TOPIC 1 Coulomb's Law

SQ 9.1.1 Define electrostatics.

Definition

Electrostatics is the study of phenomena and properties of electric charges at rest. When charges are in motion, we call it an electric current.

SQ 9.1.2 Why is charge said to be quantized?

Answer

Any amount of charge q is an integer multiple of the elementary charge e.

Formula

$q = Ne$

Here N is an integer.

SQ 9.1.3 Who made the first measurement of the force between electric charges?

Answer

The first measurement of the force between electric charges was made by the French physicist Charles de Coulomb in 1784.

SQ 9.1.4 State Coulomb's law.

Statement

The force between two point charges is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance between them.

Formula

$F = k\frac{q_1 q_2}{r^2}$

SQ 9.1.5 Along which line does Coulomb's force act?

Answer

The force F always acts along the line joining the two point charges.

SQ 9.1.6 On what does the constant k in Coulomb's law depend?

Answer

Its value depends upon the nature of the medium between the two charges, and on the system of units in which k q and r are measured.

SQ 9.1.7 Write the value of k for free space in SI units.

Formula

$k = \frac{1}{4\pi\varepsilon_0}$

Value

$k = 9 \times 10^9\,\mathrm{N\,m^2C^{-2}}$

SQ 9.1.8 Define permittivity of free space and give its value.

Definition

ε_0 is an electrical constant known as the permittivity of free space.

Value

$\varepsilon_0 = 8.85 \times 10^{-12}\,\mathrm{C^2N^{-1}m^{-2}}$

SQ 9.1.9 Write Coulomb's force in free space.

Formula

$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$

SQ 9.1.10 Why is Coulomb's force called a mutual force?

Answer

If q_1 exerts a force on q_2, then q_2 also exerts an equal and opposite force on q_1.

Formula

$\mathbf{F}_{12} = -\mathbf{F}_{21}$

SQ 9.1.11 Write Coulomb's force in vector form.

Formula

$\mathbf{F}_{21} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\hat{r}_{21}$

Here $\hat{r}_{21}$ is the unit vector directed from q_1 to q_2.

SQ 9.1.12 What determines whether Coulomb's force is attractive or repulsive?

Answer

The sign of the charges determines whether the forces are attractive or repulsive.

SQ 9.1.13 What is a dielectric?

Definition

If the medium between two charges is an insulator, it is usually referred to as a dielectric.

SQ 9.1.14 What is the effect of a dielectric on the electrostatic force?

Effect

The presence of a dielectric always reduces the electrostatic force as compared with that in free space, by a certain factor which is constant for the given dielectric.

SQ 9.1.15 Define relative permittivity.

Definition

The constant factor by which a dielectric reduces the electrostatic force is known as relative permittivity, represented by ε_r.

SQ 9.1.16 Write Coulomb's force in a medium of relative permittivity.

Formula

$F_m = \frac{1}{4\pi\varepsilon_0\varepsilon_r}\frac{q_1 q_2}{r^2}$

SQ 9.1.17 Why can Coulomb's law in free space be used for air?

Reason

The relative permittivity for air is 1.0006. This value is so close to one that, with negligible error, the free space equation gives the electric force in air.

SQ 9.1.18 **Write the relative permittivity of vacuum, water and mica.**

Values

Vacuum has
$\varepsilon_r = 1$
distilled water has
$\varepsilon_r = 78.5$
and mica has
$\varepsilon_r = 3$
to 7.5.

TOPIC 2 Electric Field Strength

SQ 9.2.1 **When is an electric field said to exist at a point?**

Answer

If a small charge placed at a point experiences an electrostatic force due to another charge, then an electric field is said to exist at that point.

SQ 9.2.2 **What does Coulomb's law suggest about the strength of a field?**

Answer

Coulomb's law suggests that the field gets stronger as the point gets closer to the charge producing it.

SQ 9.2.3 **Define electric field intensity.**

Definition

The electric intensity of the field at any point is defined as the force experienced by a unit positive charge placed at that point.

Formula

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

SQ 9.2.4 **Write the SI unit and direction of electric intensity.**

SI Unit

The unit of electric intensity is newton per coulomb $(\mathrm{N\,C^{-1}})$.

Direction

The direction of $\mathbf{E}$ is the same as that of $\mathbf{F}$.

SQ 9.2.5 **Write the electric intensity due to a point charge.**

Formula

$$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$$

In vector form,

$$\mathbf{E} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}\,\hat{r}.$$

SQ 9.2.6 **Write the force on a charge placed in an electric field.**

Formula

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

SQ 9.2.7 **What are electric field lines?**

Definition

Electric field lines are a visual map used to represent the direction and strength of an electric field around a charged object. The idea was proposed by Michael Faraday.

SQ 9.2.8 **Why are electric field lines called lines of force?**

Answer

As electric field lines provide information about the electric force exerted on a charged object, these lines are commonly called electric lines of force.

SQ 9.2.9 **What is the direction of field lines around a positive charge?**

Answer

A positive test charge experiences a repulsive force, so the electric field created by a positive charge is directed radially outward.

SQ 9.2.10 **What is the direction of field lines around a negative charge?**

Answer

The lines are directed radially inward, because the force on a positive test charge is now of attraction.

SQ 9.2.11 **How do field lines indicate the strength of the field?**

Answer

The number of lines per unit area passing perpendicularly through it is proportional to the magnitude of the electric field. Lines are closer near the charges where the field is strong.

SQ 9.2.12 **What is observed in the field pattern of two identical positive charges?**

Answer

The lines in the region between two like charges seem to repel each other, and the middle region shows the presence of a zero field spot or neutral zone.

SQ 9.2.13 **What is observed in the field pattern of two opposite charges?**

Answer

The field lines start from the positive charge and end on the negative charge. The electric field at any point is the resultant of the fields created by the two charges.

SQ 9.2.14 **When is an electric field uniform?**

Answer

In the regions where the field lines are parallel and equally spaced, the same number of lines pass per unit area, and therefore the field is uniform at all points.

Example

The field in the middle region between the plates of a parallel plate capacitor.

SQ 9.2.15 **State the four properties of electric field lines.**

Properties

Electric field lines originate from positive charges and end on negative charges.
The tangent to a field line at any point gives the direction of the electric field at that point.
The lines are closer where the field is strong and farther apart where the field is weak.
No two lines cross each other.

SQ 9.2.16 **Why do electric lines of force never cross each other?**

Reason

Because $\mathbf{E}$ has only one direction at any given point. If the lines crossed, $\mathbf{E}$ could have more than one direction at that point.

SQ 9.2.17 **Two charges 16.0 μC and 4.0 μC are 3.0 m apart. Where is the electric field zero?**

Solution

The field is zero at a point P where

$E_1 = E_2$

so

$$\frac{16}{(3.0-d)^2} = \frac{4}{d^2}.$$

Result

This gives

$d^2 + 2d - 3 = 0$

so

$d = 1.0\,\mathrm{m}$

from the smaller charge.

SQ 9.2.18 **A proton experiences an electrostatic force equal to its weight. Find the field intensity.**

Solution

Since

$qE = mg$

therefore

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

Calculation

$$E = \frac{1.67\times10^{-27}\times9.8}{1.6\times10^{-19}}$$

Result

$E = 1.02\times10^{-7}\,\mathrm{N\,C^{-1}}$

TOPIC 3 Electric Flux

SQ 9.3.1 **Define electric flux.**

Definition

The number of field lines passing through a certain element of area is known as electric flux through that area. It is denoted by ϕ_e.

SQ 9.3.2 **How is the element of area represented?**

Answer

The element of area is represented by a vector area $\mathbf{A}$ whose magnitude is equal to the surface area of the element and whose direction is along the normal to the area.

SQ 9.3.3 **Write the flux when the area is held perpendicular to the field lines.**

Answer

When the area is perpendicular to the field lines, the flux is maximum.

Formula

$\phi_e = EA$

SQ 9.3.4 **Write the flux when the area is held parallel to the field lines.**

Answer

When the area is parallel to the field lines no lines cross it, so the flux is minimum.

Formula

$\phi_e = 0$

SQ 9.3.5 **Write the general expression for electric flux.**

Formula

$\phi_e = EA\cos\theta = \mathbf{E}\cdot\mathbf{A}$

Here θ is the angle between the field lines and the normal to the area.

SQ 9.3.6 **Why is electric flux a scalar quantity? Write its unit.**

Answer

Electric flux is a scalar product, so it is a scalar quantity.

SI Unit

Its SI unit is $\mathrm{N\,m^2C^{-1}}$.

SQ 9.3.7 **Derive the electric flux through a closed sphere enclosing a charge.**

Derivation

The surface is divided into n small patches, and since $\mathbf{E}$ is parallel to each vector area,

$\theta = 0^\circ$

The total flux is E multiplied by the total spherical surface area $4\pi r^2$, with

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$$

Result

$$\phi_e = \frac{q}{\varepsilon_0}$$

SQ 9.3.8 **Does the flux through a closed surface depend on its shape?**

Answer

No. The total flux through a closed surface does not depend upon the shape or geometry of the closed surface. It depends only upon the medium and the charge enclosed.

TOPIC 4 Gauss's Law

SQ 9.4.1 **State Gauss's law.**

Statement

The total electric flux through any closed surface is $\dfrac{1}{\varepsilon_0}$ times the total charge enclosed in it.

Formula

$$\phi_e = \frac{1}{\varepsilon_0}Q$$

SQ 9.4.2 **What is a Gaussian surface?**

Definition

An imaginary closed surface which passes through the point at which the electric intensity is to be evaluated is known as a Gaussian surface. Its choice is such that the flux through it can be easily evaluated.

SQ 9.4.3 **Where does the charge reside on a conducting sphere?**

Answer
All the charge is distributed uniformly over the surface of the sphere.

SQ 9.4.4 **Why is the field of a charged sphere radial?**

Reason
From the spherical symmetry we conclude that the electric field is radial everywhere, and its magnitude depends only on the distance r from the centre of the sphere.

SQ 9.4.5 **Derive the field outside a charged conducting sphere.**

Derivation
Taking a Gaussian sphere of radius $r > R$, the total flux is $E \times 4\pi r^2$. By Gauss's law this equals $\dfrac{q}{\varepsilon_0}$.

Result
$E = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{r^2}$

SQ 9.4.6 **What does the field outside a charged sphere show?**

Answer
The field at any point outside the sphere is the same as though the entire charge were concentrated at its centre.

SQ 9.4.7 **Write the field just outside a charged conducting sphere.**

Formula
$E = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{R^2}$
Here R is the radius of the sphere.

TOPIC 5 Electric Potential

SQ 9.5.1 **What happens to a positive charge moved against an electric field?**

Answer
An external force is needed to make the charge move against the electric field, and the charge will gain potential energy.

SQ 9.5.2 **What condition of electrostatic equilibrium is imposed while moving a charge?**

Condition
The charge is moved keeping electrostatic equilibrium, that is it moves with uniform velocity. This is achieved by applying a force equal and opposite to $q\mathbf{E}$ at every point along its path.

SQ 9.5.3 **Write the change in potential energy of a charge moved in a field.**

Formula
$\Delta U = U_B - U_A = W_{AB}$

SQ 9.5.4 **Define electric potential difference.**

Definition
The potential difference between two points A and B in an electric field is the work done in carrying a unit positive charge from A to B while keeping the charges in equilibrium.

Formula
$\Delta V = V_B - V_A = \dfrac{W_{AB}}{q}$

SQ 9.5.5 **Write the relation between potential energy difference and potential difference.**

Formula
$\Delta U = q\,\Delta V$
Thus the potential difference is the difference of the potential energy per unit charge.

SQ 9.5.6 **Define the volt.**

Definition
A potential difference of 1 volt exists between two points if the work done in moving a 1 coulomb positive charge from one point to the other, keeping electrostatic equilibrium, is one joule.

Formula
$1\,\mathrm{V} = 1\,\mathrm{J\,C^{-1}}$

SQ 9.5.7 **Where is the reference of zero electric potential taken?**

Answer
The reference point at which zero electric potential is assigned is usually taken at infinity.

SQ 9.5.8 **Define electric potential at a point.**

Definition
The electric potential at any point in an electric field is equal to the work done in bringing a unit positive charge from infinity to that point, keeping it in electrostatic equilibrium.

Formula
$V = \dfrac{W}{q}$

SQ 9.5.9 **Why are potential and potential difference scalar quantities?**

Reason
Both are scalar quantities because both the work W and the charge q are scalars.

SQ 9.5.10 **Define potential gradient.**

Definition
The quantity $\dfrac{\Delta V}{\Delta d}$ gives the maximum value of the rate of change of potential with distance, and it is known as potential gradient.

SQ 9.5.11 **Write the relation between electric intensity and potential gradient.**

Formula
$E = -\dfrac{\Delta V}{\Delta d}$
Thus the electric field intensity is equal to the negative of the gradient of electric potential.

SQ 9.5.12 **What does the negative sign in E = −ΔV/Δd indicate?**

Answer
The negative sign indicates that the direction of $\mathbf{E}$ is along the decreasing potential.

SQ 9.5.13 **Show that V m⁻¹ is equal to N C⁻¹.**

Proof

$$1\,\frac{\mathrm{V}}{\mathrm{m}} = 1\,\frac{\mathrm{J\,C^{-1}}}{\mathrm{m}} = 1\,\frac{\mathrm{N\,m}}{\mathrm{m\,C}} = 1\,\mathrm{N\,C^{-1}}$$

SQ 9.5.14 **Two plates 1.0 cm apart are connected to a 12 V battery. Find the field intensity between them.**

Solution

Using

$$E = \frac{\Delta V}{\Delta d}$$

Calculation

$$E = \frac{12}{1\times 10^{-2}}$$

Result

$$E = 1200\,\mathrm{V\,m^{-1}}$$

SQ 9.5.15 **An electron is released from the negative plate of a 12 V pair of plates. Find its final velocity.**

Solution

The loss in potential energy equals the gain in kinetic energy, so

$$qV = \frac{1}{2}mv^2.$$

Calculation

$$12\times 1.6\times 10^{-19} = \frac{1}{2}\times 9.1\times 10^{-31}\times v^2$$

Result

$$v = 2.1\times 10^{6}\,\mathrm{m\,s^{-1}}$$

TOPIC 6 Electron Volt

SQ 9.6.1 **Define the electron volt.**

Definition

The electron volt is defined as the amount of energy acquired or lost by an electron as it traverses a potential difference of one volt.

SQ 9.6.2 **Write the value of one electron volt in joules.**

Value

$$1\,\mathrm{eV} = 1.6\times 10^{-19}\,\mathrm{J}$$

SQ 9.6.3 **Write the change in potential energy of a charge moved through a potential difference.**

Formula

$$\Delta U = q(V_B - V_A) = q\,\Delta V$$

SQ 9.6.4 **What happens to the change in P.E. if no external force acts on the charge?**

Answer

If no external force acts on the charge to maintain equilibrium, this change in potential energy appears in the form of a change in kinetic energy.

SQ 9.6.5 **A particle carrying a charge of 2e falls through 3.0 V. Find the energy acquired.**

Solution

$$\Delta U = q\,\Delta V = (2e)(3.0\,\mathrm{V})$$

Result

$$\Delta U = 6.0\,\mathrm{eV} = 9.6\times 10^{-19}\,\mathrm{J}$$

TOPIC 7 Motion of Charged Particles in a Uniform Electric Field

SQ 9.7.1 **How is a uniform electric field produced?**

Answer

Two oppositely charged parallel metal plates produce a uniform electric field between them. The direction of the field is from the positive to the negative plate.

SQ 9.7.2 **In which direction do positive and negative charges move in a uniform field?**

Answer

A positive charge placed in the field moves in the direction of the electric field, whereas a negative charge moves opposite to the electric field.

SQ 9.7.3 **Write the force on a charge in a uniform field between two plates.**

Formula

$$F = qE \qquad \text{where} \qquad E = \frac{V}{d}$$

Here V is the potential difference and d is the separation of the plates.

SQ 9.7.4 **For V = 20 V and d = 2.0 cm, find the electric intensity.**

Solution

$$E = \frac{V}{d} = \frac{20}{2\times 10^{-2}}$$

Result

$$E = 1000\,\mathrm{V\,m^{-1}}$$

SQ 9.7.5 **Find the acceleration of an electron in a field of 1000 V m⁻¹.**

Solution

Since

$$a = \frac{qE}{m}$$

Calculation

$$a = \frac{1.6\times 10^{-19}\times 1000}{9.1\times 10^{-31}}$$

Result

$$a = 1.76\times 10^{14}\,\mathrm{m\,s^{-2}}$$

SQ 9.7.6 **An electron with a = 1.76 × 10¹⁴ m s⁻² crosses plates 2 cm apart. Find its final velocity.**

Solution

Using

$$2aS = v_f^2 - v_i^2$$

with

$$v_i = 0$$

Calculation

$$v_f^2 = 2\times 1.76\times 10^{14}\times 2\times 10^{-2}$$

Result

$$v_f = 2.65\times 10^{6}\,\mathrm{m\,s^{-1}}$$

TOPIC 8 Path of a Charged Particle

SQ 9.8.1 By what is the path of a charged particle determined?

Answer

The path of a charged particle is determined by the electric field in the region.

SQ 9.8.2 When is the path of a charged particle straight?

Answer

The path is typically straight if the field is uniform and the charged particle is moving along the field.

SQ 9.8.3 What is the path of a charged particle entering perpendicular to a uniform field?

Answer

Its path will be parabolic, just like a projectile thrown horizontally in the gravitational field.

SQ 9.8.4 Why is the path of such a charged particle parabolic?

Reason

The horizontal component of the velocity remains constant, whereas the vertical component is accelerated due to the electric force.

SQ 9.8.5 In which direction is a positively charged particle deflected between the plates?

Answer

A positively charged particle is attracted towards the negatively charged plate and thus undergoes deflection in that direction.

SQ 9.8.6 In which direction is a negatively charged particle deflected between the plates?

Answer

A negatively charged particle is attracted towards the positively charged plate and experiences deflection in that direction.

TOPIC 9 Shielding from External Electric Field

SQ 9.9.1 What is a Faraday cage?

Definition

A Faraday cage or Faraday shield, invented by Michael Faraday in 1836, is an enclosure that blocks external electric fields in conductive materials.

SQ 9.9.2 How does a Faraday cage protect objects inside it?

Answer

It acts like a hollow conductor in which devices or objects can be placed for protection. Any electrical shock received by the cage runs through its outer surface without causing harm inside, and the field inside remains zero.

SQ 9.9.3 Why does excess charge reside on the surface of a conductor?

Reason

Each free electron experiences a force of repulsion because of the electric field of its neighbouring electrons. As a consequence, all the electrons rush to the surface of the conductor.

Statement

At equilibrium under electrostatic conditions, any excess charge resides on the surface of a conductor.

SQ 9.9.4 How do the excess charges make the interior field zero?

Answer

The excess charges arrange themselves on the conductor's surface precisely in the manner that the total field within the interior becomes zero.

SQ 9.9.5 Why is the electric field just outside a conductor perpendicular to its surface?

Reason

If the field were not perpendicular there would be a component parallel to the surface, and the free electrons would move under it. But no electron flow occurs at equilibrium, so there can be no parallel component.

SQ 9.9.6 Which materials can be used to construct a Faraday cage?

Answer

Only conductors can be used, because the principle demands a material containing many free electrons that can move freely to the surface. Insulators do not contain free electrons.

SQ 9.9.7 How does a car act as a Faraday cage?

Answer

The chassis and bodies of cars protect the people inside due to their metal framed structure during thunderstorms. The electrical charge travels over the metal surface of the vehicle into the ground.

SQ 9.9.8 How do a microwave oven and an airplane act as Faraday cages?

Microwave Oven

Its metal body prevents the microwaves from expanding into the environment.

Airplane

When lightning strikes, electricity is distributed along the metal frame surface, keeping passengers and devices safe.

TOPIC 10 Electric Current

SQ 9.10.1 What are the charge carriers in a conductor?

Answer

The charge carriers in a conductor are the free electrons.

SQ 9.10.2 **What happens when the ends of a conductor are connected to a battery?**

Answer
An electric field is set up at every point within the conductor. The free electrons experience a force in the direction of $-\mathbf{E}$ and they start moving.

SQ 9.10.3 **Why are free electrons not accelerated in a straight line?**

Reason
The free electrons keep bumping among the atoms of the conductor. The overall effect of these collisions is to transfer the energy of the accelerated electrons to the lattice.

SQ 9.10.4 **Define drift velocity and give its order of magnitude.**

Definition
As a result of collisions the electrons acquire an average velocity, called the drift velocity, in the direction of $-\mathbf{E}$.
Value
The drift velocity is of the order of $10^{-3}\,\mathrm{m\,s^{-1}}$.

SQ 9.10.5 **Why does a bulb light up immediately despite the slow drift velocity?**

Reason
On turning the switch on, all the free electrons in the circuit start drifting at once. They repel the neighbouring ones and the disturbance propagates along the wire almost instantaneously.

SQ 9.10.6 **Define electric current and write its unit.**

Formula
$I = \frac{Q}{t}$
SI Unit
The SI unit of current is the ampere, which is the current due to the flow of one coulomb of charge per second through any cross-section of a conductor.

SQ 9.10.7 **Define direct current and alternating current.**

Direct Current
If the charges move around a circuit in the same direction at all times, the current is direct current. Batteries produce direct current.
Alternating Current
If the charges move first one way and then the opposite way, changing direction at regular intervals, the current is alternating current.

SQ 9.10.8 **Which type of current is supplied by power stations?**

Answer
Mostly electric generators produce alternating current, and the electricity supplied to homes, offices and factories by power stations is A.C.

SQ 9.10.9 **Define conventional current.**

Definition
Conventional current is the hypothetical flow of positive charges that would have the same effect in the circuit as the flow of negative charges that actually occurs.

SQ 9.10.10 **What is the direction of conventional current?**

Answer
The conventional current flows from the positive terminal towards the negative terminal of a battery, that is from a point of higher potential towards a point of lower potential.

TOPIC 11 Current Through a Conductor

SQ 9.11.1 **Write the total charge in a segment of a current carrying conductor.**

Derivation
If n is the number of charge carriers per unit volume, the total number in a segment of volume AL is nAL.
Formula
$Q = nALq$

SQ 9.11.2 **Derive the expression for current in terms of drift velocity.**

Derivation
The time taken by the carriers to cross the segment is
$t = \frac{L}{v}$
and
$I = \frac{Q}{t}$
Result
$I = nAvq$

SQ 9.11.3 **A copper wire of area 2×10^{-6} m² carries 3 A with n = 8.5×10^{28} m⁻³. Find the drift velocity.**

Solution
Using
$I = nAvq$
Calculation
$3 = (2 \times 10^{-6})(8.5 \times 10^{28})v(1.6 \times 10^{-19})$
Result
$v = 1.1 \times 10^{-4}\,\mathrm{m\,s^{-1}}$

TOPIC 12 Ohm's Law

SQ 9.12.1 **State Ohm's law.**

Statement
The current flowing through a conductor is directly proportional to the potential difference applied across the conductor, provided there is no change in the physical state of the conductor.
Formula
$V = IR$

SQ 9.12.2 **Define resistance and write its SI unit.**

Definition
R is the constant of proportionality in Ohm's law and is known as the resistance of the conductor.

SI Unit

The SI unit of resistance is the ohm, denoted by Ω.

SQ 9.12.3 **Define one ohm.**

Definition

The resistance of a conductor is 1 ohm if a current of 1 ampere flows through it when a potential difference of 1 volt is applied across its ends.

TOPIC 13 Resistivity and Its Dependence upon Temperature

SQ 9.13.1 **On what does the resistance of a wire depend?**

Answer

The resistance R of a wire is directly proportional to its length ℓ and inversely proportional to its cross-sectional area A.

Formula

$$R = \rho \frac{\ell}{A}$$

SQ 9.13.2 **Define resistivity and write its SI unit.**

Definition

Resistivity or specific resistance is the resistance of a metre cube of a material.

Formula

$$\rho = \frac{RA}{\ell}$$

SI Unit

Its SI unit is ohm-metre $(\Omega\,\mathrm{m})$.

SQ 9.13.3 **Differentiate between resistance and resistivity.**

Resistance	Resistivity
It is the characteristic of a particular wire.	It is the property of the material of which the wire is made.
It depends on length and area of cross-section.	It does not depend on length and area.
Its unit is Ω.	Its unit is $\Omega\,\mathrm{m}$.

SQ 9.13.4 **Define conductance and conductivity.**

Conductance

Conductance is the reciprocal of resistance,

$$G = \frac{1}{R}$$

Conductivity

Conductivity is the reciprocal of resistivity,

$$\sigma = \frac{1}{\rho}$$

and its SI unit is $\Omega^{-1}\mathrm{m}^{-1}$.

SQ 9.13.5 **Which are the two best conducting materials?**

Answer

Silver and copper are the two best conductors. That is the reason most electric wires are made of copper.

SQ 9.13.6 **Why does the resistance of a conductor increase with temperature?**

Reason

As the temperature rises, the amplitude of vibration of the atoms in the lattice increases, so the collision cross-section of the atoms increases.

Result

This makes the collisions between free electrons and atoms more frequent, hence the resistance increases.

SQ 9.13.7 **Define temperature coefficient of resistance.**

Definition

Over a considerable range of temperature, the fractional change in resistance per kelvin is known as the temperature coefficient of resistance.

Formula

$$\alpha = \frac{R_t - R_0}{R_0\, t}$$

SQ 9.13.8 **Write the temperature coefficient in terms of resistivity.**

Formula

$$\alpha = \frac{\rho_t - \rho_0}{\rho_0\, t}$$

Here ρ_0 is the resistivity at $0\,^\circ\mathrm{C}$ and ρ_t is the resistivity at $t\,^\circ\mathrm{C}$.

SQ 9.13.9 **Which substances have negative temperature coefficients?**

Answer

There are some substances like germanium and silicon whose resistance decreases with an increase in temperature. These substances have negative temperature coefficients.

SQ 9.13.10 **A 5.0 m iron wire of area 2.5×10^{-7} m² carries 0.75 A at 1.5 V. Find its resistance.**

Solution

$$R = \frac{V}{I} = \frac{1.5}{0.75}$$

Result

$$R = 2.0\,\Omega$$

SQ 9.13.11 **For the above iron wire, compute the resistivity of iron.**

Solution

$$\rho = \frac{RA}{\ell} = \frac{2.0 \times 2.5 \times 10^{-7}}{5.0}$$

Result

$$\rho = 1.0 \times 10^{-7}\,\Omega\,\mathrm{m}$$

SQ 9.13.12 **A platinum wire has 10 Ω at 0 °C and 20 Ω at 193 °C. Find its temperature coefficient.**

Solution

$$\alpha = \frac{R_t - R_0}{R_0\, t} = \frac{20 - 10}{10 \times 193}$$

Result

$$\alpha = 5.2 \times 10^{-3}\,\mathrm{K}^{-1}$$

TOPIC 14 Electrical Power

SQ 9.14.1 **Write the work done by a battery in moving a charge.**

Formula
$W = V \times Q$
This is the energy supplied by the battery.

SQ 9.14.2 **Define electrical power of a battery.**

Definition
The rate at which the battery supplies electrical energy is the power output or electrical power of the battery.
Formula
$P = \frac{\text{Energy supplied}}{\text{Time taken}} = VI$

SQ 9.14.3 **Write the three equations for power dissipated in a resistor.**

Formulas
$P = VI$
$P = I^2R$
$P = \frac{V^2}{R}$

SQ 9.14.4 **In which units is electrical power expressed?**

Answer
If V is expressed in volts and I in amperes, then the power is expressed in watts.

SQ 9.14.5 **Which principle tells us the power dissipated equals the power supplied?**

Answer
The principle of conservation of energy tells us that the power dissipated in the resistor is also given by
$P = VI$

TOPIC 15 Electromotive Force and Potential Difference

SQ 9.15.1 **Define electromotive force.**

Definition
The emf of a source is defined as the energy supplied to unit charge by the cell.
Formula
$E = \frac{W}{q}$

SQ 9.15.2 **Is emf really a force? Write its unit.**

Answer
Electromotive force is not a force and we do not measure it in newtons.
Unit
The unit of emf is joule per coulomb, which is the volt.

SQ 9.15.3 **From where is the energy supplied by a cell derived?**

Answer
The energy supplied by the cell to the charge carriers is derived from the conversion of chemical energy into electrical energy inside the cell.

SQ 9.15.4 **What is the internal resistance of a cell?**

Definition
The resistance of a cell due to the electrolyte present between its two electrodes is called the internal resistance of the cell.

SQ 9.15.5 **To what is a cell of emf E with internal resistance equivalent?**

Answer
A cell of emf E having an internal resistance r is equivalent to a source of pure emf E with a resistance r in series.

SQ 9.15.6 **Write the relation between emf, terminal voltage and internal resistance.**

Formula
$E = IR + Ir$
Here IR is the terminal potential difference of the cell in the presence of current I.

SQ 9.15.7 **What does a voltmeter read when the switch is open?**

Answer
When the switch is open, no current passes through the resistance, so the voltmeter reads the emf as terminal voltage.

SQ 9.15.8 **Why is terminal voltage less than emf when current flows?**

Reason
A part of the energy equal to Ir is dissipated inside the cell, so the terminal voltage in the presence of current is less than the emf by Ir.

SQ 9.15.9 **Differentiate between emf and potential difference.**

EMF	Potential Difference
It is the energy supplied to unit charge by the cell.	It is the energy dissipated per unit charge in a circuit element.
It is the cause.	It is the effect.
It is always present even when no current is drawn.	It is zero when no current flows through the conductor.

SQ 9.15.10 **A battery of emf 2.2 V falls to 1.8 V across 5.0 Ω. Find the current.**

Solution
$I = \frac{V}{R} = \frac{1.8}{5.0}$
Result
$I = 0.36\,\text{A}$

SQ 9.15.11 **For the above battery, find its internal resistance.**

Solution
Using
$E = V + Ir$
Calculation
$2.2 = 1.8 + 0.36\,r$
Result
$r = 1.1\,\Omega$

TOPIC 16 Kirchhoff's Rules

SQ 9.16.1 **Why are Kirchhoff's rules needed?**

Answer

Kirchhoff's rules are two fundamental principles that help determine the current and voltage in electrical circuits. They are particularly useful for analysing complex circuits that cannot be simplified by Ohm's law and series or parallel combinations.

SQ 9.16.2 **State Kirchhoff's first rule.**

Statement

The sum of all the currents meeting at a point in a circuit is zero.

Formula

$\sum I = 0$

SQ 9.16.3 **What is the sign convention in Kirchhoff's first rule?**

Convention

A current flowing towards a point is taken as positive, and that flowing away from a point is taken as negative.

SQ 9.16.4 **State Kirchhoff's first rule in another form.**

Statement

The sum of all the currents flowing towards a point is equal to the sum of all the currents flowing away from the point.

SQ 9.16.5 **Of which conservation law is Kirchhoff's first rule a manifestation?**

Answer

Kirchhoff's first rule, also known as the point rule, is a manifestation of the law of conservation of charge.

SQ 9.16.6 **What is a node in an electric circuit?**

Definition

A node is a point in an electric circuit where two or more elements meet.

SQ 9.16.7 **State Kirchhoff's second rule.**

Statement

The algebraic sum of voltage changes in a closed circuit or loop must be equal to zero, that is the algebraic sum of potential changes in a closed circuit is zero.

SQ 9.16.8 **Of which conservation law is Kirchhoff's second rule a statement?**

Answer

This rule is simply a particular way of stating the law of conservation of energy.

SQ 9.16.9 **What is the sign of potential change across a source of emf?**

Rule

If a source of emf is traversed from positive to negative terminal, the potential change is positive. It is negative in the opposite direction.

SQ 9.16.10 **What is the sign of potential change across a resistor?**

Rule

If a resistor is traversed in the direction of the current, the change in potential is positive. It is negative in the opposite direction.

SQ 9.16.11 **How should loops be selected while applying Kirchhoff's rules?**

Answer

The choice of loops is quite arbitrary, but it should be such that each resistance is included at least once in the selected loops.

SQ 9.16.12 **What are loop currents and how are their senses chosen?**

Answer

The currents assumed to flow in each selected loop are called loop currents. The sense of the current flowing in all loops should essentially be the same, either clockwise or anticlockwise.

TOPIC 17 Wheatstone Bridge

SQ 9.17.1 **Describe the Wheatstone bridge circuit.**

Description

It consists of four resistances connected so as to form a mesh $ABCDA$. A battery is connected between points A and C, and a sensitive galvanometer is connected between points B and D.

SQ 9.17.2 **Write the balance condition of the Wheatstone bridge.**

Condition

The current through the galvanometer is zero when the loop currents are equal.

Formula

$\frac{R_1}{R_2} = \frac{R_3}{R_4}$

SQ 9.17.3 **What is observed when the Wheatstone bridge is balanced?**

Answer

When the balance condition is satisfied, no current flows through the galvanometer and it shows no deflection.

SQ 9.17.4 **How is an unknown resistance found using a Wheatstone bridge?**

Method

Three resistances of known adjustable values and a fourth of unknown value are connected. The known resistances are adjusted until the galvanometer shows no deflection.

Result

The unknown resistance is then found from the balance condition.

TOPIC 18 Potentiometer

SQ 9.18.1 **What is a potentiometer used for?**

Answer
A potentiometer is mainly used to compare potential differences and to find the value of an unknown resistance. It works on the principle of the Wheatstone bridge.

SQ 9.18.2 **Why must a voltmeter have a large resistance?**

Reason
If the resistance of the voltmeter were not large compared to the circuit resistance, an appreciable current would flow through it, which would alter the circuit current and the potential difference to be measured.

SQ 9.18.3 **What would be the resistance of an ideal voltmeter?**

Answer
An ideal voltmeter would have an infinite resistance, so it would draw no current from the circuit.

SQ 9.18.4 **Name two accurate but expensive potential measuring instruments.**

Answer
The digital voltmeter and the cathode-ray oscilloscope practically do not draw any current from the circuit because of their large resistance, but these instruments are very expensive.

SQ 9.18.5 **Describe the construction of a potentiometer.**

Construction
A potentiometer consists of a resistor R in the form of a wire on which a terminal C can slide. The resistance between A and C can be varied from 0 to R as the sliding contact is moved.

SQ 9.18.6 **What is a potential divider?**

Definition
When a battery of emf E is connected across R, the potential drop between A and C changes from 0 to E as C is moved. Such an arrangement is known as a potential divider.

SQ 9.18.7 **How is an unknown emf measured with a potentiometer?**

Method
The cell of unknown emf is connected between A and the sliding contact C through a galvanometer, with both positive terminals connected to the same point A.
The position of C is adjusted until the galvanometer shows no deflection.

SQ 9.18.8 **Write the formula for the unknown emf in terms of length.**

Formula
$$E_x = \frac{r}{R}E = \frac{\ell}{L}E$$
Here L is the total length of the wire and ℓ is its length from A to C at balance.

SQ 9.18.9 **Why must the unknown emf not exceed the emf of the potential divider?**

Reason
As the maximum potential that can be obtained between A and C is E, the unknown emf should not exceed this value, otherwise the null condition will not be obtained.

SQ 9.18.10 **Why is the potentiometer one of the most accurate methods?**

Reason
The unknown emf is determined when no current is drawn from it, so there is no loss of potential due to internal resistance.

SQ 9.18.11 **How are the emfs of two cells compared with a potentiometer?**

Method
The balancing lengths ℓ_1 and ℓ_2 are found separately for the two cells.

Formula
$$\frac{E_1}{E_2} = \frac{\ell_1}{\ell_2}$$
Thus the ratio of the emfs is equal to the ratio of the balancing lengths.

TOPIC 19 Use of a Galvanometer

SQ 9.19.1 **What is a galvanometer?**

Definition
A galvanometer is an instrument for detecting a current. It is often used in null methods to achieve precise measurements in electrical circuits.

SQ 9.19.2 **What is the null method?**

Definition
The null method involves adjusting the circuit until the galvanometer shows no deflection, that is a zero reading. This indicates that certain required conditions are met in the circuit.

SQ 9.19.3 **Why does the galvanometer's own resistance not matter at the null reading?**

Reason
At the null reading no current is passing through the galvanometer, so although it has its own resistance, that resistance does not come into play.

SQ 9.19.4 **How is the null method used in a Wheatstone bridge?**

Method
The galvanometer is connected between the mid-points of opposite sides, and the variable resistance is adjusted until the galvanometer shows no deflection.

Result
At this point the bridge is balanced and the unknown resistance can be calculated from the ratio of the known resistances.

SQ 9.19.5 How is the null method used in a potentiometer?

Method

An unknown voltage is measured by comparison with a known reference voltage applied across the resistance wire. A galvanometer and a jockey are used to make contact along the wire.

Result

At the null point, the position of the jockey gives the measure of the unknown voltage.

SQ 9.19.6 Give the three advantages of using a galvanometer in the null method.

Advantages

The null method eliminates the effect of the galvanometer's internal resistance, resulting in more accurate readings.
Galvanometers are highly sensitive and can detect very small currents of the order of 10^{-6} A.
No deflection indicates a direct and clear condition of balance, making it easier to identify the null point.

TOPIC 20 Thermistors

SQ 9.20.1 What is a thermistor?

Definition

A thermistor is a heat sensitive resistor.

SQ 9.20.2 What type of temperature coefficient do most thermistors have?

Answer

Most thermistors have a negative temperature coefficient of resistance, that is their resistance decreases when their temperature is increased. Thermistors with positive temperature coefficient are also available.

SQ 9.20.3 In what forms are thermistors available?

Answer

Thermistors may be in the form of beads, rods or washers.

SQ 9.20.4 How are thermistors used for temperature measurement?

Answer

Thermistors are used in thermometers and in electric devices such as air conditioners, refrigerators, heaters, microwave ovens and incubators, to monitor temperature.

SQ 9.20.5 Why are thermistors accurate at low temperatures?

Reason

Thermistors with a high negative temperature coefficient are very accurate for measuring low temperatures, especially near 10 K, because the higher resistance at low temperature enables more accurate measurement.

SQ 9.20.6 How are thermistors used as temperature sensors?

Answer

Thermistors convert changes of temperature into electrical voltage which is duly processed. For example, they are used in coolant temperature sensors in automobile engines to prevent overheating, and in digital thermometers.

SQ 9.20.7 Where are thermistors used for temperature compensation?

Answer

Thermistors are used in circuits where temperature changes could affect performance, such as in oscillators, battery charging circuits and power systems.

SQ 9.20.8 What is inrush current limiting?

Answer

Thermistors are used to limit the initial flow of current when a device is first turned on.

SQ 9.20.9 How is a thermistor used as a voltage divider in a fire alarm?

Working

When the temperature of the thermistor increases, its resistance decreases, so the voltage drop across it decreases and the potential at the mid-point increases.

Result

In a fire alarm this turns the NOT gate low; the output of the NOT gate goes high and turns the siren on.

TOPIC 21 Light Dependent Resistor

SQ 9.21.1 What is a light dependent resistor?

Definition

A light dependent resistor is a resistor whose resistance decreases with increasing light intensity. Due to this property it is also known as a photo resistor.

SQ 9.21.2 Of what material is an LDR made?

Answer

LDRs are typically made from a semiconductor material like cadmium sulphide, which is deposited in a special pattern on an insulating plate.

SQ 9.21.3 State the working principle of an LDR.

Principle

The principle used in an LDR is the increase in the conductivity of the material on exposing it to light.

SQ 9.21.4 Why does an LDR have high resistance in darkness?

Reason

In darkness the semiconductor material has only a few free electrons, that is few charge carriers, resulting in high resistance.

SQ 9.21.5 Why does the resistance of an LDR decrease in light?

Reason

When light photons hit the material, they transfer energy to electrons in the outer orbits, making them free to conduct electricity. The amount of light determines the number of free electrons.

SQ 9.21.6 How are LDRs used as light sensors?

Answer

LDRs are commonly used in light sensing circuits such as automatic lighting systems in homes and street lights. An LDR works just like a switch that turns on at dusk and off at dawn.

SQ 9.21.7 How are LDRs used in camera exposure control?

Answer

LDRs help in adjusting the exposure time in cameras based on the amount of available light.

SQ 9.21.8 Explain the use of an LDR as a voltage divider.

Working

In the dark the LDR has a very high resistance compared with the standard resistance, so the voltage drop across it is very large.

Result

When exposed to light its resistance falls, so the voltmeter registers a lower reading. By connecting the mid-point to a NOT gate, the LDR can be used as a switch.