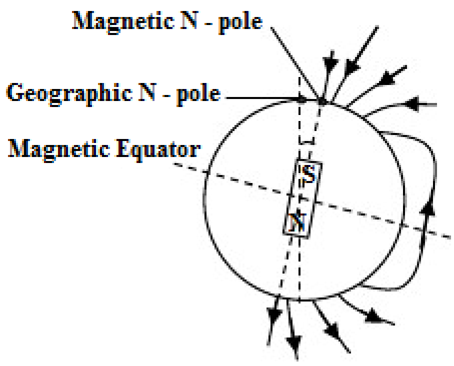


Magnetic screening may be applied in order to:
(i) protect a device from a magnetic field in the surroundings. This is done by placing the device in a soft iron enclosure.
(ii) prevent the magnetic field in one place from spreading to the surroundings. In this case the magnetic field is enclosed by soft iron.

	
The magnetic lines of force pass through the soft iron and never reach the inside of the enclosure.	The magnetic lines of force circulate through the soft iron ring without reaching the outside.

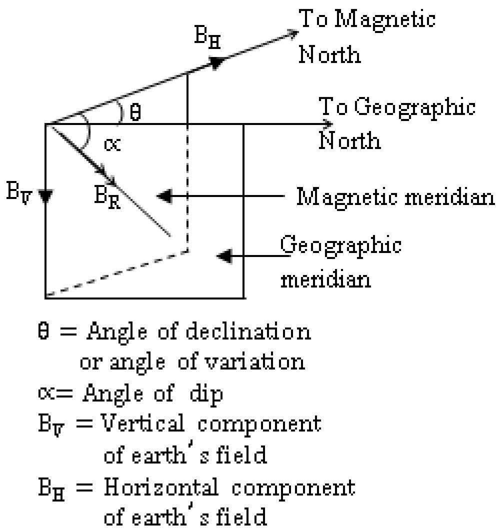
THE EARTH'S MAGNETIC FIELD

A freely suspended bar magnet always comes to rest pointing in the North-South direction.
This is due to the magnetic field of the earth
The earth behaves as though it contains a short bar magnet inclined at a small angle to its axis of rotation with its South Pole in the northern hemisphere (geographic North) and the North Pole pointing to the Southern hemisphere (geographic South).



Magnetic axis: is the imaginary line passing through the earth's magnetic north and south poles.

Geographical axis: This is the imaginary line through the center of the earth and passing through the geographical north and south.

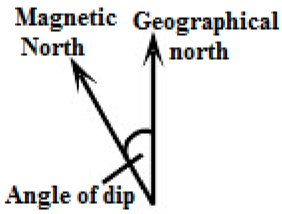


Magnetic meridian: this is the vertical plane containing or passing through the earth's magnetic north and south poles.

Geographical meridian: This is the vertical plane passing through the geographical north and south directions.

Angle of Dip, : This is the angle between the earth's magnetic field and the horizontal; **OR** Angle of dip is the angle that the axis of a freely suspended bar magnet makes with the horizontal when the magnet sets.

Angle of declination (Magnetic variation) is the angle between the earth's magnetic and geographical meridian
This is the angle between geographic North Pole and the magnetic north pole.



Variation of Angle of dip, as one moves from the magnetic equator up to the North Pole.

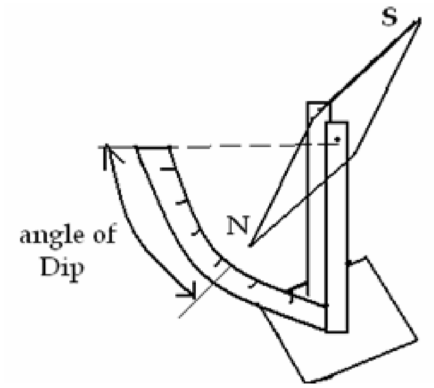
Magnetic Equator: This is the greatest circle in a horizontal plane perpendicular to the magnetic meridian where a freely suspended bar magnet experiences zero magnetic dip.

Explanation
At the magnetic equator, the earth's magnetic field lines are parallel to the horizontal; therefore the angle of dip at the equator is zero,
As one moves along a given longitude towards the North Pole, the resultant magnetic field lines meet the earth's surface at angles greater than 0^0 but less than 90^0 thus the angle of dip at such a position is also greater than zero but less than $90^{0.}$
i.e. At the North Pole, the magnetic field lines are normal to the surface of the earth, thus they are perpendicular to the horizontal. Therefore the angle of dip at the North Pole equals 90^0 i.e. .

Generally, the angle of dip increases from at the equator up to at the North Pole.

Measurement of the angle of Dip or inclination

- A magnet pivoted at its centre of gravity so that it can rotate in a vertical plane is called a **dip needle**, see the figure below. When placed in the magnetic meridian, i.e. in the vertical plane containing magnetic N and S, it comes to rest with the North Pole pointing downwards at an angle.

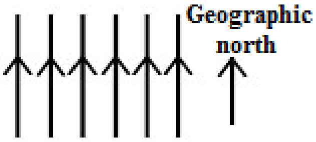


- The angle a dip needle makes with the horizontal in the magnetic meridian is called the angle of dip or inclination***. Or Angle of dip*** is the angle between the direction of the setting compass and the horizontal axis.

- The angle of dip varies over the earth's surface from 0^o at the earth's magnetic equator to 90^o at its magnetic poles.
- This can be explained if we consider the earth behaves as though it had, at its centre, a strong bar magnet whose South Pole points to the magnetic N.
- The cause of the earth's magnetism may be electric currents in the liquid core at its centre but there is no generally acceptance for this theory.

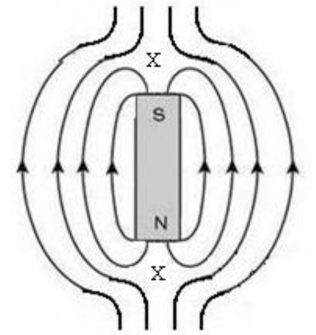
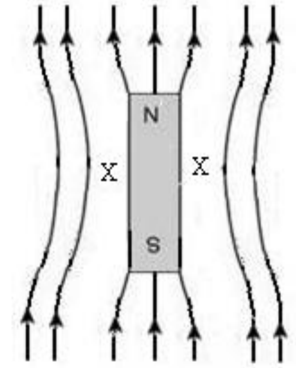
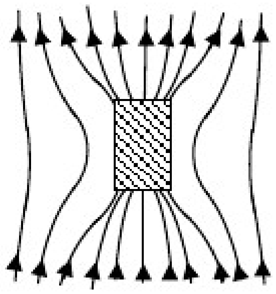
Earth's magnetic field;

This is the series of parallel lines running from geographic south to geographic north as shown below.



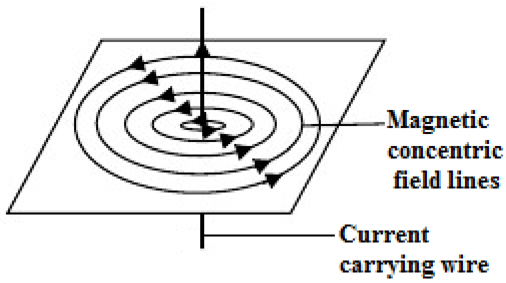
Interaction of earth's field with a bar magnet.

(a) When the South Pole of the bar magnet is pointing north and the magnet is in the magnetic meridian	(b) When the North Pole of the bar magnet is pointing north and the magnet is in the magnetic meridian

	
Soft Iron Bar in Earth's Field	
	It is easier for the magnetic lines of force to go through soft iron than air. So the field lines squeeze within the piece of soft iron.

MAGNETIC EFFECT OF AN ELECTRIC CURRENT.

Any straight conductor carrying current experiences a magnetic field around it.
The field pattern obtained can be studied by using iron fillings or plotting compass.
It is found that the magnetic lines of force form concentric circles with the wire as the centre.

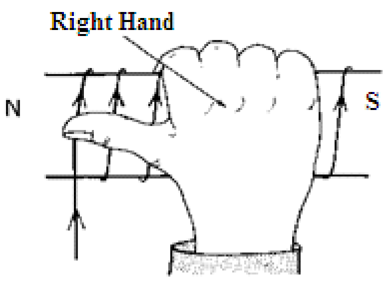


The direction of a magnetic field around the conductor is given by the right hand grip rule. which states that imagine a conductor to be griped in the right hand with the thumb pointing in the direction of the magnetic field, then the fingers will point in the direction of the current.

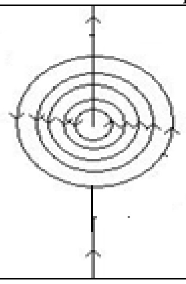
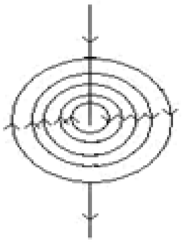
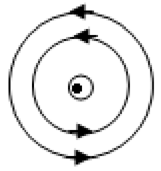
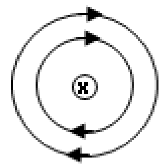
Right hand grip rule

It states that imagine a conductor to be griped in the right hand with the thumb pointing in the direction of the magnetic field, then the fingers will point in the direction of the current.

Grip the soft iron bar with the right hand figure, following the direction of current. The end where the thumb points is the north pole.



(i) Magnetic fields due to a straight wire carrying current.

Current out of the page	Current into the page
	
Current out of paper 	Current into paper 

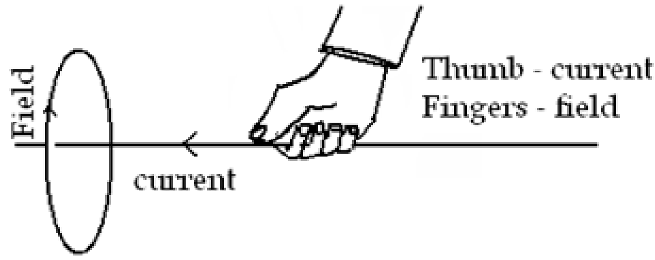
The direction of the magnetic field can be predicted by Maxwell's screw rule and the right hand grip rule.

(i) Maxwell's screw rule

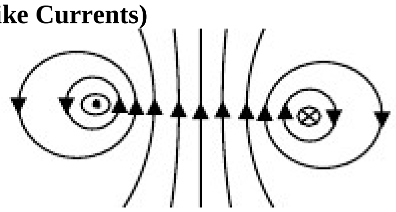
Imagine a screw being screwed along the wire in the direction of the current. The direction of rotation of the screw gives the direction of magnetic field.

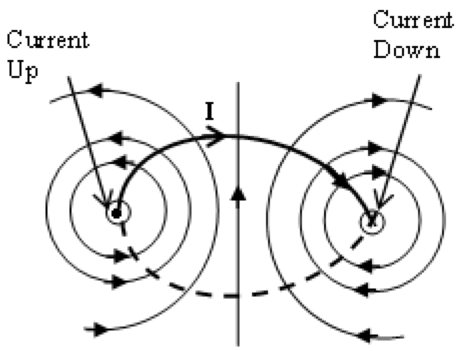
(ii) Right hand grip rule

Imagine the wire to be grasped in the right hand with the thumb pointing along the wire in the direction of the current. The direction of the fingers will give the direction of the magnetic flux as shown below.

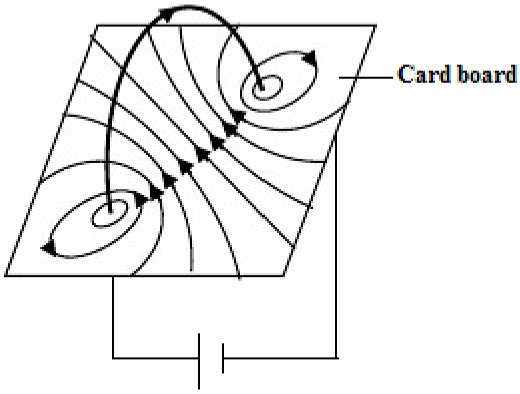


(iii) Magnetic field due to a current carrying circular coil (Un like Currents)



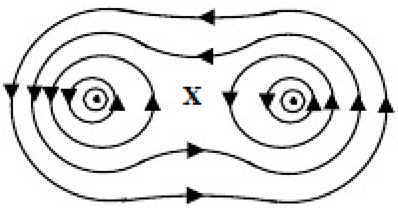


Alternatively the field lines of a current carrying circular coil can be sketched as follows;



The field lines around each side are concentric circles. Magnetic fields near the center of the circular coil are uniform hence the magnetic field lines are nearly straight and parallel.

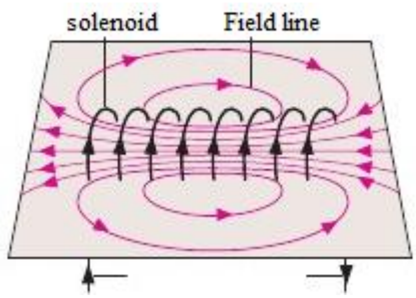
(iii) Conductors carrying currents in the same direction (Like Currents)



X = Neutral point

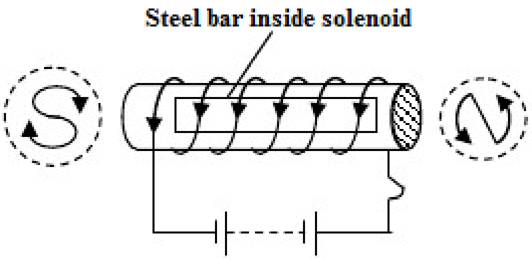
(iv) <u>Magnetic flux due to a current in a solenoid</u>

A solenoid is a coil whose diameter is smaller than its length.



The field pattern due to a solenoid is similar to that of a bar magnet when current is switched on.

The direction of the field is determined as follows:"<u>If the coil (solenoid) is viewed from one end and the current flows in an anticlockwise direction at that end, then the end is a North Pole and if the current flows in a clockwise direction, then that end is a south pole</u>"



The strength of the flux density depends on:

- The current in the solenoid
- Number of turns

EXERCISE:

1. **(1991 Qn. 23).**

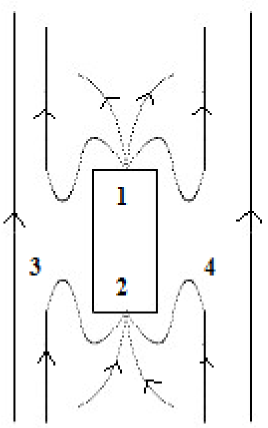
SECTION A

1994 Qn. 1	1993Qn. 37	1997Qn. 29	1998 Qn. 32
2000Qn. 36	2002Qn. 20	2004 Qn. 8	2006 Qn. 14
2008Qn. 18	1991Qn. 23		

2. Four bars of metal P, Q, R, S are tested for magnetism Q attracts both P and R but not S. S does not attract P, Q or R. P and R sometimes attract one another and sometimes repel each other. Which of the following statement is correct about P, Q, R and S.
A. P, Q, R are magnet., S is magnetic.
B. P and Q are magnets. R and S magnetic.
C. P and R are magnets. Q is magnetic, S is non magnetic.
D. P and R are magnets. Q and S are non-magnetic.

3. Which of the following statements is **not true** about magnets?
A. magnetic poles cannot be separated.
B. A paramagnetic material is a material from which a strong magnet can be made.
C. The neutral point in a magnetic field is a point where there is no force experienced.
D. heating a magnet can reduce its magnetism.

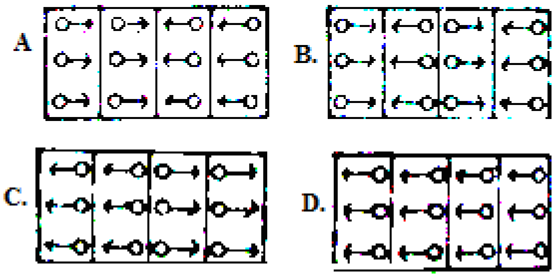
4. The figure below shows the superposition of the earth's magnetic field and the field due to a magnet.



Identify point marked 1,2,3 and 4.

	1	**2**	**3**	**4**
A.	S pole	N pole	Neutral	Neutral
B.	N pole	S pole	Neutral	Neutral
C.	Neutral	Neutral	N pole	S pole
D.	Neutral	Neutral	S pole	N pole

5. Which of the following shows apiece of material in a magnetized condition?



6. Which of the following sentences is/are true about molecular theory of magnetism
1. Breaking a magnet into two results into the formation of two magnets
2. Heating and rough treatment destroys magnetism
3.The poles of a magnet are of equal strength
4.The lines of force travel from a north pole towards a south pole
A. 1 only B. 1 and 3 only
C. 2 only D. All

7. Permanent magnets are made from:
A. diamagnetic materials
B. Ferro magnetic materials
C. paramagnetic materials
D. Hardmagnetic materials.

8. A magnetic material can be magnetized by:
(i) stroking with a permanent magnet
(ii) using a direct current
(iii) by induction
A (i) only B (i) and (ii) only
C. (ii) and (iii) only D. (i), (ii) and (iii).

9. How can a permanent magnet be demagnetized?
A. cool the magnet for a long time
B. hit the magnet repeatedly with a hammer
C. leave the magnet in a coil
D. pass a small current through the magnet

10. An electromagnet is used to separate magnetic metals from non- magnetic metals. Why is steel unsuitable as the core of the electromagnet?
A. It is a good conductor of electricity
B. It forms a permanent magnet
C. It has a high density
D. It has a high thermal density.

11. A magnet can be made to lose its strength by:
(i) Heating
(ii) Throwing it violently
(iii) Putting it in a solenoid carrying direct current
A. (i) and (iii) only B. (ii) and (iii) only
C. (i) and (ii) only D. (i), (ii) and (iii).

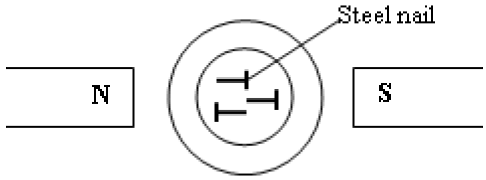
SECTION B

2. **(2008 Qn. 3).** (a) Define the following terms as applied to magnetism:
(i) Ferromagnetic material.
(ii) Neutral point
(b) Sketch he magnetic field pattern around a bar magnet whose axis lies along the magnetic north.
(c) (i) State one method of magnetizing a magnet.

(ii) What is meant by a magnetically saturated material?

3. **(1995 Qn. 7).** (a) With the aid of a diagram, explain how a piece of iron can be magnetized by a single touch method.
(b) How can you determine the polarity of a magnet?
(c) Explain why a magnet loses its magnetism when placed in a coil of wire carrying alternating current.

4. **(2004 Qn. 41).** (a) List two ways by which a magnet may lose its magnetic properties.
(b) The figure below shows an iron ring between two opposite magnetic poles.

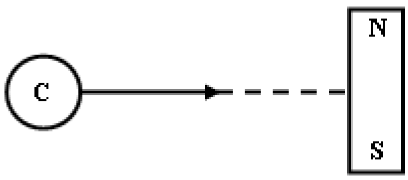


(i) Sketch the magnetic lines of force on the diagram.
(ii) Explain what happens to the steel nails.

5. **(2004 Qn. 4).** (a) (i) What is a magnetic field?
(ii) State the law of magnetism
(b) Sketch the magnetic field pattern of two bar magnets whose north poles are facing each other.

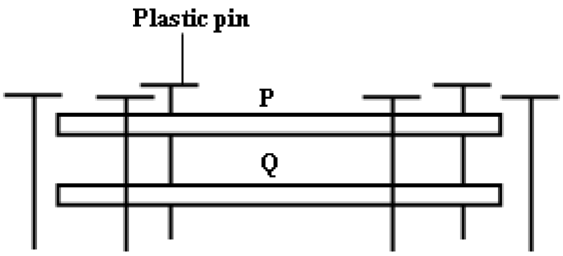
6. **(2006 Qn. 3).** (a) Distinguish between angle of dip and angle of declination.
(b) Draw a diagram to show the magnetic field pattern around a bar magnet placed in the earth's field with the north pole of the magnet pointing to the earth's magnetic south.

(c) Describe what happens to the compass needle, C, as it is moved closer to the bar magnet along the dotted line shown below.



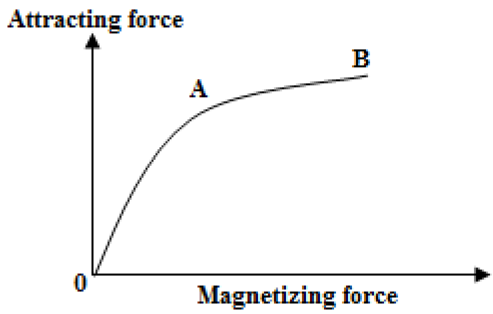
7. **(2002 Qn. 6).** (a) What happens when a magnet is ;
(i) Dipped in iron filings.
(ii) Freely suspended in air.

(b). A powerful magnet Q is placed on a soft board. Plastic pins are firmly stuck in the soft board around the magnet. An identical magnet P, is held in the space surrounded by the pins above the magnet Q. When the magnet P is released, it floats above the magnet Q as shown below.



Explain;
(i) why P floats above Q.
(ii) why are plastic pins used instead of steel pins.
(iii) What would happen to magnet to magnet P if all the pins were removed at the time.
(c) Explain in terms of the domain theory how a steel bar gets magnetized by stroking.

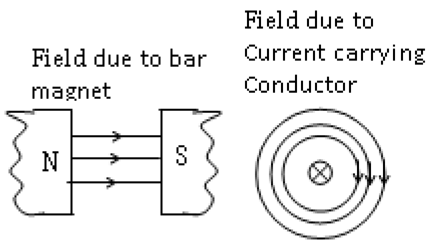
8. The graph below shows the relationship between the attractive force of an electromagnet and the magnetising current through the coil.



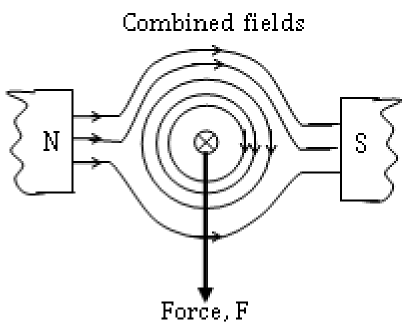
Give reasons for the shape of the curve in terms of the domain theory.

FORCE ON A CURRENT CURRYING CONDUCTOR IN A MAGNETIC FIELD

(a) <u>Origin of the force that causes motion of a current carrying conductor placed across a magnetic field.</u>
When a current carrying conductor is placed across a magnetic field (e.g between the poles of a powerful magnet), it sets up a magnetic field around itself.
The two fields then interact with each other causing a resultant force.
If the field or the current is reserved, the direction of the force also reverses.



The combined field exert a force on the current carrying conductor. The force is towards the region with fewer field lines (i.e less flux density).



On one side of the conductor, the magnetic fields oppose each other and some cancel out resulting in formation of a relatively weaker field there.

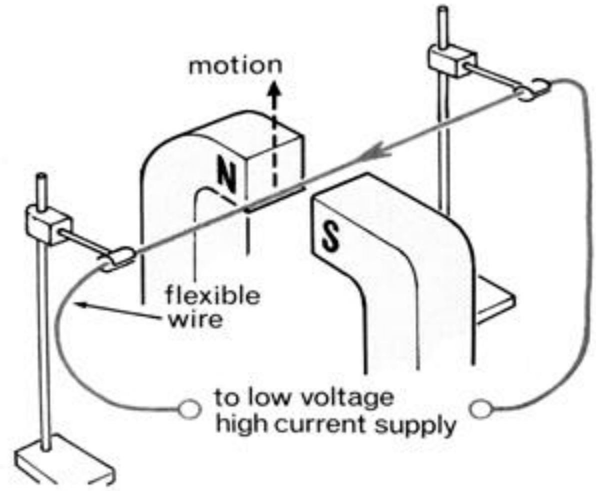
On the other side of the conductor, the applied magnetic field lines are forced to curve or concentrate resulting in formation of a strong magnetic field there.

There are more field lines above the wire since both fields act in the same direction.
A force is therefore exerted on the conductor that moves it from a region of strong magnetic field to a weaker magnetic field.

If we suppose field lines to be a stretched elastic material, these below will try to straighten out and in so doing will exert a down ward force on the wire.
[See the kicking wire experiment for verification]

The motor effect

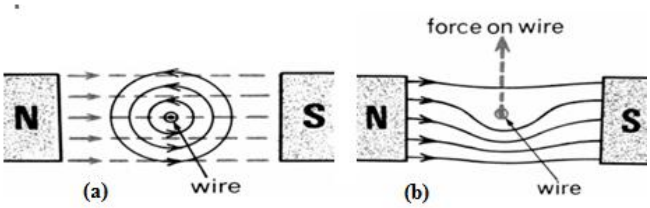
A wire carrying a current in a magnetic field experiences a force. If the wire can move it does.



- **Demonstration:** In the figure above, the flexible wire is loosely supported in the strong magnetic field of a C-shaped magnet. When the switch is pressed, current flows in the wire which jumps up as shown. If either the direction of the current or the direction of the field is reversed, the wire moves downwards.

- **Explanation:** In the figure a. below, is a side view of a magnetic field lines due to the wire and the magnet. Those due to the wire are circles and we will suppose their directions are as shown. The dotted lines represent the field lines of the magnet and their direction of to the right.

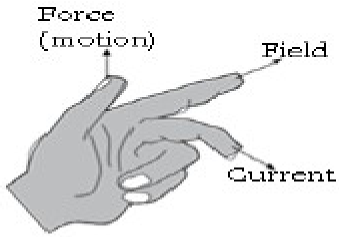
- The resultant field obtained by combining both fields is shown in the figure (b) below. There are more lines shown below than the above the wire since both fields act in the same direction below but in opposite above.

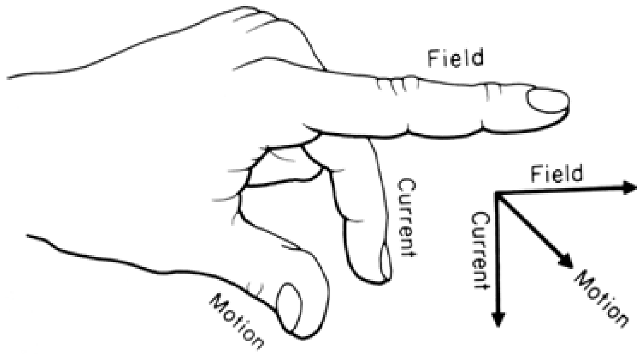


Fleming's Left Hand Rule (Motor rule)

The direction of the force in a current carrying conductor placed across a magnetic field is predicted by the Fleming's Left Hand Rule.

It states that if the thumb, first and second fingers of the left hand are held mutually at right angles with the thu**M**b pointing in the direction of magnetic force (or Motion), the **F**irst finger indicates the direction of the field while the se**C**ond finger indicates the direction of current in the conductor.





(b) Factors affecting the magnitude of a force on a current carrying conductor.

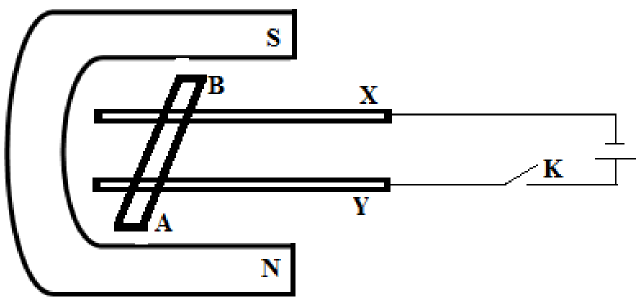
Experiments show that the magnitude of the force exerted on a current carrying conductor is proportional to the:-

(i) Current,**I** in the conductor
(ii) Length, ***l***, of the conductor.
(iii) Strength of the magnetic field by a quantity called magnetic flux density, **B**.
(iv) Number of turn in the conductor, **N**.
(v) The angle **θ**, where **θ** is the angle between the conductor and the magnetic field.

All these factors can easily be generated from the expression for the force exerted on a current carrying conductor below.

$$\mathbf{F = NBILSin\theta}$$

Question: UNEB 2013 PP2 No. 6 (c): A bare copper wire AB lies horizontally over fixed rails X and Y connected to a battery as shown below. The rails X and Y are placed between the poles of a U-shaped magnet.



(a) Explain what happens to AB when,
(i) Switch, K is closed.

When K is closed, current flows in the direction AB. The magnetic field is in the upward direction. By Fleming's Left hand rule, the force on the current carrying conductor AB, is in the direction from left to right.
Therefore, the wire AB moves along the rails X and Y from left to right.

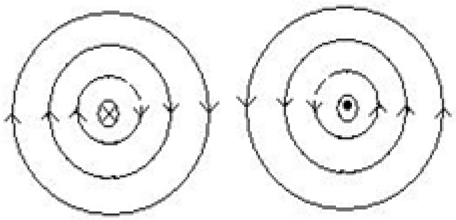
(ii) Two cells are used instead of one cell.

Whent two cells are used instead of one, the current flowing through AB increases. The Force acting on AB also increases hence increasing the speed at which the wire moves.

(b) Name **two** instruments which use the effect above.
The effect is Fleming's left hand rule. Or force on a current carrying conductor in a magnetic field.

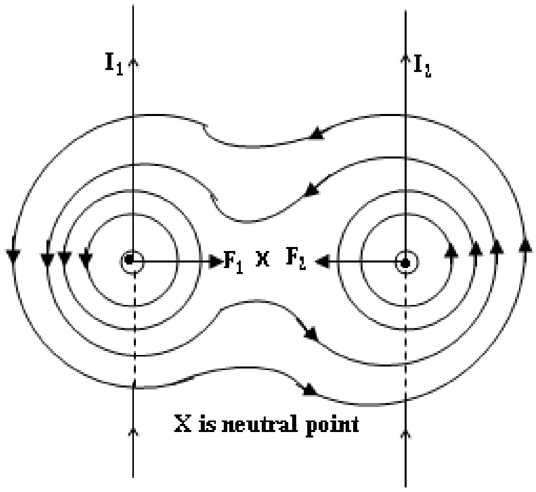
- Electric motor
- Moving coil loud speaker.

Note: current flowing into the paper is donated by (**X**) and current flowing out of the paper is denoted by(•).



Force between two straight conductors carrying current in a vacuum
Two current carrying conductors (wires) exert a force on each other due to the interaction of the magnetic fields set up around each conductor.
Depending on the direction of the currents, in the two conductors, the force exerted can be;
(i) Attractive (Same direction of)
(ii) Repulsive (Different directions of)

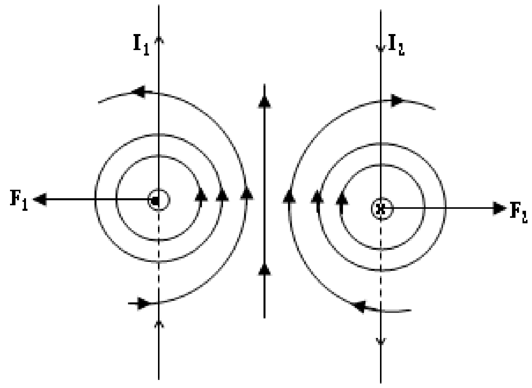
Magnetic field due to two straight wires carrying current in the same direction



The fields in the middle of the conductors are in opposite directions. Hence they attract each other.

A force on each wire acts from a region of strong field hence straight parallel wires carrying current in the same direction attract. i.e. "like currents attract"

Magnetic field due to straight wires carrying current in opposite directions



"Unlike currents repel"
The fields in the middle of the conductors are in the same direction. Hence they repel each other.

A force on each wire acts from a region of strong field hence straight parallel wires carrying current in opposite direction repel. i.e. "Unlike currents repel"

<u>Applications of Electromagnets</u>
An electromagnet is any current carrying conductor which acts as a magnet.
If a soft iron is placed in a solenoid, it will be strongly magnetized only when the current is flowing.
When the current is switched off, all the magnetism acquired is lost.

The soft iron inside the solenoid is acting as an electromagnet. The strength of the field of an electromagnet can be increased by:

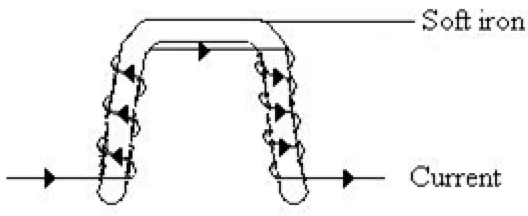
- Placing an iron core inside the coil.
- Increasing the magnitude of the current.
- Increasing the number of turns in the coil.

<u>Applications of electromagnets</u>
Electromagnets are used in:

- Lifting magnets
- Electric bells
- Moving coil loud speaker
- Telephone receivers
- Magnetic Relays, e.t.c.

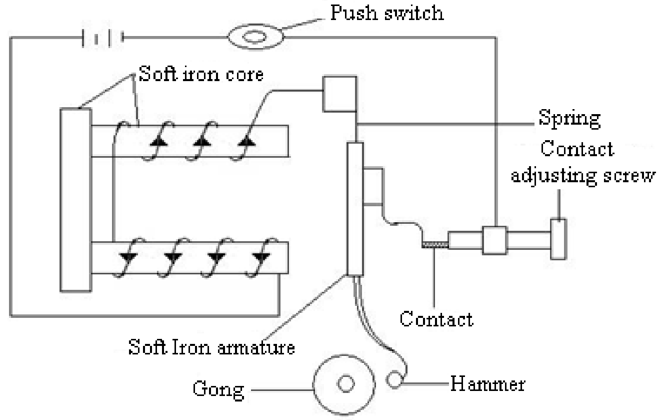
(i) **<u>Lifting magnets</u>**
They are mainly used for lifting and transporting heavy steel from one place to another in a factory. The coils are made of insulated copper wire wound on a U-shaped soft iron so that opposite polarity is produced. The opposite adjacent poles increase the lifting power of the electromagnet.

The coil is wound in opposite directions on each of the soft iron.



(ii) **<u>Electric bell</u>**

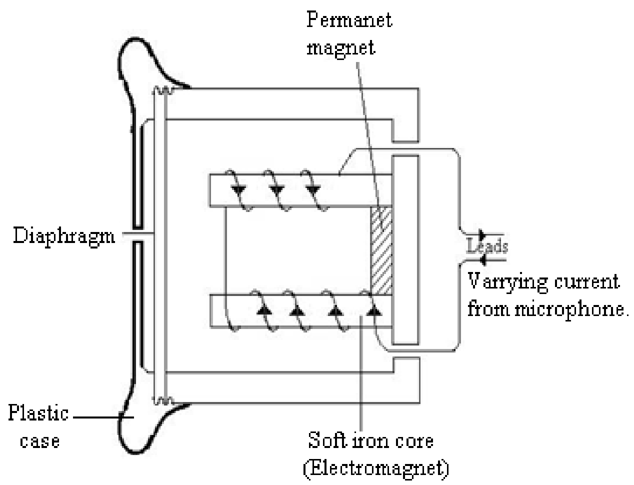
It consists of a hammer, a gong, soft iron armature, contact adjusting screw, a push switch, steel spring and an electromagnet made of two coils wound in opposite directions on the iron cores.



Action

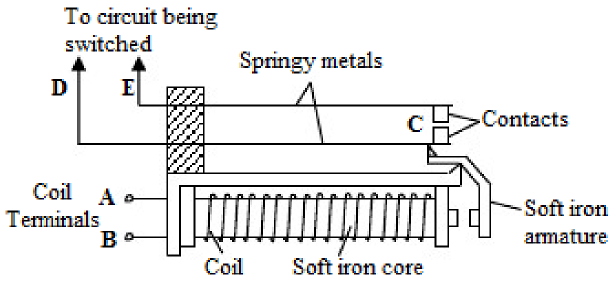
- ❖ When the switch is pressed, current flows through the electromagnet which becomes magnetized.
- ❖ It attracts the soft iron armature and hence breaking the contacts.
- ❖ This causes the hammer to strike the gong and sound is heard.
- ❖ As the armature moves, the current is broken causing the electromagnet to lose its magnetism. The spring pulls the armature again to its original position and contact is made again.
- ❖ The process is repeated on and on hence a continuous sound will be heard.

(iii) **Telephone receiver**
It consists of an electromagnet which is mad e of two coils wound in opposite directions on two soft iron cores, a diaphragm and a permanent magnet which attracts the diaphragm and keeps it under tension.



Action:
- ❖ When the phone is lifted, a steady current flows through the solenoids. However when a person speaks into the microphone on the other end, the sound energy is converted into varying electrical energy of the same frequency as the original sound.
- ❖ This is transferred through the cables to the receiver and magnetizes the electromagnet.
- ❖ The strength of the electromagnet varies according to the magnitude of the electric current which also depends on the original sound.
- ❖ This causes the magnetic alloy diaphragm which is under tension to have a varying pull. As a result, the diaphragm vibrates reproducing the vibration of the speech and so the speech is reproduced.

(iv) **Magnetic relay**
A magnetic relay switch uses a small current in the primary circuit and an electromagnet in this circuit controls (switches on or off) a larger current in the secondary circuit.

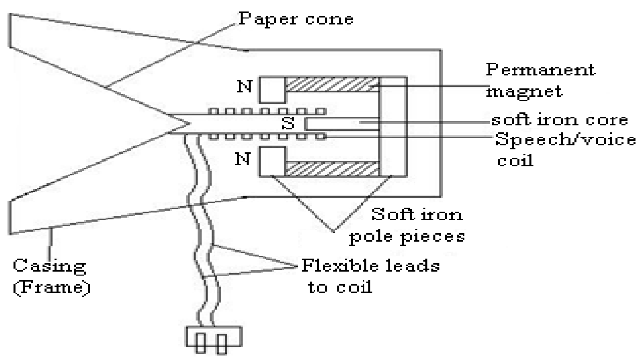


When current flows in the coil from the primary circuit AB, the soft iron core is magnetized and hence attracts the L-shaped iron armature.
As the armature is attracted, its top rises making it rock on its pivot hence closing the contacts at C in the secondary circuit connected to DE.
The relay is then said to be energized or on.

<u>Advantage of magnetic relay to switch electrical merchinery on and off.</u>
(i) It protects electrical merchinery from very high or very low voltages.
(ii) A small current in one circuit can be used to switch on and off an other circuit with a large current.
(iii) A relay facilitates a more efficient way of where the switching action is a response to a certain condition in the circuit or elsewhere.

(v) **The moving coil loud speaker**
It converts electrical energy into sound energy. It is used in radio receivers, record players, etc.

Structure



It consists of a light coil of wire known as a speech coil wound tightly round a cylindrical former to which a large thin cardboard cone is rapidly attached. The coil is in a radical magnetic field provided by the permanent magnet which has circular pole.

Action
- ❖ Varying electric currents from an amplifier flows continuously in the speech coil through the leads.
- ❖ The varying current produces a varying electromagnetic force on the coil making it to vibrate

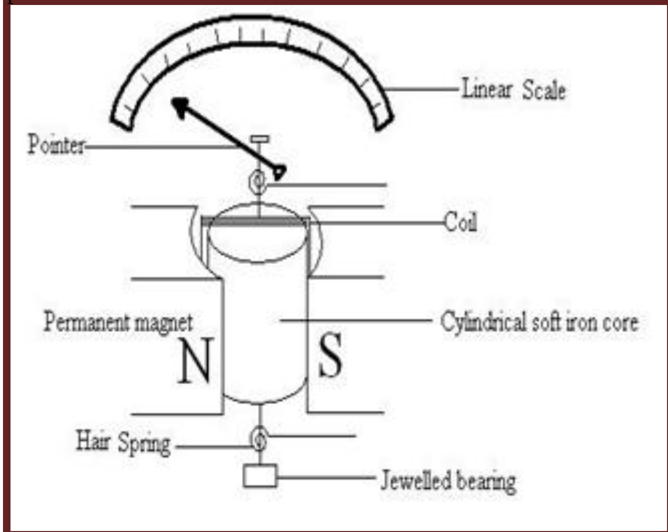
at the same frequency as the current.

- This makes the frame and the paper cone to vibrate at the same frequency sending the surrounding air in vibration hence a loud note (sound) is heard.
- The greater the electrical energy supplied to the coil, the louder the note produced.

Applications of the force on a current carrying conductor

(a) **Moving coil Galvanometer**

It is used to detect and measure an electric current and potential difference.



It consists of a rectangular coil with many insulated turns wound on an aluminum former, soft iron cylindrical core between the curved poles of a powerful permanent magnet, the springs which control the rotation of the coil, a pointer and a linear scale. The current is led in and out by two hair springs.

Action:

When the current to be measured flows through the coil, a resultant magnetic field is set up. By Fleming's left hand rule, two equal and opposite parallel forces act on the two vertical sides of the coil. The two forces together form a deflection couple causing the coil to rotate until the deflecting couple is just balanced by the opposing couple setup by the hair springs.

As the coil rotates, the pointer moves with it and hence the magnitude of the current can be obtained from the linear scale.

Sensitivity of the moving coil galvanometer

A galvanometer is said to be sensitive if it can detect very small currents.

The sensitivity can be increased by;

- Using very strong magnet to provide a strong magnetic field
- Using very weak hair springs
- Suspending the coil so that it can turn freely
- Using a coil with many turns

Advantages

(i). It has a linear scale because of the uniform field provided by the radial field.

(ii). It can be made to measure different ranges of current and potential difference.

(iii). External field around the galvanometer has no influence because the magnetic field between the magnets and the soft iron is very strong.

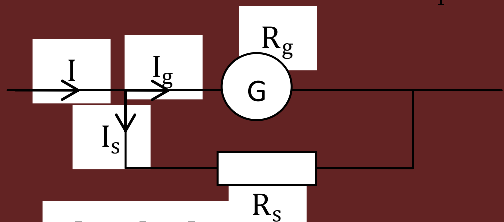
Conversion of a moving coil galvanometer into an ammeter and voltmeter.

(i). Conversion of a galvanometer to an ammeter

Use of shunts

An ammeter is constructed in such a way that it has a very low resistance so that a large current passes through it.

To convert a galvanometer into an ammeter, a low resistance called a shunt is connected in parallel with it.



$I_s = I - I_g$

I_g is the full-scale deflection of the galvanometer

P. d across the shunt = P. d across galvanometer

$\Leftrightarrow \mathbf{(I - I_g)R_s = I_gR_g}$

Most of the current will pass through the shunt and only a small part through the galvanometer.

Example:

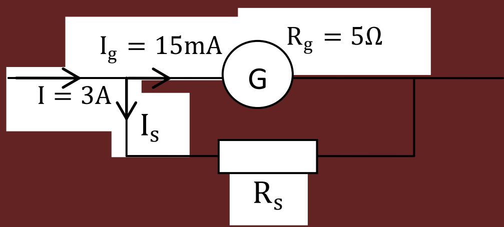
A moving coil galvanometer has a resistance of 5Ω and gives a full deflection of 15mA. How can it be converted into an ammeter to measure a maximum of 3A?

(i).

Solution

(i)

Let Rs be the resistance of the shunt required.



P. d across the shunt = P. d across galvanometer

$\Leftrightarrow (I - I_g)R_s = I_gR_g$

$\Leftrightarrow (3 - 0.015)R_s = 0.015 \times 5$

$2.985\ R_s = 0.075$

$\mathbf{R_s = 0.025\ \Omega}$

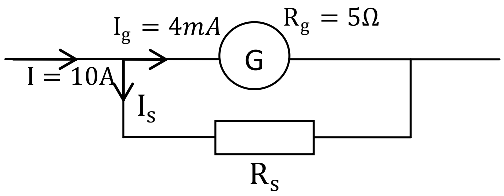
Thus a low resistance resistor of 0.025 Ω should be connected in parallel with the galvanometer.

Example1.

A moving coil galvanometer gives a full scale deflection of 4mA and has a resistance of 5Ω.How can such instrument be converted into an ammeter giving a ful-scale deflection of 10A?

Solution:

Let Rs be the resistance of the shunt required.



$\text{P. d across the shunt} = \text{P. d across galvanometer}$

$\Leftrightarrow (I - I_g)R_s = I_gR_g$

$\Leftrightarrow (10 - 0.004)R_s = 0.004 \times 5$

$$\mathbf{R_s = 0.002\Omega}$$

Thus a low resistance resistor of 0.002Ω should be connected in parallel with the instrument.

Examp 2.

A moving coil galvanometer gives a full scale deflection of 6mA and has a resistance of 4Ω.How can such instrument be converted into;

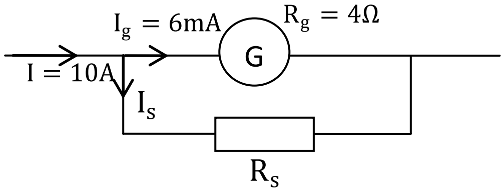
(i). an ammeter giving a ful-scale deflection of 15A?

(ii). A voltmeter reading up to 20V?

Solution:

(i)

Let Rs be the resistance of the shunt required.



$\text{P. d across the shunt} = \text{P. d across galvanometer}$

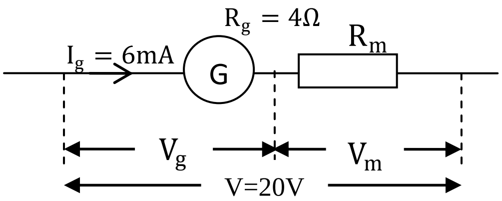
$\Leftrightarrow (I - I_g)R_s = I_gR_g$

$\Leftrightarrow (15 - 0.006)R_s = 0.006 \times 4$

$$\mathbf{R_s = 0.016\Omega}$$

Thus a low resistance resistor of 0.0016Ω should be connected in parallel with the instrument.

(ii)



$V = \begin{pmatrix}\text{P. d across}\\ \text{the multiplier}\end{pmatrix} + (\text{P. d across galvanometer})$

$V = \quad V_m \quad + \quad V_g$

$V = \quad I_gR_m \quad + \quad I_gR_g$

$$R_m = \frac{V - I_gR_g}{I_g} \Leftrightarrow R_m = \frac{20 - 0.006(4)}{0.006} = \mathbf{3329\Omega}$$

Example 3.

A moving coil galvanometer of resistance5Ω and current sensitivity of 2 divisions per milliampere, gives a full-scale deflection of 16 divisions. Explain how such an instrument can be converted into;

(i). An ammeter reading up to 20A?

(ii). A voltmeter in which each division represents 2V?

Solution:

(i)

Current sensitivity = 2div/mA

Full scale deflection = 16div.

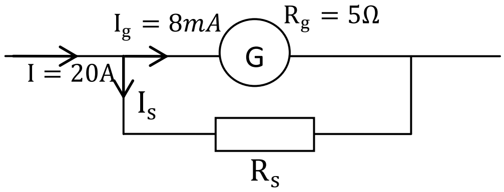
2div → 1mA

16div → x

On cross multiplying, we get;

$2x = 16mA$

$x = 8mA = 8 \times 10^{-3}A = 0.008A$



$\text{P. d across the shunt} = \text{P. d across galvanometer}$

$\Leftrightarrow (I - I_g)R_s = I_gR_g$

$\Leftrightarrow (20 - 0.008)R_s = 0.008 \times 5$

$$\mathbf{R_s = 0.002\Omega}$$

Thus a low resistance resistor of 0.0016Ω should be connected in parallel with the instrument.

Voltmeter sensitivity = 1div/2V

Full scale deflection = 16div.

1div → 2V

16div → y

On cross multiplying, we get;

$y = 16 \times 2 = 32V$

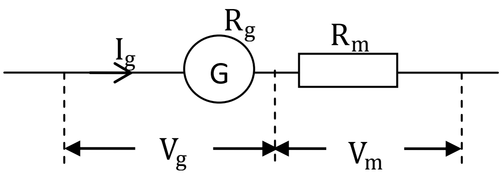
$$R_m = \frac{V - I_gR_g}{I_g} \Leftrightarrow R_m = \frac{32 - 0.008(5)}{0.008} = \mathbf{3995\Omega}$$

(i). Conversion of a galvanometer to a voltmeter

A voltmeter has a high resistance so that no current passes through it.

To convert a galvanometer to a voltmeter, a high resistance called a multiplier is connected in series with it.

Use of multipliers



$V = V_m$

$V = \begin{pmatrix}\text{P. d across the}\\ \text{multiplier}\end{pmatrix} + \begin{pmatrix}\text{P. d across}\\ \text{galvanometer}\end{pmatrix}$

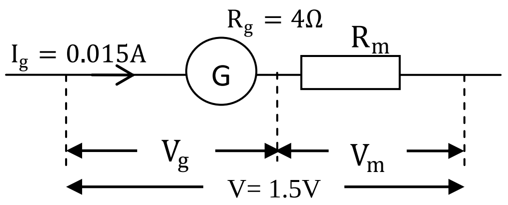
$V = V_m + V_g$

$V = I_gR_m + I_gR_g$

$\mathbf{V = I_g(R_m + R_g)}$

Example

(ii) In the above example, if the galvanometer is to measure a maximum p.d of 1.5V, the value of R can be obtained as below.



$$V = \begin{pmatrix} \text{P. d across} \\ \text{the multiplier} \end{pmatrix} + (\text{P. d across galvanometer})$$

$$V = \quad V_m \quad + \quad V_g$$

$$V = \quad I_g R_m \quad + \quad I_g R_g$$

$$\Rightarrow R_m = \frac{V - I_g R_g}{I_g}$$

$$R_m = \frac{1.5 - 0.015(5)}{0.015} = \mathbf{95\Omega}$$

Thus resistance of 95Ω must be connected in series with the galvanometer.

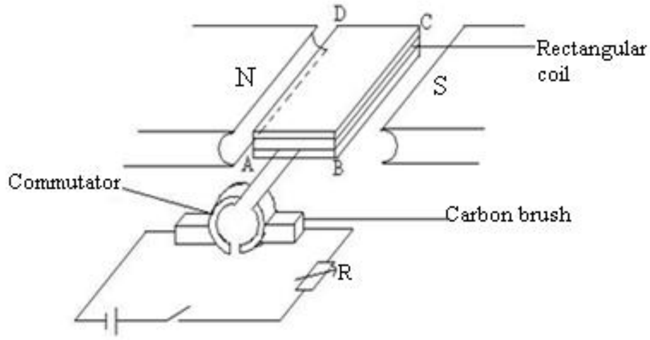
(b) The simple direct current (d.c) motor

The d.c motor changes electrical energy to mechanical energy.

Structure:

It consists of a rectangular coil which can rotate about a fixed axis in a magnetic field provided by the permanent magnet. The ends of the coil are soldered to two halves of a copper ring (commutator).

Two carbon brushes press lightly against the commutators.



Action

- ❖ When current flows in the coil, side BC experiences a downward force and AD an upward force. (Fleming's left hand rule).
- ❖ The two forces constitute a couple which rotates the coil.
- ❖ When the coil reaches the vertical position, the brushes lose contact with the commutator and current is cut off. However the coil continues to rotate past this vertical position because of the momentum gained.
- ❖ The current in the coil reverses as the brushes change contact with the commutator, side AD now experiences a downward force and BC an upward force. Thus the coil continues to rotate as long as the current is flowing.

Note: A **commutator** or **current reverser** is a split ring with brushes which are arranged such that as the coil passes through the vertical position, the two halves of the split ring change contact from one brush to another. In this position, the e.m.f induced in the coil reverses and so one brush is always positive and the other negative.

Hence in a d.c motor or d.c generator, e.m.f never changes direction and so produces direct current (d.c).

Energy losses in a d.c motor

1. Energy losses in the winding of the armature (I^2R)
2. Eddy current losses.
3. Energy losses due to friction e.g. between the brushes and the commutator.

These can be minimized by;

(i) Using low resistance copper wire
(ii) Eddy currents are minimized by winding the coil on a laminated core.
(iii) Energy losses due to friction are minimized by lubrication,

Exercise:

1. **(1994.Qn. 2).** (c) A moving coil galvanometer, has a coil of resistance 4Ω and gives a full scale deflection when a current of 25mA passes through it. Calculate the value of the resistance required to convert it to an ammeter which reads 15A at full scale deflection.[Ans: $6.68 \times 10^3 \Omega$.]

2. **(1999.Qn. 10).** A galvanometer has a resistance of 5Ω and range 0-40mA. Find the resistance of the resistor which must be connected in parallel with the galvanometer if a maximum current of 10A is to be measured. [Ans: 0.02Ω]

3. **(1994.Qn. 2).** A galvanometer of reads 0.05A at full scale deflection and has resistance of 2.0Ω. Calculate the resistance that should be connected in series with it to convert it to a voltmeter which reads 15V at full scale deflection. [Ans: 298Ω]

4. A galvanometer of internal resistance100Ω gives full a fsd of 10mA. Calculate the value of the resistance necessary to convert it to:
(a) Voltmeter reading up to 5V. [400Ω]
(b) Ammeter reading up to 10A. [0.1Ω]

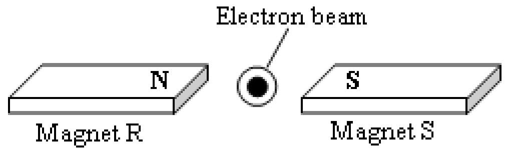
EXERCISE:

1. A moving coil galvanometer can be used to:
A. Measure a direct current.
B. Convert alternating current into direct current.
C. Covert direct current to alternating current.
D. Measure the peak value of an alternating current.

2. The strength of a magnetic field between the poles of an electromagnet remain the same if the:
(i) current in the electromagnet winding is doubled
(ii) direction of the current in the electromagnet winding are reversed
(iii) the number of turns are halved
A. (i) only B. (ii) only
C. (i) and (ii) only D. (ii) and (iii) only

3. The sensitivity of a moving coil galvanometer can be increased by using:
A. smaller coil.
B. weaker magnet.
C. weaker hairspring.
D. fewer turns of wire on the coil.

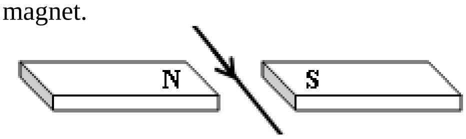
4. **(1988.Qn. 24).**



An electron beam is incident into the page at right angles to the magnetic field formed between two magnets R and S as shown in the above diagram. The beam will be deflected.

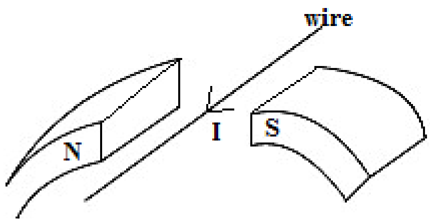
A. Down wards. B. Towards magnet R
C. Towards magnet S. D. Upwards.

5. **(1991 Qn. 13).** The diagram below shows a beam of electrons directed to pass between the poles of a magnet.



The electron beam would be;
A. deflected towards the S-pole.
B. deflected downwards
C. Slowed down.
D. reflected backwards.

6. When a current, I, flows through a wire placed in between the poles of a U-shaped magnet as shown in the figure below,

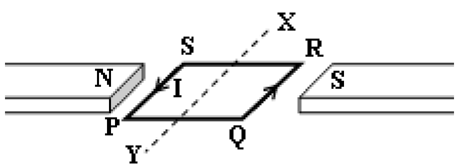


the wire will move.
A. Upwards B. Downwards
C. Towards the south pole D. Towards the north pole

7. (2003 Qn. 22). Which of the following factors affect the magnitude of force on a current –carrying conductor in a magnetic field?
(i) Direction of current.
(ii) Amount of current
(iii) Direction of the magnetic field
(iv) Strength of the magnetic field.

A. (i) and (ii) only. B. (ii) and (iii) only
C. (i) and (iii) only. D. (ii) and (iv) only.

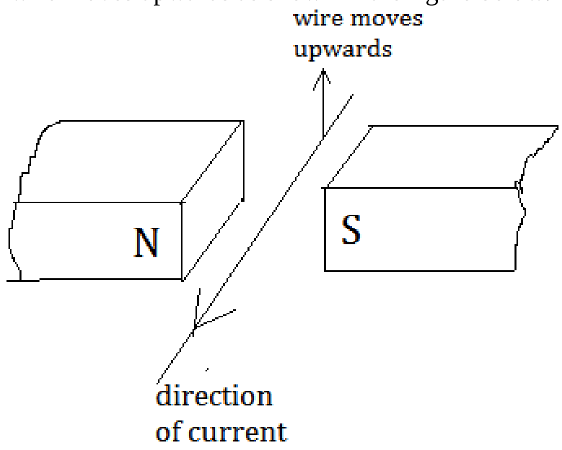
8. (1997 Qn.31). The figure below shows a current carrying coil PQRS pivoted about XY between two magnets.



Which of the following statements are true about the coil?
(i) The sides PS and QR shall experience a force.
(ii) As seen from X, the coil will rotate anticlockwise.
(iii) The force on the coil can be increased by increasing the number of turns.
(iv) The coil will come to rest with PQ at right angles to the magnet field.

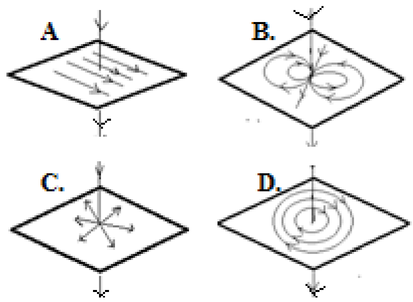
A. (i) , (ii) and (iii) only. B. (i) and (iii) only
C. (ii) and (iv) only. D. (iv) only.

9. A student carries out an experiment to see the effect of a magnetic field on a wire carrying a current. The wire moves upwards as shown in the figure below.



What should the student do to make the wire move downwards?
A. Change the direction of the current
B. Move the poles of the magnet closer together
C. Send a smaller current through the wire
D. Use a stronger magnet

10. A straight wire carrying a current produces a magnetic field. Which diagram shows the correct shape of the field?

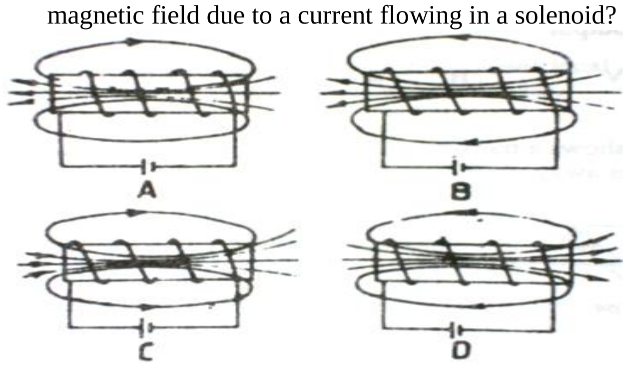


11. (2005 Qn. 2). The direction of motion of a conductor carrying current in a magnetic field can be predicted by applying ;
A. Faraday's law. B. Maxwell's screw rule
C. Fleming's left hand rule. D. Fleming's right hand rule.

(1990 Qn. 4), 1994 Qn. 38, 1995 Qn. 40, 1998 Qn.31.

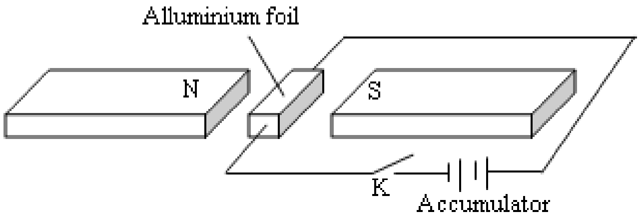
SECTION B

12. Which one of the following diagrams shows a correct magnetic field due to a current flowing in a solenoid?



13. Which of these factors affect the magnitude of force on a current-carrying conductor in a magnetic field.
(i) The direction of current
(ii) the amount of current
(iii) the direction of the magnetic field
(iv) the strength of the magnetic field
A. (i) and (ii) B. (ii) and (iii)
C. (i) and (iii) D. (ii) and (iv)

14. (1992 Qn. 10). An Alluminium foil carrying a current is placed in a magnetic field as shown below.



(a) When switch K is closed momentarily, A force acts on the foil. State ;
(i). The direction of the force
(ii). Two factors which affect the the magnitude of the force.
(iii). What happens to the force when the foil is slowly turned until its ends point exactly in N-S direction of the magnetic field.

(b) Name one device which works on the principle illustrated in the diagram above.

15. (1997 Qn. 9). (a) Why is an ammeter constructed such that it has a low resistance?
(b) A mili ammeter has an internal resistance of 4Ω and a full scale deflection of 0.015A. Calculate the value of the resistor that must be connected to the milli ammeter so that a maximum current of 5A can be measured.

16. (2000 Qn. 10). (a) State any two factors which determine the magnitude of e.m.f induced in a coil rotating in a magnetic field.
(b) Explain why soft iron is preferred to steel in making electromagnets.

17. (2007 Qn.7). (a) What is meant by a magnetic field?
(b) Explain with the aid of a diagram what happens when two vertical, parallel conductors are near one another and carry current in ;
(i). The same direction.
(ii). Opposite directions.

18. Describe the motion of abeam of electrons directed midway between the North and South poles of a permanent magnet**.**
The electrons are negatively charged, hence they are considered to be like an electric current moving in the opposite direction.
Since an electric current in a wire between the magnets experiences a force, then also these electrons will be deflected in a direction determined by Fleming's left hand rule.

ELECTROMAGNETIC INDUCTION

Electromagnetic induction is the producing of an electromotive force (electric current) in a circuit from magnetismby varying the magnetic flux linked with the circuit.

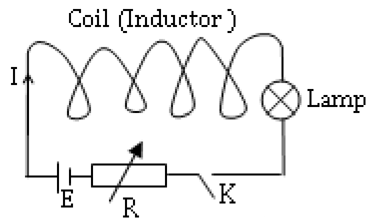
An electric current produces a magnetic field around the conductor through which it flows. Similarly, a magnetic field induces a current in a conductor when the conductor cuts the field. This effect is called **electro magnetic induction**.

The means that current or (e.m.f) can be induced when;
- The magnetic field strength around an electromagnet is increased and decreased.
- Constantly moving a permanent magnet in and out of a coil of wire.
- Constantly moving a conductor near a stationary permanent magnet.

Electromagnetic induction forms the basis of working of power generation, dynamos, generators etc.

Types of electromagnetic induction:
- Self induction
- Mutual induction.

Self induction
Self induction is the process where an e.m.f is induced in a coil (or circuit) due to a changing current in the same coil.
The flux due to the current in the coil links that coil and if the current changes, the resulting flux change induces an emf in the coil itself.
When current flows in a coil, it sets up a magnetic field within the coil and when it is switched off, the magnetic field collapses (changes). A current is induced in the coil to oppose the change.
This effect is called self induction. The coil is said to have self inductance, (L) and the coil is said to be an inductor.
Back e.m.f is the e.m.f induced in a coil (or circuit) due to a changing current in the same coil (or circuit).
The induced e.m.f tends to oppose the growth of current in the coil.
Demonstration of self induction
Consider a coil of known number of turns connected in series with the battery and switch k as shown below.



-Switch k is closed, current, I flows in a coil and the bulb (lamp) lights up slowly to maximum brightness.
-The magnetic flux linking the turns of the coil changes hence inducing an e.m.f in the coil .
-This e.m.f tends to oppose the growth of current in the coil.

Alternatively;
-The current, I is varied by using a variable resistor, R.
-The magnetic flux linking the turns of the coil changes hence inducing an e.m.f in the coil.
-This e.m.f tends to oppose the growth of current in the coil.

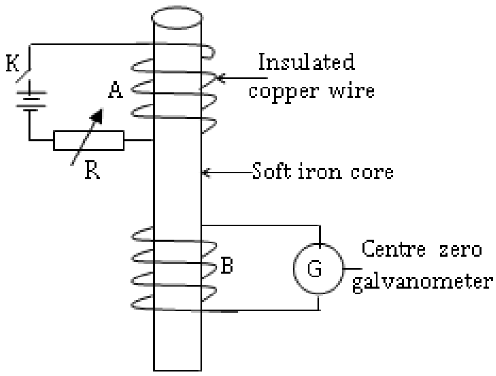
-Switch k is opened, current, I decays out from the coil and the bulb (lamp) first lights up brightly and then gradually goes off.
-The magnetic flux linking the turns of the coil changes hence inducing an e.m.f in the coil.
-This e.m.f tends to oppose the decay of current in the coil.

Note: Just as self induction opposes the growth of current in a circuit when K is closed; it also opposes its decay when K is opened.

Mutual induction
This is the generation of an e.m.f in one coil due to change in current in the nearby coil.
A magnet can be used to induce current in a coil. A secondary coil carrying current can be used instead of the magnet to induce current

Assignment; describe briefly an experiment to show mutual induction with the aid of a diagram.

Demonstration of Mutual induction
a)Based on changing magnetic field.
Experiment to show that the induced current (or e.m.f) is as a result of a changing magnetic field.
(a) Coil-coil experiment
❖ Consider cols A and B wound on a soft iron rod as shown below.



❖ When switch, K is closed, current flows in the primary coil, A and the galvanometer momentarily deflects in one direction and then quickly returns to zero. Hence no more deflection thereafter as the switch remains closed.

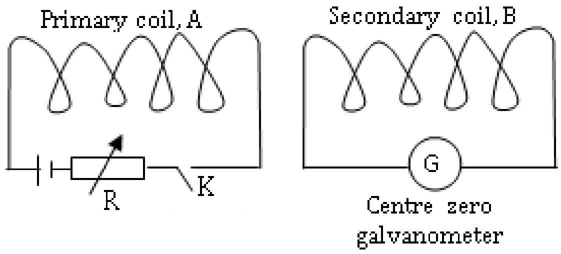
Explanation:
✓ When the switch is closed, a current begins to flow in a closed circuit and after a short time it attains a steady value.
✓ The sudden increase in current creates an increase in the magnetic flux linking the secondary coil, B hence inducing an e.m.f in this circuit.
✓ The induced e.m.f causes a current to flow in coil B giving a momentary deflection on one side of the galvanometer.
✓ When current attains a steady value, a constant magnetic flux will be created no e.m.f is induced in the circuit. Thus the deflection decreases to zero.

❖ When the rheostat, R is adjusted so as to decrease the resistance (hence increasing current), a deflection on one side of the galvanometer is obtained.

❖ When the rheostat, R is adjusted so as to increase the resistance (hence decreasing current), a deflection on the opposite side of the galvanometer is obtained.

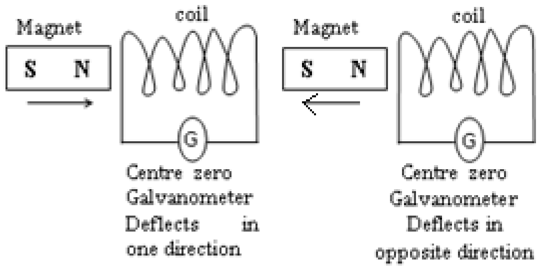
❖ When the switch is opened (at a break), the galvanometer deflects in the opposite direction and no more deflection there after as the switch remains open.

(b) Similar observations above could be made when the coils are arranged as shown below.



i) Larger deflections are obtained when a bunch of soft iron is inserted into the coil compared to hard solid iron bar or air cored coil.
ii) The deflection obtained in the secondary coil (coil B) depends on the induced e.m.f in it, which depends on the;
- Number of turns in coils A and B
- Area of coils A and B.
- Proximity of the two coils (distance between the coils)

Similar observations above could be made when there is relative motion between a magnet and a coil as shown below.



❖ When both the magnet and coil are stationary (or moved with the same velocity in the same direction), there is no deflection. This is because, there is no varying magnetic field created hence no e.m.f is induced in the coil, and so the galvanometer does not deflect.

❖ When the coil is fixed and the magnet moved into the coil or when the magnet is fixed and the coil moved towards the magnet. The magnet experiences an opposing force. This is because the induced e.m.f flows in such a direction that the magnetic flux due to it opposes that due to the magnet.
A varying magnetic field is created which induces an e.m.f in the coil, hence the galvanometer deflects in one direction.

❖ When the magnet is withdrawn from the field, the magnet experiences an attracting force. Magnetic flux threading the coil decreases. The induced e.m.f flows in such a direction that the magnetic flux due to it enhances that due to the magnet. The galvanometer deflects in the direction opposite to the first one.

Observations from the above experiments:
(i) Whenever there is relative motion between a coil and a magnet, the galvanometer shows a certain deflection. This indicates that current is induced in the coil.

(ii) The deflection is temporary. It lasts so long as the relative motion between the coil and the magnet continues.
(iii) The deflection increases with increase in relative motion.
(iv) The direction of the deflection is reversed when either the pole of the magnet is reversed or the direction of motion of either the magnet or coil is reversed.

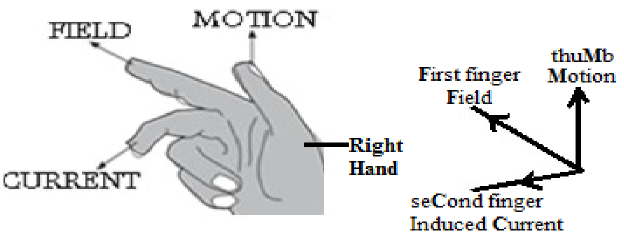
Assignment; describe briefly an experiment to show mutual induction with the aid of a diagram.

Laws of electromagnetic Induction:
(i) Faraday's law.
❖ Whenever a conductor moves through a magnetic flux or whenever there is a change in magnetic flux linked with a circuit, an e.m.f is induced.
❖ The magnitude of induced e.m.f in a circuit is directly proportional to the rate of change of the flux linking it.

(ii) Lenz's law.
The direction of the induced current is such as to oppose the change causing it.
It followed Faraday's law when Lenz studied the direction of the induced current in a complete circuit.

Direction of induced e.m.f
The direction of induced e.m.f (or induced current) is obtained by using Lenz's law.
However, if the current is being induced by the motion of a conductor in a magnetic field, it is more convenient to use the Cork's screw rule or Fleming's Right hand Rule (dynamo rule).

Fleming's right hand rule
It states that: "When the thumb, first finger and second finger of the right hand are held mutually at right angles, with the thumb pointing in the direction of motion, the first finger in the direction of the magnetic filed, then the second finger points in the direction of the induced current".

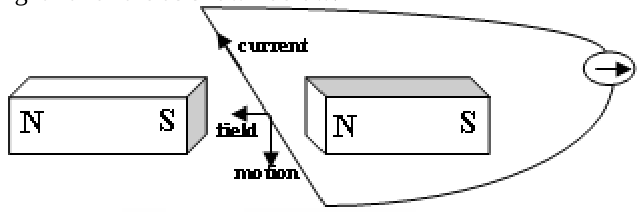


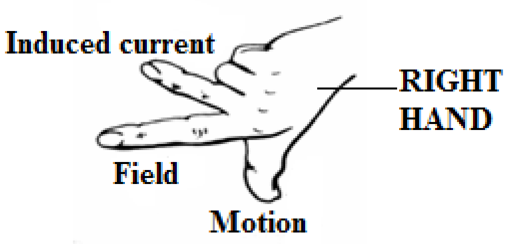
In summary; thu**M**b – motion, **F**irst finger – field ,se**C**ond finger – current.
Note: we use the **R**ight hand for **D**irection of **C**urrent produced or (**RDC**).

Direction of the induced current in a straight wire.
A wire is placed between the poles of a permanent magnet and connected to a galvanometer. The wire is moved up and down at right angles to the magnetic flux.

➢ It's observed that when the wire is moved down, the galvanometer deflects to the right meaning that induced current is flowing in the clockwise direction.
➢ When the wire is moved up, the deflection is reversed indicating that the current is reversed. (anticlockwise)

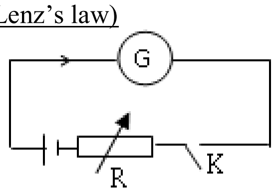
The above observation can be verified using Fleming's right hand rule as shown below.



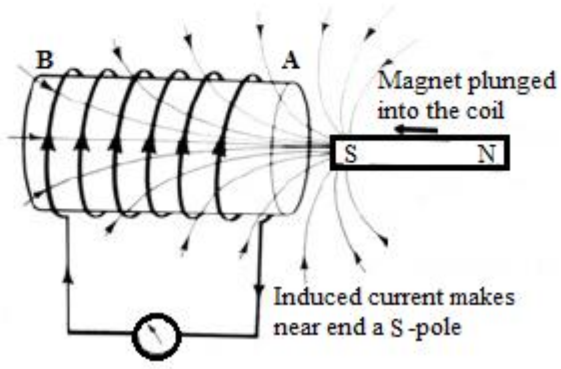


Assignment: draw a coil in a magnetic field and show its rotation when current is moving in different direction.

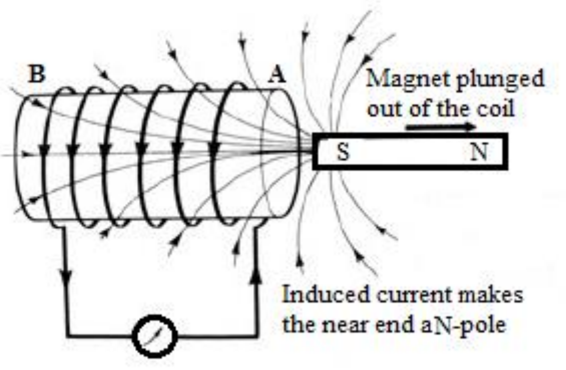
Experiment to verify Lenz's law
(Illustration of Lenz's law)



-A battery is connected in series with a galvanometer and a mega ohm resistor. Switch K is closed and the direction of flow of current is noted from the deflection of the galvanometer.
-The battery is then replaced by a coil AB of known sense of winding as shown below.



❖ When the South Pole of the magnet is moved towards the coil, the current induced in the coil flows in the direction such that the magnetic flux due to the coil opposes that due to the magnet (i.e it flows in a direction that makes end, A a south pole). The galvanometer deflects in one direction (the clockwise). End A of the coil becomes the South Pole. (Like poles repel).



- When the magnet is moved away from the coil, the galvanometer deflects in the opposite direction. The induced current flows in a direction such that the magnetic flux due to the coil reinforces that due to the magnet. (i.e it flows in a direction that makes end, A a north pole). The galvanometer deflects in the ant-clockwise direction.Thus end A of the coil becomes the north Pole.

- In both cases, the induced current flows in a direction so as to oppose the change in flux causing it. This is Lenz's law.

Lenz's law and conservation of energy

Lenz's law is an example of conservation of energy. In order not to violate the principle of conservation of energy, the effect of the induced e.m.f must oppose the motion of the magnet, so that the work done by the external agent in moving the magnet is the one converted to electrical energy.

Other wise the induced magnetic field would increase the velocity of the magnet thereby increasing its kinetic energy. However, there is no source for this energy. Thus if the induced e.m.f helped rather than opposed, the principle of conservation of energy would be violated.

Applications of Electromagnetic Induction.

1. Generators
2. Transformers
3. Induction coils

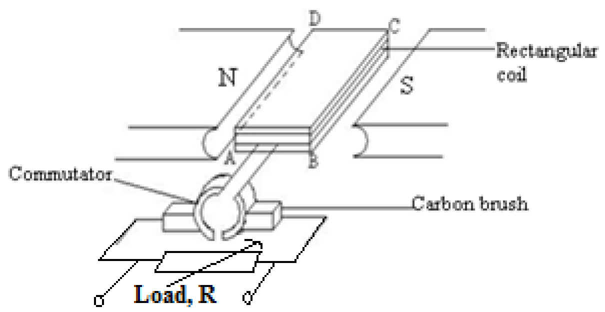
1) GENERATORS

A generator transforms mechanical energy into electrical energy.

(a) D.C generator

The d.c generator is a device used for producing direct current energy from mechanical energy.

Structure*:*

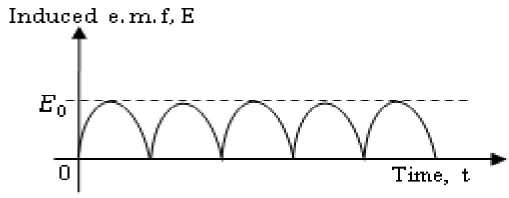


Part	Function
(i)Permanent magnet poles	Provide a strong radial magnetic field.
(ii)Armature (Rectangular coil)	It's the moving part in the radial field. It brings about electromagnetic induction in the generator.
(iii) Commutator (C_1 and C_2).	Two half rings from which current is tapped by brushes.
(iv) Carbon brushes	Blocks of carbon which convey current between the moving and the stationary parts of the generator.

Mode of operation

- When the coil rotates with uniform angular velocity in the magnetic field, in accordance to Fleming's Right Hand rule. The magnetic flux density linked with it changes and an emf is induced in the coil. The induced emf is led away by means of the slip rings S_1 and S_2.
- Applying Fleming's right hand rule, the induced current enters the coil via, AB and leaves the coil via CD.
- When the coil passes over the vertical position, after half the rotation, the slip ring changes contact. C_1 goes into contact with $B_2$and C_2 goes into contact with B_1.
- The forces on the sides of the coil change, thus the current in the coil is reversed. The current flowing through the load thus continues to flow in the same direction.
- Hence the direction of the induced e.m.f doesn't change in the external circuit during one complete revolution of the amateur coil. The output of the generator is unidirectional.

Variation of induced e.m.f, E of a D.C generator with time



Note:

-The induced e.m.f and hence current are maximum when the plane of the coil is horizontal. This is because cutting between the coil sides and the magnetic field lines are greatest.

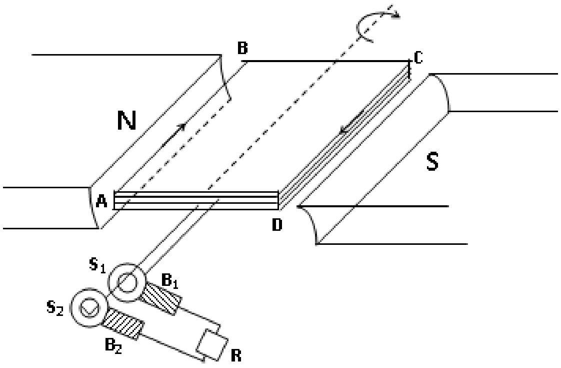
-The induced e.m.f and hence current are minimum (zero) when the plane of the coil is vertical. This is because there is no cutting between the coil sides and the magnetic field lines.

A simple A.C generator (Alternator)

Structure

-The simple a.c generator consists of a rectangular coil, ABCD, mounted between, N, S- pole pieces of a strong magnet and freely to rotate with uniform angular velocity.

-The ends of the coil are connected to copper slip rings S_1 and S_2, which press against carbon brushes B_1 and B_2.



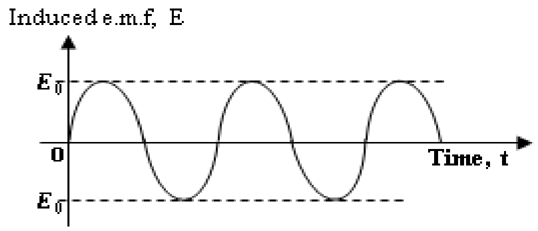
Mode of operation

- ❖ When the coil rotates with uniform angular velocity in the magnetic field, in accordance to Fleming's Right Hand rule. The magnetic flux density linked with it changes and an emf is induced in the coil. The induced emf is led away by means of the slip rings S_1 and S_2.
- ❖ When sides AP and CD interchange positions, the current in the terminals X and Y reverse the direction and the coil continues rotating in the clockwise direction.
- ❖ Therefore, the induced e.m.f generated flows following a sinusoidal wave.

Factors affecting the magnitude of e.m.f induced in a rotating coil.

- Number of turns on the coil.
- Area of the coil
- Magnetic flux density (field strength)
- Position of the coil
- Frequency of rotation of the coil.

Variation of induced e.m.f, E of an A.C generator with time



Structural modifications to convert A.C generator to a D.C generator:

- ❖ Replace the **slip rings** with two halves of slip rings current reversers called **commutators**.

2) THE TRANSFORMERS

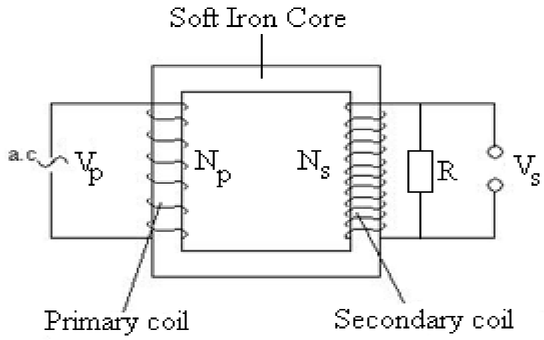
This is a device which transfers electrical energy from one circuit to another by Mutual electromagnetic induction.

Structure

-It consists of a laminated soft iron core around which primary and secondary coils are wound.

-The core with its coils is then immersed in oil which helps in cooling of the transformer and preventing arcing.

-Ideally the primary coil has zero resistance and the secondary coil has high resistance.



Action:

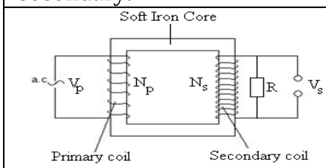
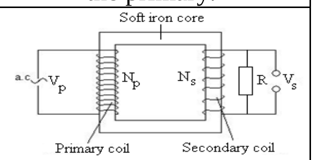
- ❖ An alternating voltage, V_p is applied to the primary coil at some instant and an alternating current I_p flows in the primary coil.
- ❖ This sets up a varying magnetic field in the soft iron core, which links up the secondary coil.
- ❖ The magnetic flux density B, is changing hence an e.m.f is induced in the secondary coil.
  The induced e.m.f is proportional to the number of turns in the secondary coil.

Types of Transformers:

There are two types of mains transformers;

(i) Step Up transformers

(ii) Step down transformers.

(i) **Step-up transformer** It has more turns in the primary circuit than in the secondary.	(ii) **Step-up transformer** It has more turns in the secondary circuit than in the primary.
 This is usually installed in power stations and transmission stations. It changes the voltage to a higher value by using more turns in the secondary coil than in the primary to the ratio of the output voltage required If $N_s>N_p$, $V_s>V_p$, $I_s< I_p$ and the transformer is called step-up.	 This is stationed near the consumers and in electrical appliances. It changes the output voltage to a lower value. The number of turns in the secondary coil is less than those in the primary coil. If $N_s<N_p$, $V_s<V_p$, $I_s> I_p$ and the transformer is called step-down.

For an **ideal transformer**, (A transformer which is 100% efficient), the power in the primary is equal to the power developed in the secondary i.e. $\mathbf{V_pI_p = V_sI_s}$, where I_p and I_s are flowing in the primary and secondary coils respectively.

Note:

- ❖ Transformers operate only on a.c and not dc because dc does not produce changing magnetic flux in the and therefore no emf is induced in the secondary coil.
- ❖ In practice, transformers are not 100% efficient because of the energy losses.

Uses of oil in a transformer.

(i) It provides an arc quenching medium. An arc is a brief , strong luminous current discharge produced when current jumps across a gap between electrodes or within a circuit.
(ii) It acts like an insulation between the windings for which energy losses due to heating reduces.
(iii) It reduces the humming noise resulting in low vibrations.
(iv) It helps to form a sludge which can easily be removed at the time of cleaning.
(v) It's used as an indicator where the buckholtz relay senses the fault in the transformer and gives a tripping)warning) signal.

Note:
Oil is used instead of water to cool the transformer because oil is not only stable at high temperatures, but also has excellent insulating properties.
Stresses of magnetic and electric field inside a transformer are high enough to ionise water. And then water losses its insulating ability.
Chemically pure water is an insulator. And water is generally a good coolant too. However there are other required characteristics which are not present in water.

Stresses of magnetic and electric field inside a transformer are high enough to ionise water. And then water losses its insulating ability.

Water allows air to be dissolved inside it unlike oil. Hence chemically pure water will contain small air pockets which will allow gradual breakdown of insulation (water) due to non-uniform electrical characteristics.

Temperature may get high as much as 105^0C or even 120^0C before a transformer trips due to overheating.

At such temperatures water becomes steam and its high pressure may cause severe damage to body of transformer or may even cause an explosion.

Because heat losses can be as high as multiple MWHs. Oil, on the other hand, stays liquid. But main issue with water is its inability to withstand electric and magnetic field stresses.
That's why water is okay as coolant in car but not in transformer.

Electric power transmission

- Electricity has to be transmitted over long distances from generating power stations to the consumers. This causes some power loss in the transmission lines.
- This loss can be minimized if the power is transmitted at **high voltage (or low current).**
- Electric power is stepped up before transmission and stepped down at the consumers' end by using transformers.

Causes and remedies of power losses in transformers

Cause of Energy or power loss	How it is minimized
(i) Resistance in the windings: -Some of the energy is dissipated as heat due to the resistance of the coil (joule-ohmic energy loss), hence power loss through the $\mathbf{I^2R}$mechanism.	Use thick copper wires of low resistance.
(ii) Eddy currents <u>Eddy currents</u> are currents induced in the soft iron core due to the changing magnetic flux linking the core.. They cause unnecessary heat in the transformer through the $\mathbf{I^2R}$ mechanism and therefore reduce the amount of electrical power transferred to the secondary.	Use a laminated core made of thin strips or laminars separated from each other by a layer of insulating varnish.
(iii)Hysteresis(Magnetic reversal): The core or frame of iron ring is constantly magnetized and demagnetized. Each time the direction of magnetization of the frame is reversed, some energy is wasted in overcoming internal friction. When a core which can not be easily magnetised and demagnetised is used, power losses occur.	Use a soft iron core, which can easily be magnetised and demagnetised
(iv) Magnetic flux leakage Flux leakage occurs when all the magnetic flux due to the currents in the primary coil do not link up with the secondary coil. A small amount of flux associated with the primary coil fails to pass through the secondary coil.	(i) Wind one coil on top of the other. (ii) Use E- shaped cores.

Transformer Equation

$$\frac{\textbf{Secondary voltage}}{\textbf{Primary voltage}} = \frac{\textbf{Number of Secondary turns}}{\textbf{Number of Primary turns}}$$

$$\frac{\mathbf{V_s}}{\mathbf{V_p}} = \frac{\mathbf{N_s}}{\mathbf{N_P}}$$

Efficiency a transformer

$$\textbf{Efficiency} = \frac{\textbf{Power out put}}{\textbf{Power in put}} \times \mathbf{100}$$

Power out put = Power in secondary circuit = $\mathbf{I_sV_s}$
Power in put = Power in primary circuit = $\mathbf{I_PV_P}$

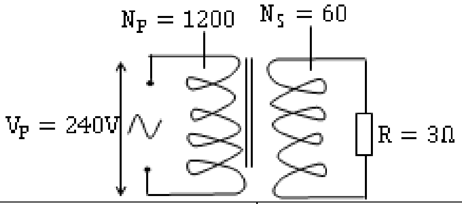
$$\textbf{Efficiency} = \frac{\mathbf{I_sV_s}}{\mathbf{I_PV_p}} \times \mathbf{100}$$

No machine (No transformer) is perfect/ ideal and therefore the value of efficiency cannot be 100% because of the energy losses discussed earlier.

Example. 1
1. A transformer whose secondary and primary coils have 60 and 1200 turns respectively has its secondary coil

connected to a 3.0Ω resistor. If the primary is connected to a 240V a.c supply. If the transformer is 80% efficient, calculate the current flowing in the primary circuit.

Solution:



$\frac{V_s}{V_p} = \frac{N_s}{N_P}$ $\frac{V_s}{240} = \frac{60}{1200}$ $1200V_s = 240 \times 60$ $1200V_s = 14400$ $V_s = 12\ V$ $V_s = I_s R$ $12 = I_s \times 3$ $I_s = 4A$ $P_o = I_s V_s$ $P_o = 4 \times 12$ $P_o = 46\ W$	$\text{Efficiency} = \frac{P_o}{P_{in}} \times 100$ $\frac{80}{100} = \frac{46}{P_{in}}$ $0.8P_{in} = 46$ $P_{in} = 57.5W$ $P_{in} = I_P V_P$ $57.5 = I_P \times 240$ $I_P = 4.174\ A$

EXERCISE:

1. UNEB 1998:

A transformer is designed to work on a 240V, 60W supply. It has 3000 turns in the primary and 200 turns in the secondary and it is 80% efficient. Calculate the current in the secondary and primary coils.

$\frac{V_s}{V_p} = \frac{N_s}{N_P}$ $\frac{V_s}{240} = \frac{200}{3000}$ $3000V_s = 240 \times 200$ $V_s = 16\ V$ $P_s = I_s V_s$ $60 = I_s \times 16$ $I_s = 0.27\ A$	$\text{Efficiency} = \frac{P_o}{P_{in}} \times 100$ $\mathbf{P_o = \eta P_{in}}$ $60 = \frac{80}{100} P_{in}$ $P_{in} = 75W$ $P_{in} = I_P V_P$ $75 = I_P \times 240$ $I_P = 0.3125\ A$

2. UNEB 1999 37, 2000 No. 6 (c), 2002 No. 5 (c), 2004 No. 5 (d),

3. UNEB 2018 PP2 No.6 (d): Explain why a transformer in use is usually submerged in oil.

Example

1. A transformer connected to 240 V A.C mains is used to light a 12V, 26 W lamp.
   (i) What current does the lamp need to light correctly?
   (ii) If the efficiency of the transformer is 75%, what current is taken from the mains?
   (iii) Calculate the magnitude of the series resistor that would be necessary if the lamp were connected directly to the mains.

2. A transmission line between a power station and a factory has resistance of 0.05 Ω in each of the two wires. If 100 A is delivered at 100 V.
   (i) What useful power is delivered into the load.
   (ii) How much power is wasted is wasted during transmission.
   (iii) What total power must be supplied by the generator?

3. A transformer with a ratio of **5:2** and efficiency of 90% has a primary voltage of 240V. If a current of 2.5A flows through the primary coil, determine the current through the secondary coil.

4. A step up transformer is designed to operate from a 20 V supply and delivers energy at 250 V. If it is 90% efficient,
a) Determine the primary and secondary currents when the output terminals are connected at 250V, 100W lamp.
b) Find the ratio of the primary turns to the secondary turns..

Assignments;

1. a) Describe with the aid of a diagram the operation of a transformer.
 b) A 240 V step down mains transformer is designed to light ten 12 V, 20 W ray box lamps and draws a current of 1 A in the primary coil.Calculate the:
   i) Power supplied to the primary coil.
   ii) Power delivered in the secondary coil
   iii) Efficiency of the transformer.

2. A transformer connected to 240 V A.C mains is used to light a 12 V 26 W lamp.
   a) What current does the lamp need to light correctly?
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   a) What useful power is delivered into the load.
   b) How much power is wasted is wasted during transmission.
   c) What total power must be supplied by the generator?

Calculating the value of alternating current.

The maximum value of an alternating current is known as its **peak value** which is reached momentarily, twice for every revolution of the coil.

We need to obtain the mean square value and then root-mean square value (r.m.s) value of the alternating voltage (or current) in order to avoid zero average.

The peak value is related to the root-mean square value by an equation;

$$\mathbf{r.m.s = \frac{peak\ value}{\sqrt{2}}}$$

1. Peak value is the maximum value of alternating

current or voltage.
Peak value is just momentarily reached twice every complete revolution. It is therefore greater than the effective value of the supply.

2. Root –mean square value is the effective value of alternating current or voltage.
It is equivalent to the direct current (or direct voltage) which would dissipate the same amount of power when passing through a resistor as the alternating current of peak value.

Example. 1
In Uganda, the A.C mains voltage is 240 V. calculate the peak value of the mains.

$$\text{peak value} = 240\text{V}$$

$$\text{r.m.s} = \frac{\text{peak value}}{\sqrt{2}}$$

$$240 = \frac{\text{peak value}}{\sqrt{2}}$$

$$V_0 = 240 \times \sqrt{2} = 339.4$$

Advantages of a.c over d.c
- A.C is easy to generate.
- A.C is is easy to transmit to around the country with minimal power loss.
- Alternating current can easily be stepped up and down for home consumption.

Disadvantages of a.c over d.c
- A.C cannot be used to charge a battery.
- A.C cannot be used in electroplating.
- A.C cannot be used in electrolysis.

Rectification is the converting of A.C to D.C which is already discussed under electronics in modern physics.

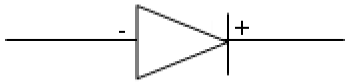
Similarities between a.c and d.c.
Both can be cause: -Magnetisation, -Heating, -Lighting

Differences between a.c and d.c.

D.c	A.c
-Can be used in electrochemical processes. E.g electro plating	-Ac is useless in this aspect
-Can be used in electric trains for locomotion.	-The train would simply move forward and backwards at the frequency of the a.c supply.
-Can't be stepped up or down	-Can easily be stepped up and down by using transformers.
-cannot	-Can be transported for long distances with minimum power loss
-D.c can't be conducted by capacitors	-A.c can be conducted by capacitors
-D.c is already rectified	-A.c can easily be converted to d.c using rectifiers

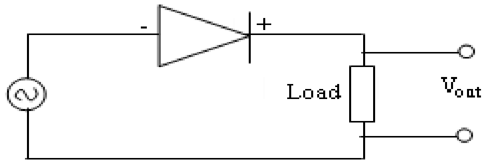
RECTIFICATION

Rectification is the process by which a.c is converted to d.c.
During rectification, a diode which shows low resistance to the flow of current in one direction and a very high resistance to current flow in the opposite direction is used.



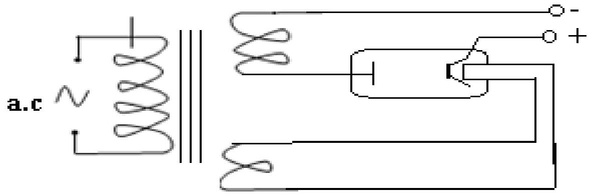
Types of Rectification:

(a) Half-wave rectification
This is where a.c is converted to d. c such that current in the second half cycle is blocked by the diode.

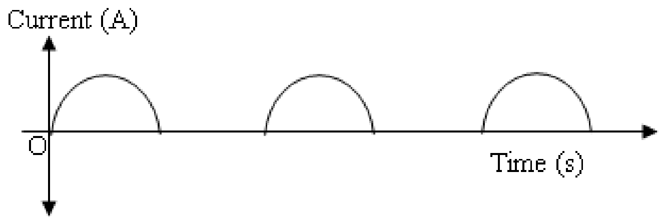


-When current flows clockwise, the resistance of the diode is low.
-In the 2nd half cycle, when current would be flowing in the opposite direction (anti- clockwise), the resistance of the diode is very high and so current is switched off.
-The energy in the switched off half cycle appears as heat energy and warms up the diode.

Alternatively, we can use a vacuum- tube.
When the anode becomes positive, electrons are attracted from the cathode hence current flows in the circuit.
And when the anode becomes negative, electrons from the cathode are repelled and therefore no flow of current.
The result is that the current in the circuit is uni-directional.



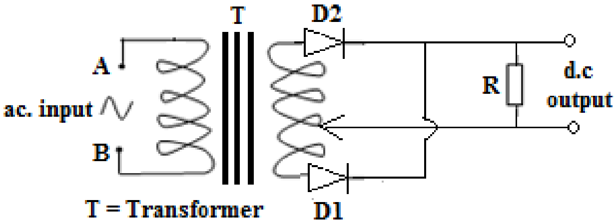
The graph of the out put of half wave rectification is as shown below.



A moving coil galvanometer can be used to measure the average value of the current, $< I >$.

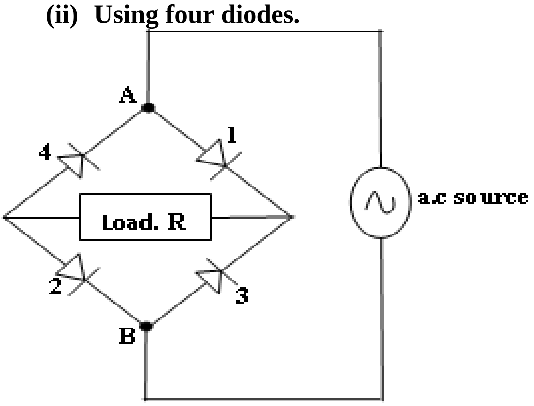
(b) Full-wave rectification:
Although current has been rectified and made to flow in one direction, during half wave rectification, half of the energy is lost.
To overcome this problem, we use full- wave rectification in which two diodes or four diodes arranged in a circuit bridge are used.

(i) Using two diodes.

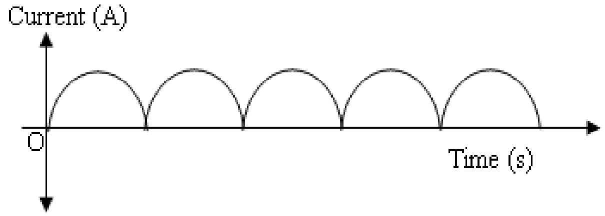


- ✓ During the first half of the cycle, when A is positive with respect to B, diodes D2 conducts and diode D1 does not. Current flows through R.
- ✓ During the next half cycle, when B is positive with respect to A, diode D1 conducts and D2 does not. Current flows through R.
- ✓ Therefore, current flows through R during both cycles hence both cycles have been rectified.

(ii) Using four diodes.



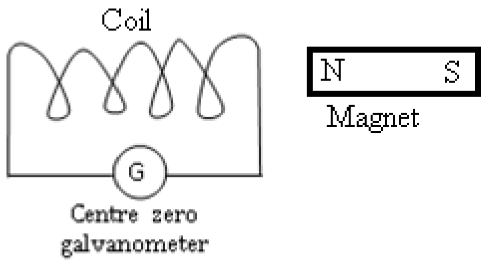
- During the 1st half cycle, point A is positive relative B. Thus current flows through diodes 1 and 2. Diode 2 takes back the current to the source.
- During the 2nd half cycle, point B is made positive relative B. Thus current flows through diodes 3 and 4. Diode 4 takes back the current to the source.
- Thus there is always a current flowing in the same direction through the load, R.



A moving coil galvanometer can be used to measure the average value of the current, < I > .
From the definition of mean value;

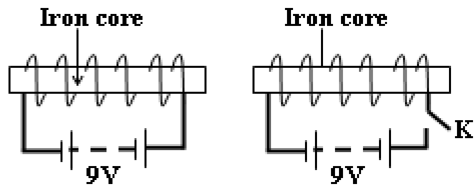
EXERCISE

13. (2000 Qn.6): The arrangement in figure below is used to produce an e.m.f. what causes the e.m.f?



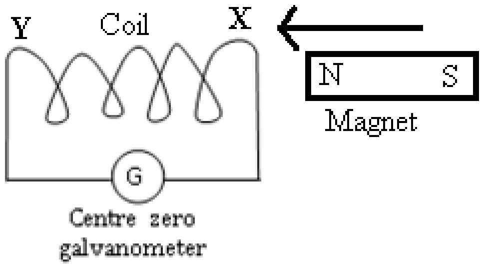
A. The attraction between the coil and the magnet
B. The magnetic field outside the coil
C. The magnet placed close to the coil.
D. The variation of magnetic lines linking the coil.

14. (2000 Qn.22): In the figure below when switch K is closed, the two soft iron cores will;



A. Repel each other all the time
B. Attract each other all the time.
C. Attract each other for just a brief moment
D. Have no force of attraction or repulsion between them.

15. (2002 Qn.5): The figure below shows a coil connected to a center zero galvanometer G.



The poles produced at the ends X and Y of the coil when the north pole of the magnet approaches it , is;
A. X- north pole Y-south pole
B. X-south pole Y-north pole
C. X-north pole Y-north pole
D. X-south pole X-south pole

16. (2002 Qn.40): The induced current in a generator
A. Is a maximum when the coil is vertical
B. Is a minimum when the coil is horizontal
C. Changes direction when the coil is horizontal
D. Increases when the speed of rotation increases

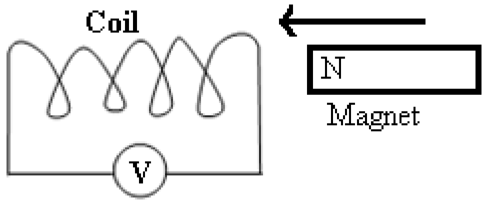
17. (2004 Qn.9): Which of the following is the correct order of energy changes or conversions in a generator
A. Heat energy in cylinder →
kinetic energy in piston → electrical energy

B. chemical energy from fuel →
heat energy from cylinders →
kinetic energy in pistons →
rotational kinetic energy in dynamo →
electrical energy

C. chemical energy from fuel →
rotational kinetic energy in a dynamo →
rotational kinetic energy in piston →
electrical energy.

D. electrical energy →
rotational kinetic energy in dynamo →
rotational kinetic energy in pistons →
sound energy.

18. (2004 Qn.42):
a) State two differences between a.c and d.c generators.
b)

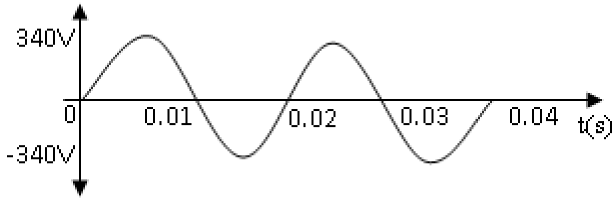


Briefly describe what happens when a magnet is moved into a coil as shown in figure above.

19. (2001 Qn.47):

a) State **one** advantage of a.c over d.c in a main supply.

b)



The graph in figure above sows the variation of an a.c with time. Find;

(i) The peak value.

(ii) The frequency

20. (1999 Qn.37): A transformer is used to step down an alternating voltage from 240V to 12V. Calculate the number of turns on the secondary coil if the primary coil has 1200 turns.

A. . 3 B. 5 C. 60 D. 100

21. (1995 Qn.31): A transformer has twice as many turns in the secondary as in the primary coil. The a.c input to the primary is 4V. Find the output voltage.

A. . 2 V B. 8 V C.4 V D. 16 V

22. (1997 Qn.10): A transformer whose efficiency is 80% has an output of 12 W. Calculate the input current if the input voltage is 240 V. (Ans: 0.0625A).

23. (2003 Qn.6): A transformer is connected to 240V a.c mains is used to light a 12 V, 36 W. What current does the lampdraw?

A. 20.0 A B. 6.7A C. 3.0 A D. 0.33A

24. Which of the following is true about a transformer

A. The efficiency is 100%

B. The magnitude of e.m.f induced in the secondary does not depend on the e.m.f induced in the primary coil.

C. There are no power losses as the core is well laminated.

D. Passing direct current through the primary has no effect on the secondary coil.

25. Which one of the following would be suitable to use in the construction of a transformer core?

A. Lead C. Copper

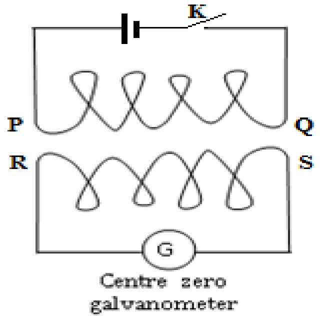
B. Soft iron D. Aluminium

26. The main function of a step-up transformer

A. Change a.c to d.c C. Change d.c to a.c

B. Increase the current D. Increase voltage

27. PQ and RS are two coils placed near each other as shown in the diagram.



What will happen to the pointer of the galvanometer when switch, K is closed and kept closed.

A. It oscillates about the zero point.

B. It registers a momentary deflection and quickly returns to zero.

C. It registers a steady deflection to one side.

D. It registers a deflection to one side and slowly returns to a lower steady reading on the same side.

28. A transformer can't function normally with a d.c because a d.c

A. Has an extremely high heating effect

B. Reduces the efficiency of the transformer

C. Cannot produce a changing magnetic field

D. Cannot provide voltages required for power transmission.

29. An a.c input voltage of 250Vis connected to a transformerwith 100 turns. Calculate the number of turns in the secondary coil, if an output of 15V is required.

30. Which one of the following is the most economical means of transmitting electricity over a long distance?

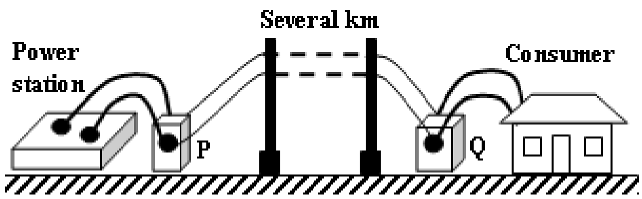
A. At a high voltage and a low current

B. At a high voltage and a high current

C. At a low voltage and a low current

D. At a low voltage and a low current.

31. The figure below shows a transmission line from power station to a consumer several kilometers away.



Which one of the following is the correct type of transformers at P and Q?

	P	Q
A	Step-up	Step-up
B	Step-down	Step-down
C	Step-up	Step-down
D	Step-down	Step-up

32. When transmitting energy, electrical power over long distances, the voltage is stepped up in order to

A. Transmit it

B. Reduce power loss

C. Increase current for transmission
D. Prevent electric shocks.

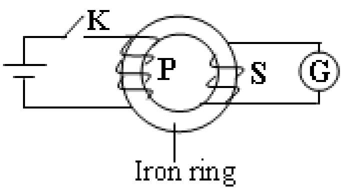
33. Power loss due to eddy currents in the core of a transformer can be minimized by
A. Laminating the core
B. Using thick copper wires in the windings
C. Using soft iron core
D. Winding the secondary coil on top of the primary coil

34. A voltage of 440V is applied to a primary coil of a transformer of 2000 turns. If the voltage across the secondary is 11kV, what is the number of turns in the secondary coil?
A. 50 C. 80
B. 5×10^4 D. 8.0×10^4

35.
a) Give the advantages of alternating current over direct current in power transmission
b) Describe, with the aid of a diagram, the construction and action of a transformer
c) A transformer is designed to operate at 240V mains supply and deliver 9V. The current drawn from the mains is 1.0A. if the efficiency of the transformer is 90%, calculate;
(i) The maximum output current
(ii) The power loss
d) State the possible causes of the power loss in © (ii) above

36.
(i) Explain briefly what is meant by mutual induction
(ii) Mention the causes of energy loss by a transformer and state how the loss can be minimized
(iii) A transformer has 200 turns on the primary coil. Calculate the number of turns on the secondary coil if 240V is to be stepped to 415 V

37.
a) What is a **transformer?**
b) The diagram in fig below shows a model of a transformer in which the primary coil **P** is connected to d.c and the secondary coil, **S** is connected to a galvanometer.

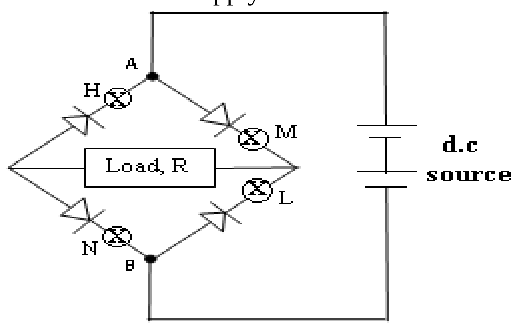


(i) What is observed justas the switch K is closed?
(ii) What would be the effect of closing switch K very fast in (i) above?
(iii) What is observed when the switch K is closed?
(iv) What is observed just as switch K is opened?
(v) What would be observed if the d.c source is replaced by an a.c source of a low frequency.

c) A transformer of efficiency 80% is connected to 240Va.c supply to operate a heater of resistance 240Ω. If the current flowing in the primary circuit is 5A,
(i) Calculate the potential difference (p.d) across the heater.
(ii) If the transformer is cooled by oil of specific heat capacity $2100 Jkg^{-1}K^{-1}$ and the temperature of the oil rises by 20^0C in 3 minutes, find the mass of the oil in the transformer

38.
a) Describe briefly the structure and action of a transformer.
b) (i) State any three causes of energy losses in a transformer.
(ii) How are these losses reduced in a practical transformer?
c) Explain why it is an advantage to transmit electrical power at high voltage.
d) Electrical power is generated at 11kV. Transformers are used to raise the voltage to 440kV for transmission over large distances using cables. The output of the transformer is 19.8MV and they are 90% efficient. Find the;
(i) Input current to the transformer.
(ii) Output current to the cables

39. The circuit below shows diodes and bulbs connected to a d.c supply.



Which of the following pairs of bulbs will light up?
A. M and N C. N and H
B. M and L D. H and L

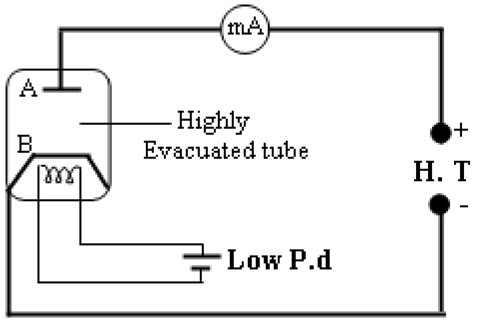
40. Rectification of alternating current means
A. Stepping up alternating current by a transformer
B. Converting alternating current into direct current
C. Stepping down alternating current by a transformer
D. Generating alternating current from a dynamo.

41. What device could be connected to the secondary of a transformer in order to get d.c in the output ?
A. Diode C. Resistor
B. Rheostat D. Thermostat

42. A rectifier is used to?
A. Step up an a.c voltage
B. Step up an a.c current
C. Change an a.c voltage to a d.c voltage
D. Change a d.c voltage to an a.c voltage

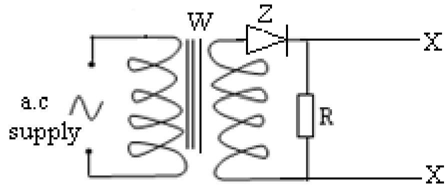
43. The number of rectifiers used in a full-wave rectification is?
A. 1 B. 2 C. 3 D. 4

44. The diagram below shows the current circuit of a thermionic diode.



a) Name the parts labeled A and B
b) Why the thermionic diode is is highly evacuated?
c) Describe briefly the action of a thermionic diode.

45. The figure below shows a charging circuit.



a) Name and state the use of each parts labeled;
   (i) W
   (ii) Z
b) Sketch the wave form that is obtained from terminals XX.

U SEFUL INFORMATION IN PHYSICS

❶ MECHANICS	
Fundamental quantities; fundamental quantities are quantities which can not be expressed in terms of other quantities.	
Mass	Mass is the quantity of matter which a body contains.
Length	Llength refers distance between two points irrespective of the path taken.
Time	Time refers to the measure of duration of an event
Derived quantities; derived quantities are quantities which can be expressed in terms of fundamental quantities	
Area	Area is the measure of the surface of an object
Volume	Volume is the amount of space occupied by an object
Density	Density is mass per unit volume of a substance
	$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$
Relative density	Relative density is the ratio of the density of a substance to the density of of water.
	$\text{RelativeDensity} = \frac{\text{Density of asubstance}}{\text{Density of water}}$ $= \frac{\text{Mass of substance}}{\text{Mass of equal Volume of water}}$ $= \frac{\text{Weight of substance}}{\text{Weight of equal Volume of water}}$
Diffusion	Is the spreading of molecules from a region of their high concentration to a region of their low concentration.
Brownian motion	Is the random movement of particles due to collision with invisible air molecules which are in a state of random motion.

FORCES	
Scalar quantity	A scalar quantity is a quantity which has magnitude only.
Vector quantity	A vector quantity is a quantity which has both magnitude and direction.
Resultant vector	
Force	Force is a physical quantity which changes a body's state of rest or of uniform motion in a straight line. **F = ma**
A newton	A newton is a force which gives a mass of 1kg an acceleration of $1ms^2$.
Acceleration due to gravity	Is the rate of change of velocity of a freely falling body.
Weight	Weight of a body is the force of gravity on it. OR: Weight is the force which a body exerts on anything which freely supports it. **weight = mg** **<u>The weight of a body varies because of;</u>** **-Earth is not a perfect sphere.**(If a body is taken from the pole to the equator, its distance from the earth's centre increases hence reducing its weight) **-The rotation of the earth. (**Part of the gravitational attraction provides the necessary centripetal force**)** Centripetal force is the force which keeps a body moving in a circular path.
Friction	Friction is the force that opposes relative sliding motionbetween two surfaces in contact.
Static friction	Static friction is the friction between two surfaces that are tending to slide over each other.

Kinetic friction	Kinetic or sliding friction is the friction between two surfaces that are moving relative to each other. It is always less than static friction.
Limiting friction	Is the maximum friction force between two surfaces which are at the verge of sliding over each other. (They are about to slide over each other)
Coefficient of static friction	Is the ratio of limiting friction to the normal reaction.
Cohesion force	**Cohesion** is the force of attraction between molecules of the same substance.
Adhesion force	**Adhesion** is the force of attraction between molecules of different substance.
Surface tension	**Surface tension** is the tangential force acting normally per unit length across any line in the surface of a liquid. **Or** It is the force which causes the surface of a liquid to behave like a stretched elastic membrane.
Centripetal force	Is the force acting on a body moving in a circle and directed towards the centre of the circular path.
Up thrust	Is the upward force which acts on bodies in fluids. $\mathbf{U = W_a - W_f}$
Viscous drag	Is the force that opposes motion of a body through a fluid.
MOMENTS	
Moment	<u>**Moment of a force** is the product of</u> the force and the perpendicular distance of its line of action from the turning point (or pivot). $\begin{pmatrix}\text{Moment}\\ \text{of a force}\end{pmatrix} = \text{force X}\begin{pmatrix}\text{perp.}\\ \text{distance}\\ \text{from}\\ \text{pivot}\end{pmatrix}$ ***<u>Principle Moments:</u>*** *When a body is in equilibrium the sum of the clockwise moment about ay point equal the sum of the anti-clock wise moment.* **<u>For parallel forces in equilibrium</u>** ❖ *Sum of upward force = sum of downward forces* ❖ *Sum of anticlockwise moments = Sum of clockwise moments*
Couple	<u>A **Couple:** Is a pair of equal but opposite parallel forces whose lines of action do not meet.</u> • It causes rotation of the body • It cannot be replaced by a single fore. It can only be balanced by an equal but opposite couple. <u>A **torque**: </u>Is the moment of a couple.

Centre of gravity	**Centre of gravity** of a body is the point of application of the resultant force due to the earth's attraction on it.
Neutral Equilibrium	Is a form of equilibrium in which when a body is slightly tilted, its centre of gravity does not change position relative to the ground.
Stable Equilibrium	Is a form of equilibrium in which when a body is slightly tilted, its centre of gravity is raised and the body returns to its original position.
Unstable equilibrium	Is a form of equilibrium in which when a body is slightly tilted, its centre of gravity is lowered and the body does not return to its original position.
WORK, ENERGY AND POWER	
Work	Work is the product of force and distance moved by its point of application in the direction of the force. **Work = Force X Displacement** **i.e. W= F X S** <u>A **joule**</u> is the work done when a force of 1N moves its point of application through a distance of 1m.
Energy	Energy is the ability to do work. <u>Kinetic energy</u> is the energy which a body has because of its motion. $\mathbf{K.e = \frac{1}{2}mv^2}$ <u>Potential energy</u> is the energy which a body has because of its position or condition. $\mathbf{P.e = mgh}$ <u>Principle of conservation of energy</u>*:* *Energy is neither created nor destroyed but changes from one form to another*
Power	Power is the rate of doing work $\text{Power} = \frac{\text{work done}}{\text{Time}} = \frac{F \times d}{t}$ Power is the rate of transfer of energy $\text{Power } = \frac{\text{Energychanged}}{\text{Timetaken}}$ In some cases you will find it easier to use; $\mathbf{Power\ = Force \times Velocity}$
MACHINES	
Machine	**A machine** is a device which enables force acting at one point to overcome force acting at some other point.
Load	Is the force that a machine overcomes
Effort	Is the force exerted to overcome the load

Pitch	Is the distance between two successive threads of a screw.
Mechanical advantage	Mechanical advantage is the ratio of the load to effort. MechanicalAdvantage; $\mathrm{M.A} = \frac{\mathrm{Load}}{\mathrm{Effort}}$
Velocity ratio	Velocity ratio is the ratio of distance moved by effort to distance moved by the load in the same time. $\mathrm{Velocity\,Ratio(V.R)} = \frac{\mathrm{Effortdistance}}{\mathrm{Loaddistance}}$ $\boldsymbol{V.R\ of\ an\ inclined\ Plane}$ $= \frac{\mathrm{lengthoftheplane}}{\mathrm{heightoftheplane}} = \frac{l}{h}$ $\boldsymbol{V.R\ of\ a\ screw}$ $= \frac{\mathrm{circumferanceofcirclemadebyeffort}}{\mathrm{Pitchofthescrew}}$ $= \frac{2\pi\mathrm{r}}{\mathrm{P}}$ $\boldsymbol{V.R\ of\ a\ wheel\ and\ axle}$ $= \frac{\mathrm{circumferanceofwheel}}{\mathrm{Circumferenceofaxle}}$ $= \frac{2\pi\mathrm{R}}{2\pi\mathrm{r}} = \frac{\mathrm{R}}{\mathrm{r}}$
Efficiency	Efficiency is the ratio of useful work done by a machine to the total work put into in the machine. $\mathrm{Efficiency} = \frac{\mathrm{workoutput}}{\mathrm{workinput}} \times 100\%$ $\mathrm{orEfficiency} = \frac{\mathrm{M.A}}{\mathrm{V.R}} \times 100\%$
PRESSURE	
Pressure	**Pressure** is the force acting normally per unit area. $\mathrm{Pressure} = \frac{\mathrm{Force}}{\mathrm{Area}}$ i.e $\mathbf{P} = \frac{\mathbf{F}}{\mathbf{A}}$ Pressureinliquid $= \begin{pmatrix}\text{height of}\\ \text{liquid}\\ \text{column}\end{pmatrix} \times \begin{pmatrix}\text{Density}\\ \text{of liquid}\\ \text{column}\end{pmatrix} \times$ Accelerationduetogravity $\mathbf{P = h\rho g}$ In a manometer: $\begin{pmatrix}\text{Gas}\\ \text{pressure}\end{pmatrix} = \begin{pmatrix}\text{atmosp.}\\ \text{pressure}\end{pmatrix} + \mathrm{h\rho g}$ ***Pascal`s principle*** It states that pressure in an enclosed fluid is equally transmitted throughout the fluid in all directions.

	Archimedes's principle *When a body is wholly or partially immersed in a fluid it experiences an upthrust equal to the weight of the fluid displaced.* *Upthrust = weight of fluid displaced* $U = m_f g$ $\boldsymbol{U = (\rho_f V_f) g}$ ***Principle flotation*** *A floating body displaces its own weight of the fluid.* *Upthrust = weight of the floating body* $U = m_b g$ $\boldsymbol{U = (\rho_b V_b) g}$
Pascal	Is the pressure exerted when a force of 1N acts on an area of $1\mathrm{m}^2$.
MOTION	
Displacement	Displacement is the distance moved in a specified direction.
Speed	Speed is the rate of change of distance moved with time. $\mathrm{Speed} = \frac{\mathrm{Distance}}{\mathrm{Time}}$
Velocity	Velocity is the rate of change of displacement with time. OR: Velocity is the rate of change of distance moved with time in a specified direction.
Uniform velocity	Is the constant rate of change of displacement with time.
Acceleration	Acceleration is the rate of change of velocity with time.
Uniform acceleration	Uniform Accelerationis the constant rate of change of velocity with time .
	Equations of motion $1^{st}: \boldsymbol{v = u + at}$ $2^{nd}: \boldsymbol{s = ut + \frac{1}{2}at}$ $3^{rd}: \boldsymbol{v^2 = u^2 + 2as}$ $\boldsymbol{s = \frac{1}{2}gt^2}\ (for\ a\ free\ fall)$ **Newton's law of motion** ***1st law*** *Everybody continues in its state of rest or of uniform motion in a straight line unless an external force makes it behave differently.* ***2nd law*** *The rate of change of momentum of a body is proportional to the applied force and takes place in the direction in which the force acts.* $\boldsymbol{F = ma}$

	3rd law *To every action there is an equal and opposite reaction*
Momentum	Momentum of a body is the product of its mass and velocity **Momentum = Mass × Velocity** <u>Principle of conservation of momentum:</u> When two or more bodies act on one another, their total momentum remains constant, provided no external force acts. **OR**: In a system of colliding bodies, total momentum before collision is equal to total momentum after collision provided no external force acts. <u>Inelastic collisions:</u> This is where the colliding bodies stick together and move with a common velocity, V after the collision. i.e. $\mathbf{m_1u_1 + m_2u_2 = (m_1 + m_2)\,V}$ <u>Elastic collisions:</u> This is where the colliding bodies separate and move with different velocities after the collision. i.e. $\mathbf{m_1u_1 + m_2u_2 = m_1u_1 + m_2u_2}$
Impulse	Is the change in momentum. $\mathbf{I} = \begin{pmatrix}\textbf{Final}\\ \textbf{momentum}\end{pmatrix} - \begin{pmatrix}\textbf{Initial}\\ \textbf{momentum}\end{pmatrix}$ **OR;** It is the product of the force and the time of action of the force. $\mathbf{I = F \times t}$
Inertia	Inertia is the tendency of a body to remain at rest or, if moving, to continue its motion in a straight line.
Terminal velocity	Is the maximum constant velocity attained by a body falling vertically through a fluid.
Stream line flow	Is the form of fluid flow in which the successive particles flowing past a section at a time are in the same direction and have the same velocity parallel to each other.
Turbulent flow	Is the form of fluid flow in which the successive particles flowing past a section at a time are in different directions, have different velocities and are not parallel to each other.
Elasticity	<u>Elasticity</u>is the ability of a substance to recover its original shape and size after distortion. <u>An elastic material</u> is one which recovers its originals shape and size after the force deforming it has been removed.

	Hook's law: *The extension of a material is directly proportional to the applied force provided elastic limit is not exceeded.* Force = k(extension) $\Leftrightarrow \frac{\text{Force}}{\text{extension}} = \text{k} \Leftrightarrow \frac{\text{F}_1}{\text{e}_1} = \frac{\text{F}_2}{\text{e}_2} = \text{k}$ $or\ \frac{\mathbf{F_1}}{\mathbf{F_2}} = \frac{\mathbf{e_1}}{\mathbf{e_2}}$
Plasticity	Is the property which makes materials stretched (deformed) permanently even when the applied force is removed. Materials which have this property are called plastic materials e.g. plasticine, clay, putty or tar etc.
Strength	Is the ability of a material to withstand forces which try to break it. e.g concrete, metals etc. OR Strength is the ability of a material to resist deformation.
Stiffness	Is the measure of the rigidity of a material. It is the property of material that makes it resist being bent. Materials with this property are said to be stiff e.g steel, iron and concrete.
Hardness	Is a measure of how difficult it is to scratch a surface of a material. Hard materials include; metals, stones etc.
Brittle Material	Is a material which bends very little and breaks suddenly when a tensile force acts on it.
Ductile material	Is a material which stretches first classically and then plastically before it breaks when a force acts on it.
Concrete	Is a mixture of cement, sand, gravel and water.
Stress	$\text{Stress} = \frac{\text{Force}}{\text{crosssectionalArea}} = \frac{\mathbf{F}}{\mathbf{A}}$
Strain	$\text{Strain} = \frac{\text{extension}}{\text{originallength}} = \frac{\boldsymbol{e}}{\boldsymbol{l_0}}$ $\text{Young's modulus} = \frac{\text{stress}}{\text{strain}}$
Tie	**A tie** is a girder which is in tension.
Strut	**A strut** is a girder which is in compression.

UNEB sample Questions:		
1993 Qn.5 2002 Qn.29 2004 Qn.17 2004 Qn.39	2007 Qn.1 1997 Qn5 1999 Qn.12 2000 Qn.24	2001 Qn.11 2003 Qn.11 2006 Qn.10
Particulate nature 1987 Qn36 1997 Qn.13 1999 Qn.23 2006 Qn.19	2007 Qn.25 1987 Qn.2 2001 Qn.43 2003 Qn.3 2005 Qn.49	**Size of oil molecule** 1987 Qn.7 1992 Qn.31 2004 Qn.40 1993 Qn.7 2002 Qn 45
Moments and centre of gravity 2003 Qn.5 1987 Qn.10 1988 Qn.2	1988 Qn.7 1989 Qn.15 1989 Qn.38 1991 Qn.30 1993 Qn.14 2000 Qn.11	2002 Qn.11 2003 Qn.5 2007 Qn.17 2000 Qn.2 2007 Qn.5
Work, Energy and Power 1994 Qn.17 1989 Qn.29 2007 Qn.33 1987 Qn.24 1993 Qn.18 2006 Qn.6 1993 Qn.4	1994 Qn.5 1995 Qn.9 1987 Qn.3 1991 Qn.11 1992 Qn.11 1997 Qn.9 1997 Qn.10 1999 Qn.8	2000 Qn.23 2001 Qn.26 2003 Qn.15 2007 Qn.6 1993 Qn.4 1999 Qn.2 2005 Qn.45
Machines 1999 Qn.2 1994 Qn.8 1987 Qn.36	1988 Qn.34 1991 Qn.26 1998 Qn.6 2006 Qn.4	1992 Qn.6 2001 Qn.42 2007 Qn1
Pressure 1994 Qn.25 2003 Qn.10 1992 Qn.33 1988 Qn.13 1991 Qn.5 1995 Qn.15 1996 Qn.39 2002 Qn.9 2001 Qn.27	2001 Qn.10 1999 Qn.17 1994 Qn.3 1993 Qn.1 1987 Qn.40 1989 Qn.12 1990 Qn.17 1991 Qn.3 1993 Qn.2	1993 Qn.20 1994 Qn16 1997 Qn.11 2002 Qn.9 2007 Qn.27 2007 Qn.30 2000 Qn.2 2003 Qn. 43 1995 Qn. 2
Archimedes principle and Floatation	1991 Qn.7 1995 Qn.7 1990 Qn.8 1990 Qn.9 2000 Qn.16 2001 Qn.40	1988 Qn.11 1990 Qn.5 PP2 1989 Qn.4 2001 Qn.2
Motion 1993 Qn.25 1997 Qn.2 PP2 1996 Qn.1 PP2 2000 Qn.1 PP1 1998 Qn1(b) 2000 Qn.20 1995 Qn.10	2003 Qn.26 1987 Qn.12 1987 Qn.25 1989 Qn.1	1992 Qn.23 1993 Qn.25 1994 Qn.10 1994 Qn.26 1996 Qn.24 2001 Qn.25 2006 Qn.9 1991 Qn2 1993 Qn5 PP2 1999 Qn.1PP2
Momentum and Newton's laws of motion		
2001 Qn.1 1988 Qn.9 1994 Qn.5 1995 Qn.8 1988 Qn.20 2003 Qn2	2006 Qn.32 2007 Qn.24 1992 Qn.2 1994 Qn.3 1990 Qn.8 1990 Qn.9	2000 Qn.16 2001 Qn.40 1990 Qn.5 PP2 1989 Qn.4 2001 Qn.2

Mechanical Properties of matter

1993 Qn10 1997 Qn19 1989 Qn.10 1994 Qn.4	2002 Qn.47 1996 Qn.21 2006 Qn.8 2007 Qn.40	1987 Qn.9 1990 Qn.5 1994 Qn.5

❸ GEOMETRIC OPTICS:-LIGHT

REFLECTION

(a)<u>Reflection At Plane Surfaces:</u>

Light	Is a form of energy that stimulates the sense of vision or sight.
Luminous object	An Object that produces its own light. E.g Sun.
Non luminous object	An object that does not produce its own light but reflects light from other objects. E.g moon.
Incandescent object	An object that give off light when it is hot.
Fluorescent object	An object that gives off light without necessarily being hot.
Phosphorescent object.	An object that absorbs light falling on it and later emits it as light energy.
Transparent medium	Is a medium that allows **all**the light incident on it to pass through it.
Translucent medium	Is a medium that allows **some** of the light incident on it to pass through it.
Opaque medium	Is a medium that does not allow any of the light incident on it to pass through it.
Rectilinear propagation of light	Is a process by which light travels in a straight line from the source.
Eclipse	Is the obstruction of light from the sun either by the moon or earth. It occurs when the sun, moon and earth are in a straight line.
Solar eclipse	Is an eclipse that occurs when the moon is between the sun and the earth, such that the moon casts its shadow onto the earth's surface. **<u>Annular eclipse</u>**: Is a solar eclipse that occurs when the earth is very far from the moon such that the moon's shadow does not reach the earth's surface.

Lunar eclipse	Is an eclipse that occurs when the earth is between the sun and the moon, such that the earth casts its shadow onto the moon's surface.
Reflection	Reflection is the change in the direction of a light ray or a beam of light after striking a surface.
	A ray is the direction of the path taken by light
	A beam is a stream of light energy
	Laws of reflection: **1:** The incident ray, reflected ray and the normal at the point of incidence all lie in the same plane. **2:** The angle of incidence is equal to the angle of reflection.
Types of Reflection	**(i) Regular reflection:** Is a type of reflection where an incident parallel beam is reflected as a parallel beam. It occurs on a smooth surface. **(ii) Irregular (Diffuse) Reflection:** Is a type of reflection where an incident parallel beam is reflected in different directions. It occurs on a rough surface.

(b)Reflection At Curved Surfaces:

Focal length	Focal length is the distance between the principal focus and the pole (for a mirror) or optical centre (for a lens)
Principal focus	Is a point on the principal axis at which all rays close and parallel to the principal axis converge after reflection at the mirror or refraction at the lens.
Centre of Curvature	Is the centre of the sphere of which the mirror or lens forms part.
Radius of Curvature	Is the radius of the sphere of which the mirror or lens forms part.
Parallax	Is the apparent relative movement of two objects owing to the movement on a part of the observer.
Magnification	Is the ratio of the height of the image to the height of the object. It is also defined as the ratio of the image distance to the object distance.
Real image	Is the image formed by actual intersection of reflected rays. It's the image which can be formed on a screen.
virtual image	Is the image formed by apparent intersection of reflected rays. It's the image which **cannot** be formed on a screen.

REFRACTION

Refraction	Is the change in the direction of light as it moves from one medium to another. **Laws of Refraction:** **1:** The incident and refracted rays are on opposite sides of the normal at the point of incidence and all the three are in the same plane. **2: [Snell's law]:** The ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant for a given pair of media. For all calculations, use; $\cap_1 \sin i = \cap_2 \sin r$
Refractive index	Is the ratio of the sine of the angle of incidence to the sine of the angle of refraction.
Power of a Lens	Is the reciprocal of the lens's focal length in metres. A **diopter** is the power of a lens of focal length 1m.
Total internal reflection	Is when light moving from a denser medium to a less dense medium is reflected when the critical angle is exceeded.
Critical angle, c	Is the angle of incidence in a denser medium when the angle of refraction in the less dense medium is 90^0.
Accommodation	Is the automatic adjustment of the eye to focus far and nearby objects by changing the focal length of the eye lens.
Short sightedness (Myopia)	Is a defect of vision where a person cannot see far objects clearly but can see nearby objects clearly.
Long sightedness (Hypermetropia)	Is a defect of vision where a person cannot see nearby objects clearly but can see far objects clearly.
Astigmatism	Is a defect of vision where a person sees a distorted image. It is due to changes in the spherical curvatures of the eye lens.
Minimum deviation	Is the deviation that occurs when the angle of incidence is equal to the angle of emergency.
Dispersion	Is the separation of white light into its component colours by a glass prism.

Spectrum	Is a band of colours of white light formed on a screen when white light passes through a glass prism. A pure spectrum is a spectrum formed without overlapping of the colour bands.
Primary colours	Are colours that cannot be obtained by mixing any other colours.
Secondary colours	Are colours that can be obtained by mixing any two primary colours.
Complementary colours	Are two colours one primary and the other secondary, such that when mixed they form white light.
Colour filter	Is a transparent material that allows light of a particular wavelength (or colour) to pass through it and absorbs the rest.

UNEB sample Questions:

Rectilinear propagation of light	**Reflection at curved surfaces**	**Lenses and optical instruments**
1997 Qn.22 2000 Qn.34 2002 Qn.27 2006 Qn.29 2006 Qn.27 Section. B 1992 Qn.1 1997 Qn.4 1998 Qn.7 **Reflection at plane surfaces** 1996 Qn.25 1999 Qn.28 1997 Qn.24 2005 Qn.40 2007 Qn.16	2001 Qn.8 2003 Qn.20 2005 Qn.29 2007 Qn.2 Section B 1995 Qn.5 1997 Qn.2 PP2 2002 Qn.2 PP2 **Refraction of light** 1994 Qn40 1995 Qn24 1996 Qn1 1996 Qn35 1990 Qn4 1993 Qn9 1996Qn3PP2	1993 Qn7 2000 Qn21 2004 Qn14 2007 Qn10 1993 Qn.7 PP2 1994 Qn2 1998 Qn6 2000 Qn8

WAVES

Mechanical wave motion; is a mechanism by which energy is transferred from one point to another through a material medium

Transverse Wave	Is one in which the direction of vibration of the particles is perpendicular to the wave travel.
Longitudinal Wave	Is one in which the direction of vibration of a particle is in the same direction as the wave travel.
Wavelength	Is the distance between two successive particles which are in the same phase. *The wave length of a wave,* $\boldsymbol{\lambda}$ *in which the distance between* $\boldsymbol{n}$ *successive crests or troughs is* $\boldsymbol{x}$*, is given by;* $\boldsymbol{\lambda = \frac{x}{n-1}}$ |4
Frequency	Is the number of complete oscillations made per second. Frequency $= \frac{\text{number of oscilations}}{\text{time taken}} = \frac{1}{\text{Period time}}$ i.e $\mathbf{f = \frac{1}{T}}$
Amplitude	Is the maximum displacement of particles from its rest position.
Period	Is the time taken for a wave to make one complete oscillation.
Velocity of a wave	Is the distance moved by any point on a wave in one second. $\mathbf{V = f\lambda}$
Wave Front	Is a line or section taken through by an advancing wave along which all particles are in phase.
Diffraction	Is the spreading of waves as they pass through a narrow opening.
Interference	Is a combination of waves to give a wave of larger or smaller amplitude. **Interference** is the effect which occurs when two waves of the same speed, frequency and wave length moving in <u>the same direction</u> meet.

Constructive interference; is a type of interference which occurs when a crest of one wave meets a crest of another wave.

Destructive interference; is a type of interference which occurs when a crest of one wave meets a trough of another wave.

An echo	Is a reflected sound from a hard surface.
Reverberation	Is when the original sound and its echo merge so that they cannot de distinguished. This makes the original sound appear prolonged.
Resonance	Is when a body is set into vibrations of maximum amplitude with its own natural frequency by another nearby body vibrating with the same frequency.

Stationary wave	Is a wave formed when two progressive waves of equal frequency and amplitude travelling in opposite directions are superposed on each other.
Progressive waves;	These are waves which carry energy away from the source.
Electromagnetic waves;	these are waves made up of electric and magnetic vibrations of high frequency
✓ ***Radio waves;***	these are waves produced when electrons are accelerated in an aerial
✓ ***Infrared radiations;***	these are radiations that cause the body temperature to rise due to heat energy
✓ ***Ultraviolet light;***	these are radiations that cause certain metal surfaces to emit electrons and aid photosynthesis in green plants

Wave motion 1992 Qn7 1989 Qn30 1990 Qn21 1992 Qn1 1994 Qn23 1998 Qn23 1998 Qn26 2001 Qn18 2006 Qn22 2007 Qn35 2007 Qn39 2008 Qn31 1989 Qn6 1993 Qn4 2006 Qn5	**Electromagnetic waves** 1987 Qn30 1989 Qn16 2001 Qn21 2006 Qn31 2007 Qn13 **Sound waves** 2001 Qn19 1990 Qn40 1995 Qn22 1989 Qn27 1997 Qn23 1994 Qn10 2006 Qn42 2008 Qn26 1997 Qn26 1989 Qn2 1991 Qn14 1991 Qn40 1992 Qn32 1997 Qn33	1998 Qn25 1999 Qn27 2002 Qn17 2002 Qn25 **Progressive and /stationary waves** 1988 Qn25 1989 Qn9 1995 Qn21 2000 Qn12 2000 Qn29 2000 Qn30 2002 Qn22 2005 Qn39 2008 Qn31 2008 Qn35 Section B 1990 Qn6 2000 Qn6 2004 Qn7 2008 Qn6

MAGNETISM

Ferromagnetic Materials	Are materials which are strongly attracted by magnets. (i) **Paramagnetic** materials are materials that are slightly attracted by a strong magnetic field e.g Wood, Aluminium, brass, copper, platinum etc. (i)**Diamagnetic** materials are materials that are slightly repelled by a strong magnetic field e.g Zinc, Bismuth, sodium chloride, gold, mercury, e.t.c. Diamagnetic materials become weakly magnetized in a direction opposite to the magnetizing field.
Magnetic poles	Poles are places in the magnet where the resultant attractive forces appear to be concentrated. **1st law of magnetism:** *Like pole repel unlike pole attract.*
Magnetic field	Is the region surrounding a magnet in which the magnetic force is exerted.
Magnetic Meridian	Is a vertical plane containing the magnetic axis of a freely suspended magnet at rest under the action of the earth's field.
Geographical Meridian	Is a vertical plane containing the earth's axis of rotation.
Magnetic Declination	Is the angle between the magnetic and Geographical meridians
Angle of dip (angle of Inclination)	Is the angle between the direction of the earth's resultant magnetic flux and the horizontal.
A neutral Point	Is a point at which the resultant magnetic field is zero.
Magnetic saturation	Is the limit beyond which the strength of a magnet cannot be increased.
Right–hand grip rule.	If the fingers of the right hand grip the solenoid in the direction of current, the thumb points to the North Pole.
Maxwell's screw rule (Right – hand screw rule)	If a right – handed screw moves forward in the direction of the current, the direction of rotation of the screw gives the direction of the field.
Electromagnetic induction	Electromagnetic induction is the production of an e.m.f in a conductor when the conductor cuts magnetic field lines.
Fleming's left hand rule (motor rule)	If the first finger, second finger and the thumb of the left hand are held at right angles, then the **F**irst finger points in the direction of the **F**ield, the se**C**ond finger in the direction of **C**urrent and the thu**M**b in the direction of the **M**otion.
Back e.m.f:	Is the e.m.f set up in opposition to the e.m.f applied to drive an electric motor.
Faradays laws	**Law 1:** Whenever a conductor cuts a magnetic field lines (or Whenever there is a change in magnetic flux linking a circuit), an e.m.f is induced. **Law 2:**The size of an induced e.m.f is directly proportional to the rate at which the conductor cuts the magnetic field lines.
Lenz's law:	The direction of induced current is such as to oppose the change causing it.

Fleming's right hand rule (Dynamo rule):	If the first finger, second finger and the thumb of the right hand are held at right angles to each other, then the **F**irst finger points in the direction of the induced **F**ield, the se**C**ond finger in the direction of induced **C**urrent and the thu**M**b in the direction of the **M**otion.
Self induction:	Is the process where an e.m.f is induced in a coil due to a changing current in the same coil.
Mutual induction:	Is the process where an e.m.f is induced in a coil due to a changing current in a near by coil not connected to the first one.

Transformer equation:

$$\frac{\text{Seconary voltage}}{\text{Primary voltage}} = \frac{\text{Number of turns in secondary}}{\text{Number of turns in primary}}$$

$$\frac{\mathbf{V_s}}{\mathbf{V_p}} = \frac{\mathbf{N_S}}{\mathbf{N_p}}$$

Rectification	Is the process of changing alternating current to direct current. **A rectifier** is a device which converts a.c to d.c. **OR** It is a device which allows current to pass in one direction only.

UNEB sample Questions:

Magnetism	1994 Qn38	**Transformers**
Magnets and materials	1995 Qn40	1999 Qn37
1991 Qn23	1997 Qn31	1995 Qn31
1994 Qn1	1998 Qn31	1997 Qn10
1993 Qn37	2001 Qn23	2003 Qn25
1997 Qn29	2003 Qn22	1989 Qn6
1998 Qn32	2005 Qn2	1989 Qn37
2000 Qn36	Section B	1992 Qn29
2002 Qn20	1992 Qn10	1993 Qn30
2004 Qn8	1997 Qn9	1994 Qn19
2006 Qn14	2000 Qn10	1994 Qn35
2008 Qn18	2007 Qn7	1995 Qn32
2004 Qn41	1987 Qn8	2002 Qn32
1995 Qn7	1993 Qn8	2005 Qn25
2002 Qn6	1997 Qn7	2007 Qn31
2004 Qn4	2001 Qn6	Section B
2006 Qn3	**Electromagnetic Induction**	1987 Qn8
2008 Qn3	2000 Qn6	1993 Qn8
Magnetic effect of electric current	2000 Qn22	1997 Qn7
1994 Qn2	2002 Qn5	2001 Qn6
1999 Qn10	2002 Qn40	**Rectification**
1990 Qn19	2004 Qn9	1987 Qn32
1988 Q24	Section B	1993 Qn17
1990 Qn4	2004 Qn42	1994 Qn30
1991 Qn13	2001 Qn47	2000 Qn39
		Section B
		1992 Qn8
		1995 Qn9

ELECTRICITY

1st Law of electricity:	Like charges repel, unlike charge attract.
Charge	is the quantity of electricity that passes any section of a conductor.
Charge density	is charge per unit density
A **coulomb**	Is the charge passing any point in a circuit when a current of 1 ampere flows for 1 second.
A conductor	is a substance in which electrons are free to move and conducts heat and electricity easily
An insulator	is a substance in which electrons are not free to move and do not conduct electricity easily
Electrostatic induction	is the method of charging a conductor using the charged body without touching it.
Lightening	this occurs when two oppositely charged clouds meet
Corona discharge	is the electrical discharge brought about by ionization of air surrounding a charged conductor.
Electric Cell	Is a devise which produces electricity from a chemical reaction. It is a device which is capable of driving an electric charge around the circuit in form of current.
Primary cells	Cells that produce electricity from an irreversible chemical reaction. Or are cells which cannot be restored to their original condition once their components are used up.
Secondary cells	Cells that produce electricity from a reversible chemical reaction. They are cells which can be recharged after they run down by passing a current through them.
Polarization	Is a defect in a simple cell which results from formation of a layer of hydrogen bubbles on the copper plate.
Local action	Is a defect in a simple cell due to impurities in zinc which results in the zinc being used up even when current is not supplied.
An electrolyte	is a substance when in solution or molten form conducts electricity
Electric field	is an area around a charge where an electric force is experienced.
Electric field line	is the line drawn such that its direction at any point is the direction of electric field line at that point

Resistance	Is the opposition of a conductor to the flow of current. Effective resistance for resistors in series: $R = R_1 + R_2 + R_3 + \dots\dots$ Effective resistance for resistors in parallel: $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots\dots.$
	An Ohm is the resistance of a conductor in which a current of **1A** flows when a p.d of **1V** is applied across it.
	Ohm's Law: *The current passing through a metallic conductor is directly proportional to the potential difference between its ends at constant temperature.* $\text{Voltage(P.d)} = \text{Current} \times \text{Resistance}$
Potential different (p.d)	**P.d b**etween two points is the work down when 1C of electricity moves from one point to the other. $\mathbf{V = IR}$
Electromotive force (e.m.f)	E.m.fof a cell is its terminal p.d on an open circuit. OR: Is the terminal p.d of the cell when it is not supplying current. $\begin{pmatrix}\text{Electromotive}\\ \text{force}\end{pmatrix} = (\text{external P.d}) + (\text{internal P.d})$ $E = (IR) + (Ir)$ $\mathbf{E = I(R + r)}$
A volt	Is the p.d between two points such that **1J** of electrical energy is changed into other forms of energy when **1C** of charge passes from one point to the other.
Short circuit;	this occurs when the positive terminal is connected to the negative terminal.
Kilowatt hour (kWh)	Is the energy supplied by a device which does work at a rate of 1000J in one hour.

$$\begin{bmatrix}\text{Electricity}\\ \text{(or electrical}\\ \text{energy)}\end{bmatrix} = \text{Current} \times \text{Voltage} \times \text{time}$$

$$\mathbf{E = IVt = I^2Rt = \frac{V^2t}{R}}$$

$$\text{Ectrical Power} = \text{Current} \times \text{Voltage}$$

$$\mathbf{P = IV = I^2R = \frac{V^2}{R}}$$

A fuse	Is short length of wire of material with a low melting point which melts and breaks the circuit when the current through it exceed a certain value.
Electrolysis	Is the process by which a substance is decomposed by passing an electric current. **1st Law of electrolysis** *The mass of substance liberated in electrolysis is proportional to the charge passed.*

UNEB sample Questions:

Current Electricity	1989 Qn11	2006 Qn36
2008 Qn32	1991 Qn28	2007 Qn14
2007 Qn48	1994 Qn24	Section B
1991 Qn35	1995 Qn29	1992 Qn2
1997 Qn35	1998 Qn37	1997 Qn8
1993 Qn15	2004 Qn6	2008 Qn4
2007 Qn3	2007 Qn12	**Electric lighting**
1987 Qn29	1994 Qn32	1990 Qn39
2001 Qn31	Section B	1991 Qn7
1989 Qn32	1989 Qn7	1991 Qn20
1990 Qn32	1998 Qn6	1992 Qn2
1992 Qn8	**Electrical energy and power**	1993 Qn33
1994 Qn21		1999 Qn39
1997 Qn30	1997 Qn37	2000 Qn31
1998 Qn34	1989 Qn8	2002 Qn18
1999 Qn35	2007 Qn4	1989 Qn17
2000 Qn37	2003 Qn38	2008 Qn17
2003 Qn23	1992 Qn6	Section B
2006 Qn38	1990 Qn3	1991 Qn3
Section B	**Commercial electricity**	2000 Qn8
2002 Qn50		**Electric cells**
1994 Qn5	1995 Qn33	19995 Qn28
1997 Qn8	2002 Qn36	1998 Qn33
1998 Qn8	1988 Qn10	1998 Qn39
2000 Qn9	1990 Qn37	2002 Qn15
2002 Qn7	1991 Qn15	Section B
2000 Qn9	1998 Qn35	1993 Qn6
2002 Qn7	1999 Qn36	1994 Qn4
1992 Qn15	1999 Qn40	1995 Qn6
	2003 Qn37	1996 Qn10
	2006 Qn28	

MODERN PHYSICS

Atomic number:	Is the number of protons in the nucleus of an atom.
Mass number:	Is the total number of protons and neutrons in the nucleus of an atom.
Isotopes:	Are atoms of the same element having the same atomic number but different mass numbers. **OR** Are atoms of the same element having the same number of Protons but different number of neutrons.
Cathode rays:	Are streams of fast-moving electrons.
Thermionic emission:	Is the process by which electrons are released from a heated metal surface.
Photo electric effect:	Is the process by which electrons are released from a metal surface when radiation of the right (sufficient) frequency falls on it.

X-Rays:	Are radiations of electromagnetic waves that are produced when fast moving electrons are stopped by matter.
Radioactivity	Is the spontaneous disintegration of unstable element with emission of radiations.
Radioisotope	Is an isotope which undergoes spontaneous disintegration with emission of radiations.
An alpha Particle	Is a helium nucleus which has lost two electrons. α–decay: ${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$
Bata particles	are streams of high – energy electrons. β – decay: ${}^{A}_{Z}X \rightarrow {}_{Z+1}^{A}Y + {}_{-1}^{0}e$
Gamma rays	are electromagnetic radiation of short wavelength. γ – decay: ${}^{A}_{Z}X \rightarrow {}^{A}_{Z}Y + \gamma - rays$
Activity	is the number of disintegrations per second
Half – life	Is the time taken for a radioactive substance to decay to a half its original amount. The mass remaining after a time T, $\mathbf{M_T}$, when an original sample of mass $\mathbf{M_o}$decays with a half- life of $\mathbf{t_{\frac{1}{2}}}$is given *by;* $\mathbf{M_T} = \mathbf{M_o}\left(\frac{1}{2}\right)^{\frac{T}{t_{\frac{1}{2}}}}$**:** Then the mass decayed after a time T is given by; $\mathbf{M_{Decayed}} = \mathbf{M_o} - \mathbf{M_T}$

OR: Using the table

Time taken T	**Mass remaining $\mathbf{M_T}$**	**Mass Decayed $\mathbf{M_D} = \mathbf{M_o} - \mathbf{M_T}$**
0	M_0	0
$t_{\frac{1}{2}}$	$\frac{1}{2^1}M_o$	
$2t_{\frac{1}{2}}$	$\frac{1}{2^2}M_o$	
$3t_{\frac{1}{2}}$	$\frac{1}{2^3}M_o$	
-	-	
-	-	
$nt_{\frac{1}{2}}$	$\frac{1}{2^n}M_o$	

Where***:***
$\mathbf{nt_{\frac{1}{2}} = T}$

OR: Using the crude method:

$M_0 \xrightarrow{t_{\frac{1}{2}}} \frac{1}{2}M_o \xrightarrow{t_{\frac{1}{2}}} \frac{1}{4}M_o \xrightarrow{t_{\frac{1}{2}}} \frac{1}{8}M_o \longrightarrow$
.

Nuclear fission	Is a process whereby a heavy nucleus splits into lighter nuclei with release of energy.
Nuclear fusion	Is a process whereby light nuclei combine to form a heavy nucleus with release of energy
Background radiation	Is the radiation which originates from radioactive compounds in the earth's crust and from particles and rays from outer space.
Transmutation;	is the change of an element into another element

UNEB sample Questions

Atomic physics	2007 Qn38	Section B
1991 Qn18	2008 Qn25	1990 Qn2
1990 Qn7	Section B	1994 Qn6
1990 Qn11	1991 Qn8	1997 Qn6
1991 Qn8	2002 Qn8	1999 Qn6
1994 Qn9	2005 Qn48	2001 Qn50
1995 Qn18	**X-rays**	**Half - life**
2004 Qn22	1987 Qn16	1994 Qn15
2004 Qn32	1987 Qn22	1987 Qn6
2006 Qn21	1989 Qn36	2005 Qn36
2007 Qn20	1990 Qn16	1994 Qn6
2008 Qn2	1991 Qn38	2001 Qn4
Section B	1992 Qn22	2002 Qn23
1987 Qn3	1994 Qn39	2008 Qn8
2004 Qn.	1995 Qn25	1992 Qn18
Thermionic emission	1999 Qn30	1993 Qn28
	2002 Qn10	1995 Qn19
1987 Qn28	Section B	1995 Qn20
1988 Qn3	1988 Qn5	1997 Qn40
1997 Qn18	2000 Qn4	1999 Qn23
1999 Qn20	2000 Qn6	2000 Qn4
2002 Qn19	2007 Qn8	2004 Qn30
2004 Qn23	**Radioactivity**	2005 Qn36
2004 Qn34	1997 Qn8	2006 Qn23
2005 Qn33	1989 Qn6	Section B
2007 Qn5	1988 Qn9	1988 Qn3
2008 Qn27	1998 Qn8	1990 Qn2
Section B	1989 Qn7	1996 Qn6
1995 Qn1	1990 Qn3	2000 Qn4
2000 Qn6	1992 Qn7	**Nuclear reactions**
2003 Qn8	1993 Qn31	
2004 Qn8	1997 Qn20	2008 Qn44
Cathode ray oscilloscope	1997 Qn38	1991 Qn1
	1998 Qn27	1993 Qn22
1988 Qn40	2000 Qn2	1994 Qn18
1994 Qn34	2000 Qn28	2000 Qn7
1998 Qn11	2002 Qn3	2001 Qn17
1999 Qn21	2003 Qn17	Section B
1999 Qn22	2004 Qn20	1993 Qn2
2001 Qn16	2005 Qn18	2006 Qn6
2002 Qn7	2008 Qn16	1999 Qn5
2002 Qn21		

HEAT

Heat	**Heat** is a form of energy which is transferred from one place to another due to a temperature difference between them.
Temperature	**Temperature** is the degree of hotness of a substance. T in Kelvin is obtained using: $T = 273 + \theta$ **Lower fixed point** is the temperature of pure melting ice.

Lower fixed point	Is the temperature of pure melting ice
Upper fixed point	Is the temperature of the steam above water boiling at standard atmospheric pressure of 760mmHg.
Fundamental Interval	Is the length between the upper and lower fixed points.
	To obtain unknown temperature θ we use***:*** $\frac{\theta}{100} = \frac{l_\theta - l_0}{l_{100} - l_0}$ $\theta = \frac{x}{y} \times 100$ Where x is the length of mercury thread at temperature θ and **y** is the distance on the stem between the upper and lower fixed points (***fundamental interval***).
Conduction	**Conduction** is the flow of heat through matter from the places of higher to places of lower temperature without movement of matter as a whole.
Convection	**Convection** is the flow of a fluid from the places of higher to places of lower temperature by movement of a fluid itself.
Radiation	**Radiation** is the flow of heat from one place to another by means of electromagnetic waves

UNEB sample Questions:

Heat, temperature and expansion

1997 Qn3 PP2	**Heat transfer**	2004 Qn33
2002 Qn38	1988 Qn12	2006 Qn17
1996 Qn31	1988 Qn18	2007 Qn36
1997 Qn17	1988 Qn31	
1998 Qn8	1991 Qn4	Section B
1999 Qn16	1994 Qn33	1989 Qn2
2003 Qn30	1999 Qn9	1994 Qn1
Section B	2004 Qn11	1998 Qn3
1997 Qn3		1998 Qn5
2003 Qn44		

Gas laws	❖ ***Boyle's law:*** *The volume of a fixed mass of a gas is inversely proportional to the pressure at constant temperature.* $PV = \text{aconstant}$ i.e. $P_1V_1 = P_2V_2$ ❖ ***Charles's law:*** *The volume of a fixed mass of a gas is directly proportional to the absolute temperature at constant volume.* $\frac{V}{T} = \text{aconstant}$ i.e. $\frac{V_1}{T_1} = \frac{V_2}{T_2}$ ❖ ***Pressure law:*** *The pressure of a fixed mass of a gas is at constant volume is directly proportional to its absolute temperature.* $\frac{P}{T} = \text{aconstant}$ i.e. $\frac{P_1}{T_1} = \frac{P_2}{T_2}$ **Gas laws combined (Universal Gas Equation)** $\frac{PV}{T} = \text{aconstant}; \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$
Absolute temperature	***Absolute zero*** *is the temperature at which the molecules of the gas have their possible lowest kinetic energy.* ***Or*** *Absolute zero is the lowest temperature attained before a gas liquefies and its volume reduces to zero.*

UNEB sample Questions:

Gas laws

2005 Qn4	1989 Qn13	Section B
1997 Qn3	1992 Qn6	1989 Qn7
1998 Qn16	2000 Qn33	1991 Qn10
2007 Qn4	2002 Qn12	1993 Qn3
2007 Qn43	2006 Qn15	2001 Qn3

UNEB sample Questions:

Measurement of heat

1992 Qn4	2003 Qn39	1987 Qn14
2003 Qn13	2007 Qn28	1988 Qn19
2000 Qn4	Section B	1999 Qn15
1993 Qn3	1991 Qn3	2001 Qn34
1997 Qn15	2007 Qn2	2007 Qn8
2001 Qn34	2008 Qn2	Section B
1997 Qn4	**Latent heat**	1988 Qn5
2000 Qn3	1995 Qn11	1998 Qn2
2000 Qn38	2004 Qn3	1999 Qn3
2002 Qn26	1989 Qn33	2003 Qn3
2003 Qn33	2006 Qn8	1992 Qn8

Heat capacity	**Heat capacity** is the heat required to raise the temperature of any mass of a body by 1K. Heat energy given out (received) $= c\Delta\theta$ $= c(\theta_2 - \theta_1)$

Specific heat capacity	**Specific Heat capacity** is the heat required to rise the temperature of 1Kg mass of a substance by 1K. Heat energy given out (received) = $mc\Delta\theta$ $= mc(\theta_2 - \theta_1)$
Latent Heat	**Latent heat**is the quantity of heat required to change the state of a substance at constant temperature.
	Specific latent heatis the quantity of heat required to change the state of a 1Kg mass of a substance without change of temperature. Heat energy given out or gained = ml (During change of state). Specific Latent heat of fusion is the quantity of heat required to change a 1Kg mass of a substance from solid state to liquid state without change of temperature. Specific latent heat of vaporization is the quantity of heat required to change a 1Kg mass of a substance from liquid sate to vapor state without change of temperature

Evaporation	Is the gradual change of state from liquid to gas that occurs at the liquid's surface.
Saturated Vapour	A saturated vapour is one which is in a dynamic equilibrium with its own liquid
Saturated Vapour Pressure	Saturated vapor pressure is the pressure exerted by a vapour is in a dynamic equilibrium with its own liquid
Boiling Point	Boiling point of a substance is the temperature at which its saturated vapour pressure becomes equal to the external atmospheric pressure.
Dew point	Dew point is the temperature at which the water vapour presents in the air is just sufficient to saturate it.

UNEB sample Questions:		
Boiling, Evaporation and vapours		
1987 Qn15 1989 Qn35 1990 Qn10	1991 Qn31 1997 Qn16 2001 Qn6 2008 Qn4	1988 Qn10 1997 Qn9 1995 Qn4 2008 Qn41

-END-

Thanks for enjoying Physics

STUDY AND LEARNING SKILLS

How do you learn?

To get the most out of your studies, you should find out how you learn best – that is, what kind of learner you are.

Types of learners

There are three types of learners, namely:auditory learner, visual learner and the kinaesthetic learner

- An **auditory learner** learns by listening. If you are an auditory learner, you should find friends to study with, so you can ask questions and discuss the text. If you have to study alone, you can reinforce your learning by reciting the key concepts out loud.

- A **visual learner** learns by reading. If you learn best this way, you should concentrate on finding a quiet place where you can focus on material you are reading.

- A **kinaesthetic learner** learns by doing. If you learn best by doing something, you have to be creative in the way in which you study. For example, highlight your text or take notes as you read. Think about practical ways to apply what you are reading about.

LEARNING SKILLS

In this final section, you are going to examine some specific suggestions on how you can make your study time more valuable. Not every method will be appropriate for your study habits. Choose what you think will help you, or adapt some to fit your needs. Ignore those that you feel won't contribute to your understanding of the materials.

The SQ3R method:

The SQ3R stands for: Survey, Question, Read, Recite, and Review

SQ3R was developed in1941 by Francis P. Robinson of Ohio State University. It's an old system, but it still works, Millions of students have successfully used this system, or a variation of it, to improve their reading and studying. SQ3R stands for Survey, Questions, Read, Recite, and Review. Let's take a look at each one of these elements in SQ3R.

1. **Survey**

You first survey the material you are going to study.The purpose of the survey step in SQ3R is to help you become familiar with your text book organization. To survey material you are about to read, look quickly at the following types of features:

- ✓ Tiles and other headings.
- ✓ Illustration, diagrams, charts, maps and graphs.
- ✓ Text printed in highlighted boxes.
- ✓ Boldface and italic type.
- ✓ Self-check questions.
- ✓ Summary, if appropriate.

Scanning these features will give you a good idea of what topics you are about to study.

2. **Questions**

The next step in the **SQ3R** method is question. This step requires you to go through the pages you are about to read and turn the headings into questions. Doing this helps direct your reading and your thinking. Then as you read and study the material, you can look for the answers to your questions. For example, look at the first few headings at the beginning of this book. Here is how you can turn them into questions:

- What is physics?
- How important is physics to us or why is physics taught in Secondary Schools?
- What are the meanings of the following words?
    - Hypothesis
    - Scientific law or Scientific Principle
    - Scientific theory

Note: *The better your questions are, the better will be your understanding of the material*.

3. **The 3Rs. (Read, Recite, Review)**

The 1st R: Read

Begin to read the material slowly and carefully, one section at a time. Don't worry about how long it takes. As you read, look for answers to the questions you have just formed under 'Q' above. Make brief notes, and look up any words you don't understand. If you have completed the first two steps (*Survey* and *questions*), the material should seem familiar to you. You are prepared to read the new material more efficiently. You have an idea of the information you are required to learn and you are able to read with clearer intent. You know why you are reading a section and what to focus on.

Specifically, mark definitions, formulae, examples, names, principles, laws, rules, and characteristics.

The 2nd R: Recite
Every time you come to a new heading in the text, stop and repeat, either silently or loud, the main point is to help you to remember what you have just read. Recite it from memory or refer to your marginal notes or the information you have highlighted. If you have trouble with this step, reread the section until it becomes clear to you. Reciting the material in your own words is a tremendous aid to learning .It makes it easier to retain the information.

The 3rd R : Review
Review any material you read as soon as you can. Review it again before you complete a self-check and gain confidence before you prepare for an examination .This part of **SQ3R** helps to keep information fresh in your mind. I believe by now you should be able to agree that; the SQ3R method is real helping to make your revisions effective.

TAKING EXAMINATIONS

Begin by surveying the examination questions. Read the directions/instructions carefully and be sure to follow them exactly. Do the easy questions first. Skip any you are unsure of. While taking the examination, maintain a positive attitude. If you feel negative thoughts creeping in, say to yourself, "I've studied hard."

Types of questions
There are two types of questions:
- Multiple Choice
- Structured and semi-structured

Multiple Choice questions
Before you do anything on the question paper,
- First write your name and then read the instructions carefully.
- Read the questions very carefully. Careless reading of the instructions and the questions often leads to loss of marks. Carefully reading of the instructions and the questions help you to know exactly what you are to do and how to do it.

For multiple type questions**,** try to answer from your mind before you look at the answers.
- Read each answer thoroughly even if you think you have already spotted the correct one. Note that some answers may be correct. But the question always requires you to choose the most correct answer. Be aware the wrong answers are always plausible.
- Be active: sketch a diagram; write down a relationship, do anything that helps you think clearly.
- Do not be worried by too many of one letter since they are random.
- Be absolutely sure to get the easier questions right, by not rushing them. The questions carry the same marks.
- Finally if in doubt guess, illuminate the patently wrong answers first. If you can whittle the choice down to two you have a 50% chance of being right.

For Structured and semi-structured questions:
- Use simple straightforward English.
- Use clear-labelled diagrams.
- Where necessary leave space so you can add answers that occur to you later.
- Explain all your working and put in correct ***units***. Remember wrong units led to loss of marks.
- Round off your final answers to a sensible number of significant figures.
- Check your work as you continue.
- Look at the marks given besides the question to gauge how much detail is likely to be expected and, in the case of papers where you answer on the question paper, look at the space available. For example, six marks probably mean six important ideas are needed in the answer.

DON'TS IN AN EXAMINATION
❖ Don't cross out work that may be partly correct
Avoid this unless you have finished replacing it with something better.
❖ Don't write out the question. This wastes time.
The marks are for your solution!
❖ What are the examiners looking for?
The most common compliant of the examiner is "candidate failing to answer the question" This complaint is expressed in a number of ways, e.g.
- Answer too short
- Answer too long
- Irrelevant material included
- Relevant material left out
- Answer suffers from lack of substance, absence of diagram(s) graphs / Calculations which are clearly asked for, entire parts of questions missing
- Failure to give correct responses to question beginning with the direct words (or key words) e.g. define, state, explain, describe, etc.

DURATION OF THE PHYSICS EXAMINATION PAPERS

535/1 Physics Paper 1: (2¼ hours)
It will consist of two sections, A and B. Section A will contain forty (40) objective test items and section B will contain ten (10) structured short answer questions set on any part of the syllabus each 4 marks. All questions will be compulsory. (**80 marks**)

535/2 Physics Paper 2: (2¼ hours)
It will consist of eight (8) semi-structured /essay type questions drawn evenly from the whole syllabus as follows.

Topic	No. of questions set
1. Mchanics and propertie of matter	2
2. Light	1
3. Waves	1
4. Heat	1
5. Modern Physics	1
6. Electrostatics and Electricity.	1
7. Magnetism and Electomagnetism	1

Candidates will be required to answer five (5) questions each 16 marks. (**80 marks**)
Only the first 5 attempted questions will be marked!

535/3 /4 Physics Paper 3: (2¼ hours)
It will consist of three (3) questions. Question 1 will be compulsory. In addition, candidates will be required to answer one of the questions 2 or 3. (**60 marks**)

How to excel in Physics papers
- ✓ Be confident to remember the concepts
- ✓ Be brief to hit on only the relevant points
- ✓ Avoid guessing on concepts. Leave guessing only as a last resort
- ✓ Answer your questions strategically to earn marks
- ✓ Read the question well enough to understand what it expects from you. Don't just rush through the question and start answering.
- ✓ Mind your drawings, be neat and mind the smallest details. A non-workable diagram earns no marks.
- ✓ Avoid giving general examples when asked for specific examples. E.g Give two medical uses of x-rays. Student's response: In hospitals. In this case the candidate is not specific hence no marks are awarded.
- ✓ Above It All, Do All That Your Teachers Have Been Telling You.

DIRECTION WORDS USED BY EXAMINERS IN INSTRUCTIONS

Examiners use certain direction words in their instruction to let you know what they are expecting in the answer. Make sure that you know what they mean so that you give the right response.
Questions in physics examinations may use any of the following direction –words define, state, write down, mention, list, calculate, find, determine, deduce, hence, explain, describe, draw, sketch, what is meant by, etc. Interpreting this word wrongly can be very expensive in terms of marks or time lost. To determine how long an answer should be, a student can use:
- ❖ *Direction (key) word used, e.g. State, explain, etc.*
- ❖ *Marks allocated to the question*

1. Define (the term (s)……)
This only requires a formal statement, definitions must be absolutely precise. It should have the necessary key words.
There cannot be a nearly correct definition.
Avoid writng a formula istead of a definition: e.g $\rho = \frac{M}{V}$
Problem:
*Define a **newton**?*
A newton is the force which gives a mass of 1kg an acceleration of 1ms^{-2}

2. State
This requires a concise answer with no supporting argument. You can write your answer without having to show how it was obtained. Physical laws and principals must be stated in a precise form.
They must be complete and correct.
Laws should not be altered. i.e don't change the words of a law. Do not omit the conditions of a given principle when stating it.

3. List
This requires a number of points with no collaboration. If the number of points is specified, this should not be exceeded. Avoid contradicting answers eg. Properties of cathode rays: +vely charged and –vely charged = No mark!

Problem: List **three** properties of alpha- particles

Solution:
- They carry a positive charge
- They are deflected towards the negative plate in an electric field.
- They are deflected in a magnetic field.

It should be noted that in this case only the first three properties given whether correct or wrong will be considered.

Problem: *State Boyle's law*
Boyle's law states thatthe volume of a fixed mass of a gas is inversely proportional to its pressure if temperature is constant.

4. What is meant by ……?
This normally requires a definition, together with some relevant comment and the terms concerned.
The amount of additional comment intended should be interpreted in the light of indicated mark value

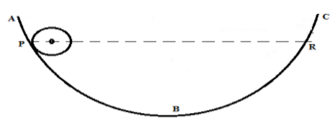
Problem:
*What is meant by **dispersion** of light?*
***Solution:** Dispersion of light is the splitting of white light into its components colours by a glass prism.*
This is because glass (prism) has different refractive indices for the different colours of white light.

5. Explain
This requires a candidate to make a given term or piece of information clear basing on scientific concepts and principles. Some laws and principals may be applied. Sometime a diagram or a graph may be useful.

Example:1: Explain why the handle of a door is near its outside edge.
Student's response: Because the door is heavy and can easily be opened.

Correct Response: *The force is applied at the greatest possible distance from the hinges or fulcrum. This gives the greatest moment and hence the force applied to open the door is minimum.*

Example 2:
The diagram in the figure below shows a large smooth bowl ABC. Explain what happens when a ball is released from P.



Correct Response:
When released from P it lossesit potential energy as it gains kinetic energy which is maximumat B. Past B it rises reducing in speed(kinetic energy) but gaining equivalent potential energy.
There is loss of energy due to friction with the bowl and air resistance.

The ball returns and repeats withdecreasing height till when it comes to rest at B

Example 3: Explain, in terms of molecules, what is meant by **a saturated vapour**.
A saturated vapour is a vapourthat is in dynamic equilibriumwith its own liquid or in contactwith its own liquid.
In terms of the molecules of the liquid, thevapour in contact with its liquidsuch that the number of vapourmolecules condensing to liquid stateis equal to the number of liquidmolecules changing to the vapour state.

Example 4: Explain how evaporationtakes place.
Correct response
Evaporation takes place when liquid molecules have or are given high molecular speed by heating them and they escape from the attraction of their neighbouring liquid molecules to vapour or gaseous state.
When this occurs for more liquid molecules at any temperature, then we say that theliquid is evaporating.

Examples: 5: Use the kinetic theory of matter to explain why the temperature of a boiling liquid at constant pressure remains constant.
Student's response: Because the liquid has reached its maximum temperature. [**No marks**]

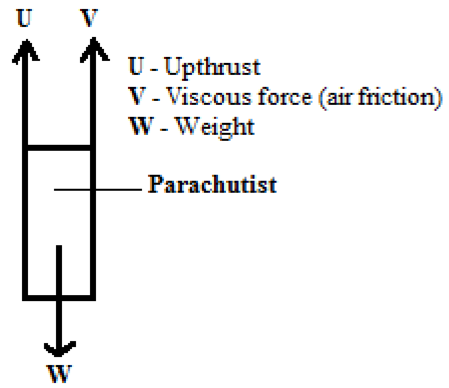
Correct Response: *When the liquid is boiling, heat energy supplied provides latent heat to the liquid molecules. These molecules use this energy to break away from the attractive forces between themselves to become gas molecules. As they break away from the liquid body, the temperature of the liquid remains constant as boiling occurs.*

Problem:
Explain how heat is transferred in metals..

Solution: *Heat is transferred in metals by conduction.*
When a metal is heated at one place, the atoms and electrons there gain more kinetic energy and therefore move faster towards the cooler part. They collide with other electrons and atoms in the cooler part to which, they pass on their energy. In this way, heat is transferred in the metal.

Examples: 6:UNEB 2010 P2 No. 1(b). Explain what happens to a parachutist who jumps from a high flying plane.

Soution: *At first, the parachutist accelerates downwards and then later falls with a constant velocity called Terminal velocity.*
He is acted upon by three major forces as shown below.



The up thrust is constant at constant temperature but the Viscous force increases with velocity.
Initially, W is greater than (U + V) hence the parachutist has a net down ward force which makes him accelerate down wards.
As he does so, his velocity increases and thus, V increases and reduces the acceleration.
Eventually, a point is reached when (U + V) is equal to W and the net force on the parachutist is zero. By Newtons first law of motion, the parachutist then falls with a constant velocity called Terminal velocity.

6. Describe
This require a candidate to state in words (with the aid f diagram where appropriate) the main points of the topic. It is often used with reference either to a particular phenomenon or to a particular experiment.
In the former case, the answer should include reference to observations associated with the phenomenon.
In the letter case, full details of the method, measurements, apparatus and treatment of result are required.
In both cases logical flow of the information is important.
No marks are awarded if the procedures are not flowing/ un workable. i.e if one followed such procedures the expected results cannot be obtained.

- **Diagram(**workable and fully labeled**)**
- **Activities to get results**

✓ Step by step activities(logical flow)
✓ Physical quantities to be measured and recorded identified.
✓ Each quantity given a symbol.
✓ Formular or graph
✓ Each step should be followed by a key condition that makes experiment work.

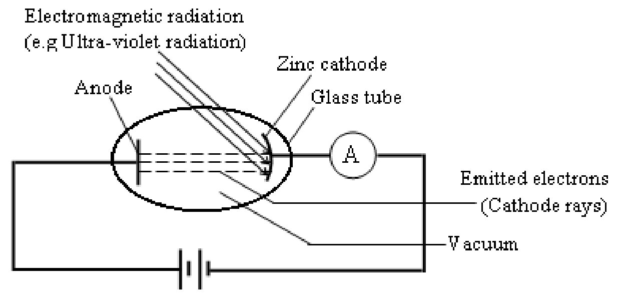
E.g Describe an experiment to determine the **coefficient of static friction, μ_s .**
✓ M on block placed on a table.
✓ m added on scale pan
✓ More , m added until block just starts to move.
✓ m is recorded
✓ Repeat for other values of M
✓ Plot a graph of mg Vs. Mg
✓ Slope, S= μ_s

Example 1
Describe a simple model of the atom.

Response:
An tom is made up of a nucleus which contain protons andneutrons. This nucleus is surrounded by electrons moving aroundit.

The electrons are negatively charged, the protons are positively charged and neutrons have no charge.

Example 2
A zinc cathode was enclosed inan evacuated glass tube as shown in the figure below.



When the cathode was irradiated with ultraviolet radiations, the ammeter gave a reading.
(i) Explain why the ammeter gavea reading.
(ii) A gas was gradually introduced into the glass tube. Explain what happened.

Solution.
(i) this is because the electronswere emitted by photoelectriceffect by the zinc cathode, whenthe ultra violet radiations fellon it. These electrons completed the circuit and currenthad to flow hence the ammeter gave a reading.

(ii) the ammeter reading decreasesbecause not all the emittedelectrons would reach the anode, since some would collidewith the molecules of the introduced gas.

<u>Example: 3</u>
Describe an experiment to show the variation of pressure in a liquid.
<u>Student's response</u>: A can is filled with water. Holes are made on the sides. Water flows out from the bottom hole fastest and furthest from the can than the hole at the top. This shows that pressure increases with depth.

Example: 4
Describe an experiment to measure acceleration of a body using a ticker timer.

<u>Student's response</u>: A paper tape is pulled by a trolley through a ticker timer. Dots are made on the paper. The distance between 10 dots is measured. The acceleration of the trolley is calculated from the dots. [**No marks for this answer! Since the procedures are not flowing]**

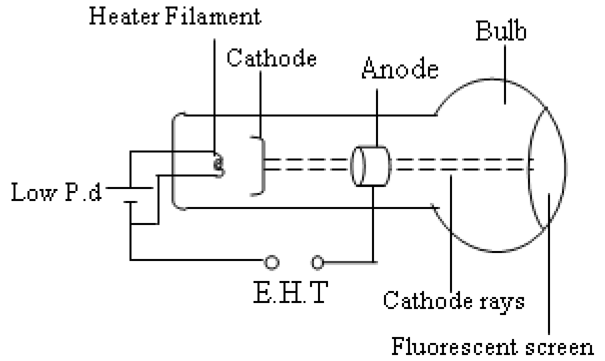
Problem
Describe an experiment to **verify Hooke's law** using a spring.

Solution: See question **3(c), 2002 P_2**
Note: The candidate must be careful to cut back on the details if the question asks to "describe briefly" or to "describe concisely". Here the candidate's ability to isolate the key feature of the experiment / topics is being tested.
Diagrams should never be omitted if they are specifically asked.
Diagrams involving a switch, it must be closed before taking any reading.

- ✓ Electrical method expts
- ✓ Verification of Ohms law
- ✓ Determining, r of a cell etc.

Problem. With the aid of a diagram, describe how cathode rays are produced.

Solution: Production of Cathode rays:

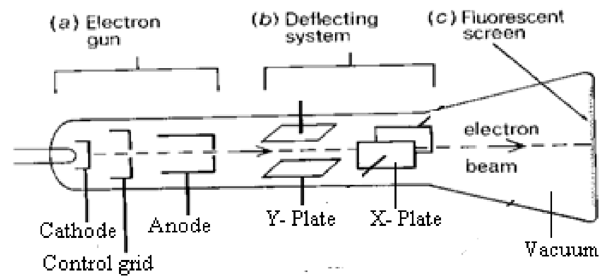


The cathode is heated by a low P.d applied across the filament.
The cathode then emits electrons by thermionic emission. The emitted electrons are then accelerated by a high p.d (E.H.T) applied between the filament and the anode so that they move with a very high speed to constitute the cathode rays.

Problem
With the aid of a diagram, describe briefly how a pure spectrum is produced

Solution: See question 6(b), 2004/2
In this case ***a workable correctly labeled diagram*** is a must!

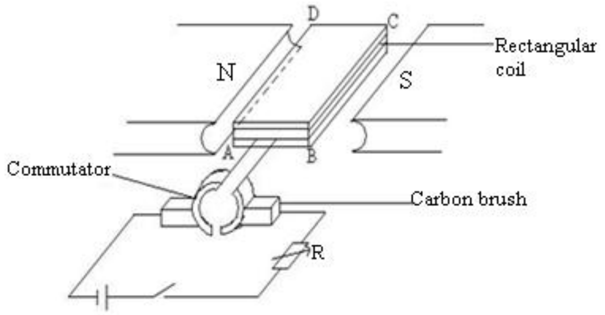
(a) (i) Describe the principles of **operation of a C.R.O.**



Electrons are produced by thermionic emission by the hot filament and accelerated to a certain speed by the High voltage, the Extra High Tension (E.H.T).
The moving electrons are deflected, by the electric fields between the deflection plates.
When the elections hit the screen, the fluorescent material on it emits visible light which enables one to see the electron beam as a bright spot.

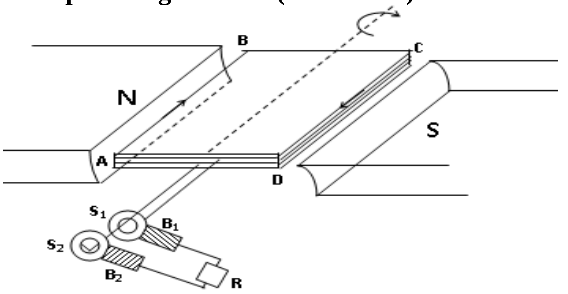
(ii) How is the bright spotformed on the screen?
the bright spot is formed by the electrons which hit the fluorescent material that gives out the visible light seen as a bright spot, if the time base is off.

Problem: With the aid of a diagram, describe the mode of action of a simple d.c motor.
Solution:



-When current flows in the coil, side BC experiences a downward force and AD an upward force. (Fleming's left hand rule).
-The two forces constitute a couple which rotates the coil.
-When the coil reaches the vertical position, the brushes lose contact with the commutator and current is cut off. However the coil continues to rotate past this vertical position because of the momentum gained.
-The current in the coil reverses as the brushes change contact with the commutator, side AD now experiences a downward force and BC an upward force. However the current in the external circuit continue to flow in the same direction.
-Thus the coil continues to rotate as long as the current is flowing.

A simple A.C generator (Alternator)



-When the coil rotates with uniform angular velocity in the magnetic field, in accordance to Fleming's Right Hand rule. The magnetic flux density linked with it changes and an emf is induced in the coil. The induced emf is led away by means of the slip rings S1 and S2.

-When sides AB and CD interchange positions, the current in the terminals reverse the direction and the coil continues rotating in the clockwise direction.

-Therefore, the induced e.m.f generated flows following a sinusoidal wave.

For D.C generator, *When the coil passes over the vertical position, after half the rotation, the slip ring changes contact. C1 goes into contact with B2and C2 goes into contact with B1.*
The forces on the sides of the coil change, thus the current in the coil is reversed. The current flowing through the load thus continues to flow in the same direction.

Structural modifications to convert A.C generator to a D.C generator:
-Replace the slip rings with two halves of slip rings (commutators).

7. Distinguish.
This requires the definitions of the given terms.

8. Differentiate
This requires the definitions of the given terms and any other differences. The differences must have similar properties.

9. Calculations.
The following steps are suggested in questions involving calculations

- ✓ Summaries the information given in the question. Use standard symbols (Clearly define any symbol which is not standard) and convert quantities too S1 units.
- ✓ A sketch diagram may sometimes be helpful.
- ✓ Spot the law or principle and equations which relate to the situation. If necessary, make reasonable assumptions or approximations and show clearly where it is done.
- ✓ Write down all your working [Remember that marks are given for the correct working even if the final answer is wrong!
- ✓ Evaluate your answer to be lowest form. Do not give answer like $\frac{g}{5}$ unless you are running out of time
- ✓ Indicate units on your final answer.
- ✓ Check that your final answer is sensible with the context of the question.

Problem: *A sound wave has a velocity of 330ms^{-1} and a wavelength of 1.5m. Calculate its frequency*
Solution:

- ❖ *(Summaries the given information using standard symbols and with correct units)*
  Given:
  V = 330ms^{-}, ^{1}x = 1.5 m, F =?

- ❖ *(Write down the relevant question)*
  Using the wave equation:
  V = fʎ

- ❖ *(Show your working)*
  330 = f x 1.5

$$\frac{1.5f}{1.5} = \frac{330}{1.5}$$

f = 220Hz

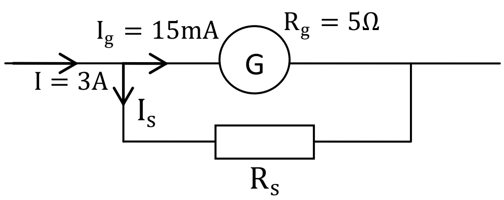
- ❖ *(Final answer with units)*

Hence the frequency of the wave is 220Hz.

Problem: A moving coil galvanometer has a resistance of 5Ω and gives a full deflection of 15mA. How can it be converted into an ammeter to measure a maximum of 3A?

Solution

(i)Let Rs be the resistance of the shunt required.



$$\text{P.d across the shunt} = \text{P.d across galvanometer}$$
$$\Leftrightarrow (I - I_g)R_s = I_gR_g$$

$\Leftrightarrow (3 - 0.015)R_s = 0.015 \times 5$

$2.985\ R_s = 0.075$

$\mathbf{R_s = 0.025\ \Omega}$

Thus a low resistance resistor of $0.025\ \Omega$ should be connected in parallel with the galvanometer.

END

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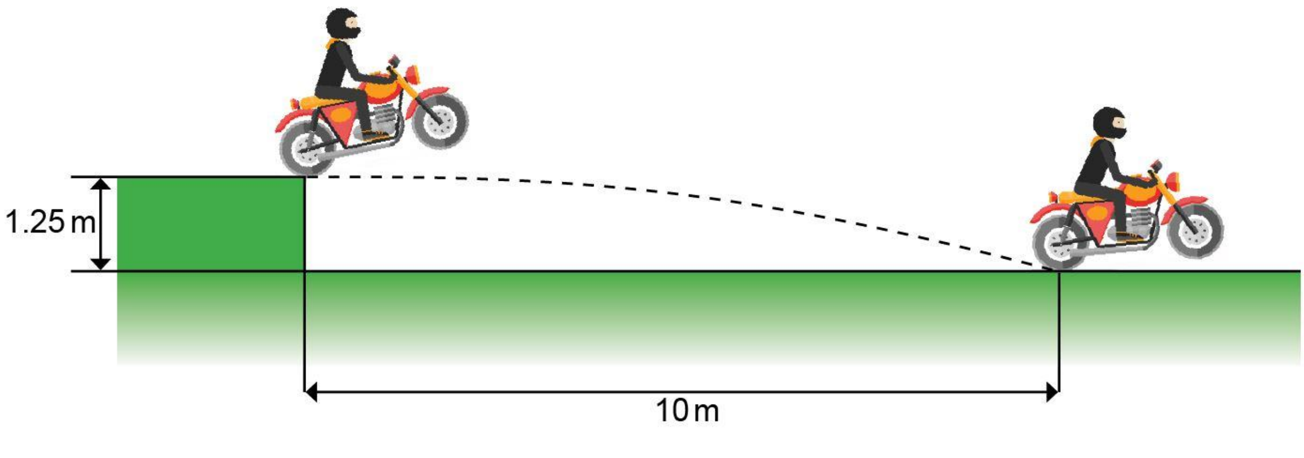

ABOUT THE AUTHOR

Mr. Bagira Daniel is a professional teacher who has taught Physics and Mathematics at both “O” and “A” level.

He has taught the subjects in schools like Kajjansi Progressive Secondary School, Trinity college Nabbingo and Kasenyi Secondary school- Mubende.

He can be contacted on TEL: **0771-900008** or **0703-300400.**