Unit 4
Static and Current Electricity

Introduction to Electricity

Electricity is a physical phenomenon associated with the presence and flow of electric charge. It is crucial in modern life, powering home appliances, industries, and more. We often take electricity for granted until a power outage disrupts our daily activities. In this unit, we will explore key concepts related to electricity, including its basic properties, methods of charging, and more.

Charges in Nature

Types of Electric Charges

There are two types of electric charge:

- **Positive Charge**: Carried by protons.
- **Negative Charge**: Carried by electrons.

In a neutral object, positive and negative charges are balanced. If an object has more positive or negative charges, it is said to be electrically charged.

Unit of Charge

The SI unit of electric charge is the coulomb (C). One coulomb is equivalent to the charge of 6.25×10^{18} electrons. In practical scenarios, we often use smaller units like microcoulombs (μC) and nanocoulombs (nC).

Conservation of Charge

Electric charge is neither created nor destroyed; it is transferred from one object to another. This principle is known as the conservation of charge. For example, when a comb is rubbed on hair, electrons transfer from the comb to the hair, causing the comb to become negatively charged and the hair to become positively charged.

Quantization of Charge

Charge is quantized, meaning it exists in discrete amounts, such as the charge of an electron or proton. The magnitude of charge is denoted by e, and any charge q is a multiple of e, expressed as $q=ne$, where n is an integer.

Methods of Charging a Body

Charging by Rubbing

When two neutral materials are rubbed together, electrons transfer from one to the other. This method can result in one material becoming positively charged and the other negatively charged. For example, rubbing a comb with hair can make the comb negatively charged and the hair positively charged.

Charging by Conduction

Charging by conduction involves direct contact between a charged object and a neutral object. When a charged object touches a neutral object, charge transfers between them. For instance, touching a positively charged aluminum plate to a neutral metal sphere will transfer positive charge to the sphere.

Charging by Induction

Charging by induction involves bringing a charged object near a neutral conductive material without direct contact. The presence of the charged object causes the electrons in the neutral material to move, creating regions of positive and negative charge. Grounding the neutral material allows it to gain or lose electrons, leaving it with a charge opposite to that of the charged object.

The Electroscope

Purpose of an Electroscope: An electroscope is a sensitive instrument used to detect the presence of an electric charge on a body.

Components: An electroscope typically consists of:

- A glass container.
- A metal rod inside the container with two thin pieces of gold foil attached at the bottom.
- A metal plate attached to the top end of the rod outside the glass container.

How It Works:

1. **Detection of Charge:**
    - When a charged object (like a positively charged rod) is brought close to the metal plate of the electroscope (but does not touch it), the metal plate and gold foil will respond.

    - The negative charges in the gold foil, metal rod, and metal plate are attracted to the positively charged rod. This causes the gold foil leaves to become positively charged (since electrons move away from them), and they repel each other.
2. **Induced Charge:**
    - The movement of charges caused by the nearby charged object is known as induced charge. Even though the electroscope remains neutral overall, the distribution of charges changes. The gold foil leaves repel each other because they have the same positive charge.
3. **Return to Neutral State:**
    - When the charged object is removed, the charges in the electroscope redistribute evenly, and the gold foil leaves fall back together because the induced charge is no longer present.

Key Concept: The collapsing or diverging of the gold foil leaves indicates the presence of an electric charge.

Electrical Discharge

Concept of Electrical Discharge:

- **Definition:** Electrical discharge is the process when electric charges are transferred quickly from a charged object to another object or the ground, neutralizing the charge.

Lightning:

- **Formation:** In a thunderstorm, a negative charge builds up at the base of a cloud. This creates a positive charge on the ground through induction. When enough charge accumulates, it forms a path for discharge. The cloud then releases excess electrons, creating lightning.
- **Thunder:** The rapid expansion of heated air from the lightning bolt causes the sound of thunder.

Grounding:

- **Purpose:** Grounding is the process of providing a pathway for excess electric charge to flow safely into the ground, preventing damage from electrical discharges like lightning.
- **Lightning Rods:** Metal rods on buildings are used to safely conduct lightning strikes into the ground.

Coulomb’s Law of Electrostatics

Coulomb's Law:

- **Statement:** The electrostatic force between two charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between them.

Mathematical Expression: $F=k\frac{q_1 q_2}{r^2}$ where F is the force between the charges, q_1 and q_2 are the charges, r is the distance between them, and k is the electrostatic constant (9×10^9 N m^2/C^2.

Example Calculation: For charges $q_1=5.0\,\mu C$ and $q_2=-12.0\,\mu C$ separated by 30 cm: $F=9\times10^9\frac{(5\times10^{-6})(-12\times10^{-6})}{(0.3)^2} = -6.0$ N The negative sign indicates the force is attractive.

Key Concept:

- The force is attractive if the charges are of opposite signs and repulsive if they are of the same sign.

The Electric Field

Definition of an Electric Field

An electric field is a region around an electric charge where other electric charges experience a force. Just like a football field is where a game is played, the electric field is where electric forces act on charges.

Electric Field Lines

Electric field lines help us visualize electric fields. Michael Faraday first introduced these lines. Here's what you need to know:

- **Field Lines Never Cross**: Electric field lines never intersect.
- **Perpendicular to Surface**: They are perpendicular to the surface of the charge.
- **Proportional to Charge**: The number of field lines is proportional to the magnitude of the charge.
- **Direction**: Field lines start at positive charges and end at negative charges.
- **Behavior**: Field lines bend towards each other when opposite charges attract and bend away from each other when like charges repel.

Example Illustration:

- **Positive Charge**: Field lines radiate outward.
- **Negative Charge**: Field lines converge inward.

Electric Field Strength

The strength of an electric field (E) is defined as the force (F) per unit charge (q). Mathematically, this is expressed as:

$$E=\frac{F}{q}$$

Where:

- **E** is the electric field strength.
- **F** is the force experienced by the test charge.
- **q** is the magnitude of the test charge.

Direction: If the test charge is positive, the electric field points in the direction of the force. If the test charge is negative, the field points in the opposite direction.

The unit of electric field strength is Newton per Coulomb (N/C).

Calculating Electric Field Strength

For a point charge, the electric field strength (E) at a distance rrr from the charge qqq is given by:

$$E=\frac{k\cdot q}{r^2}$$

Where:

- **k** is Coulomb's constant (9×10^9 $N\cdot m^2/C^2$).
- **q** is the charge creating the field.
- **r** is the distance from the charge.

Example Calculation: To find the electric field strength due to a point charge of 2.0 nC (nanoCoulombs) at a distance of 5.0 mm (millimeters):

- Convert the units: $q=2.0\times10^{-9}$ C and $r=5.0\times10^{-3}$ m.
- Apply the formula:

$$E=\frac{9\times10^9\times2.0\times10^{-9}}{(5.0\times10-3)^2}\approx 7.2\times10^5 \text{ N/C}$$

Superposition Principle

The total electric field at a point due to multiple charges is the vector sum of the electric fields created by each charge individually.

Key Points to Remember

- **Test Charge**: A small positive charge used to detect the presence of an electric field.
- **Electric Field Lines**: Visualize the direction and strength of an electric field.
- **Electric Field Strength**: Force per unit charge; calculated using Coulomb's law for point charges.

Current, Voltage, and Ohm's Law

Introduction:

In this section, we will learn about three key concepts in electricity: current, voltage, and resistance, and how they are related through Ohm's Law.

1. Electric Current:

Electric current is the flow of electric charge through a conductor. Imagine a torch: when the battery is connected, it pushes charges through the wire, lighting up the bulb. This flow of charges is known as electric current.

- **Definition:** Electric current is the rate at which electric charges flow through a conductor.
- **SI Unit:** The unit of electric current is the ampere (A), where 1 ampere equals 1 coulomb of charge flowing per second. Smaller currents are measured in milliamperes (mA) or microamperes (μA).

Formula: $I=\frac{\Delta Q}{\Delta t}$ Where:

- I = Current (in amperes)
- ΔQ = Charge (in coulombs)
- Δt = Time (in seconds)

Example: A current of 0.5 A flows for 10 minutes (600 seconds). The charge ΔQ that flows is: $\Delta Q=I\times\Delta t=0.5\text{ A}\times 600\text{ s}=300\text{ C}$

2. Voltage (Potential Difference):

Voltage, or potential difference, is the driving force that pushes electric charges through a conductor, similar to how water pressure pushes water through a pipe.

- **Definition:** Voltage is the work done to move a unit charge from one point to another in an electric circuit.
- **SI Unit:** The unit of voltage is the volt (V), where 1 volt equals 1 joule of work done per coulomb of charge.

Formula: $\Delta V = \frac{W}{Q}$ Where:

- ΔV = Voltage (in volts)
- W = Work done (in joules)
- Q = Charge (in coulombs)

Example: To move a charge of 2 C across a potential difference of 12 V, the work done is: $W=\Delta V \times Q = 12\,V \times 2\,C = 24\,J$

3. Ohm's Law:

Ohm's Law relates current, voltage, and resistance in an electrical circuit. It states that the current through a conductor between two points is directly proportional to the voltage across the two points.

- **Ohm's Law Formula:** $\Delta V = I \times R$ Where:
- ΔV = Voltage (in volts)
- I = Current (in amperes)
- R = Resistance (in ohms)
- **Resistance (R):** Resistance is a measure of how much a conductor opposes the flow of current. It depends on the material, length, and cross-sectional area of the conductor.

Example: If an electric bulb with a resistance of 1200 Ω is connected to a 220 V source, the current drawn is: $I=\frac{\Delta V}{R} = \frac{220\,V}{1200\,\Omega} = 0.18\,A$

Key Points:

1. **Current** is the rate of flow of charge and is measured in amperes (A).
2. **Voltage** is the potential difference that drives the current and is measured in volts (V).
3. **Resistance** opposes the flow of current and is measured in ohms (Ω).

4. **Ohm's Law** provides a relationship between current, voltage, and resistance: $\Delta V = I \times R$.

Combination of Resistors in a Circuit

Introduction: In electrical circuits, resistors can be connected either in series or in parallel. Understanding these connections is crucial for analyzing how current and potential difference (voltage) behave in a circuit.

Resistors in Series

Concept:

- In a series circuit, resistors are connected one after another, providing a single path for the electric current to flow.

Characteristics:

- **Current:** The same current flows through each resistor because there is only one path for the current to follow.
- **Potential Difference:** The total potential difference across the series circuit is the sum of the potential differences across each resistor.

Formula:

- **Equivalent Resistance (R_{eq}):** For resistors in series, the equivalent resistance is the sum of their individual resistances. $R_{eq} = R_1 + R_2 + R_3 + \cdots + R_n$

Example Calculation:

- Given resistors $R_1 = 12\,\Omega$, $R_2 = 3\,\Omega$, and $R_3 = 4\,\Omega$ in series: $R_{eq} = 12\,\Omega + 3\,\Omega + 4\,\Omega = 19\,\Omega$

Resistors in Parallel

Concept:

- In a parallel circuit, resistors are connected across common points, creating multiple paths for the electric current to flow.

Characteristics:

- **Current:** The total current is the sum of the currents through each parallel branch.

- **Potential Difference:** The potential difference across each resistor in parallel is the same as the total potential difference of the circuit.

Formula:

- **Equivalent Resistance (Req):** For resistors in parallel, the reciprocal of the equivalent resistance is the sum of the reciprocals of the individual resistances.

$$\frac{1}{R_{eq}}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}+\dots+\frac{1}{R_n}$$

Example Calculation:

- Given resistors $R_1=12\,\Omega$, $R_2=12\,\Omega$, and $R_3=6\,\Omega$ in parallel:

$$\frac{1}{R_{eq}}=\frac{1}{12\,\Omega}+\frac{1}{12\,\Omega}+\frac{1}{6\,\Omega}=\frac{1}{4\,\Omega}$$

$R_{eq}=4\,\Omega$

Analyzing Mixed Series-Parallel Circuits

1. **Identify Series and Parallel Parts:**
   - Break down complex circuits into simpler series and parallel sections.
2. **Calculate Equivalent Resistances:**
   - First, find the equivalent resistance for parts of the circuit in parallel or series, then combine these results.
3. **Determine Currents and Voltages:**
   - Use Ohm's Law to find the total current and voltage drops across each resistor.

Example: For resistors $R_1=4\,\Omega$, $R_2=5\,\Omega$, and $R_3=9\,\Omega$ in a mixed series-parallel circuit:

- Find parallel equivalent resistance for R_2 and R_3:

$$\frac{1}{R_{par}}=\frac{1}{5\,\Omega}+\frac{1}{9\,\Omega}=\frac{1}{3.21\,\Omega}$$

Rpar=3.21 Ω

- Combine this with R_1 in series: $R_{eq}=4\,\Omega+3.21\,\Omega=7.21\,\Omega$

Connection of Voltmeter and Ammeter in a Circuit

Overview

In an electric circuit, two essential devices for measuring electrical properties are the **voltmeter** and the **ammeter**. Each device has a specific role and is connected in a particular way to ensure accurate measurements.

Measuring Instruments

1. **Voltmeter**:
   - **Purpose**: Measures the potential difference (voltage) across a component in the circuit.
   - **Connection**: Connected in parallel with the component whose voltage you want to measure.
   - **Reason**: In parallel connections, the voltmeter receives the same potential difference as the component. This is crucial because the voltmeter needs to measure the exact voltage drop without altering the circuit's operation. The voltmeter has high resistance to ensure minimal current draw, preventing changes in the circuit's behavior.
   - **Analogy**: Think of a voltmeter like a pressure gauge in a water system, measuring the difference in pressure between two points.
2. **Ammeter**:
   - **Purpose**: Measures the flow of electric current in amperes.
   - **Connection**: Connected in series with the component whose current you want to measure.
   - **Reason**: In series connections, the ammeter ensures that all the current flowing through the circuit also passes through it. This is necessary for an accurate measurement of the total current. An ammeter has low resistance to avoid altering the circuit's total resistance and current flow.
   - **Analogy**: Consider an ammeter like a flow meter in a water system, measuring the volume of water passing through a specific point.

Key Points for Connection

- **Voltmeter Connection**:
  - **In Parallel**: To measure the voltage across a component, the voltmeter should be connected parallel to it. This ensures that the voltmeter reads the potential difference accurately without affecting the circuit's operation.
- **Ammeter Connection**:

- **In Series**: To measure the current, the ammeter should be placed in series with the component. This allows the entire current flowing through the circuit to pass through the ammeter for accurate measurement.

Summary Table

Instrument	Measured Quantity	Proper Connection
Voltmeter	Voltage	In Parallel
Ammeter	Current	In Series

Important Notes

- **Connecting a Voltmeter in Series**: If a voltmeter is connected in series, it will increase the circuit's resistance and potentially prevent current from flowing. This is why it must be connected in parallel.
- **Connecting an Ammeter in Parallel**: If an ammeter is connected in parallel, it will draw excessive current, which can damage the ammeter and affect the circuit. Therefore, it must be connected in series.

By understanding these connections and their purposes, you can accurately measure both voltage and current in electrical circuits.

Electric Projects

Electric projects help us understand how electrical circuits work and how we can use them to power devices. This section will guide you through two simple electrical projects and a more complex one. By the end, you should be able to:

1. Draw an electric circuit diagram with a battery, connecting wires, resistors, switch, and bulb using their symbols.
2. Construct an electric circuit using wires, resistors, switch, and bulb.

Understanding Electrical Circuits

Electrical circuits are the pathways that allow current to flow through electronic devices, such as motors, washing machines, and light bulbs. These circuits can be simple or complex and involve components like batteries, wires, and lamps. Let's dive into a couple of projects to see how these components work together.

End of Unit Summary

- **Charges:** There are positive and negative charges. Like charges repel; opposite charges attract.
- **Charging Methods:** Rubbing, conduction, and induction.
- **Electric Field:** Defined by the force per unit charge. Field lines start at positive charges and end at negative charges.
- **Circuits:** Open circuits don’t allow current to flow, while closed circuits do. Ohm’s law relates current, voltage, and resistance.
- **Resistance:** Depends on length, cross-sectional area, and material properties.