TOPIC 17: ELECTROSTATICS

Competency: The learner investigates the behaviour of charges at rest and their applications in printing and energy storage in batteries.

Learning Outcome: The learner should be able to apply the concept of Electrostatics in production of charge in real-life situation

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1.0 Introduction to Electrostatics

Electrostatics is the study of electric charges at rest (static electricity). In this branch of physics, we explore how charges are produced, how they interact, and how we can harness these phenomena for practical technology.

There are two kinds of charges i.e., **unlike charges** which attract and **like charges** which repel.

Positive and negative charges

Glass rubbed with silk develops a positive charge whereas an ebonite rod rubbed with fur develops a negative charge. This is because during rubbing electrons move from glass to silk whence the glass become positively charged whereas silk becomes negatively charged.

Similarly, electrons move from fur to rubber during rubbing and rubber becomes negatively charged while fur becomes positively charged.

Insulators and conductors

In insulators, electrons in the atoms are firmly bound to the nucleus and the removal or addition of electrons at a place does not cause flow of electrons elsewhere.

In conductors, the electrons are free to move from individual atoms and if such materials gain electrons these can move about in them. The loss of electrons by conductors cause a redistribution of those left. A charge on the conduct therefore spreads over entire surface.

Examples of insulators include glass, rubber and plastics.

Examples of conductors include metals, water, and electrolytic solutions

Origin of Charge (Structure of an Atom)

An atom consists of electrons (negatively charged, protons (positively charged) and neutrons(neutral). Electrons are contained in shells around the nucleus of an atom while protons and neutrons are contained in the nucleus of an atom.

When a material looses some electrons, it acquires excess positive charge and when it gains electrons, it acquires excess negative charge.

1.1 Methods of Producing Charges

Charges are produced when there is a transfer of electrons between substances. The three primary methods used in real-life and laboratory settings are:

- **Friction (Triboelectric Charging):** This involves rubbing two different materials together. Electrons are transferred from the material with a lower work function to the one with a higher work function. For example, rubbing a glass rod with silk or a plastic rod with fur (Insulators).

  Insulators can only be charged by contact rubbing or friction. Consider two bodies A and B of different work functions.

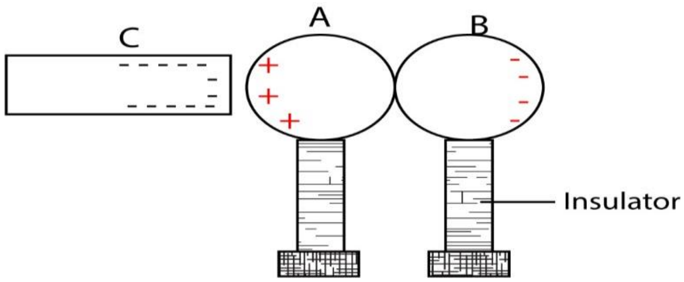
  NB. Work function is the minimum energy required by an electron to escape from the surface of an atom.

  When a body A has a low work function compared to B, then, during rubbing, body A will lose electron to body B due to heat energy that increases the kinetic energy of electrons.

  Body A becomes positively charged while body B becomes negatively charged.

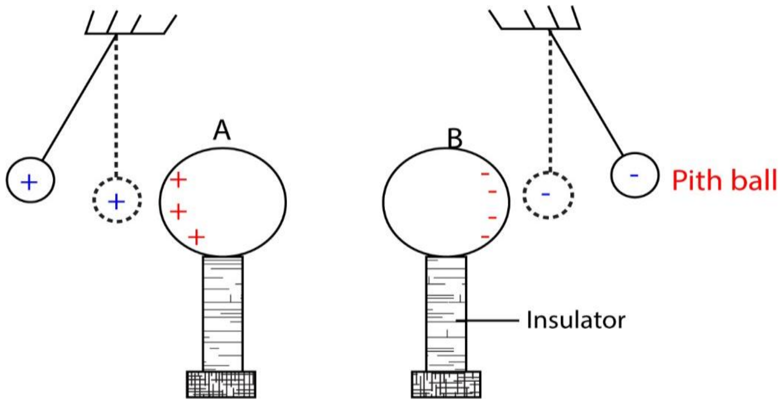
- **Induction:** A method of charging a conductor without making physical contact. A charged object is brought near a neutral conductor, causing a redistribution of charges. If the conductor is then "earthed" (grounded), it retains a net charge of the opposite sign to the charging object.

  Consider two insulated metal spheres A and B, arranged such that they touch one another. A negatively charged rod C is brought near A.



  While keeping the inducing rod C in position, the spheres are separated and tested with a

  charged pith ball. It is discovered that A has a positive charged and B has a negative charge.



If the spheres are brought back in contact, it is found that they have no effect on the pith ball.

Their charges have neutralized each other. This shows that

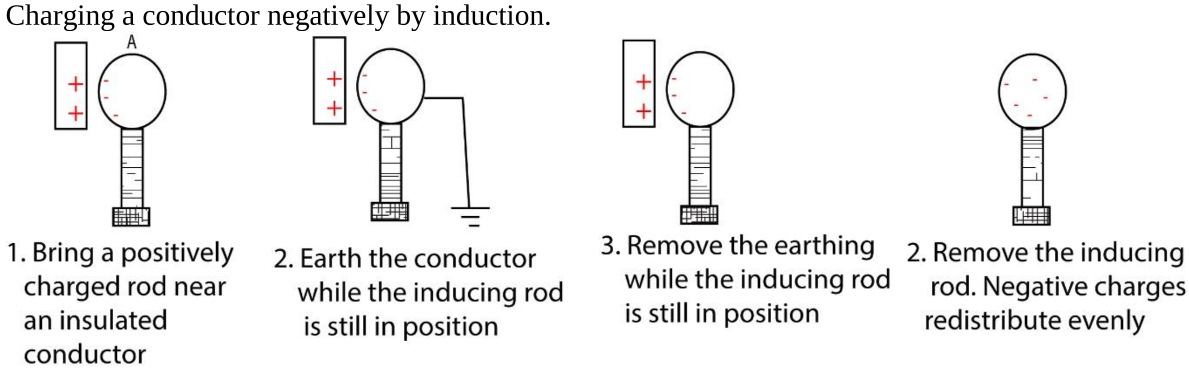
(i) Positive and negative charges are created.

(ii) The number of electrons which move is equal to the number of positive charges

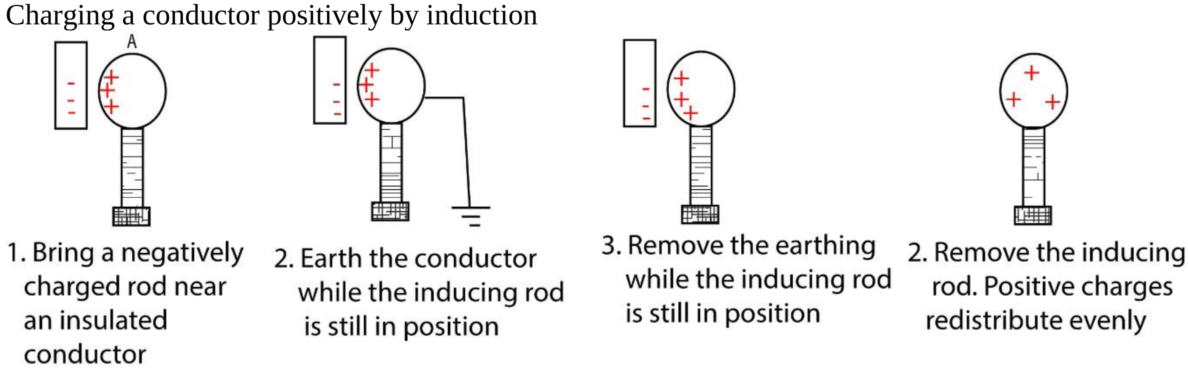
that are created.

Charging by induction

(a) Charging a conductor negatively by induction.



(b) Charging a conductor positively by induction



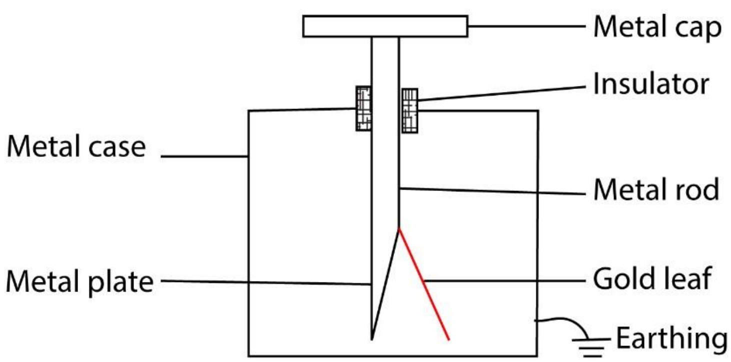
- **Conduction (Contact):** Charging a neutral body by touching it with a charged body. Electrons flow between the objects until the electrical potential is equalized.

The Gold Leaf Electroscope

This is an instrument for testing the presence, the sign and the magnitude of the charge.

It consists of a circular metal disc (cap) attached to a metal rod with a brass plate to which is attached a thin foil of gold or aluminium.

It is fitted in a metal case with help of a plug (insulator) using perspex windows. The metal case is earthed in order to screen the electroscope from outside influ ences other than those brought nearer the cap and it is insulated from the ground.



Mode of action

When a charged body id brought near or in contact with the cap of the electroscope, the cap will acquire an opposite charge by induction. The charge on the body will repel all charges similar to it down to the rod, to the plate and the leaf.

Due to presence of like charges on the plate and gold leaf, the leaf diverges as it is repelled by the plate.

Leaf divergence indicates that the body brought nearer or in contact with the cap carries a charge.

Uses of the gold leaf electroscope

(i) Detecting of charge on a body
(ii) Testing the nature and sign of charge on the body
(iii) Comparing the magnitude of charge on various bodies
(iv) Test the insulating and conducting properties of various substances
(v) Measure potential difference

1. Testing for the nature or sign of charge

Charge a gold electroscope (GLE) negatively. Bring the body under test near the cap of GLE, it the leaf diverges further, then the body has a negative charge but if the gold leaf collapses, then that body is either has a positive or a neutral conductor.

The experiment is repeated is repeated where the GLE is charged is charged positively. A charged body is brought near the cap; if the gold leaf diverges more, the body is positively charged. If the gold leaf collapses, the charged body is either negatively charged or neutral conductor.

Note that an increase in divergence occurs when the charge on electroscope and the tested charge are the same. Therefore, an increase in divergence is the only sure test for a sign of charge on the body.

2. To detect the presence of a charge on a body

Bring the b0dy to be tested near the metal cap of a neutral gold leaf electroscope. When the leaf deflected, then the body has got a charge. However, it the leaf remain undeflected, then a charge is absent on the body.

3. To compare and measure potentials

Two bodies which are similarly charged are brought into contact with the metal cap of the gold electroscope one after another. The body that cause a big divergence has a big charge.

4. To classify conductors and insulators

Bring the body to be tested in contact with the metal cap of a charged gold leaf electroscope. When the leaf collapses suddenly, then the body is a good conductor. If it collapses gradually, the body is a bad conductor. However, if it does not collapse then, it is an insulator.

QN:

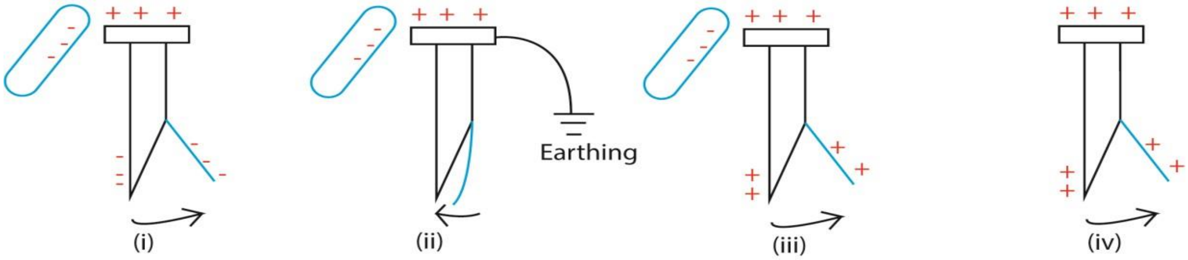
Describe how a gold leaf can be charged positively and negatively by induction.

(a) Charging gold leaf electroscope positively by induction

Procedures

- A negatively charged rod is brought a cap of GLE - The cap is earthed while the charged body is still in place.
- Earth connection is removed.
- Lastly the charged body is removed.

Observation/explanation



(i) When a negatively charged body is brought near a cap of GLE, positive charges are induced on the cap while electrons are repelled to the metal plate and the gold leaf. The gold leaf is repelled and diverges.

(ii) When the cap is earthed say by touching it with a finger, electrons flow to the earth and the leaf collapses.

(iii) When the earth connection is removed, the remaining positive charge on the cap redistributes itself on the Gold leaf and the leaf diverges again.

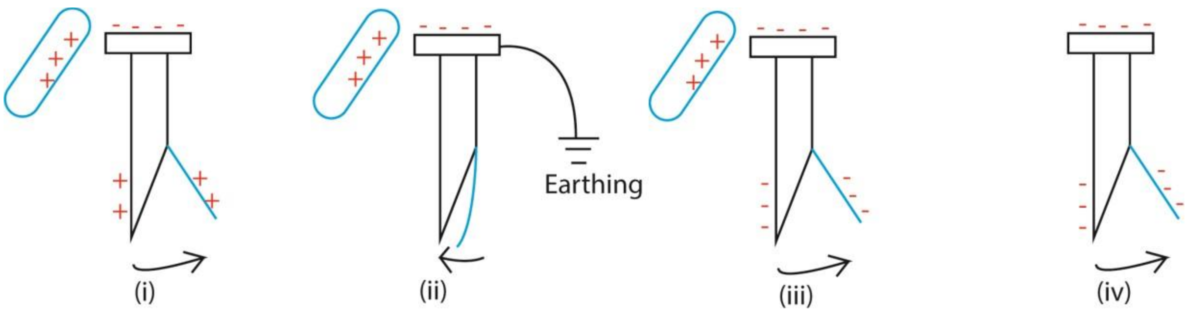
(iv) When the charged body is removed, the GLE acquires a permanent positive charge.

(b) Charging gold leaf electroscope negatively by induction

Procedures

- A Positively charged rod is brought a cap of GLE
- The cap is earthed while the charged body is still in place.
- The earth connection is removed.
- Lastly the charged body is removed.

Observation/explanation



(i) When a positively charged body is brought near a cap of GLE, positive charges are induced on the cap while electrons are repelled to the metal plate and the gold leaf. The gold leaf is repelled and diverges.

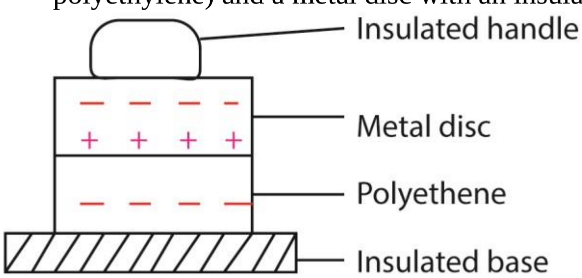
(ii) When the cap is earthed say by touching it with a finger, electrons flow from the earth and the leaf collapses.

(iii) When the earth connection is removed, the acquired negative charge on the cap redistributes itself on the Gold leaf and the leaf diverges again.

(iv) When the charged body is removed, the GLE acquires a permanent negative charge.

Electrophorus

This a device which provides large quantities of charge by induction. It consists of an insulator (e.g. polyethylene) and a metal disc with an insulated metal handle.



Procedure

The polyethene is charged negatively by rubbing it vigorously with a duster, when the metal disc is laid up on it. It acquires induced positive charge after earthing it with a finger. Very little negative charge from the polyethene to disc because the material has uneven surface preventing them from touching at more than a few points. Little charge escapes from these points only because the polyethene is a nonconductor. On removing the disc, it has a sufficient positive charge.

The disc can be discharged and charged again until the charge on the polyethene has disappeared by linkage.

Electrophorus is a device used for converting mechanical energy into electrical energy. Since work is done in raising the disc against the attraction of the opposite charge.

Electrophorus and the advantage of charging by induction

(i) Supply of charge is almost unlimited because the origin of charge in not carried away.

(ii) A greater charge nearly equal to that of the whole of polyethene can be concentrated on the conducting disc.

(iii) Only a very small charge can be transferred by contact leakage because the polyethene is not a conductor.

The disc can be discharged and recharged.

1.2 Distribution of Charge on Conductors

The way charge settles on a conductor depends significantly on its shape:

- **Uniform Spheres:** Charge distributes itself evenly over the outer surface.
- **Irregular Shapes:** Charge tends to accumulate at regions of high curvature (sharp points). The surface charge density is highest where the radius of curvature is smallest.

1.3 Corona Discharge (Action at Points)

When a conductor has a very sharp point, the charge density becomes so high that the surrounding air molecules are ionized. This leads to a gradual "leakage" of charge into the air, accompanied by a faint glow and a "hissing" sound, known as **Corona Discharge**.

The Principle: Action at Points (Corona Discharge)

Corona discharge occurs because the electric field strength is highest at sharp points of a charged conductor.

- **Charge Concentration**: On a conductor, surface charge density is greatest where the radius of curvature is smallest (i.e., at sharp points).
- **Ionization**: The intense electric field at these points ionizes the surrounding air molecules.
- **Electric Wind**: Ions with the same charge as the point are repelled, creating a stream of moving air known as an "electric wind," while ions of the opposite charge are attracted to the point and neutralize it.

Real-Life Applications of Corona Discharge:

1. The Lightning Conductor

A lightning conductor protects buildings by providing a low-resistance path for lightning to reach the ground safely, utilizing corona discharge to prevent or safely manage a strike.

How it Works:

- **Induction**: When a negatively charged thundercloud passes over a building, it induces a positive charge on the sharp spikes of the lightning conductor.
- **Corona Discharge (Discharging)**: The high concentration of positive charge at the sharp spikes ionizes the air. Positive ions are repelled toward the cloud (the "electric wind"), while negative ions are attracted to the spikes and neutralized.
- **Neutralization**: The positive ions moving toward the cloud help neutralize the cloud's negative charge, often preventing a lightning strike altogether.
- **Safe Conduction**: If a strike does occur, the thick copper strip provides a direct, low-resistance path for the electrons to flow from the cloud to the earth, bypassing the structure of the building and preventing damage.

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2. Inkjet Printers

While many modern printers use piezoelectric or thermal technology, some high-speed industrial inkjet printers utilize electrostatic deflection and corona discharge principles to direct ink droplets.

How it Works:

- **Droplet Formation**: A nozzle breaks a continuous stream of ink into tiny, uniform droplets.
- **Charging via Corona Discharge**: As the droplets form, they pass through a charging electrode. This electrode uses a high voltage to create a corona discharge, which imparts a specific electrostatic charge to each ink droplet.
- **Deflection**: The charged droplets then fly between two high-voltage deflection plates (an electric field). The amount of charge on a droplet determines how much it is deflected by the electric field.
- **Printing**:
  - ✓ **Targeted Drops**: Droplets meant for the paper are deflected to precise positions to form characters or images.
  - ✓ **Recycled Drops**: Droplets that are not needed for the image are not charged (or deflected differently) and fall into a "gutter" to be reused.

1.4 Real-Life Applications and Devices

Electrostatics is not just a theoretical concept; it is the foundation of several modern technologies.

A. Electrostatic Paint Spraying (e.g., Car Sprayers)

In industrial car painting, the paint droplets are given a specific charge (e.g., positive) as they leave the nozzle. The car body is grounded or given an opposite charge.

- **Benefit:** The droplets repel each other (ensuring a fine, even mist) and are strongly attracted to the car body, reducing waste and ensuring paint reaches hidden corners.

B. Ink-Jet Printers

Small droplets of ink are charged and then passed through an electric field created by deflection plates. By varying the field, the printer precisely directs the ink to the correct spot on the paper to form characters and images.

C. Laser Printers

A laser printer works by converting a digital image into an electrostatic format and then into a physical print. The process involves several key steps:

A laser beam selectively discharges areas of a rotating drum, creating a latent electrostatic image that corresponds to the digital input. Toner, a dry ink powder, is attracted to the charged areas of the drum, forming the image.

The drum then rolls over paper, transferring the toner to create the printed image, which is then fused to the paper using heat. This method allows for high-quality prints with sharp text and images.

D. Electrostatic Air Cleaners (Precipitators)

Used in factories and homes to remove dust and smoke from the air. Dirty air passes through a highly charged grid that ionizes the particles. These charged particles are then attracted to collection plates of the opposite charge, leaving the air clean.

E. Safety Measures in Fuel Handling

Electrostatics is also critical in safety protocols for handling flammable liquids. For instance, when fuel is transferred, static electricity can build up, posing a fire risk. To mitigate this, fuel trucks and airplanes are grounded to prevent static discharge, ensuring safe operations during refueling.

F. Van de Graaf Generator

A device used to produce very high voltages (millions of volts) through the continuous transfer of charge via a moving belt to a hollow metal dome. It is used in particle accelerators during the study of nuclear processes and for educational demonstrations of electrostatic principles.

Van de Graaff generator is a high-voltage electrostatic generator that uses a moving belt to accumulate very high levels of electric potential on a hollow metal globe. It is a primary application of **corona discharge** (the "action of points"), which is used both to "spray" charge onto the belt and to collect it.

Structure of a Van de Graaff Generator

The generator consists of several key components:

- **Hollow Metal Sphere (Dome):** A large, smooth conducting sphere mounted on an insulating column. This is where the high-voltage charge is stored.
- **Insulating Belt:** A continuous belt made of a non-conducting material (like rubber or silk) that carries the charge from the base to the sphere.
- **Pulleys:** Two rollers (one at the bottom and one inside the sphere) that keep the belt moving. Often, these rollers are made of different materials to help generate initial charge via the triboelectric effect.

- **Comb-like Spikes (Electrodes):** Two pointed metal electrodes/combs. The lower comb is connected to a high-voltage supply (or grounded), and the upper comb is connected to the inside of the metal sphere.

(Skip about 6 lines for the diagram)

Working Principle and the Role of Corona Discharge

The operation of the generator relies on the **action of points** (corona discharge) and the property that charges on a conductor reside on its outer surface.

1. **Charging the Belt (Lower Corona):** A high-voltage power source is connected to the lower pointed comb. The high electric field at the sharp points causes a **corona discharge**, ionizing the air molecules around it. Positive ions are repelled from the points and sprayed onto the moving insulating belt.
2. **Transport:** The belt carries these positive charges upward into the hollow metal sphere.
3. **Collecting the Charge (Upper Corona):** Inside the sphere, the upper pointed comb is placed very close to the belt. The positive charges on the belt induce a negative charge at the sharp points of the comb. This creates another **corona discharge**, which neutralizes the charge on the belt and transfers the resulting positive charge to the exterior of the metal sphere.
4. **Accumulation:** Because the charge is transferred to the *inside* of the conducting sphere, it immediately moves to the *outside* surface due to electrostatic repulsion. This allows the sphere to continue accumulating charge and increasing its potential to millions of volts until the air around the sphere begins to break down (sparking).

Applications

In the context of the Uganda Physics curriculum, the Van de Graaff generator is used to demonstrate:

- **High-voltage phenomena:** Such as electric sparks and the ionization of air.
- **Electric field patterns:** Visualizing how charges interact around a conductor.
- **Particle acceleration:** Historically, these generators were used as early particle accelerators to provide the high potential needed to move subatomic particles.

1.5 Faraday's Ice Pail Experiment

This classic experiment demonstrates that:

1. Charge resides entirely on the **outer surface** of a hollow conductor.
2. The total charge induced on the inside of a hollow conductor is equal and opposite to the inducing charge.

This experiment was performed by Michael Faraday to demonstrate that any excess charge on a hollow conductor resides entirely on its **outer surface** and that no charge exists on the inner surface.

Experimental Setup

(Skip about 8 lines for the set up)

- **Materials:** A hollow metal container (originally an actual ice pail) placed on an insulating stand, a gold-leaf electroscope (GLE), a metal lid, and a charged metal ball suspended by a silk thread.
- **Connection:** The outer surface of the ice pail is connected to the cap of the gold-leaf electroscope.

Step-by-Step Procedure and Observations

1. **Lowering the Charge:** A positively charged metal ball is lowered into the pail without touching the walls.
   - **Observation:** The leaves of the electroscope diverge.
   - **Inference:** The positive ball induces a negative charge on the inner wall of the pail and an equal positive charge on the outer wall.
2. **Touching the Interior:** The ball is allowed to touch the bottom or the inner wall of the pail.
   - **Observation:** The divergence of the electroscope leaves remains unchanged.
   - **Inference:** When the ball touches the inner wall, its positive charge is exactly neutralized by the induced negative charge on the inner surface. This confirms that the induced inner charge was equal and opposite to the ball's charge.
3. **Removing the Ball:** The ball is removed and tested for charge.
   - **Observation:** The ball is found to be completely discharged, while the electroscope remains diverged.
   - **Conclusion:** All the charge from the ball was transferred to the **outer surface** of the pail. No charge remains inside the hollow conductor.

Sample Assessment Items

Item 1: Concept Application

Explain why a person's hair might stand on end when they touch the dome of a Van de Graaf generator.

- **Model Response:**

  The generator transfers a large amount of charge to the person's body. Since like charges repel, the individual strands of hair (now carrying the same charge) repel each other and move as far apart as possible, causing them to stand up.

Item 2: Problem Solving

A technician is painting a metal gate using an electrostatic sprayer. Describe two advantages of using this method over a traditional brush or non-electrostatic spray.

- **Model Response:**

  1. **Uniformity:** Repulsion between droplets ensures a very fine and even coat.

  2. **Efficiency/Wrap-around effect:** The attraction between the charged paint and the grounded gate ensures that even the back and edges of the bars are coated, reducing paint wastage.

Item 3: Investigation

Mbarara Auto-Finishers is a busy workshop that specializes in car body repairs. Recently, the manager, Mr. Okello, upgraded to an electrostatic paint spraying system to reduce paint wastage and improve the finish quality. In this system, the paint droplets are given a high positive charge as they exit the spray gun nozzle, while the metal car body is connected to a large copper rod buried deep in the ground.

During a trial run, a junior technician noticed two things:

As the paint leaves the gun, it forms a very fine, wide mist rather than a narrow stream.

If the grounding wire to the car body accidentally becomes disconnected, the paint droplets begin to bounce off the car surface instead of sticking to it, and the technician feels a slight tingle when standing near the car.

Mr. Okello has asked you, as a Physics student, to help the team understand the science behind these observations to ensure the workshop operates efficiently and safely.

Tasks:

(a) Explain the physics mechanism used by the spray gun to charge the paint droplets and why this results in a fine mist rather than a narrow stream. (06 Scores)

(b) Using the concept of electrostatic forces, analyse why the paint sticks more effectively to the metal car body when it is grounded compared to when it is not. Suggest how the distance between the gun and the car affects the force of attraction. (09 Scores)

(c) Evaluate the implications of the electric field created between the spray gun and the car. Explain why the technician feels a tingle when the grounding is disconnected and propose a safety measure to prevent this. (10 Scores)

Item Number	Task	Basis of Assessment	Sample Response	Score
(a)	Explain charging mechanism and mist formation.	Understanding of charge production (e.g., induction/friction) and Coulombic repulsion.	As paint passes through the nozzle, it gains a high positive charge through contact. Because all droplets have the same positive charge, they exert repulsive electrostatic forces on one another. This mutual repulsion causes the stream to spread out into a fine, wide mist, increasing coverage and reducing waste.	6 Scores (2m mechanism; 2m repulsion; 2m impact on mist).
(b)	Analyse force of attraction and effect of distance.	Application of Coulomb's Law and electrostatic induction.	Grounding provides a path for electrons to flow onto the car body, making it strongly negative. The (+) paint and (-) car experience a strong attractive force. Without grounding, the car accumulates positive charge from the paint, causing repulsion. Force $F \propto 1/r^2$; as distance (r)	9 Scores (3m induction; 3m grounding vs floating; 3m distance relation).

Item Number	Task	Basis of Assessment	Sample Response	Score
			increases, force decreases exponentially, weakening the bond.	
(c)	Evaluate E-fields, tingle sensation, and safety.	Examination of electric field strength and ionisation/discharge.	A strong electric field exists between the gun and the car. When disconnected, the car retains charge, creating a high potential difference. The "tingle" is caused by a small corona discharge or spark as charge tries to neutralize through the technician. Safety: Ensure a continuous low-resistance ground path and provide the technician with conductive/anti-static footwear.	10 Scores (3m E-field; 3m discharge mechanism; 4m safety proposal).

Item 4: Investigation

In a local industrial furniture workshop, workers are struggling with conventional painting methods, which lead to significant waste of paint and uneven finishes on metallic chair frames. An engineering student, Sarah, observes that the spray gun uses mechanical force, causing paint droplets to disperse into the air rather than adhering to the target. Sarah proposes an "Electrostatic Spray Painting" system. She suggests that by charging the paint particles and keeping the chair frame at an opposite potential, the paint will be attracted directly to the metal, drastically reducing waste and improving coating uniformity.

Tasks

(a) Using the principles of electrostatics, explain the mechanism by which the paint droplets become charged as they exit the nozzle, and describe why this process is more efficient than mechanical spraying. (5 scores)

(b) The system requires the metallic chair frame to be grounded. Discuss why this grounding is essential for the successful attraction of the charged paint particles and what might happen to the coating process if the chair were insulated from the ground. (5 scores)

(c) As an innovator, suggest two additional modifications to the spray nozzle or the environment that could enhance the uniform distribution of the paint, and justify how these modifications use electrostatic concepts to improve the final finish. (5 scores)

Item Part	Basis of Assessment	Sample Response	Score
(a)	Understanding of charge production and efficiency.	Paint is charged by contact at the nozzle. This creates an electrostatic attraction (Coulomb force) between the paint and the grounded object, preventing "overspray" and ensuring particles follow electric field lines.	5
(b)	Understanding of grounding and field potential.	Grounding ensures the chair remains at zero potential relative to the spray, maintaining a constant potential difference for attraction. If	5

Item Part	Basis of Assessment	Sample Response	Score
		insulated, the chair would accumulate charge, causing repulsion of subsequent paint particles and stopping the deposition.	
(c)	Application of creativity and electrostatic theory.	1. Use of a sharp-edged needle at the nozzle to increase field intensity (corona discharge). 2. Controlling the humidity in the room to prevent leakage of charge. These enhance the field strength and maintain the charge on particles.	5

TOPIC 17: ELECTROSTATICS

Competency: The learner investigates the behaviour of charges at rest and their applications in printing and energy storage in batteries.

Learning Outcome: The learner should be able to appreciate the existence of a force between charges and its implications

1.0 Coulomb's Law

The fundamental force between stationary electric charges is described by Coulomb's Law. It states that the magnitude of the electrostatic force (F) between two-point charges is directly proportional to the product of the magnitudes of the charges ($Q_1 Q_2$) and inversely proportional to the square of the distance (r) between them.

Mathematical Expression:

$$F \alpha \frac{Q_1 Q_2}{r^2}$$

$$Thus\ F = k\frac{Q_1 Q_2}{r^2}\ and\ k = \frac{1}{4\pi\varepsilon}$$

Where:

- F = Force(N)
- Q_1 and Q_2 = Charge(C)
- ε = Permittivity of the medium between the charges in farads per metre.

For free space or vacuum, $\varepsilon = \varepsilon_o (Permitivity\ of\ free\ space)$

$$\varepsilon_o = 8.85 \times 10^{-12} Fm^{-1}$$

$$\rightarrow k = \frac{1}{4\pi\varepsilon_o} = \frac{1}{4\pi \times 8.85 \times 10^{-12}} = 9.0 \times 10^{9}\ mF^{-1}$$

Note:

1. The direction of force at a given point due to a positive charge is away from a positive charge towards the point.
2. The direction of force at a given point due to a negative charge is towards the negative charge from the point.

A coulomb is a quantity of charge which flows through any section of a conductor when a current of one ampere flows for one second; $Q = It$

Micro Coulomb; $1\mu C = 10^{-6} C$

Relative permittivity,ε_r(Dielectric Constant)

This is defined as the ratio of permitivity of a medium/material to the permitivity of free space i.e

$$Relative\ Permitivity, \varepsilon_o = \frac{Permitivity\ of\ medium, \varepsilon}{Permitivity\ of\ free\ space, \varepsilon_o} \rightarrow \varepsilon_r = \frac{\varepsilon}{\varepsilon_o}$$

$$\varepsilon = \varepsilon_r \varepsilon_o$$

(Proceed after Monday's Lesson)

1.2 Implications of Electrostatic Forces

The existence of force between charges has profound implications in both nature and technology:

- **Atomic Stability:** The electrostatic force of attraction between the positive nucleus and negative electrons keeps atoms together.
- **Capacitance:** The force allows for the storage of energy in capacitors by holding opposite charges on closely spaced plates.
- **Safety Hazards:** Large accumulations of charge can lead to high-energy discharges (lightning), which can be destructive.