TOPIC: ELECTRICITY
General Objective: The Learner should be able to establish properties of electric charges and explain their behaviour and distribution.
SUB-TOPIC: Electric charges; Electrification and testing for charge.
SPECIFIC OBJECTIVES: The Learner should be able to;
- Prove the existence of two types of charges experimentally.
- Verify the law of charges.
- Draw and label a Gold-leaf electroscope.
- Describe the use of an electroscope to determine the sign of a charge and detect charge.
- Charge insulators by friction.
- Use movement of electrons to explain charging by frictions and induction.

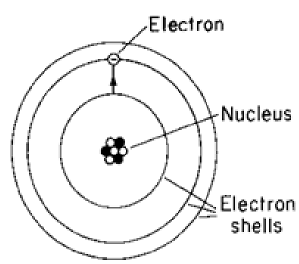
SUB-TOPIC: Distribution of charge.
SPECIFIC OBJECTIVES: The Learner should be able to;
- Describe charge distribution on a conductor.
- Investigate the distribution of electric charge inside a hollow metal conductor using metal –pail experiment.
- Investigate and explain the distribution of charge in a flame and in the atmosphere.
- Explain the action of a lightening conductor.

SUB-TOPIC: Electric fields
SPECIFIC OBJECTIVES: The Learner should be able to;
- Define electric field and electric field lines.
- Draw electric field patterns for different charge distributions.

ELECTROSTATICS

This refers to the study of charge at rest.
To understand the nature of charge, it is necessary to know the structure of an atom.

Structure of an 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 which allows charge to flow through it.

It has loosely bound electrons known as conduction electrons. The flow of these electrons constitutes a current.
Conductors allow heat and electric current to flow through them with ease.

Examples of conductors:
All metals, carbon in form of graphite, acids, bases and salt solutions.

Facts about conductors:
- They have free electrons which are responsible for conducting heat and electricity.
- A conductor can gain or lose electrons.
- Loss of electrons leaves the conductor with a net positive charge and the conductor is said to be positively charged.
- Gain of electrons leaves a conductor with a net negative charge and the conductor is said to be negatively charged.

Insulators:
An insulator is a material which does not allow flow of charge through it.

It has no conduction electrons because its electrons are strongly bound by the nuclear attractive forces.

Examples of insulators:
Rubber, Dry wood, Glass, Plastic, Sugar solutions etc.
Insulators do not allow heat and electric current to flow through them.

Facts about insulators:
- They do not have free electrons.
- Their electrons are tightly held and as a result there is essentially no electron flow through them. Therefore, insulators are poor conductors of heat and electricity.
- Insulators can lose or gain electrons.
- Loss of electrons leaves a net positive charge and the substance is said to be positively charged.
- Gain of electrons leaves the substance negatively charged and the substance is said to be negatively charged.
- Insulators can be charged by friction.

ELECTRIFICATION

This is the process of producing electric charges which are either positive or negative.

Methods of producing Electric charges
- By friction or rubbing (good for insulators and nonconductors).
- By induction (conductors).
- By contact. (weakest of charge).

Electrification by friction

Two uncharged bodies (insulators) are rubbed together. Electrons are transferred from one body to the other. The body which loses electrons becomes positively charged and that which gains electrons becomes negatively charged.

The table below shows which body acquires which charge when they are rubbed together.

Body that acquires positive charge	Body that acquires negative charge
Glass	silk
Fur	Ebonite (hard rubber)
Cellulose Acetate	Polythene

Explanation of charging by friction:

When two bodies are rubbed together, work is done in transferring electrons from one body to another. This results into the two bodies acquiring opposite charges.

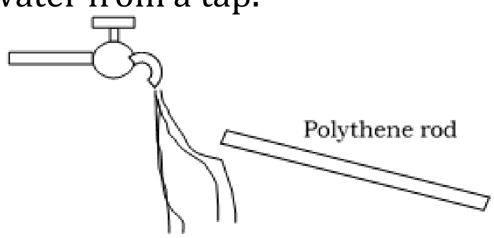
EXAMPLES OF CHARGING BY FRICTION:

Take a plastic pen and rub it vigorously in dry hair. Bring the plastic pen to small pieces of dry paper.

OBSERVATION:

The pen attracts the small pieces of paper.

Take a polythene straw and rub it against fur or a dry piece of cotton cloth. Take the strip near a thin stream of flowing water from a tap.



The stream of water is attracted towards the charged polythene rod.

Law of Electrostatics

Like charges repel each other, while unlike charges attract each other.

EVIDENCE OF ELECTROSTATICS.

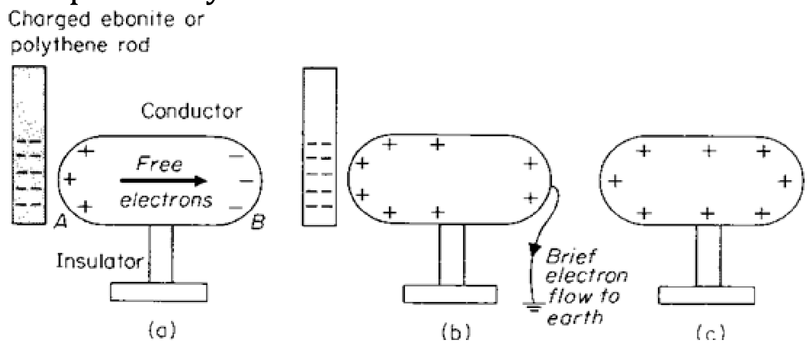
Dust particles stick to a window pane when the pane is wiped with a dry piece of cloth.

A polythene wrapping tends to stick to the hands when it is being unwrapped with the production of crackling noise.

A metal chain is usually attached to the trucks carrying petrol or other flammable materials. (the purpose of the chain link is to conduct away charges from the flammable materials in the tank)

Electrification by induction

Charging a metal sphere positively.



Procedure

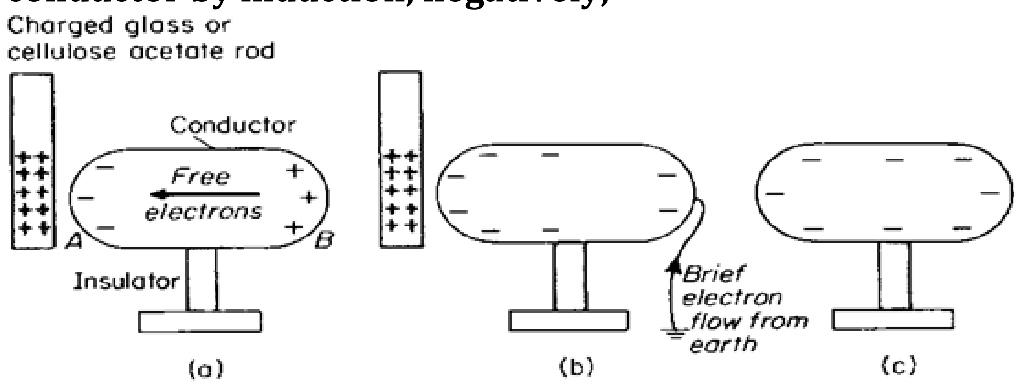
The metal sphere is mounted on an insulated stand as shown in (a).

A negatively charged rod is brought near end A of the metal sphere. Electrons are repelled to the far side B of the metal conductor leaving the end A with a net positive charge.

With the charged rod still in position, the metal conductor is earthed momentarily by touching it with a finger and electrons flow from it to the earth as shown in (b).

The charged rod is then removed and the conductor is left with a net positive charge (due to deficiency of electrons) as shown in (c).

Charging the conductor by induction, negatively,



Procedure

The conductor is placed on an insulated stand as in (a)

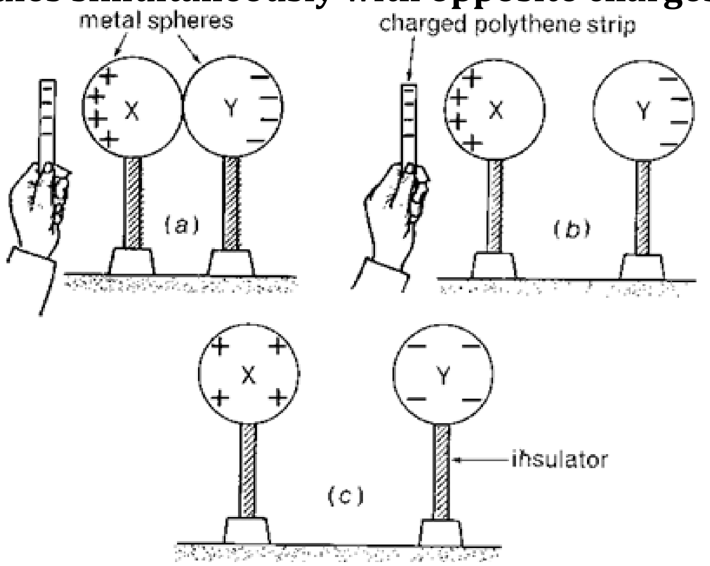
A positively charged rod is brought near the conductor.

The positive and negative charges separate as shown in (a), i.e electrons are attracted towards end A of the conductor by the positive charge on the rod, leaving end B with a positive charge.

With the charged rod still in position, the conductor is momentarily earthed by touching it with a finger. Electrons flow from the earth to the conductor via the earth connection.

Finally, the charged rod is removed and the conductor is left with a net negative charge. (The metal sphere acquired electrons from the earth during the process of earthing.)

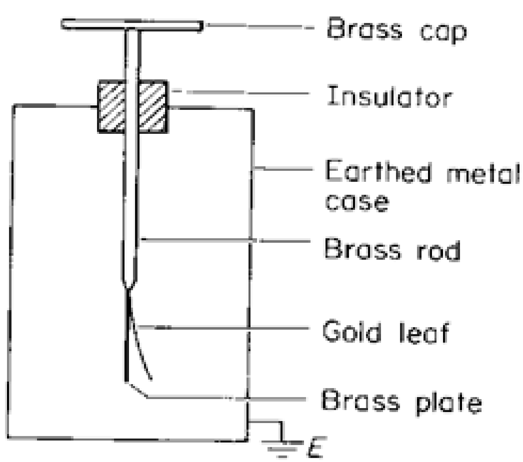
(c) **Charging two bodies simultaneously with opposite charges**

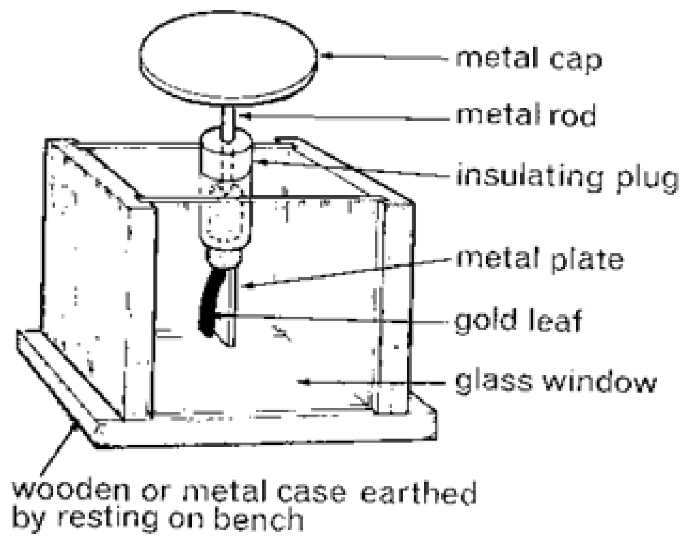


Two metal spheres X and Y that are mounted on insulated stands are placed in contact with each other as shown in (a)
A negatively charged rod is brought close to sphere X. Electrons are repelled from X to sphere Y, leaving X with a concentration of positive charges.
X from Y are separated **in presence of the inducing charge**.
The inducing charge is removed, X will be left with a positive charge and Y with a negative charge.

NOTE: IMPORTANCE OF DRY CONDITIONS IN EXPERIMENTS INVOLVING ELECTRICITY.
Impure water is a conductor and a film of moisture from condensation or moist hands on the surface of an insulator allows electricity to be conducted away to earth. Therefore, for successful results, all apparatus used in electrical experiments must be thoroughly dry.

THE GOLD LEAF ELECTROSCOPE:

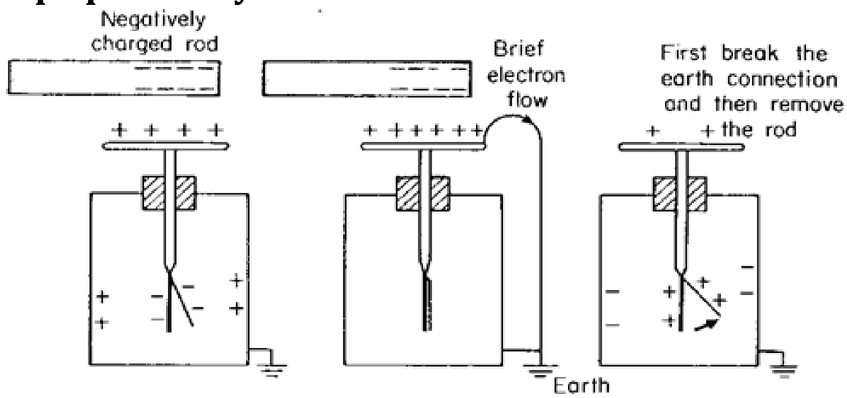




The gold- leaf electroscope consists of a brass cap and brass plate connected by a brass rod.
A gold leaf is fixed together with a brass plate onto the brass rod.
The brass plate, gold leaf and part of brass rod are put inside a metallic box which is enclosed with glass window.

CHARGING A GOLD LEAF ELECTROSCOPE BY INDUCTION.

Charging electroscope positively:



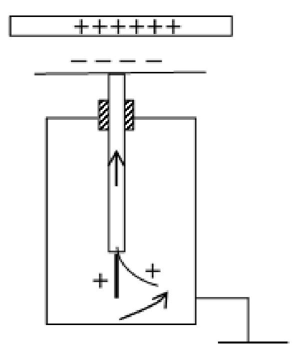
A negatively charged rod is brought near the cap of the gold leaf electroscope.
Positive charges are attracted to the cap and negative charges are repelled to the plate and gold leaf.
The leaf diverges due to repulsion of the same number of charges on the plate.
The gold leaf electroscope is then earthed momentarily in the presence of a positively charged rod by touching its cap.
Electrons from the plate and leaf flow to the earth via the earth connection.
The leaf collapses.

N.B. The earth connection is removed before removing the charged rod in order to prevent the electrons from flowing back to the electroscope.

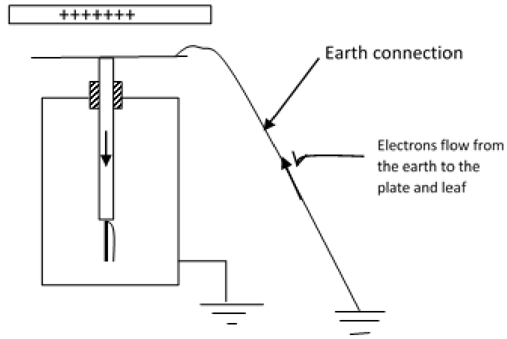
The earth connection is then removed, after which the negatively charged rod is also removed. The positive charges on the cap spread out to the rod and leaf therefore the leaf diverges hence the gold leaf is positively charged.

Charging an electroscope negatively.

A positively charged rod is brought near the cap of the gold leaf electroscope.
Negative charges are attracted to the cap, leaving the plate and gold leaf with positive charges.
The leaf diverges due to repulsion of the same number of charges on the plate.

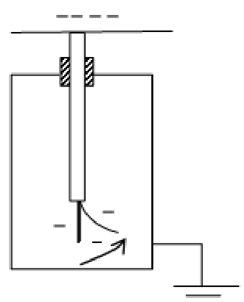


The gold leaf electroscope is then earthed momentarily in the presence of a positively charged rod by touching its cap.



Electrons flow from the earth via the earth connection to the plate and leaf to neutralize the positive charge on them.
The leaf collapses.

N.B. The earth connection is broken quickly to prevent electrons to flow back to the ground. The earth connection is then removed, after which the positively charged rod is also removed. The negative charges on the plate and leaf spread throughout the rod and leaf diverges. The gold leaf is negatively charged because it gained electrons from the earth when it was earthed.



NOTE: In induction process, the electroscope acquires the opposite charge to that of the rod/body used to charge it.

Uses of a gold leaf electroscope:
The table below gives the functions /uses of a GLE

	Use / Function of the GLD	Nature of the GLE used.	Procedure
1.	To detect for presence of charge on a body.	Uncharged electroscope.	When a charged rod is brought near the cap of an uncharged GLE, leaf divergence will occur. When the rod is removed, the leaf collapses. The charged rod induces an identical charge on the leaf and plate of the GLE, and repulsion occurs between them. When no leaf divergence is observed, it means that there is no charge on the rod.
2.	To distinguish between conductors and insulators.	A charged electroscope.	A sample of the substance is held in the hand and placed in contact with the cap of the charged GLE. If the substance is a good insulator, there will be no leakage of charge through it and the leaf divergence will not alter.

			If instant leaf collapse occurs, it shows that the substance is a good conductor. Elements that cause a slow collapse of the leaf are classified as poor insulators of poor conductors. E.g paper, wool, cotton, wood. If these materials are thoroughly dried, they become good insulators. This implies that their ability to conduct electricity depends on their moisture content.

3. Testing for the nature of charge on a charged body using a charged GLE.

Procedure:
Charge a GLE either positively or negatively by induction.
Bring the charged body near the cap of the GLE of known charge and note the effect on the leaf divergence.

The table below shows the summary of results.

Charge on GLE.	Charge on the body brought near the cap of the GLE.	Effect on the angle of divergence of the leaf.
+	+	Increase
–	–	Increase
+	–	Decrease
–	+	Decrease
+ or –	Uncharged conductor	Decrease

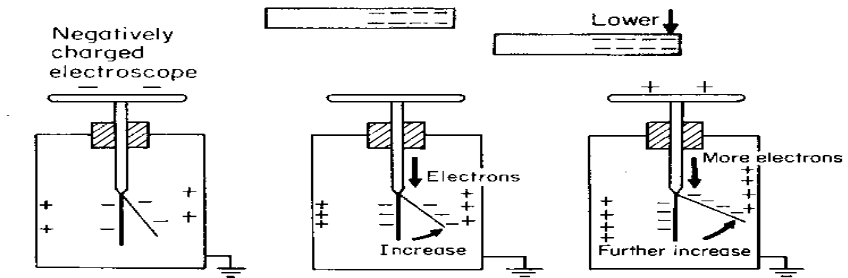
Facts about the results above:

Charge on GLE.	Charge on body	Effect on leaf divergence/Explanation
+	+	Increase. The positive charge near the cap attracts some of the electrons upwards leaving the leaf and plate with a net positive charge. The plate and leaf repel each other leading to increase in the leaf divergence.
–	–	Increase. The negative charge near the cap repels electrons downwards to the plate and leaf. The force of repulsion between the plate and leaf increases causing an increase in the leaf divergence.
+	–	Decrease. The negative charge near the cap repels electrons upwards. The electrons neutralize the positive charge on the plate and leaf. This results into decrease in the force of repulsion between the plate and leaf and the leaf divergence decreases.
–	+	Decrease. The positive charge near the cap attracts electrons from the plate and leaf. This leads to decrease in the force of repulsion between the leaf and plate, hence a decrease in leaf divergence will be observed.
+	Uncharged conductor	Decrease. Repulsion occurs between the electrons in the uncharged body and electrons in the GLE. The electrons in the GLE move to the plate and leaf and neutralize the positive charge on them. Therefore, a decrease in leaf divergence takes place.

–	Uncharged conductor	Decrease. Charge separation occurs in the insulator and the side close to the cap of the GLE acquiring a positive charge. Electrons are therefore attracted from the plate and leaf resulting into a decrease in the leaf divergence.

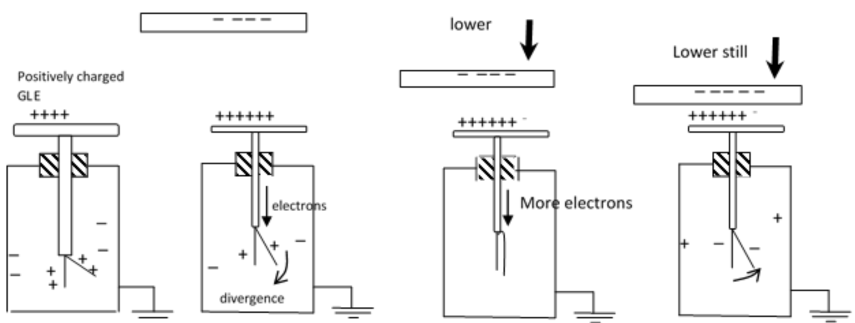
Conclusion: The results above suggest that the only true test for the type of charge on a charged body is repulsion.

Illustration: Testing for presence of charge using a negatively charged electroscope.



Precaution when using a GLE:

A charged body must be brought slowly from a good height above the charged GLE in order to make a correct conclusion on the type of charge on the body. This is explained as below:



An electroscope is first charged positively.

A negatively charged rod is held high above the charged GLE slowly lowered towards the cap. The leaf divergence decreases as the positive charge on the plate and leaf becomes partially neutralized by free electrons which are repelled downwards.

As the charged rod continues to be lowered, more electrons will be repelled to the plate and leaf, until the leaf collapses completely when the positive charge on both plate and leaf have been exactly neutralized.

After this stage, further lowering of the charged rod will cause a leaf divergence that is a result of the leaf and plate acquiring excess electrons.

NOTE: If the intermediate stage of leaf collapse is not observed, it may be wrongly assumed that the test charge on the rod is identical to the charge on the GLE.

Effects and applications of electrostatic charges:

- Dust and smoke particles are extracted from the inside of a chimney or car exhaust system by electrostatic attraction. This reduces the air pollution as a health hazard.
- Electrostatic induction is used in the photocopying machines.

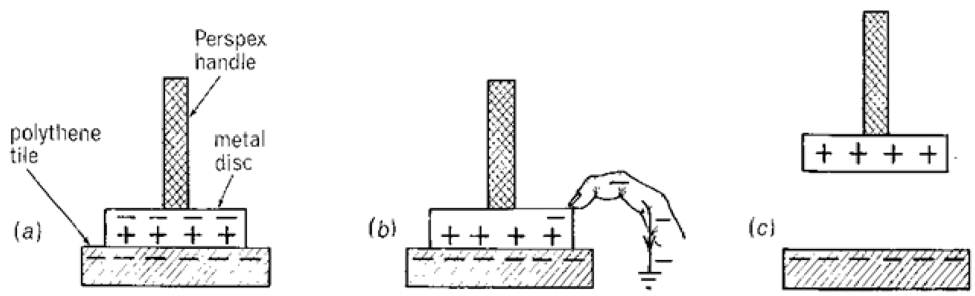
- Cars are painted using a spray gun. The car is usually earthed and the paint droplets coming out of the spray gun are given a positive charge. The car attracts these charged droplets of paint uniformly.

Negative effects of electrostatics:

- One may get a shock on touching the metal knob of the door of a car while getting out of the car. Electric charges build up on the surface of a car due to friction with the road as well as with the air molecules. When the metal knob is touched, charges flow from the knob to the earth through the person. The discharge of charges on the surface of the car through the person gives a shock. If a metal chain is attached to the car on the outside, the charges can pass easily to the earth and the charges cannot build up.

THE ELECTROPHOROUS:

This is an inexhaustible source of electric charge.
It consists of a slab of insulating material together with a metal conductor mounted on insulating handle.



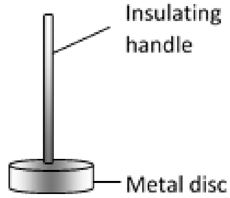
The slab of insulating material is charged negatively by friction.
The metal conductor is placed on top of the slab. This results in positive and negative charges becoming induced respectively on the lower and upper surfaces of the metal disc.
The metal disc is them earthed momentarily by touching it so that the induced negative charge is repelled to earth.
When the metal disc is removed from the slab, it is found to be positively charged.

NB: The insulated handle prevents flow of charge away from the conductor. To charge the conductor negatively, a positively charged slab is used.

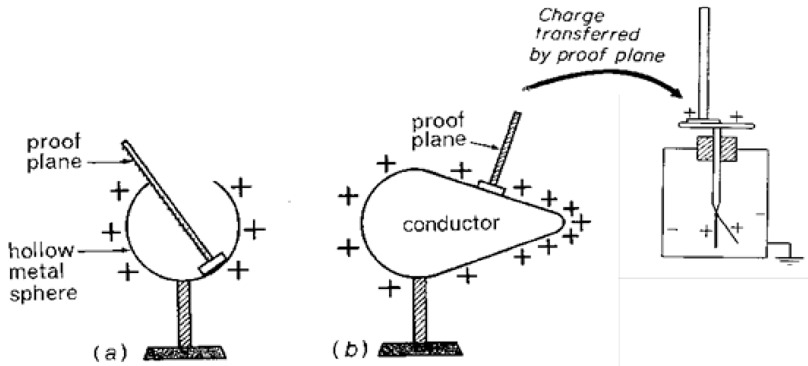
NOTE: When separating the metal disc from the slab, mechanical work has to be done against the force of attraction between the charges on the disc and the slab. This work is transferred to electrical energy in the disc after separation has occurred.

DISRIBUTION OF CHARGE OVER THE SURFACE OF A CONDUCTOR.

Proof plane: It consist of a small metal disc with an insulating handle.
It is used to transfer a small sample of charge from the surface of charged body to the cap of GLE.



Hollow conductor

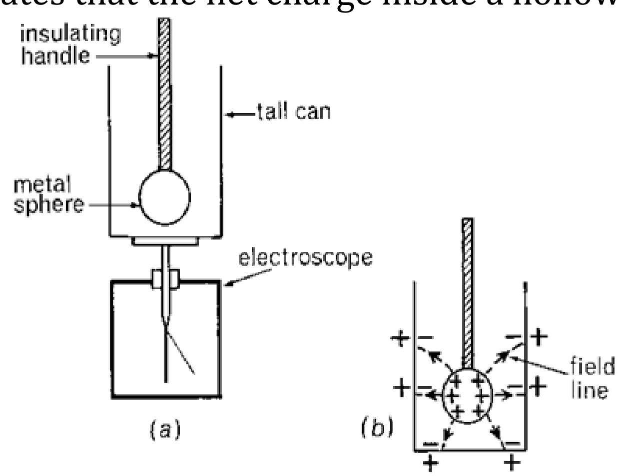


When the proof plane is placed on the outside surface of a charged hollow conductor mounted on an insulating stand, and then transferred to the cap of an uncharged G.L.E, the leaf diverges as shown in (a). This proves that charge was present on the outside of the surface.

When the proof plane is placed on the inside of a charged hollow conductor and then transferred to the cap of an uncharged G.L.E, the leaf does not diverge as in (b). Therefore, no charge resides inside a hollow charged conductor but charge resides only on the outside of the hollow conductor.

The ice pail experiment:

The experiment demonstrates that the net charge inside a hollow conductor is zero.



A metal pail is placed on the cap of an uncharged GLE.

A charged metal ball suspended from a silk string is gently lowered into the metal pail without touching the walls of the pail. The gold leaf will be observed to diverge implying that a charge has been induced on the leaf and plate.

When the charged metal ball is moved about inside the pail without it touching its walls, there will be no change in leaf divergence.

When the ball is allowed to touch the inside wall of the pail, there will be no change in the leaf divergence.
When the metal ball is removed from the pail and tested for charge, it is found to be without charge.

The above experiment shows that:
A charged body, once inside a hollow conductor, it induces on the inside of the container a charge equal but opposite to its own and on the outside, a charge equal and identical to its own charge.
The net charge inside the hollow container is always zero.

Curved bodies

Similarly, the proof plane is placed on the different parts of surface of a pear shaped charged conductor mounted on an insulating stand after which it is transferred to the cap of an uncharged GLE. The results show that the divergence of the leaf is almost uniform over the curved surface whereas the divergence is bigger at the pointed edge.
This implies that charges are almost equally distributed near the curved spherical side, but are crowded over the pointed end.

Surface charge density

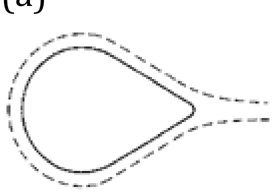
Surface charge density is the ratio of charge to the surface area.
S.I unit of surface charge density is the Coulomb per square metre (Cm^{-2})

$$\text{Charge density} = \frac{\text{charge}}{\text{area}}$$

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 while a large or sharp curvature has a large surface charge density.

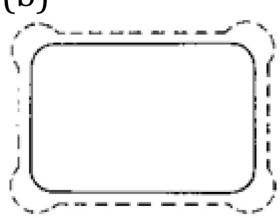
The illustrations below represent surface charge density over different shapes of charged conductors.

(a)



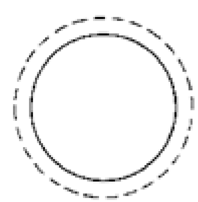
Pear shaped

(b)



Cylindrical

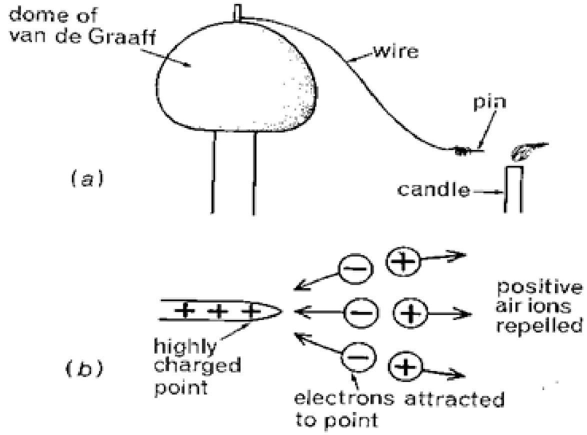
(c)



Spherical

Action of points:

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.



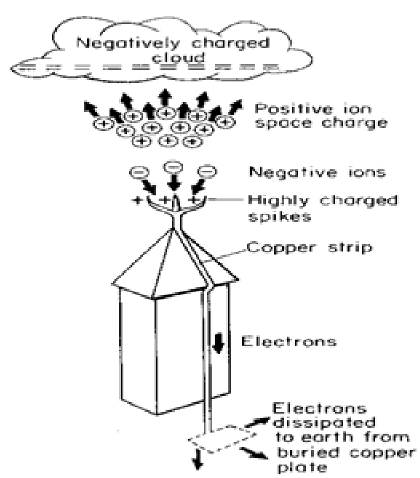
Therefore, a charged sharp point acts as;

- Spray off' of its own charge in form of an electric wind.
- Collector of unlike charges.
- The spray off and collecting of charges by the points is known as corona discharge (action of points).

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 to disembark. Air crafts get electrified but charge remains on the outer surface.

The Lightening conductor:



A lightening conductor is used to protect buildings from damage once struck by lightning by providing a path for electrons to flow easily through it.
A lightening conductor is made up of a thick copper strip. The lower end of the strip is attached to a metal plate that is buried deep in the ground. The other with pointed spikes is held high above the highest point of the building.

If a negatively charged cloud approaches the lightening conductor, it induces positive charge on the spikes of the conductor and a negative charge on the plate buried in the ground. The negative charge on the pate is dissipated into the ground.
At the same time, the high charge density on the spikes ionizes the air molecules.
The negative ions are attracted towards the spikes and become discharged by giving up their electrons. The electrons are safely conducted to the earth through a copper strip.
The positive ions are repelled towards the negatively charged cloud to form a space charge.
The positive space charge may not be sufficient to completely neutralize the cloud. Any excess charge on the cloud will be conducted away harmlessly by the lightening conductor which projects above the highest part of a building.

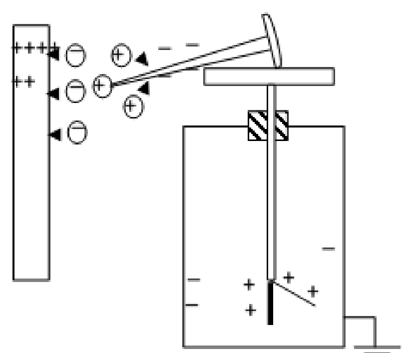
Precautions taken to avoid being struck by lightning:

- Avoid taking shelter under isolated trees when it is raining.
- Avoid umbrellas especially in open places (they increase your height)
- Avoid external antenna during rain.
- Avoid being the highest point in an open locality like a football field during a thunderstorm.

Collection of charge and loss of charge through sharp points

A sharp point can enable a conductor to lose charge or collect charge.

Points as collectors of charge:



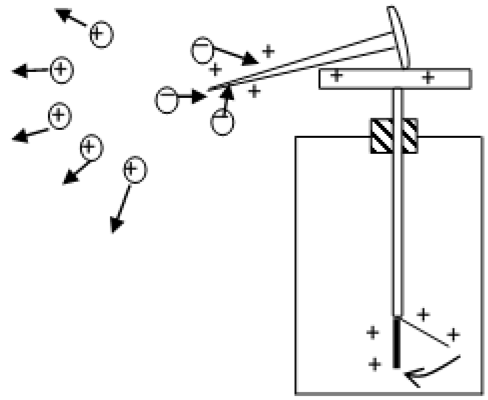
A needle is placed on the cap of an uncharged GLE to act as a sharp point.
When a positively charged rod is brought near to the sharp end of the needle, the leaf rapidly diverges and stays diverged even when the rod is removed.
On testing, the GLE is found to be positively charged.

Explanation:

The positive charge on the rod induces a negative charge at the tip of the needle and a positive charge at the leaf and plate, which repel each other and the leaf diverges.
Point action then takes place resulting into positive ions being attracted towards the sharp point where they receive electrons and become neutralized. The GLE therefore loses negative charge i.e it acquires a net positive charge.
At the same time negative ions are attracted towards the positively charged rod, where they give up electrons to it and neutralize its positive charge.

The resultant effect is a gain of positive charge by the GLE and a loss of positive charge by the rod.

Discharge (loss of charge) through a sharp point:



The pin placed on the cap of the positively charged GLE becomes positively charged as the GLE but with a high charge density at the sharp point.
Point action takes place at the point causing ionization of air molecules around it.
At the same time, the positive ions are repelled away by the sharp point, while the negative ions are attracted towards the point neutralizing some of the positive charge on the GLE.
This is observed by a reduction in the divergence of the leaf.
Eventually, the GLE loses all its charge.

Electric fields

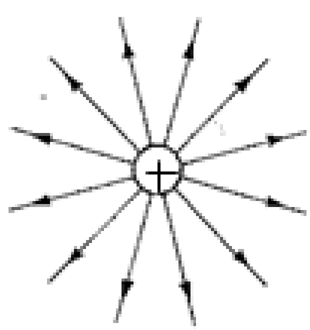
This is a region around the charged body where electric forces are experienced.
Electric fields may be represented by field lines. Field lines are lines drawn in an electric field such that their directions at any point give a direction of electric field at that point.
The direction of any field at any given point is the direction of the forces on a small positive charge placed at that point.

Properties of electric field lines

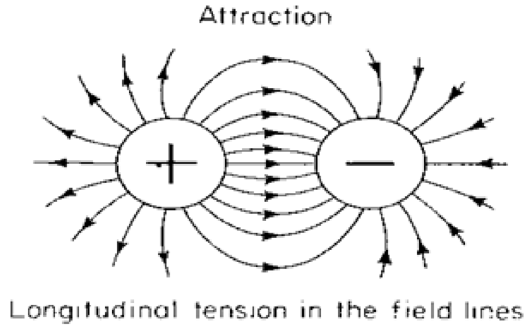
- They begin and end on equal quantities of charge.
- They are in a state of tension which causes them to shorten.
- They repel one another side ways.

Field patterns

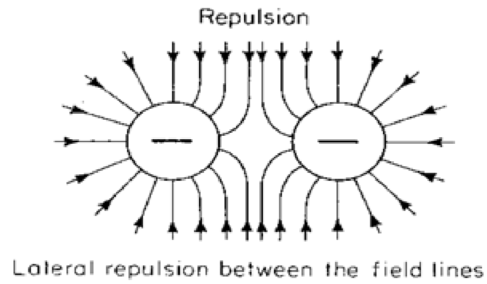
Isolated charge



Unlike charges close together



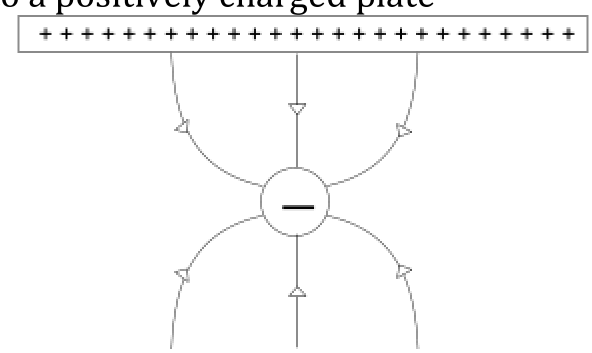
Like charges close together



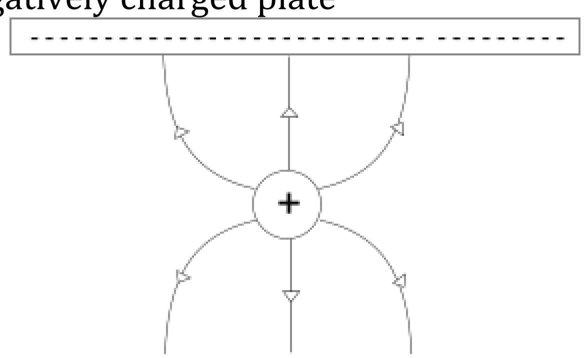
A neutral point is a region where the resultant electric field is zero.
i.e. field lines cancel each other and therefore no resultant electrostatic forces is zero.

Field between charged points and plates

(i) Negative charge close to a positively charged plate



(ii) Positive charge on a negatively charged plate



END.