# MECHANICS

## DIMENSIONS AND PHYSICAL QUANTITIES

ITEM 1

You are working as a design engineer at a manufacturing company. Your team is developing a new high-precision weighing scale that will be used in laboratories to measure small masses accurately. The device must be calibrated correctly to ensure precision in its measurements. Before proceeding with the design, you need to verify the consistency of the formulas used in the calculations.

Task:

1. Identify the fundamental and derived physical quantities required in the calibration of the weighing scale.
2. Use dimensional analysis to check whether the following equations used in the scale design are dimensionally consistent:
    - The force acting on the mass: $F=mg$
    - The oscillation period of the scale's pan: $T=2\pi\sqrt{\frac{l}{g}}$
3. Explain why dimensional analysis is crucial in verifying these equations before building the prototype.
4. Discuss any potential design challenges that could arise due to errors in dimensions and how they can be corrected.

**ITEM 2**

You are an engineer working on the construction of a bridge. The bridge's support beams must be designed to withstand the forces acting on them without bending excessively. You need to determine whether the stress equation used in the design is dimensionally consistent.

**Task:**

1. Identify the fundamental and derived quantities involved in stress calculation.
2. Use dimensional analysis to verify the equation for stress: $\sigma=\frac{F}{A}$ where F is the applied force and A is the cross-sectional area.
3. Explain why ensuring dimensional consistency is important in structural engineering.
4. Discuss potential problems if an incorrect formula is used and how to resolve them.

**ITEM 3**

You are an astrophysicist designing a communication satellite that will orbit Earth. The satellite's velocity must be calculated correctly to ensure it remains in a stable orbit.

**Task:**

1. Identify the fundamental and derived quantities needed to describe the motion of a satellite.
2. Use dimensional analysis to verify the equation for orbital velocity: $v=\sqrt{\frac{GM}{r}}$ where G is the gravitational constant, M is the Earth's mass, and r is the orbital radius.
3. Explain the importance of using correct dimensions in space mission planning.
4. Discuss potential challenges if incorrect values are used in calculations and how they could be corrected.

**ITEM 4**

You are a mechanical engineer working on the braking system of an electric car. You need to verify whether the equation for braking force is dimensionally consistent to ensure passenger safety.

**Task:**

1. Identify the fundamental and derived quantities involved in stopping a moving car.
2. Verify the dimensional consistency of the equation: $F=ma$ where F is the braking force, m is the car's mass, and a is acceleration.
3. Explain the significance of checking dimensions in car safety systems.
4. Discuss how errors in dimensional analysis could lead to mechanical failure.

**ITEM 6**

You are a biomedical engineer designing a device to measure blood pressure. The velocity of blood flow in arteries must be calculated accurately for diagnosing heart conditions.

**Task:**

1. Identify the fundamental and derived quantities related to blood flow.
2. Use dimensional analysis to verify the Bernoulli equation applied to blood flow: $P+\frac{1}{2}\rho v^2+\rho gh=\text{constant}$ where P is pressure, ρ is blood density, v is velocity, g is gravitational acceleration, and h is height.
3. Explain why checking dimensional consistency is critical in medical device development.

4. Discuss the risks of using incorrect dimensions in medical applications and how to avoid them.

**ITEM 7**

You are an electrical engineer designing power transmission cables. The equation used to calculate electrical resistance must be verified before selecting materials.

**Task:**

1. Identify the fundamental and derived quantities related to electrical resistance.
2. Use dimensional analysis to check the equation: $R=\rho\frac{l}{A}$ where R is resistance, ρ is resistivity, L is length, and A is cross-sectional area.
3. Explain why using correct dimensions is essential in electrical circuit design.
4. Discuss the risks of incorrect resistance calculations in electrical grids.

**ITEM 8**

You are a sports scientist analysing the motion of sprinters to optimize their performance. The equations used to calculate acceleration and force must be verified for accuracy.

**Task:**

1. Identify the fundamental and derived quantities involved in an athlete's motion.
2. Use dimensional analysis to check the validity of the equation: v=u+at where v is final velocity, u is initial velocity, a is acceleration, and t is time.
3. Explain why verifying dimensions is necessary in sports biomechanics.
4. Discuss how incorrect calculations could affect an athlete's performance analysis.

**ITEM 9**

You are a marine engineer designing cargo ships. The ship's buoyancy force must be accurately calculated to ensure it remains afloat with different loads.

**Task:**

1. Identify the fundamental and derived quantities related to buoyancy.
2. Use dimensional analysis to verify Archimedes' principle: $F_B = \rho g V$ where FB is buoyant force, ρ is fluid density, g is gravitational acceleration, and V is displaced volume.
3. Explain why correct dimensional analysis is essential in ship design.
4. Discuss how incorrect calculations could lead to ship instability.

**ITEM 10**

You are an astronomer calculating the escape velocity needed for a spacecraft to leave a planet's gravitational field. The formula must be dimensionally verified before launching missions.

**Task:**

1. Identify the fundamental and derived quantities related to escape velocity.
2. Use dimensional analysis to verify the escape velocity equation: $V_e = \sqrt{\frac{2GM}{R}}$ where $V_e$ is escape velocity, G is the gravitational constant, M is planetary mass, and R is planetary radius.
3. Explain why checking dimensions is crucial in space exploration.
4. Discuss risks if incorrect escape velocity calculations are used in spacecraft launches.

## MOTION

**ITEM 1**

You are a stunt coordinator designing a high-speed car chase scene for an action movie. In one scene, a hero's car moving at **30 m/s** must catch up to a villain's car, which has a **5-second head start** and is moving at **25 m/s**.

**Task:**

1. Calculate the time required for the hero's car to catch up with the villain.
2. Determine the distance the hero's car will travel before reaching the villain.
3. Discuss how road conditions and driver reaction time could impact the actual chase scene.
4. Explain the effect of increasing or decreasing the hero's car acceleration on the outcome.

**ITEM 2**

A construction worker accidentally drops a **hammer** from the top of a **100 m** tall building. You need to determine how long it will take for the hammer to reach the ground and its speed just before impact.

**Task:**

1. Calculate the time it takes for the hammer to reach the ground assuming free fall.
2. Determine the velocity of the hammer just before it hits the ground.

3. Discuss real-world factors like **air resistance** and how they might affect the motion.
4. Suggest safety measures that could prevent such accidents at construction sites.

**ITEM 3**

You are a football coach analysing a player's free kick. The player strikes the ball at **25 m/s** at an angle of **40°** to the ground. You need to determine whether the ball will clear a **2.5 m tall** wall located **15 m away** from the player.

**Task:**

1. Determine the time it takes for the ball to reach the wall.
2. Calculate the height of the ball when it reaches the wall.
3. Discuss how factors like **wind speed, ball spin, and air resistance** could affect the outcome.
4. Suggest ways for the player to adjust their kicking technique for better accuracy.

**ITEM 4**

You are a highway safety engineer designing an **emergency escape ramp** for runaway trucks. A **10,000 kg truck** moving downhill at **30 m/s** must stop safely using the ramp, which is **500 meters** long and has a **gravel surface** providing friction.

**Task:**

1. Calculate the **minimum deceleration** needed for the truck to stop within the 500-meter distance.
2. Determine the **time required** for the truck to come to a complete stop.
3. Explain how the choice of **gravel, sand, or other surfaces** affects the stopping distance.
4. Discuss real-world factors like **brake failure and weather conditions** that impact the design.

**ITEM 5**

You are a road safety expert investigating a bus accident. The bus was moving at **20 m/s** when the driver applied the brakes, bringing the bus to a stop in **4 seconds**. A passenger inside the bus was **not wearing a seatbelt** and continued moving forward after the bus stopped.

**Task:**

1. Calculate the deceleration of the bus.

2. Determine how far the passenger would travel forward before stopping, assuming no external force acts on them.
3. Explain the importance of **seatbelts** in preventing injuries.
4. Discuss how **Newton's First Law of Motion** applies to this scenario.

**ITEM 6**

You are a coach analysing a sprinter's **100-meter dash**. The sprinter starts from rest and accelerates at **2.5 m/s²** for the first **4 seconds**, then continues at a constant velocity until the finish line.

**Task:**

1. Calculate the **maximum velocity** the sprinter reaches.
2. Determine the **total time** the sprinter takes to complete the race.
3. Explain how **reaction time and running technique** affect overall performance.
4. Discuss how **aerodynamics and footwear** can impact a sprinter's speed.

**ITEM 7**

A ship in distress fires a **flare** vertically upward with an initial speed of **50 m/s** to signal for help. You must calculate how long the flare will be visible before it returns to the sea.

**Task:**

1. Calculate the **maximum height** the flare reaches.
2. Determine the **total time** before the flare returns to the water.
3. Discuss the effects of **wind and air resistance** on the flare's trajectory.
4. Suggest alternative emergency signals that could be used in poor weather conditions.

**ITEM 8**

You are a basketball coach analysing a **three-point shot**. A player releases the ball at **6 m/s** at an angle of **45°** from a height of **2.5 meters**. You need to determine if the ball will go through the hoop, which is **3.05 meters high** and **7 meters away**.

**Task:**

1. Calculate the **time of flight** of the basketball.
2. Determine the **height of the ball** when it reaches the hoop.
3. Explain how **shooting technique, ball spin, and angle** affect accuracy.

4. Discuss ways players can improve their shooting precision.

**ITEM 9**

A skydiver jumps from an airplane at **4,000 meters** above the ground. You need to calculate how long the skydiver will fall before deploying their parachute, assuming **free fall without air resistance**.

**Task:**

1. Calculate the **time taken** to fall **4,000 meters** under gravity.
2. Determine the **velocity** just before deploying the parachute.
3. Explain how **air resistance and terminal velocity** affect real-world skydiving.
4. Discuss the importance of **parachute design and deployment timing** in ensuring safety.

**ITEM 10**

An aircraft flying horizontally at **300 km/h** at an altitude of **1,000 meters** is dropping **relief supplies** to flood victims. The package must land as close to the target as possible.

**Task:**

1. Calculate the **time** the package takes to reach the ground.
2. Determine how far **horizontally** the package will travel before impact.
3. Explain how pilots **adjust release timing** to ensure accuracy.
4. Discuss the role of **parachutes and wind conditions** in delivering supplies safely.



## THERMOMETRY

ITEM 1

A community health center in a remote area lacks digital thermometers. Instead, they use liquid-in-glass thermometers. However, during a malaria outbreak, many patients show high fevers, and accurate temperature readings become crucial for treatment.

(a) Explain how a liquid-in-glass thermometer functions and its thermometric property.

(b) Discuss the limitations of using this thermometer in a high-patient flow setting and suggest an alternative.

ITEM 2

A dairy processing plant needs to pasteurize milk by heating it to 72°C and holding it at this temperature for 15 seconds. Workers rely on a platinum resistance thermometer for accurate temperature measurement.

(a) Describe how the platinum resistance thermometer works in monitoring the temperature.

(b) Explain why a constant-volume gas thermometer would not be suitable for this process.

ITEM 3

A fire department is testing a new fire-resistant suit for firefighters. They need to measure the temperature inside the suit when exposed to a fire of 800°C.

(a) Identify a suitable thermometer for this application and justify your choice.

(b) Explain how the selected thermometer operates and how it withstands high temperatures.

ITEM 4

Scientists studying climate change need to record air temperature in a desert where temperatures range from -5°C at night to 50°C during the day.

(a) Which type of thermometer would be best suited for this purpose? Explain your choice.

(b) Discuss how different thermometric properties may lead to discrepancies in readings when using different thermometer types.

ITEM 5

A homeowner wants to reduce energy consumption by adjusting their air conditioning system efficiently. They need a highly sensitive thermometer to monitor room temperature changes.

(a) Compare the effectiveness of a thermocouple thermometer and a resistance thermometer for this purpose.

(b) Suggest a practical solution for automating the air conditioning system using temperature sensors.

ITEM 6

A grocery store uses a refrigeration system to store perishable food items at 4°C. However, power outages frequently occur, and the store manager needs to determine how long food can remain safe at higher temperatures.

(a) Explain the role of a thermometric property in monitoring temperature changes during a power outage.

(b) How can the concept of heat transfer be applied to improve food preservation during power outages?

ITEM 7
A pharmaceutical company manufactures vaccines that must be stored at -70°C. They use thermocouple thermometers to monitor storage temperatures.

(a) Explain the principle of operation of a thermocouple thermometer.

(b) Discuss why a liquid-in-glass thermometer would not be suitable for this application.

**Calorimetry**

ITEM 1
A chef wants to heat **2 litres of soup** in an aluminium pot over a gas stove. He notices that using a **copper pot** heats the soup faster than the aluminium pot.

(a) Explain how the specific heat capacity of the pot material affects the heating process.

(b) Which pot is more energy-efficient for heating the soup? Justify your answer with calculations.

ITEM 2
A community in an arid region stores **ice blocks** in underground coolers to preserve vegetables. During the hottest part of the day, the ice melts completely.

(a) Explain how the **latent heat of fusion** plays a role in keeping the vegetables cool.

(b) If **20 kg of ice at 0°C** is used, how much heat is absorbed before it completely melts? (Assume **latent heat of fusion of ice = $3.34 \times 10^5$ J/kg**).

ITEM 3
A **firefighter** sprays **water** on a burning wooden house to control the fire. Water is preferred because it absorbs large amounts of heat before evaporating.

(a) Explain why **water is more effective** than other liquids for absorbing heat.

(b) Calculate the **heat energy absorbed** by **100 litres of water** when its temperature rises from **20°C to 100°C**. (**Specific heat capacity of water = 4200 J/kgK**)

ITEM 4
A **solar water heater** is used in a household where water enters at **20°C** and is heated to **60°C** before use.

(a) Calculate the **energy required** to heat **50 kg** of water to this temperature. (**Specific heat capacity of water = 4200 J/kgK**)

(b) If a gas boiler is used instead, which **produces steam at 100°C**, explain why **boiling water before use would require additional energy**.

ITEM 5
In a **steam power plant**, water is heated to steam at **100°C** and used to turn turbines before being condensed back to water.

(a) Explain why **steam has more energy** than hot water at the same temperature.

(b) Calculate the **energy required** to convert **1 kg of water at 100°C** into steam. (**Latent heat of vaporization of water = $2.26 \times 10^6$ J/kg**)

ITEM 6
In **cold climates**, people **heat bricks or stones** and place them in beds to stay warm overnight.

(a) Explain why materials with a **high specific heat capacity** are better for this purpose.

(b) A **5 kg stone** at **90°C** is used to warm a bed. If its **specific heat capacity** is **900 J/kgK**, calculate the **heat released** as it cools to **30°C**.

ITEM 7
A **fish vendor** transports fresh fish in **ice boxes** over long distances. The ice helps maintain low temperatures even after the electricity in the cooler fails.

(a) Explain how **latent heat of fusion** helps maintain the freshness of the fish.

(b) If **15 kg of ice at 0°C** melts during the trip, calculate the **heat absorbed** by the ice. (**Latent heat of fusion of ice = $3.34 \times 10^5$ J/kg**)

ITEM 8
A dairy company **pasteurizes milk** by heating it to **72°C** and then cooling it rapidly. The process requires precise heat control.

(a) Explain how **calorimetry** principles apply in this process.

(b) If **30 litres of milk** (density = **1 kg/L**) is heated from **20°C to 72°C**, calculate the **energy required**. (**Specific heat capacity of milk ≈ 3900 J/kg·K**)

**Photoelectric Emission**

1. Solar Panel Efficiency in Rural Areas
   A village in Uganda installs solar panels for electricity. However, they notice that power generation is affected on cloudy days.

(a) Explain how the **photoelectric effect** relates to the operation of solar panels.

(b) Discuss why increasing **light intensity** affects the **current** but not the **voltage** of a solar panel.

2. Automatic Doors and Security Systems
Supermarkets use **photoelectric sensors** for automatic doors. The doors open when a person approaches and blocks a light beam.

    (a) Explain how **photoelectric cells** detect the presence of a person.

    (b) Why does **infrared light** not trigger the same effect as ultraviolet light in some systems?

3. Digital Cameras and Image Sensors
A digital camera uses a **photoelectric sensor** to capture images by converting light into an electronic signal.

    (a) Explain how the **photoelectric effect** is applied in digital cameras.

    (b) Discuss how the energy of emitted electrons depends on **frequency** rather than **intensity** of light.

**Nuclear Structure**

1. Medical Use of Radioisotopes in Cancer Treatment
A hospital uses **Cobalt-60** to treat cancer by emitting **gamma radiation** to destroy cancer cells.

    (a) Explain why **gamma rays** are used for this purpose.

    (b) How does the **half-life** of Cobalt-60 affect the frequency of hospital equipment replacement?

2. Nuclear Power and Energy Crisis
Some countries rely on **nuclear fission** for electricity. However, nuclear power plants require **fuel rods** made of **Uranium-235**.

    (a) Explain how **nuclear fission** produces energy.

    (b) Discuss the risks of **nuclear waste disposal** and possible solutions.

3. Carbon-14 Dating in Archaeology
A museum wants to determine the age of an ancient artifact using **radiocarbon dating**.

    (a) Explain how the **radioactive decay of Carbon-14** helps in estimating the artifact's age.

(b) Given that the **half-life of Carbon-14** is **5730 years**, how much of an original sample remains after **17,190 years**?

**Kinetic Theory of Gases**

1. Cooking with Gas: Why Gas Expands in a Cylinder
A gas cylinder at home gets cold after continuous use.

(a) Use the **kinetic theory of gases** to explain why gas expansion causes cooling.

(b) Apply **Boyle's Law** to explain why gas pressure decreases when the cylinder is nearly empty.

2. Tire Pressure in Changing Weather
A motorcyclist notices that **tire pressure increases** on a hot day.

(a) Use **Charles's Law** to explain why tire pressure increases.

(b) Why do tires sometimes burst in extremely hot conditions?

3. Air Conditioning and Cooling Effect
Air conditioners work by compressing and expanding a **refrigerant gas** to cool a room.

(a) Explain how **kinetic theory** accounts for the cooling effect when gas expands.

(b) Why does increasing the **molecular speed** of gas particles affect temperature?

**Thermodynamics**

1. Efficient Car Engines and Heat Transfer
Engineers design car engines to maximize fuel efficiency. However, some of the energy is lost as heat.

(a) Use the **First Law of Thermodynamics** to explain energy transfer in an engine.

(b) Discuss how **adiabatic compression** helps increase engine efficiency.

2. Solar Water Heaters and Energy Conservation
A school installs a **solar water heater** to reduce electricity costs.

(a) Explain how the **Second Law of Thermodynamics** applies to this heating system.

(b) How does increasing the **surface area** of the solar panels improve efficiency?

3. Refrigeration and Entropy
A refrigerator removes heat from food items and expels it into the surrounding air.

(a) Explain how a **refrigerator** works based on **entropy changes**.

(b) Why does a refrigerator's **compressor** get hot while cooling food inside?

## X-Rays and Applications

1. X-Ray Scanners at Airports
   Airports use **X-ray machines** to scan luggage.

   (a) Explain how **X-rays** are generated in an X-ray tube.

   (b) Why are **dense materials** such as metal more visible in X-ray images?

2. Medical X-Rays and Radiation Exposure
   A hospital uses **X-ray machines** for diagnosing fractures but limits the number of scans per patient.

   (a) Explain how **X-rays penetrate human tissues** to produce images.

   (b) Why should frequent X-ray exposure be minimized for patients and technicians?

3. Industrial Use of X-Rays for Material Inspection
   A manufacturing company uses **X-rays** to check for cracks in airplane parts.

   (a) Explain how **X-ray diffraction** helps detect structural defects.

   (b) Why must workers wear **protective shields** when working with X-ray machines?

## Radioactivity and Half-Life

1. Handling Radioactive Waste from Nuclear Plants
   A nuclear power station produces **radioactive waste** that needs safe disposal.

   (a) Explain why **some radioactive isotopes remain hazardous** for thousands of years.

   (b) Suggest a practical method for storing nuclear waste safely.

2. Smoke Detectors and Radioactive Decay
   Smoke detectors contain a **small amount of Americium-241**, a radioactive element that emits **alpha particles**.

   (a) Explain how **radioactive decay** is used in smoke detection.

   (b) Why are **alpha particles** safe inside the smoke detector but harmful if inhaled?

3. Effects of Radiation Exposure on Human Health
   Workers in uranium mines are exposed to **ionizing radiation** over long periods.

   (a) Explain how prolonged exposure to **gamma rays** can damage body cells.

   (b) Why do workers wear **radiation badges** and protective suits?

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