

Chapter # 09

Electrostatics and Current Electricity

STUDENT'S LEARNING OUTCOMES (SLO's)

After studying this unit, the students will be able to:

- Define and calculate electric field strength.
[Use $F = qE$ for the force on a charge in an electric field. Use $E = \frac{\Delta V}{\Delta d}$ to calculate the field strength of the uniform field between charged parallel plates]
- Describe the effect of a uniform electric field on the motion of charged particles.
- State that, for a point outside a spherical conductor, the charge on the sphere may be considered to be a point charge at its centre.
- Explain how a Faraday cage works.
[by inducing internal electric fields that work to shield the inside from the influence of external electric fields]
- State and apply Coulomb's law.
 $F = k \frac{q_1 q_2}{r^2}$ for the force between two point charges in free space, [where $k = \frac{1}{4\pi \epsilon_0}$]
Use for the electric field strength due to a point charge in free space.
- Use, for a current-carrying conductor, the expression $I = Anvq$, [where n is the number of charge carriers per unit volume]
- State and use $V = W/Q$.
- State and use $P = IV$, $P = I^2 R$ and $P = V^2/R$.
- State and use $R = \rho \frac{L}{A}$.
- State that the resistance of a light dependent resistor (LDR) decreases as the light intensity increases.
- State Kirchhoff's first law and describe that it is a consequence of conservation of charge.
- State Kirchhoff's second law and describe that it is a consequence of conservation of energy.
- Use Kirchhoff's laws to solve simple circuit problems.
- State and use the principle of the potentiometer as a means of comparing potential differences.
- Explain the use of a galvanometer in null methods.
- Explain the use of thermistors and light-dependent resistors in potential dividers.
[to provide a potential difference that is dependent on temperature and light intensity]
- Explain the internal resistance of sources and its consequences for external circuits.
- Explain how inspectors can easily check the reliability of a concrete bridge with carbon fibres as the fibres conduct electricity.

9.1 COULOMB'S LAW



1. State and explain Coulomb's law.

Ans. Coulomb's Law

Statement

The force between two-point charges is directly proportional to the product of the magnitudes of charges and inversely proportional to the square of the distance between them. Mathematically; it can be expressed as:

$$F \propto \frac{q_1 q_2}{r^2}$$

or $F = k \frac{q_1 q_2}{r^2}$ (i)

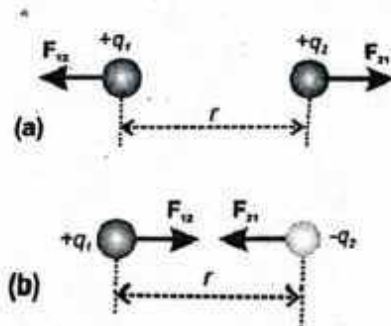


Fig. 1: (a) Repulsive forces between like charges and
(b) attractive forces between unlike charges.

where F is the magnitude of the mutual force that acts on each of the two point charges q_1 , q_2 and r is the distance between them.

Explanation:

The force F always acts along the line joining the two point charges; Fig. 1, k is the constant of proportionality. Its value depends upon the nature of medium between the two charges and system of units in which F , q and r are measured. If the medium between the two point charges is free space and the system of units is SI, then k is represented as:

$$k = \frac{1}{4\pi\epsilon_0} \quad \text{..... (ii)}$$

where ϵ_0 is an electrical constant, known as permittivity of free space. In SI units, its value is $8.85 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$. Substituting the value of ϵ_0 the constant:

$$k = \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$$

Thus, Coulomb's force in free space is:

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} \quad \text{..... (iii)}$$

As Coulomb's force is a mutual force, therefore, if q_1 exerts a force on q_2 , then q_2 also exerts an equal and opposite force on q_1 . If we denote the force exerted on q_2 by q_1 as F_{21} and that on charge q_1 due to q_2 as F_{12} , then

$$F_{12} = -F_{21} \quad \text{..... (iv)}$$

The magnitude of both these two forces is the same and is given by Eq. (iii).

To represent the direction of these forces, we introduce unit vectors. If $\hat{r}_{21}$ is the unit vector directed from q_1 to q_2 and $\hat{r}_{12}$ is the unit vector directed from q_2 to q_1 , then

$$F_{21} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} \hat{r}_{21} \quad \text{..... (v)}$$

$$F_{12} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} \hat{r}_{12} \quad \text{..... (vi)}$$

The forces F_{21} and F_{12} are shown in Fig. 2 (a) and (b). It can be seen that $\hat{r}_{21} = -\hat{r}_{12}$, so Eqs. (v) and (vi) show that;

$$F_{21} = -F_{12}$$

The sign of the charges in Eqs. (v) and (vi) determine whether the forces are attractive or repulsive.

Effect of Medium Between Two Charges

We shall now consider the effect of medium between the two charges upon the Coulomb's force. If the medium is an insulator, it is usually referred as dielectric. It has been found that the presence of a dielectric always reduces the electrostatic force as compared with that in free space by a certain factor which is a constant for the given dielectric. This constant is known as relative permittivity and is represented by ϵ_r . The

Point to ponder!

Does an electrostatic force exist between a charged and an uncharged object?

Ans. Yes, an electrostatic force can exist between a charged and an uncharged object.

- While the uncharged object has no net charge, it is made up of atoms with positive nuclei and negative electrons.
- When a charged object is brought near an uncharged object, it can cause polarization – the charges in the uncharged object rearrange slightly.
- For example, if a negatively charged object is brought near a neutral conductor, electrons in the conductor are repelled, and the side closer to the charged object becomes positively charged. This causes an induced dipole.
- As a result, there is an attractive electrostatic force between the charged object and the induced opposite charge on the uncharged object.

This effect is more noticeable if the uncharged object is a conductor, but it also occurs (to a lesser degree) in insulators, due to slight shifts in the electron clouds of molecules (called dielectric polarization).

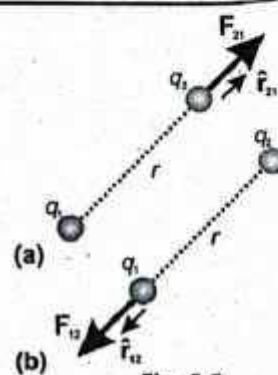


Fig. 9.2

Table 9.1

Material	ϵ_r
Vacuum	1
Air (atm)	1.0006
Ammonia (liquid)	22-25
Bakelite	5-15
Benzene	2.284
Germanium	16
Glass	4.8-10
Mica	3-7.5

values of relative permittivity of different dielectrics are given in Table 9.1. Thus, the Coulomb's force in a medium of relative permittivity ϵ_r is given by

$$F = \frac{1}{4\pi\epsilon_0\epsilon_r} \frac{q_1q_2}{r^2}$$

It can be seen in the table that ϵ_r for air is 1.0006. This value is so close to one that with negligible error, the Eq. (iii) gives the electric force in air.

Paraffined paper	2
Plexiglass	3.40
Rubber	2.94
Teflon	2.1
Transformer oil	7.1
Water (distilled)	78.5

Example 9.1: Three point charges q_1 , q_2 and q_3 are lying in the same plane as shown in the figure (a). Find the magnitude and direction of the net force acting on q_1 .

Calculations: Force on q_1 exerted by q_2 is attractive. Let it be F_{12} . Its magnitude is given by

$$F_{12} = k \frac{q_1q_2}{r_{12}^2} = \frac{(9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}) (40 \times 10^{-6} \text{ C}) (60 \times 10^{-6} \text{ C})}{(0.15 \text{ m})^2} = 960 \text{ N}$$

For on q_1 exerted by q_3 is also attractive. Let it be F_{13} . Its magnitude is given by

$$F_{13} = k \frac{q_1q_3}{r_{13}^2} = \frac{(9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}) (40 \times 10^{-6} \text{ C}) (50 \times 10^{-6} \text{ C})}{(0.12 \text{ m})^2} = 1250 \text{ N}$$

To find the resultant of F_{12} and F_{13} , let us make free-body diagram, resolving F_{13} into its rectangular components, we have

$$F_{13x} = F_{13} \cos 60^\circ = 1250 \text{ N} \times 0.5 = 625 \text{ N}$$

$$F_{13y} = F_{13} \sin 60^\circ = 1250 \text{ N} \times 0.86 = 1075 \text{ N}$$

The x-component of resultant F is

$$F_x = F_{12} + F_{13} \cos 60^\circ$$

$$F_x = 960 \text{ N} + 625 \text{ N}$$

$$F_x = 1585 \text{ N}$$

y-component of F is:

$$F_y = F_{13} \sin 60^\circ = 1075 \text{ N}$$

Magnitude of F is given by

$$F = \sqrt{F_x^2 + F_y^2} = 1975 \text{ N}$$

For direction of F :

$$\tan \theta = \frac{F_y}{F_x} = \frac{1075}{1585} = 0.68 \text{ Ans.}$$

Therefore, $\theta = 34^\circ$ with the line joining q_1 and q_2 .

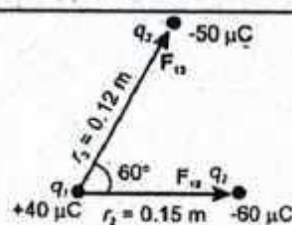


Fig. 9.3 (a)

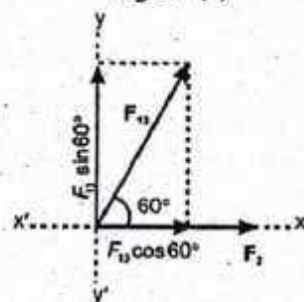


Fig. 9.3 (b)

Do you know?

A Van de Graaff generator is an electrostatic generator which uses a moving belt to accumulate electric charge on a hollow metal globe on the top of an insulated column, creating very high voltage direct current (DC) at low current levels. It was invented by an American physicist Robert J. Van de Graff in 1929.

The potential difference achieved in modern Van de Graaff generators can reach 5 megavolts. A tabletop version can produce of the order of 100,000 volts and can produce enough energy to produce a visible spark. A pulley drives an insulating belt by a sharply pointed metal comb which has been given a positive charge by a power supply. Electrons are removed from the belt, leaving it positively charged. A similar comb at the top allows the net positive charge to spread to the dome. Why do the hairs lift when VAN DE GRAAFF GENERATOR is touched?



1. The value of relative permittivity for all the dielectrics other than air or vacuum is always:

- (A) Less than unity (B) Greater than unity ✓
(C) Equal to unity (D) Zero

2. If $\vec{F}_1$ and $\vec{F}_2$ are forces acting on α -particle and electron respectively in an electric field, then:

- (A) $F_1 = F_2$ (B) $F_1 > F_2$ ✓
(C) $F_1 < F_2$ (D) $F_1 = 4F_2$

3. The constant of proportionality "k" depends upon:

- (A) Nature of medium between two charges
(B) The system of units
(C) Nature of charged bodies

- (D) Nature of medium between two charges and system of units ✓
- The value of Coulomb's constant k in SI units is:
 (A) $9 \times 10^9 \text{ Nm}^2 \text{ C}^{-2}$ ✓ (B) $9 \times 10^9 \text{ NC}^2 \text{ m}^{-2}$
 (C) $9 \times 10^9 \text{ N}^{-1} \text{ m}^2 \text{ C}^{-2}$ (D) $9 \times 10^9 \text{ Nm}^2 \text{ C}^2$
 - The force between two similar unit charges placed one metre apart in air is:
 (A) Zero (B) One newton
 (C) $9 \times 10^9 \text{ N}$ ✓ (D) $9 \times 10^{19} \text{ N}$
 - The value of ϵ_0 for free space is:
 (A) $8.85 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$ ✓
 (B) $8.88 \times 10^{-12} \text{ Nm}^2 \text{ C}^{-2}$
 (C) $8.85 \times 10^{-12} \text{ NmC}^{-2}$
 (D) $8.85 \times 10^{-12} \text{ m}^2 \text{ N}^{-1} \text{ C}^2$
 - The electrostatic force of repulsion between two electrons at a distance 1 m is:
 (A) $2.3 \times 10^{-24} \text{ N}$ (B) $2.3 \times 10^{-25} \text{ N}$
 (C) $2.3 \times 10^{-28} \text{ N}$ ✓ (D) $2.3 \times 10^{-30} \text{ N}$
 - Relative permittivity for air is:
 (A) 1.06 (B) 1.006
 (C) 1.0006 ✓ (D) 1.6
 - The electrostatic force between two charges is 42 N. If we place a dielectric of $\epsilon_r = 2.1$ between the charges, then the force becomes equal to:
 (A) 42 N (B) 83.2 N
 (C) 20 N ✓ (D) 2 N
 - Presence of dielectric always:
 (A) Increases the electrostatic force
 (B) Reduces the electrostatic force ✓
 (C) Does not affect the electrostatic force
 (D) Doubles the electrostatic force
 - The force between two point charges separated by air is 4 N. When separated by a medium of relative permittivity 3, the force between them becomes:
 (A) $\frac{1}{2} \text{ N}$ (B) 2 N
 (C) 4 N (D) 8 N ✓
 - Two charges $1 \mu\text{C}$ and $5 \mu\text{C}$ are separated by 20 cm, the ratio of electrical forces acting on them will be:
 (A) 1 : 2 (B) 1 : 5
 (C) 1 : 1 ✓ (D) 5 : 1
 - The SI unit of relative permittivity is:
 (A) $\text{C}^2 \text{ N}^{-1} \text{ m}^{-2}$ (B) $\text{C}^{-2} \text{ N}^{-1} \text{ m}^{-2}$
 (C) $\text{Nm}^{-2} \text{ C}^{-1}$ (D) None of these ✓
 - If the distance between two charged bodies is halved, the force between them becomes:
 (A) Double (B) Half
 (C) Four times ✓ (D) One-fourth
 - If both the magnitude of charge and distance between them is doubled, the coulomb's force will be:
 (A) Doubled (B) Half
 (C) Remains the same ✓ (D) One-fourth
 - Two oppositely charged balls A and B attract the third ball C, when placed near them turn by turn. The third ball C must be:
 (A) positively charged (B) negatively charged
 (C) electrically neutral ✓
 (D) positively and negatively charged
 - The force between two charges in 28 N. If paraffin wax of relative permittivity 2.8 is introduced between the charges as medium, then the force is reduced to:
 (A) 25 N (B) 20 N
 (C) 15 N (D) 10^5 N ✓
 - The study of electric charges at rest under the action of electric forces is known as:
 (A) Electromagnetism (B) Electrostatics ✓
 (C) Magnetic Induction (D) Electric field
 - The Coulomb force between two charges $q_1 = 2\text{C}$ and q_2 is 2N, the distance between charges is 3m. What is the charge of q_2 ?
 (A) $1 \times 10^9 \text{ C}$ (B) $1 \times 10^{-9} \text{ C}$ ✓
 (C) $2 \times 10^9 \text{ C}$ (D) $4 \times 10^9 \text{ C}$
 - Coulomb's law is given by the formula $F = k \frac{q_1 q_2}{r^2}$. The magnitude of k having the unit of $\text{Nm}^2 \text{ C}^{-2}$ for free space is equal to:
 (A) 9×10^7 (B) 6×10^7
 (C) 10×10^9 (D) 9×10^9 ✓
 - Electric potential due to $2\mu\text{C}$ charge at distance of one meter is equal to:
 (A) $18 \times 10^4 \text{ volt}$ (B) $1.8 \times 10^6 \text{ volt}$
 (C) $1.8 \times 10^9 \text{ volt}$ (D) $1.8 \times 10^4 \text{ volt}$ ✓
 - Electric field strength at a point between oppositely charged plates is E . If the distance between plates is reduced to half, what will be the new value of electric intensity?
 (A) $4E$ (B) $E/2$
 (C) $E/4$ (D) $2E$ ✓
 - If the potential at a point which is 1m from a charge is 1 volt, then the potential at a point which is 2m from the same charge will be:
 (A) 2v (B) 1v
 (C) 0.5v ✓ (D) 3v
 - What is the magnitude of a point charge which produces an electric field of 2 NC^{-1} at a distance of 60 cm?
 (A) $8 \times 10^{-11} \text{ C}$ ✓ (B) $2 \times 10^{-12} \text{ C}$
 (C) $3 \times 10^{-11} \text{ C}$ (D) $6 \times 10^{-10} \text{ C}$
 - There are two charges $+3 \mu\text{C}$ and $+8 \mu\text{C}$, the ratio of the force acting on them will be:
 (A) 3 : 1 (B) 1 : 1 ✓
 (C) 11 : 8 (D) 3 : 8
 - If we double the separation between two charges, then coulomb's force will become?
 (A) Doubled (B) Half
 (C) 4-times (D) $1/4^{\text{th}}$ ✓
 - The number of electrons in one coulomb charge is equal to:
 (A) 1.6×10^{-19} (B) 6.25×10^{-19}

- (C) 6.26×10^{18} ✓ (D) 6.26×10^{19}
28. The minimum charge on any object cannot be less than:
 (A) 1.6×10^{19} C (B) 9.1×10^{-31} C
 (C) 1.6×10^{-27} C (D) 1.6×10^{-19} C ✓
29. The value of charge on 1.0×10^7 electrons is:
 (A) 1.6×10^{-12} C ✓ (B) 1.6×10^{-11} C
 (C) 1.6×10^{-19} C (D) 1.6×10^{-19} C
30. The number of electrons in one coulomb charge are equal to:
 (A) 1.6×10^{-19} (B) 6.02×10^{-18}
 (C) 6.25×10^{20} (D) 6.25×10^{18} ✓

31. A particle of mass m and charge q is released from rest in a uniform electric field E . the K.E. attained by the particle after moving a distance ' d ' is:
 (A) $\frac{Ed}{q}$ (B) qE^2d
 (C) qEd ✓ (D) $\frac{qE}{d^2}$
32. Gravitational force cannot be:
 (A) Mass dependant ✓ (B) Distance dependant
 (C) Shielded (D) Stronger than electric field

9.2 ELECTRIC FIELD STRENGTH



2. What is electric field strength or electric intensity? Write its relation.

Ans. Electric Field Strength

Definition

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

Explanation

Consider a positively charged object Q . If we place a small charge $+q$ at point A , it will experience an electrostatic force F due to the charge Q . Thus, an electric field is said to exist at point A . The field gets stronger as the point A gets closer to Q . The **strength of the field** at a point is known as its **intensity** at that point.

Electric intensity is a force, so it is a vector quantity and is usually denoted by E . It can be obtained by the relation:

$$E = \frac{F}{q} \quad \dots (i)$$

As

$$F = \frac{1}{4\pi\epsilon_0} \frac{qQ}{r^2}$$

$$E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$$

In vector form: $E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2} \hat{r}$

From Eq. (i), the unit of electric intensity is newton per coulomb $N C^{-1}$. The direction of E is the same as that of F . The Eq. (i) can also be written as:

$$F = qE$$

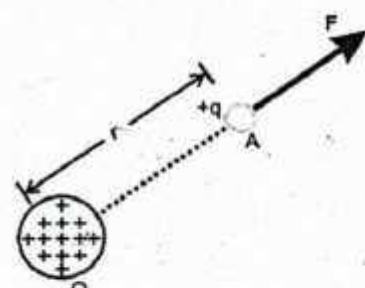


Fig. 9.4

Example 9.2: Two positive point charges $q_1 = 16.0 \mu C$ and $q_2 = 4.0 \mu C$ are separated by a distance of 3.0 m, as shown in Figure. Find the spot on the line joining the two charges where electric field is zero.

Solution:

Given that:

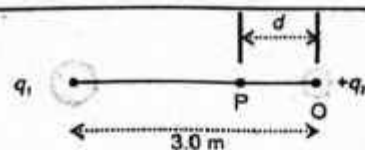
$$q_1 = 16.0 \mu C, \quad q_2 = 4.0 \mu C \quad \text{and} \quad d = 3.0 \text{ m}$$

To Find:

$$d = ?$$

Calculations: Between the two charges, the fields contributed by them have opposite directions, and electric field would be zero at a point P , where the magnitude of E_1 equals to E_2 . In Figure, let the distance of P from q_2 be d .

At P , $E_1 = E_2$ which implies that:



$$\frac{1}{4\pi\epsilon_0} \frac{q_1}{(3.0 - d)^2} = \frac{1}{4\pi\epsilon_0} \frac{q_2}{d^2}$$

or $\frac{16.0 \times 10^{-6} \text{ C}}{9.0 + d^2 - 6d} = \frac{4.0 \times 10^{-6} \text{ C}}{d^2}$ or $d^2 + 2d - 3 = 0$, which gives $d = +1 \text{ m}, -3 \text{ m}$

There are two values of d , the negative value corresponds to a location off to the right of both the charges where magnitudes of E_1 and E_2 are equal but directions are same. In this case E_1 and E_2 do not cancel at this spot. The positive value corresponds to the location shown in the figure and is the zero field location, hence, $d = +1.0 \text{ m}$.

Example 9.3: A proton experiences an electrostatic force equal to its weight at a particular point in an electric field. What is the field intensity at that point?

Mass of proton = $1.67 \times 10^{-27} \text{ kg}$ and charge, $e = 1.6 \times 10^{-19} \text{ C}$

Solution:

Given that:

$$m = 1.67 \times 10^{-27} \text{ kg} \quad \text{and} \quad e = 1.6 \times 10^{-19} \text{ C}$$

To Find:

$$E = ?$$

Calculations:

Using $E = \frac{F}{q} = \frac{mg}{e}$

Substituting the values,

$$E = \frac{1.67 \times 10^{-27} \text{ kg} \times 9.8 \text{ m s}^{-2}}{1.6 \times 10^{-19} \text{ C}} = 1.0 \times 10^{-7} \text{ N C}^{-1} \text{ Ans.}$$



3. What is electric field and electric field lines or lines of force?

Ans. Electric Field

Definition

The electric field is the region around an electric charge where its influence can be observed.

The formula for an electric field is:

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

The direction of the electric field is taken as the direction of the force which is exerted on the positive charge.

Electric Field Lines

Definition

An electric field line is an imaginary continuous line or curve drawn in an electric field such that tangent to it at any point gives the direction of the electric force at that point.

The direction of a line of force is the direction along which a small free positive charge will move along the line. It is always directed from positive charge to negative charge.



4. Describe, how electric field lines are generated or introduced.

Ans. Electric field lines are a conceptual tool used to represent the electric field visually and to understand how electric forces act in space. They are not physical entities but are introduced based on the behaviour of the electric field, which arises from electric charges. Electric field lines begin on positive charges and end on negative charges.



5. Enlist the properties or characteristics of electric field lines.

Ans. The properties of electric field lines are:

1. Electric field lines originate from positive charges and end on negative charges.
2. The tangent to a field line at any point gives the direction of the electric field at that point.
3. The lines are closer where the field is strong and the lines are farther apart where the field is weak.

4. No two lines cross each other. This is because E has only one direction at any given point. If the lines cross each other, E could have more than one direction.



6. What is the significance of electric field lines?

Ans. Significance of Electric Field Lines

Electric field lines are a visual and conceptual tool used to represent electric fields. Their significance lies in how they help us to understand the direction, strength, and behaviour of electric fields created by charged objects.

Overall, electric field lines are a crucial conceptual tool in electrostatic and help in solving problems related to electric forces and potentials.

Do you know?

There is no electric field inside the conductor.



7. What is the behaviour of electric field lines in case of:

- two identical separated charges
- two opposite charges
- parallel and equally spaced plate capacitors

Ans. (i) Behaviour of Electric Field Lines Between Two Identical Separated Charges

The electric field lines are curved in case of two identical separated charges. Figure 4 shows the pattern of lines associated with two identical positive point charges of equal magnitude. The lines in the region between two like charges seem to repel each other. The behaviour of two identical negatively charges will be exactly the same. The middle region shows the presence of a zero field spot or neutral zone.

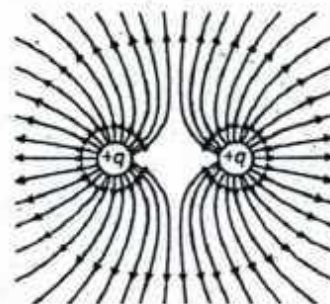


Fig. 4: The electric field lines for two identical opposite point charges.

(ii) Behaviour of Electric Field Lines Between Two Opposite Charges

Figure 5 shows the electric field pattern of two opposite charges of equal magnitudes. The field lines start from positive charge and end on a negative charge. The electric field at points such as 1, 2, 3 is the resultant of fields created by the two charges at these points. The directions of the resultant intensities is given by the tangents drawn to the field lines at these points.

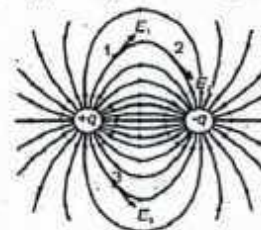


Fig. 5: The electric field lines are directed radially inward towards a negative point charge $-q$.

(iii) Behaviour of Electric Field Lines for Parallel and Equally Spaced Plate Charges

In the regions where the field lines are parallel and equally spaced, the same number of lines pass per unit area and therefore, field is uniform on all points. Figure 6 shows the field lines between the plates of a parallel plate capacitor. The field is uniform in the middle region where field lines are equally spaced.

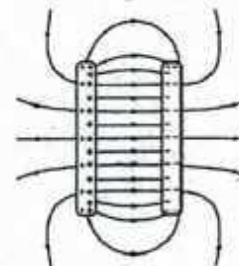


Fig. 6: In the central region of a parallel plate capacitor, the electric field lines are parallel and evenly spaced, indicating that the electric field there has the same magnitude and direction at points.

- | | |
|--|--|
| <p>1. The electric field lines are closer where the field is:
 (A) Strong ✓ (B) Weak
 (C) Uniform (D) Variable</p> <p>2. The electric field created by positive charge is:
 (A) Radially inward (B) Zero
 (C) Circular (D) Radially outward ✓</p> <p>3. The SI unit of strength of electric field is:
 (A) $J C^{-1}$ (B) $C V^{-1}$
 (C) $N C^{-1}$ ✓ (D) $J N^{-1}$</p> <p>4. A charge of 4 coulomb is in the field of intensity $4 NC^{-1}$. The force on the charge is:
 (A) 8 N (B) 16 N ✓
 (C) 4 N (D) 1 N</p> <p>5. If electric lines of force are equally spaced, the electric field is:
 (A) Uniform ✓ (B) Non-uniform
 (C) Weak (D) Strong</p> <p>6. The force on an electron in a field of $1 \times 10^8 NC^{-1}$ will be:
 (A) $1.6 \times 10^{-8} N$ (B) $1.6 \times 10^{-11} N$ ✓</p> | <p>(C) $1.6 \times 10^{-19} N$ (D) $1.6 \times 10^{27} N$</p> <p>7. Concept of electric field was given by
 (A) Michaelson (B) Henry
 (C) Michael Faraday ✓ (D) Orested</p> <p>8. The fact that electric field exists in space around an electrical charge is:
 (A) Electrical property (B) Gravitational field
 (C) Intrinsic property of nature ✓
 (D) All of these</p> <p>9. The force experienced per unit positive charge placed at a point in an electric field is called:
 (A) Coulomb's force (B) Faraday's force
 (C) Electric field intensity ✓ (D) None of these</p> <p>10. The force on neutron due to a field of $10^2 NC^{-1}$ is:
 (A) $1.6 \times 10^{-17} N$ (B) $1.6 \times 10^{-19} N$
 (C) Zero ✓ (D) $1.6 \times 10^{-21} N$</p> <p>11. The direction of field lines around an isolated charge "$-q$" is:
 (A) Radically inward ✓ (B) Radically outward
 (C) Elliptical (D) Circular</p> |
|--|--|

9.3 ELECTRIC FLUX



8. Define electric flux and find an expression for it through a patch of flat surface.

Ans. Electric Flux

Definition

Electric flux is a measure of the total electric field passing through a given surface.

or

Electric flux is the dot product of the electric field vector $\vec{E}$ and the area vector $\vec{A}$ through which the field passes.

Explanation

When we place an element of area in an electric field, some of the lines of force pass through it Fig. 7.

The number of the field lines passing through a certain element of area is known as electric flux through that area.

It is usually denoted by Greek letter ϕ_e . For example, the electric flux ϕ_e through the area A is 4 while the flux through B is 2.

In order to give a quantitative meaning to flux, the field lines are drawn such that the number of field lines passing through a unit area held perpendicular to field lines at a point represent the intensity E of the field at that point.

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

In Fig. 8(a), area A is held perpendicular to the field lines, then EA lines pass through it. The flux ϕ_e in this case is:

$$\phi_e = EA \quad \dots\dots (i)$$

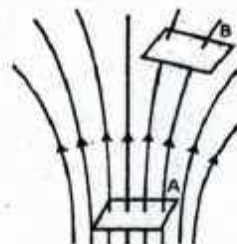


Fig. 7: Electric flux through a surface normal to E .

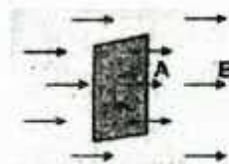


Fig. 8(a) : maximum

In Fig. 8(b), area A is held parallel to field lines and, as is obvious no lines cross this area, so that flux ϕ_e in this case is:

$$\phi_e = EA = 0 \quad \dots\dots (ii)$$

Figure 8(c) shows the case when A is neither perpendicular nor parallel to field lines but is inclined at an angle θ with the field E . In this case, we have to find the projection of the area which is perpendicular to the field lines. The area of this projection; Fig. 8(c) is $A \cos \theta$. The flux ϕ_e in this case is:

$$\phi_e = EA \cos \theta \quad \dots\dots (iii)$$

The electric flux ϕ_e , through a patch of flat surface in terms of E and A is then given by

$$\phi_e = EA \cos \theta = \mathbf{E} \cdot \mathbf{A} \quad \dots\dots (iv)$$

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

Unit: Electric flux being a scalar product, is a scalar quantity. Its SI unit is $\text{N m}^2 \text{C}^{-1}$.



9. Calculate the electric flux through a closed surface in the shape of a sphere.

Ans. Electric Flux through the Surface of a Sphere Enclosing a Charge

Let us calculate the electric flux through a closed surface, in shape of a sphere of radius r due to a point charge q placed at the centre of sphere; Fig. 9. To apply the formula $\phi_e = \mathbf{E} \cdot \mathbf{A}$ for the calculation of electric flux, the surface area should be flat. For this reason the total surface area of the sphere is divided into n small patches with areas of magnitudes $\Delta A_1, \Delta A_2, \Delta A_3, \dots, \Delta A_n$, respectively. The direction of each vector area is along perpendicular drawn outward to the corresponding patch. The electric intensities at the centres of vector areas $\Delta A_1, \Delta A_2, \Delta A_3, \dots, \Delta A_n$ are $\mathbf{E}_1, \mathbf{E}_2, \mathbf{E}_3, \dots, \mathbf{E}_n$, respectively.

According to the equation; $\phi_e = E \cos \theta = \mathbf{E} \cdot \mathbf{A}$, the total flux passing through the closed surface is:

$$\phi_e = \mathbf{E}_1 \cdot \Delta \mathbf{A}_1 + \mathbf{E}_2 \cdot \Delta \mathbf{A}_2 + \mathbf{E}_3 \cdot \Delta \mathbf{A}_3 + \dots\dots\dots + \mathbf{E}_n \cdot \Delta \mathbf{A}_n$$

The direction of electric intensity and vector area is the same at each patch. Moreover,

$$|\mathbf{E}_1| = |\mathbf{E}_2| = |\mathbf{E}_3| = \dots\dots\dots = |\mathbf{E}_n| = E = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2}$$

Since $\mathbf{E}$ is parallel to vector area $\mathbf{A}$, therefore, $\theta = 0^\circ$ (Fig. 9), so for each $\mathbf{E} \cdot \Delta \mathbf{A} = EA \cos \theta$

$$= EA \cos 0^\circ = EA \quad (\because \cos 0^\circ = 1)$$

$$\phi_e = E\Delta A_1 + E\Delta A_2 + E\Delta A_3 + \dots\dots\dots + E\Delta A_n$$

$$= E (\Delta A_1 + \Delta A_2 + \Delta A_3 + \dots\dots\dots + \Delta A_n)$$

$$= E (\text{Total spherical surface area})$$

$$= \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \times 4\pi r^2$$

$$\phi_e = \frac{q}{\epsilon_0} \quad \dots\dots (i)$$

Now imagine that a closed surface S is enclosing this sphere. It can be seen in Fig. 10 that the flux through the closed surface S is the same as that through the sphere. So, we can conclude that total flux through a closed surface does not depend upon the shape or geometry of the closed surface. It depends upon the medium and the charge enclosed.

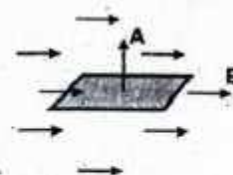


Fig. 8(b): Minimum

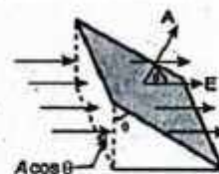


Fig. 8(c)

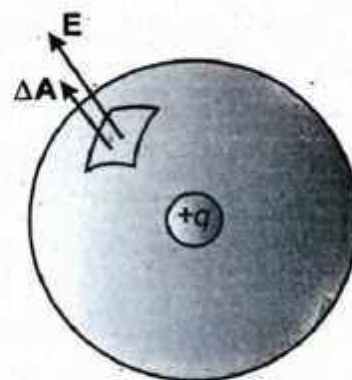


Fig. 9: The total electric flux through the surface of the sphere due to a charge q at its centre is q/ϵ_0 .

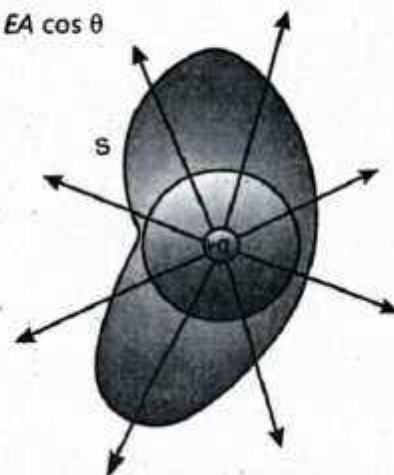


Fig. 10



10. State and explain Gauss's law.

Ans. Gauss's Law

Statement

The total electric flux through any closed surface is $1/\epsilon_0$ times the total charge enclosed in it.

Explanation

Suppose that point charges $q_1, q_2, q_3, \dots, q_n$ are arbitrarily distributed within an arbitrarily shaped closed surface; Fig. 11. Since $\phi_e = q/\epsilon_0$, so the electric flux passing through the closed surface is:

$$\phi_e = \frac{q_1}{\epsilon_0} + \frac{q_2}{\epsilon_0} + \frac{q_3}{\epsilon_0} + \dots + \frac{q_n}{\epsilon_0}$$

$$\phi_e = \frac{1}{\epsilon_0} \times (q_1 + q_2 + q_3 + \dots + q_n)$$

$$\phi_e = \frac{1}{\epsilon_0} \times (\text{Total charge enclosed by closed surface})$$

$$\phi_e = \frac{1}{\epsilon_0} \times Q \quad \dots (i)$$

where $Q = q_1 + q_2 + q_3 + \dots + q_n$ is the total charge enclosed by closed surface.

Equation (i) is mathematical expression of Gauss's law

Applications of Gauss's Law

- (i) Gauss's law relates electric flux through a closed surface to the charge enclosed by that surface.
- (ii) Gauss's law can be applied to calculate the electric intensity due to different charge configurations.
- (iii) It determines the electric fields inside a conductor.
- (iv) It helps to explain shielding effect.

Gaussian surface

A Gaussian surface is an imaginary surface used in Gauss's law to calculate the electric field due to given charge distribution. It is not a physical object; it is a mathematical tool that helps in applying the law effectively.



11. Find the electric field at any point outside a sphere on which a charge is placed.

Ans. The Field of a Charged Conducting Sphere:

Consider a conducting sphere of radius R containing a charge q . As all the charge is distributed uniformly over the surface of sphere; Fig. 12, therefore, we conclude from the spherical symmetry that the electric field is radial everywhere and that its magnitude depends only on the distance r from the centre of the sphere. Thus, the magnitude E is uniform over a spherical surface with any radius r concentric with the spherical conductor. Therefore, we take our Gaussian surface as an imaginary sphere with radius r greater than the radius R of the conducting sphere.

The area of the Gaussian sphere is $4\pi r^2$, and because E is uniform over the sphere, the total flux through the whole surface will be:

$$\text{Electric flux } \phi_e = EA = E \times 4\pi r^2$$

By Gauss's law, total flux is:

$$\phi_e = \frac{q}{\epsilon_0}$$

$$\text{Therefore } E \times 4\pi r^2 = \frac{q}{\epsilon_0}$$

$$\text{or } E = \frac{q}{\epsilon_0 4\pi r^2}$$

$$\text{or } E = \frac{1}{4\pi\epsilon_0} \times \frac{q}{r^2}$$

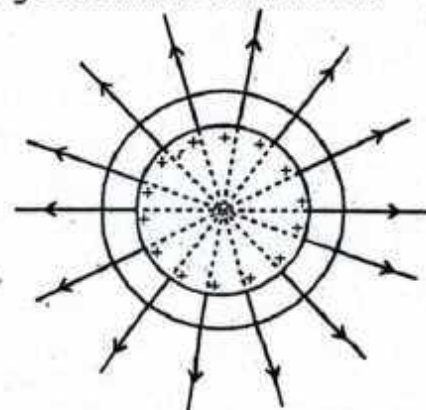


Fig. 12

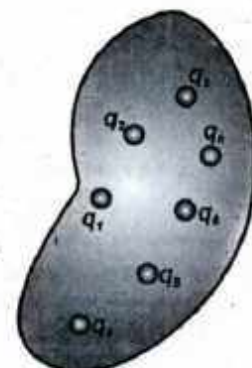


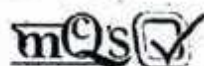
Fig. 9.11

This shows that the field at any point outside the sphere is the same as though the entire charge were concentrated at its centre. Just outside of the sphere, where $r = R$, i.e.,

$$E = \frac{1}{4\pi\epsilon_0} \frac{q}{R^2}$$

In vector form; $\mathbf{E} = \frac{1}{4\pi\epsilon_0} \frac{q}{R^2} \hat{\mathbf{r}}$

where $\hat{\mathbf{r}}$ is the direction of $\mathbf{E}$.



- The SI unit of electric flux is:**
(A) NmC^{-1} (B) $\text{Nm}^{-1}\text{C}^{-1}$
(C) Nm^2C^{-1} ✓ (D) Nm^3C^{-1}
- Total flux through a closed surface depends on:**
(A) Shape of surface (B) Charge enclosed only
(C) Medium only (D) Both B and C ✓
- The electric intensity near an infinite plate of positive charge will be:**
(A) $\frac{q}{\epsilon_0}$ (B) $\frac{\pi}{2\epsilon_0}$ ✓
(C) $\frac{q}{A}$ (D) None of these
- Electric intensity inside the hollow sphere is:**
(A) $\frac{\pi}{\epsilon_0}$ (B) $\frac{\sigma}{2\epsilon_0}$
(C) $\frac{1}{\epsilon_0}$ (D) Zero ✓
- A charged conductor has charge on its:**
(A) Inner-surface (B) Outer-surface ✓
(C) Middle point (D) Surrounding space
- Electric flux is expressed as:**
(A) $\phi_0 = \vec{E} \times \vec{A}$ (B) $\phi_0 = \vec{E} \times \vec{Q}$
(C) $\vec{E} \times \vec{A}$ ✓ (D) $\phi_0 = EA^2$
- Gauss's law can only be applied to:**
(A) A curved surface (B) A flat surface
(C) A surface of any shape (D) A closed surface ✓
- A rubber ball of radius 2 cm has a charge of $5 \mu\text{C}$ on its surface which is uniformly distributed, the value of $\vec{E}$ at its centre is:**
(A) 10 NC^{-1} (B) zero ✓
(C) 2.5 NC^{-1} (D) $5 \times 10^6 \text{ NC}^{-1}$
- Electric flux through a surface enclosing a charge depends on:**
(A) Charge only (B) Medium only ✓
(C) Shape of closed surface
(D) Medium and charge enclosed
- For computation of electric flux, the surface area should be:**
(A) Parallel (B) Flat ✓
(C) Curved (D) Spherical
- A one coulomb charge of mass one gram is in electric field of 1 NC^{-1} , acceleration will be:**
(A) 100 ms^{-2} (B) 1000 ms^{-2} ✓
(C) 1 ms^{-2} (D) 10 ms^{-2}
- The shape of Gaussian surface should be:**
(A) Closed ✓ (B) Spherical
(C) Circular (D) Box type

9.5 ELECTRIC POTENTIAL



12. Explain electric potential and show that the electric potential at any point in an electric field is equal to the work done.

Ans. Electric Potential

Definition

Electric potential is the amount of electric potential energy per unit charge at a specific point in an electric field.

Explanation

Figure 13 shows two oppositely charged parallel plates which produce a uniform electric field.

Let us consider a positive charge q which is allowed to move in this uniform electric field. The positive charge will move from plate B to A and will gain K.E. If it is to be moved from A to B, an external force is needed to make the charge move against the electric field and will gain P.E. Let us impose a condition that as the charge is moved from A to B, it is moved keeping electrostatic equilibrium, i.e., it moves with uniform velocity. This condition could be achieved by applying a force F equal and opposite to qE at every point along its path.

The work done by the external force against the electric field increases electrical potential energy of the charge that is moved.

Let W_{AB} be the work done by the force in carrying the positive charge q

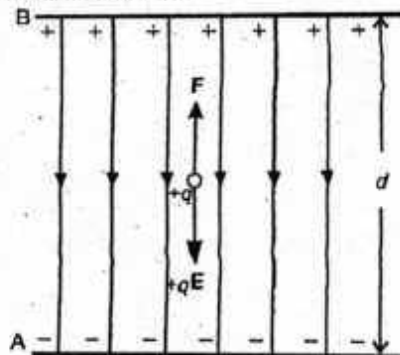


Fig. 13

from A to B while keeping the charge in equilibrium. The change in its potential energy $\Delta U = W_{AB}$.

or $U_B - U_A = W_{AB}$ (i)

where U_A and U_B are the potential energies at points A and B, respectively.

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 charge in equilibrium.

i.e., $\Delta V = V_B - V_A = \frac{W_{AB}}{q} = \frac{\Delta U}{q}$ (ii)

Electric potential energy difference and electric potential difference between the points A and B are related as:

$\Delta U = q\Delta V$ (iii)

The potential difference between the two points can be defined as the difference of the potential energy per unit charge.

As the unit of P.E. is joule, equation (ii) shows that the unit of potential difference is joule per coulomb. It is called volt.

Volt: One volt is defined as the p.d. when one joule of work is done to move one coulomb of charge between two points.

So, $1 \text{ V} = \frac{1 \text{ J}}{1 \text{ C}}$

$1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}}$ (iv)

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

In order to give a concept of electric potential at a point in an electric field, we must have a reference to which we assign zero electric potential. This point is usually taken at infinity. Thus, in Eq. (ii), if we take point A to be at

infinity and choose $V_A = 0$, the electric potential at B will be $V_B = \frac{W_{AB}}{q}$. Generally,

$V = \frac{W}{q}$ (v)

which states that 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. So, the potential at a point is always relative to potential at infinity.

Do you know?



An ECG records the "voltage" between points on human skin generated by electrical process in the heart. This ECG is made in running position providing information about the heart's performance under stress.

Point to ponder!

Why is it advised to wear rubber soled shoes while handling electric appliances?

Ans. It is advised to wear rubber-soled shoes while handling electric appliances because rubber is an excellent insulator. This means, it does not conduct electricity well.



13. Prove that electric field intensity is equal to the negative of potential gradient.

Ans. Electric Field as Potential Gradient

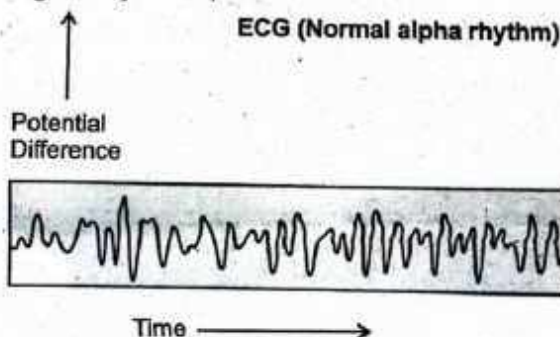
Let us consider the situation shown in Fig. 13. The electric field between the two charged plates is uniform and its value is E ; Fig. 13. The potential difference between A and B is given by the equation:

$V_B - V_A = \frac{W_{AB}}{q}$ (i)

where $W_{AB} = Fd = -qEd$ (the negative sign is needed because F must be applied opposite to qE so as to keep it in equilibrium). With this, Eq. (i) becomes:

$V_B - V_A = \frac{-qEd}{q} = -Ed$

or $E = \frac{(V_B - V_A)}{d} = -\frac{\Delta V}{d}$ (ii)



If the plates A and B are separated by infinitesimally small distance Δd , the Eq. (ii) is modified as:

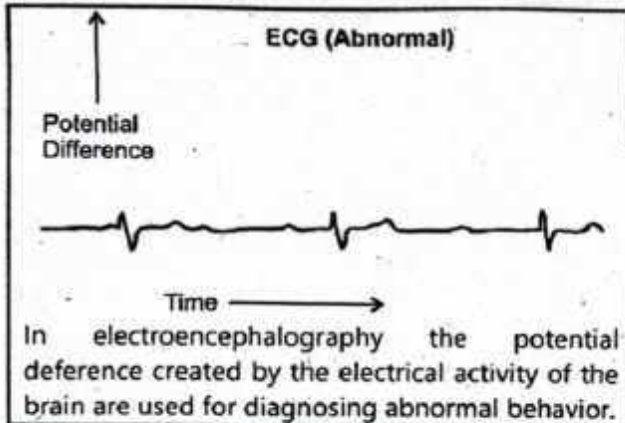
$$E = -\frac{\Delta V}{\Delta d} \quad \dots\dots(iii)$$

The quantity $\frac{\Delta V}{\Delta d}$ gives the maximum value of the rate of change of potential with distance because the charge has been moved along a field line in which the distance Δd between the two plates is minimum. It is known as potential gradient. Thus, the electric field intensity is equal to the negative of the gradient of electric potential. The negative

sign indicates that the direction of E is along the decreasing potential.

The unit of electric intensity from Eq. (iii) is volt/metre ($V m^{-1}$) which is equal to $N C^{-1}$ as given below:

$$1 \frac{\text{volt}}{\text{metre}} = 1 \frac{\text{joule/coulomb}}{\text{metre}} = 1 \frac{\text{newton} \times \text{metre}}{\text{metre} \times \text{coulomb}} = 1 \frac{\text{newton}}{\text{coulomb}} = 1 N C^{-1}$$



Example 9.4: Two parallel metal plates are 1.0 cm apart. These are connected to a battery of 12 volts. Find the magnitude of electric field intensity between them.

Solution:

Given that;

$$\Delta V = 12 V, \Delta d = 1.0 \text{ cm} = 1 \times 10^{-2} \text{ m}$$

To Find:

$$E = ?$$

Calculations: Using the equation

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

Substituting the values,

$$E = \frac{12 V}{1 \times 10^{-2} \text{ m}} = 1200 V m^{-1} \text{ Ans.}$$

Example 9.5: Two horizontal parallel metal plates are connected to a 12 volt battery. An electron is released from the negative plate. Determine its velocity as it reaches the positive plate. Mass of electron = $9.1 \times 10^{-31} \text{ kg}$ and charge = $q = e = 1.6 \times 10^{-19} \text{ C}$.

Solution:

Given that;

$$\Delta V = 12 V, m = 9.1 \times 10^{-31} \text{ kg} \text{ and } q = e = 1.6 \times 10^{-19} \text{ C}$$

To Find:

$$V = ?$$

Calculations: The electron is repelled by the negative plate and attracted by the positive plate. It will be accelerated towards positive plate. Therefore, its P.E. will be lost that will be converted into its K.E.

Loss of P.E = Gain in K.E

$$\Delta V \times e = \frac{1}{2} mv^2$$

Submitting the values,

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

$$v^2 = 4.2 \times 10^{12} \text{ m}^2 \text{ s}^{-2}$$

or

$$v = 2.1 \times 10^6 \text{ m s}^{-1} \text{ Ans.}$$



14. Define and explain electron volt.

Ans. We know that when a particle of charge q moves from point A at potential V_A to a point B at potential V_B keeping electrostatic equilibrium, the change in potential energy ΔU of particle is:

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

If no external force acts on the charge to maintain equilibrium, this change in P.E. appears in the form of change in K.E.

Suppose charge on the particle is $q = e = 1.6 \times 10^{-19} \text{ C}$.

Thus, in this case, the energy acquired by the charge will be:

$$\Delta \text{K.E.} = q\Delta V = e\Delta V = (1.6 \times 10^{-19} \text{ C}) (\Delta V)$$

$$\Delta V = 1 \text{ volt, then}$$

$$\Delta \text{K.E.} = q\Delta V = (1.6 \times 10^{-19} \text{ C}) \times (1 \text{ volt})$$

$$\Delta \text{K.E.} = (1.6 \times 10^{-19}) \times (\text{C} \times \text{V}) = 1.6 \times 10^{-19} \text{ J}$$

One Electron Volt

The amount of energy equal to $1.6 \times 10^{-19} \text{ J}$ is called one electron-volt and is denoted by 1 eV. It is defined as "the amount of energy gained or lost by an electron as it traverses a potential difference of one volt".

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

Example 9.6: A particle carrying a charge of $2e$ falls through a potential difference of 3.0 V. Calculate the energy required by it.

Solution:

Given that;

$$q = 2e, \Delta V = 3.0 \text{ V}$$

To Find:

$$\Delta U = ?$$

Calculations: The energy acquired by the particle is:

$$\Delta U = q\Delta V = (2e)(3.0 \text{ V}) = 6.0 \text{ eV}$$

$$\Delta U = 6.0 \times 1.6 \times 10^{-19} \text{ J} = 9.6 \times 10^{-19} \text{ J} \text{ Ans.}$$

9.7 MOTION OF CHARGED PARTICLES IN A UNIFORM ELECTRIC FIELD



15. Describe the motion of charged particles in a uniform electric field.

Ans. Two oppositely charged parallel metal plates produce uniform electric field between them. The direction of electric field is from positive to negative plate. A positive charge $+q$ placed in the field will move in the direction of electric field whereas a negative charge $-q$ will move opposite to the electric field. The magnitude of electric force acting on a charge q ; Fig. 14 is given by

$$F = qE$$

where E is the electric intensity of the uniform electric field. If V is the potential difference between the plates and d is the separation of plates, then

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

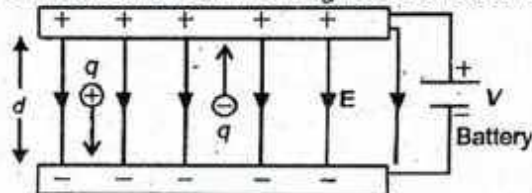


Fig. 14

Example: To understand the effect of uniform electric field on the motion of charged particles, let us consider an electron placed between the two plates. The electron accelerates towards the positive plate due to a force F acting on it.

For example, let $V = 20 \text{ V}$, $d = 2.0 \text{ cm} = 2 \times 10^{-2} \text{ m}$, the magnitude of E will be:

$$E = \frac{V}{d} = \frac{20 \text{ V}}{2 \times 10^{-2} \text{ m}} = 1000 \text{ N C}^{-1}$$

The acceleration for the electron will be given by

$$F = ma$$

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

The charge on an electron $q = e = 1.6 \times 10^{-19} \text{ C}$ and mass of electron $m = 9.1 \times 10^{-31} \text{ kg}$. So,

$$a = \frac{1.6 \times 10^{-19} \text{ C} \times 1000 \text{ N C}^{-1}}{9.1 \times 10^{-31} \text{ kg}} \\ = 1.76 \times 10^{14} \text{ m s}^{-2}$$

If the electron is released from the negative plate, the velocity gained by it when it reaches positive plate can be found by the third equation of motion.

$$2aS = v_f^2 - v_i^2 \quad \dots\dots (i)$$

Here $S = d = 2 \times 10^{-2} \text{ m}$, $v_i = 0$, $v_f = v = ?$

Putting the values in Eq. (i)

$$2 \times 1.76 \times 10^{14} \text{ m s}^{-2} \times 2 \times 10^{-2} \text{ m} = v^2$$

or $v = 7.04 \times 10^{12} \text{ m}^2 \text{ s}^{-2}$

or $v = 2.65 \times 10^8 \text{ m s}^{-1}$

9.8 PATH OF A CHARGED PARTICLE



16. How is the path of a charged particle determined by the electric field in the region?

Ans. Determination of Path of a Charged Particle

The path of a charged particle is determined by the electric field in the region. The path is typically straight if the field is uniform and the charged particle is moving along the field. However, if a charged particle enters perpendicularly to the uniform field between the oppositely charged parallel plates with a certain velocity; Fig. 15, it will not go straight. Its path will be parabolic just like a projectile thrown horizontally in the gravitational field. The horizontal component of the velocity of the charged particle remains constant whereas vertical component is accelerated due to the electric force.

Figure 15 shows that a positively charged particle is attracted towards the negatively charged plate and thus undergoes deflection in that direction.

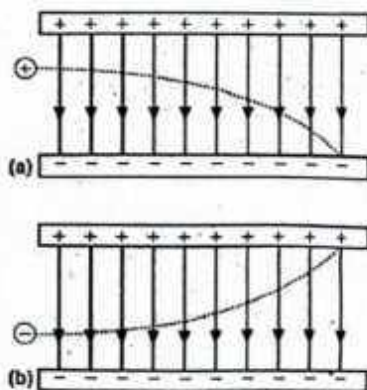


Fig. 15

On the other hand, a negatively charged particle is attracted towards the positively charged plate and experiences deflection in that direction.



- | | |
|--|--|
| <p>1. The unit of Electric Intensity other than NC^{-1} is:
(A) VA^{-1} (B) Vm^{-1} ✓
(C) VC^{-1} (D) NV^{-1}</p> <p>2. A charge 10^{-10} C between two parallel plates 1 cm apart experience a force of 10^{-4} N. The p.d between the plates is:
(A) 10 V (B) 10^2 V
(C) 10^3 V ✓ (D) 10^4 V</p> <p>3. Which one of the following relation is correct?
(A) joule = volt $\times$ ampere (B) joule = coulomb / volt
(C) joule = volt / ampere
(D) joule = coulomb $\times$ volt ✓</p> <p>4. The electron volt (eV) is the unit of:
(A) Electric current (B) Electric energy ✓
(C) Electric potential (D) Electric flux</p> | <p>5. If an electron is accelerated through a potential difference of 10V, then energy gained by electron is:
(A) $1.6 \times 10^{-20} \text{ J}$ (B) 1.6 eV
(C) 10 eV ✓ (D) $1.6 \times 10^{-19} \text{ eV}$</p> <p>6. If a charged body is moved against the electric field, it will gain:
(A) P.E. (B) K.E.
(C) Mechanical energy
(D) Electrical potential energy ✓</p> <p>7. The velocity of an oscillating charge as it moves to and for along the wire is:
(A) Infinite (B) Constant
(C) Changing ✓ (D) Zero</p> <p>8. A Particle carrying a charge of $2e$ falls through potential difference of 3V. The energy acquired by it will be:
(A) 1.5 eV (B) 0.66 eV</p> |
|--|--|

- (C) 6 eV ✓ (D) 3 eV
9. Two opposite point charges of same magnitude separated by distance $2d$, electric potential mid-way between them is:
 (A) 1V (B) 2V
 (C) Zero ✓ (D) $\frac{V}{2}$
10. The work done in moving a positive charge on an equipotential surface is:
 (A) Finite and Positive (B) Infinite
 (C) Finite and Negative (D) Zero ✓
11. One Electron Volt is equal to:
 (A) 6.25×10^{18} J (B) 6.25×10^{-18} J
 (C) 1.6×10^{-19} J (D) 1.6×10^{19} J ✓
12. If an electron of charge " e " is accelerated through a potential difference of 1 V, it will acquire energy:
 (A) Ve (B) $V/2$
 (C) $E/2$ ✓ (D) Ve^2
13. One joule is equal to:
 (A) 1.6×10^{-19} eV (B) 1.6×10^{19} eV
 (C) 6.25×10^{-18} eV (D) 6.25×10^{18} eV ✓
14. The electron volt is the unit of:
 (A) Electric current (B) Electric energy ✓
 (C) Potential (D) Potential difference
15. The quantity $\frac{\Delta V}{\Delta r}$ is called:
 (A) Electric potential (B) Electric energy
 (C) Potential barrier (D) Potential gradient ✓
16. The work done in bringing a unit positive charge from infinity to that point in an electric field is called:
 (A) Electric field (B) Potential difference
 (C) Absolute potential ✓ (D) All of these
17. The absolute electric potential at a point distance 20cm from a charge of $2\mu\text{C}$ is:
 (A) 9×10^2 V (B) 9×10^3 V
 (C) 9×10^4 V ✓ (D) 9×10^5 V
18. The electric potential at a mid-point in electric dipole is:
 (A) 0 V ✓ (B) 0.5 V
 (C) 1 V (D) 1.5 V
19. The formula for electric field as potential gradient is:
 (A) $E = \frac{-\Delta V}{\Delta r}$ ✓ (B) $E = \frac{-\Delta V}{\Delta t}$
 (C) $E = \frac{-\Delta U}{\Delta r}$ (D) $E = \frac{-\Delta V}{\Delta t}$
20. The Gradient of the Scalar field is always be a:
 (A) Scalar quantity (B) Vector quantity ✓
 (C) Variable quantity (D) Fixed quantity
21. The SI unit of electric potential is:
 (A) $\text{kg m}^2 \text{s}^{-1} \text{C}$ (B) $\text{kg m}^2 \text{s}^{-2} \text{C}$
 (C) $\text{kg m}^2 \text{s}^{-2} \text{C}^{-1}$ ✓ (D) $\text{kg m}^2 \text{s}^2 \text{C}^{-1}$
22. The negative sign in the expression of potential gradient $\vec{E} = \frac{\Delta V}{\Delta r}$ shows that direction of is $\vec{E}$ along:
 (A) Increasing potential (B) Decreasing potential ✓
 (C) Increasing strength (D) Negative potential
23. The difference of potential energy between two points per charge is:
 (A) Electrical potential (B) Potential difference ✓
 (C) Absolute potential (D) All of these
24. The absolute potential at a point distant 20 cm from a charge of $2\mu\text{C}$ is:
 (A) 9×10^2 V (B) 9×10^3 V
 (C) 9×10^4 V ✓ (D) 9×10^5 V
25. The potential difference between two plates is 100 V and separation of plates is 5 cm, then potential gradient is:
 (A) 2000 NC^{-1} ✓ (B) 20 NC^{-1}
 (C) 5000 NC^{-1} (D) 2 NC^{-1}

9.9 SHIELDING FROM EXTERNAL ELECTRIC FIELD



17. What is Faraday's cage? Describe its working and principle.

Ans. Faraday's Cage

Faraday cage is an enclosure that blocks the external electric fields in conductive materials. It acts like a hollow conductor where devices or objects can be put for protection from electrical external fields. Any electrical shock received by the cage runs through its outer surface without causing any harm inside. The electric field inside the hollow conductor remains zero.

Working

To understand the working of Faraday cage, suppose that a piece of conductor (say copper) carries a number of free electrons. Each electron will experience 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. Once static equilibrium is established with all of the excess charges on the surface, no further movement of charge occurs. If some electrons shift from the conductor to another object due to friction etc., a net positive charge appears on the surface of the conductor. We can say,

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

Now consider the interior of the hollow conductor. The excess charges arrange themselves on the conductor's surface precisely in the manner that the total field within the interior becomes zero. In other words,

The conductor shields any charge within it from electric fields outside the conductor.

To eliminate the interference of external fields, circuits are often enclosed within metal boxes that provide shielding from such fields. Figure 16 shows another aspect of how conductors alter the electric field lines created by external charges.

The lines are altered because the electric field just outside the surface of a conductor is perpendicular to the surface at equilibrium under electrostatic conditions. If the field were not perpendicular, there would be a component of the field parallel to the surface. Since the free electrons on the surface of the conductor can move, they would do so under the force exerted by the parallel component. But in reality, no electron flow occurs at equilibrium. Therefore, there can be no parallel component, and the electric field is perpendicular to the surface.

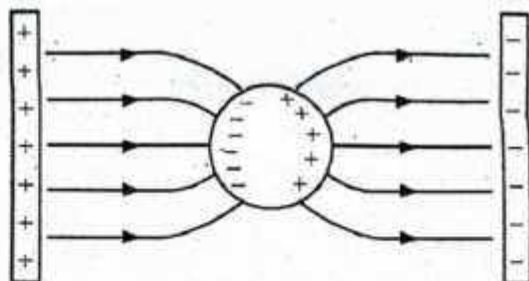


Fig. 16

Principle

The principle of Faraday cage demands a material that contains a lot of free electrons that can move freely to the surface of the material. Only the conductors have free electrons whereas insulators do not contain free electron, so the insulators cannot be used to construct Faraday cage.

Examples

1. A good example of Faraday cage in our daily life is that of cars. The chassis and bodies of cars protect people inside due to its metal framed structure during the thunderstorms. The electrical charge travels over the metal surface of the vehicle into the ground and prevent the passengers inside.
2. A metal body of the microwave oven acts as a Faraday cage. Thus, they prevent the microwaves in an oven from expanding into the environment. Metal frame of an airplane also acts as a Faraday cage. When lightning strikes an airplane, electricity is distributed along its metal frame surface that keeps passengers and all devices inside the airplane safe.



- | | |
|---|---|
| <p>1. What is the primary function of Faraday's cage?</p> <p>(A) To amplify electric fields
(B) To block external static and non-static ✓
(C) To produce electricity
(D) To convert electric energy into magnetic energy</p> <p>2. What happens to the electric field inside a closed Faraday cage made of a conductive material?</p> <p>(A) It becomes very strong (B) It oscillates rapidly
(C) It becomes zero ✓ (D) It is doubled</p> <p>3. Which of the following materials would best work for a Faraday cage?</p> <p>(A) Wood (B) Glass
(C) Plastic (D) Copper ✓</p> | <p>4. A Faraday cage protects the interior from which of the following?</p> <p>(A) Sound waves (B) Gravitational waves
(C) Electromagnetic radiation ✓
(D) Light</p> <p>5. Which of these applications makes use of the Faraday's cage principle?</p> <p>(A) MRI rooms ✓ (B) Loudspeakers
(C) Solar panels (D) Telescopes</p> <p>6. In a Faraday cage, the electric charge resides:</p> <p>(A) Inside the cage (B) On the outer surface ✓
(C) In the air within the cage
(D) Equally inside and outside</p> |
|---|---|

9.10 ELECTRIC CURRENT



18. Describly briefly electric current, drift velocity and conventional current.

Ans. Electric Current

An electric current is a flow of charged particles, such as electrons or ions, moving through an electrical conductor or space. It is defined as:

The net rate of flow of electric charge through a surface.

Mathematically;

$$\text{Electric current} = \frac{\text{Flow of charges}}{\text{Time}}$$

or

$$I = \frac{Q}{t}$$

Unit: The SI unit of electric current is ampere (A).

Ampere: If one coulomb charge flows through a conductor in one second, then current will be one ampere.

Direction Current (D.C)

Definition

If the charges move around a circuit in the same direction at all times, the current is said to be direct current.

For example, batteries produce direct current.

Alternating Current (A.C)

Definition

If the charges move first one way and then the opposite way, changing direction in regular intervals, the current is said to be alternating current.

For example, mostly the electric generators produces A.C. The electricity supplied, to our homes, offices, factories, etc. by power station is A.C.

Drift Velocity

Definition

It is the average velocity attained by charged particles, such as electrons, in a material due to an electric field.

Drift velocity is proportional to current. In a resistive material, it is also proportional to the magnitude of an external electric field.

Conventional Current

Definition

The direction of conventional current is always from a point of higher potential towards a point of lower potential i.e., from the positive terminal towards the negative terminal.

9.11 CURRENT THROUGH A CONDUCTOR



19. Find an expression for current flowing through a conductor. *

Ans. Expression for Current through a Conductor

Consider a segment of the current-carrying conductor having length L and area of cross-section A . The volume of the segment is AL ; Fig. 17. Let n be the number of charge carriers per unit volume, then total number of charge carriers in the segment at any time are nAL .

If the charge on a charge carrier is q , the total charge present inside the segment at any instant is:

$$Q = nALq$$

Usually, the charge carriers in a conductor are free electrons which have negative charge.

Suppose that charge carriers move towards left face of the segment when a potential difference is applied across the conductor. Then electric current is set up in the conductor directed towards right face. Assuming that drift velocity of the charge carriers to be v , the time taken t by all the charge carriers originally present in the segment to exit through the left face will be:

$$t = \frac{L}{v}$$

By definition of the current

$$I = \frac{Q}{t}$$

Putting the value of Q and t in the above equation:

$$I = \frac{nALq}{L/v}$$

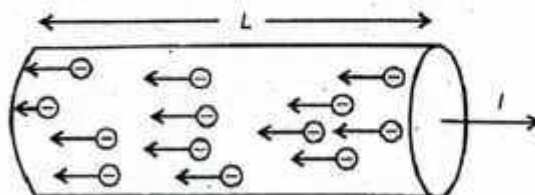


Fig. 17: Negative charge carriers

Do you know?

- Flow of current is directly proportional to the potential difference.
- Flow of heat is directly proportional to the temperature difference.
- Flow of fluid is directly proportional to the pressure difference.

For your information

Current is a flow of charge, pressured into motion by voltage and hampered

or

$$I = nAvq$$

by resistance.

Example 9.7: A copper wire has a cross-sectional area of $2 \times 10^{-6} \text{ m}^2$ and carries a current of 3 A. If the number of electrons per unit volume is $8.5 \times 10^{28} \text{ m}^{-3}$, calculate the drift velocity of the electrons in the wire. Charge on an electron is $1.6 \times 10^{-19} \text{ C}$.

Solution:

Given that;

$$I = 3 \text{ A}, A = 2 \times 10^{-6} \text{ m}^2, n = 8.5 \times 10^{28} \text{ m}^{-3}, q = 1.6 \times 10^{-19} \text{ C}, v = ?$$

To Find:

Drift velocity $V = ?$

Calculations: Using equation;

$$I = nAvq$$

Substituting the values,

$$3 = (2 \times 10^{-6} \text{ m}^2) (8.5 \times 10^{28} \text{ m}^{-3}) v (1.6 \times 10^{-19} \text{ C})$$

$$v = 1.1 \times 10^{-4} \text{ m s}^{-1} \text{ Ans.}$$

9.12 OHM'S LAW



20. State and explain Ohm's law.

Ans. 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.

Mathematically;

$$I \propto V$$

or

$$V = IR$$

where R is a constant of proportionality known as resistance of the conductor. The SI unit of resistance is ohm (Ω), and is defined as:

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.

9.13 RESISTIVITY AND ITS DEPENDENCE UPON TEMPERATURE



21. Briefly describe the terms resistivity and conductance.

Ans. Resistivity

It has been experimentally seen that the resistance R of a wire is directly proportional to its length L and inversely proportional to its cross sectional area A . Mathematically,

$$R \propto \frac{L}{A}$$

or

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

or

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

Note

- The resistance is the characteristic of a particular wire whereas the resistivity is the property of the material of which the wire is made.
- Silver and copper are two best conductors. That is the reason, most of electric wires are made of copper.

Resistivity

Definition

It is defined as the resistance of a material per unit length and per unit cross-sectional area.

Unit: The SI unit of resistivity is ohm-metre (Ωm).

Conductance

Definition

The ability of a component or circuit to conduct electric current is called conductance. It is the reciprocal of resistance.

i.e., $\text{Conductance} = \frac{1}{\text{Resistance}}$ or $G = \frac{1}{R}$, where G is the conductance.

Unit: The SI unit of conductance is Siemens (S).

Conductivity**Definition**

The intrinsic property of a material that indicates how well it can conduct electric current is known as conductivity.

Conductivity is the reciprocal of resistivity.

Mathematically,

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

Unit: The unit of conductivity is Siemens per metre (Sm^{-1}).

Resistivity of various materials is given in Table 9.2.



22. How does the resistivity of a substance depend upon temperature? Explain.

Ans. The resistivity of a substance depends upon the temperature. It can be explained by recalling that the resistance offered by a conductor to the flow of electric current is due to collisions, which the free electrons encounter with atoms of the lattice. As the temperature of the conductor rises, the amplitude of vibration of the atoms in the lattice increases and hence, the probability of their collision with free electrons also increases. The atoms then offer a bigger target, that is the collision cross-section of the atoms increases with temperature. This makes the collisions between free electrons and the atoms in the lattice more frequent and hence, the resistance of the conductor increases.

Experimentally, the change in resistance of a metallic conductor with temperature is nearly linear over a considerable range of temperature above and below 0°C ; Fig. 18. Over such a range the fractional change in resistance per Kelvin is known as the temperature coefficient (α) of resistance, i.e.,

$$\alpha = \frac{R_t - R_0}{R_0 t} \quad \dots\dots (i)$$

where R_0 and R_t are resistances at temperatures 0°C and $t^\circ\text{C}$ respectively.

As resistivity ρ depends upon the temperature, Eq. 9.35 gives

$$R_t = \rho_t \frac{L}{A} \quad \text{and} \quad R_0 = \rho_0 \frac{L}{A} \quad \dots\dots (ii)$$

Substituting the values of R_t and R_0 in Eq. (ii)

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

where ρ_0 is the resistivity of a conductor at 0°C and ρ_t is the resistivity at $t^\circ\text{C}$.

Note: Values of temperature coefficients of resistance of some substances are also listed in Table 9.2. There are some substances like

Substance	ρ ($\Omega \text{ m}$)	α (K^{-1})
Silver	1.52×10^{-8}	0.00380
Copper	1.69×10^{-8}	0.00390
Gold	2.27×10^{-8}	0.00340
Aluminium	2.63×10^{-8}	0.00390
Tungsten	5.00×10^{-8}	0.00460
Iron	11.00×10^{-8}	0.00520
Platinum	11.00×10^{-8}	0.00520
Constantan	49.00×10^{-8}	0.00001
Mercury	94.00×10^{-8}	0.00091
Nichrome	100.0×10^{-8}	0.00020
Carbon	3.5×10^{-5}	-0.00005
Germanium	0.5	-0.05
Silicon	20-2300	-0.07

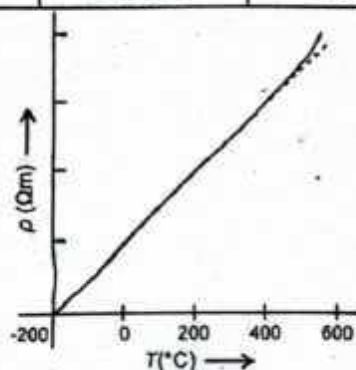


Fig. 18: Variation of resistivity of Cu with temperature

For your Information

Inspectors can easily check the

germanium, silicon, etc. whose resistance decreases with increase in temperature, these substances have **negative temperature coefficients**.

reliability of a concrete bridge made with carbon fibers. The fibers conduct electricity. If sensors show that electrical resistance is increasing over time the fibers are separating because of cracks.

Example 9.8: 0.75 A current flows through an iron wire when a battery of 1.5 V is connected across its ends. The length of the wire is 5.0 m and its cross-sectional area is $2.5 \times 10^{-7} \text{ m}^2$. Compute the resistivity of iron.

Solution:

Given that;

$$I = 0.75 \text{ A} ; V = 1.5 \text{ V} , L = 5.0 \text{ m} , A = 2.5 \times 10^{-7} \text{ m}^2$$

To Find:

$$\rho = ?$$

Calculations: The resistance R of the wire can be calculated by using the equation:

$$\text{i.e. } R = \frac{V}{I} = \frac{1.5 \text{ V}}{0.75 \text{ A}} = 2.0 \text{ V A}^{-1} = 2.0 \Omega$$

The resistivity ρ of iron of which the wire is made of is given by

$$\rho = R \frac{A}{L} = \frac{2.0 \Omega \times 2.5 \times 10^{-7} \text{ m}^2}{5.0 \text{ m}} = 1.0 \times 10^{-7} \Omega \text{m} \text{ Ans.}$$

Example 9.9: A platinum wire has resistance of 10Ω at 0°C and 20Ω at 193°C . Find the value of temperature coefficient of resistance of platinum.

Solution:

Given that;

$$R_0 = 10 \Omega , R_t = 20 \Omega , t = 466 \text{ K} - 273 \text{ K} = 193 \text{ K}$$

To Find:

$$\alpha = ?$$

Calculations: Temperature coefficient of resistance can be found by

$$\alpha = \frac{R_t - R_0}{R_0 t} = \frac{20 \Omega - 10 \Omega}{10 \Omega \times 193 \text{ K}} = \frac{1}{193 \text{ K}} = 5.18 \times 10^{-3} \text{ K}^{-1} \text{ Ans.}$$



- | | |
|--|---|
| <p>1. In case of metallic conductors, the charge carriers are:
 (A) Protons (B) Positive and negative ions
 (C) Electrons ✓ (D) Protons and electrons</p> <p>2. Charge carriers in electrolytes are:
 (A) Protons (B) Electrons
 (C) Holes
 (D) Positive and negative ions ✓</p> <p>3. Current flows in the gases due to:
 (A) Electrons only (B) electrons and ions ✓
 (C) Positive and negative ions
 (D) electrons and holes</p> <p>4. A battery made a charge of 40 C around a circuit at constant rate in 20 s. The current will be:
 (A) 2 A ✓ (B) 0.5 A
 (C) 80 A (D) 60 A</p> <p>5. Ampere second stands for the unit of:
 (A) Current ✓ (B) Emf
 (C) Energy (D) Power</p> <p>6. Drift velocity of electrons is:</p> | <p>(A) 10^{-1} ms^{-1} (B) 10^{-2} ms^{-1}
 (C) 10^{-3} ms^{-1} ✓ (D) 10^{-4} ms^{-1}</p> <p>7. The current which flow from a point at higher potential to a point at lower potential is called:
 (A) Electrical current (B) Conventional current ✓
 (C) Either of these (D) None of these</p> <p>8. If 1×10^7 electrons pass through a conductor in $1.0 \mu\text{s}$, then the current is:
 (A) 2A (B) 1.6A
 (C) $2.6 \times 10^{-6} \text{ A}$ (D) $1.6 \times 10^{-6} \text{ A}$ ✓</p> <p>9. 5A of current flows through a conductor in 2 minutes, charge in the wire is:
 (A) 500 C (B) 600 C ✓
 (C) 400 C (D) 10 C</p> |
|--|---|

10. Heat generated by a 50 Watt bulb in one hour is:
(A) 36000 J (B) 48000 J
(C) 1800 J (D) 180000 J ✓
11. The graphical representation of Ohm's law is:
(A) Hyperbola (B) Ellipse
(C) Parabola (D) straight line ✓
12. A student has five resistances each of value $\frac{1}{5} \Omega$. The minimum resistance that can be obtained by combining them in parallel is:
(A) $\frac{1}{50} \Omega$ (B) $\frac{1}{25} \Omega$ ✓
(C) $\frac{1}{10} \Omega$ (D) 5 Ω
13. Heat generated by a 40 W bulb in one hour is:
(A) 140 J (B) 1440 J
(C) 14400 J (D) 144000 J ✓
14. One Ohm is equal to:
(A) VC^{-1} (B) CV^{-1}
(C) AC^{-1} (D) VA^{-1} ✓
15. For Ohmic device the graph between V and I is:
(A) A straight line ✓ (B) Curve
(C) Hyperbola (D) Parabola
16. The current through a resistance of 100Ω when connected across a source of 220 V is:
(A) 22000 A (B) 22 A
(C) 2.2 A ✓ (D) 0.45 A
17. The current flowing through each resistor of equal resistance in parallel combination is:
(A) Same ✓ (B) Difference
(C) Zero (D) Infinite
18. A 100 W bulb is switched on for an hour. Heat lost due to flow of current is:
(A) 0.36 MJ ✓ (B) 18 MJ
(C) 3 kJ (D) 0.18 MJ
19. Three resistance each of 4Ω are connected to form a triangle, the resistance between any two terminals is:
(A) 4Ω (B) 12Ω
(C) $8/3 \Omega$ ✓ (D) $3/8 \Omega$
20. Magnetic effect of current is used in:
(A) Toaster (B) Electric motor ✓
(C) Electric iron (D) D.C battery
21. The amount of heat produced in a resistor when a current is passed through it, can be found by using:
(A) Joule's law ✓ (B) Kirchhoff's rule
(C) Faraday's law (D) Lenz's law
22. Three resistances 1Ω , 2Ω and 3Ω are connected in series to a battery of 9 volts. The value of current will be:
(A) 1.5 A ✓ (B) 1.0 A
(C) 0.5 A (D) 2.0 A
23. Three resistors of resistance 2Ω , 3Ω , 6Ω are connected in series. Their equivalent resistance is:
(A) 10Ω (B) 11Ω ✓
(C) $1/10 \Omega$ (D) $1/11 \Omega$
24. The heat produced by the passage of current through a resistor is:
(A) $H = I^2 R t$ ✓ (B) $H = I R^2 t$
(C) $H = \frac{1}{H t}$ (D) $H = \frac{I^2}{R t}$
25. The temperature coefficient of resistance of a semiconductor is:
(A) Positive (B) Negative ✓
(C) Imaginary (D) Zero
26. Calculate the rate at which energy is transferred by 220 V mains supply which provides a current of 0.1 A to a LED?
(A) 22 kW ✓ (B) 22 W
(C) 2.2 kW (D) 2.2 W
27. The change in a resistance of metallic conductor below $0^\circ C$?
(A) Nonlinear (B) Curve
(C) Linear ✓ (D) Curvilinear
28. When a wire is compressed and its radius becomes $2R$, then its resistance will be:
(A) 16 R (B) 4 R
(C) $1/16 R$ ✓ (D) $1/4 R$
29. The resistance of a wire of uniform diameter d and length l is R . The resistance of another wire of the same material but diameter $2d$ and length $4l$ will be:
(A) $2R$ (B) $\frac{R}{2}$
(C) R ✓ (D) $\frac{R}{3}$
30. A 100 W, 200 V bulb is connected to a 160 V supply. The actual power consumption would be:
(A) 64 W ✓ (B) 100 W
(C) 72 W (D) 90 W
31. A typical mobile phone of 5.0 V and an internal resistance of $200 m \Omega$. What is the terminal P.D of the battery when it supports a current of 500 mA?
(A) 4.8 V (B) 4.9 V ✓
(C) 5.0 V (D) 5.1 V
32. A car battery has EMF of 12 Volts and internal resistance $5 \times 10^{-2} \Omega$. If it draws 60 ampere current, then terminal voltage of the battery will be:
(A) 5 volts (B) 3 volts
(C) 15 volts (D) 9 volts ✓
33. A new flashlight cell of emf 1.5 volts gives a current of 15 A, when connected directly to an ammeter of resistance 0.04Ω . The internal resistance of cell is:
(A) 0.04Ω (B) 0.10Ω
(C) 0.06Ω ✓ (D) 10Ω
34. What will be energy used by the battery if the battery has to drive 6.28×10^{18} electrons with potential difference of 20V across the terminal?
(A) 5 joules (B) 15 joules
(C) 10 joules (D) 20 joules ✓
35. The reciprocal of resistance is called:
(A) Capacitance (B) Resistance
(C) Conductance ✓ (D) Inductance

36. By increasing the temperature of the conductor, the flow rate of charge:
 (A) Increases (B) remain constant
 (C) Change exponentially (D) decreases ✓
37. Heat sensitive resistors are called:
 (A) Resistors (B) Capacitors
 (C) Thermistors ✓ (D) Inductors
38. The resistance of a conductor of length L , cross-sectional area 'A' and resistivity ' ρ ' is given by:
 (A) $R = \frac{\rho}{AL}$ (B) $R = \rho AL$
 (C) $R = \rho \frac{L}{A}$ ✓ (D) $R = \rho \frac{A}{L}$
39. The reciprocal of resistance is called:
 (A) Reactance (B) Inductance
 (C) Conductance ✓ (D) Conductivity
40. mho m^{-1} is the SI unit of:
 (A) Conductance (B) Conductivity ✓
 (C) Resistance (D) Resistivity
41. When a wire of resistance R is cut into two equal parts then resistance of each wire is:
 (A) Double (B) Half ✓
 (C) Remain same (D) One forth
42. Resistivity at a given temperature depends upon:
 (A) Area of cross-section (B) Length
 (C) Nature of material of conductor ✓
 (D) Both length and area
43. The resistivity of a conductor increases with:
 (A) Increase in its length (B) Increase in its area
 (C) Increase in its temperature ✓
 (D) Decrease in its length
44. Siemens is the unit of:
 (A) Resistance (B) Conductance ✓
 (C) Resistivity (D) Conductivity
45. A wire of resistance R is cut into two equal parts, its resistance becomes $R/2$. What happens to resistivity:
 (A) Double (B) Same ✓
 (C) Half (D) One fourth
46. Temperature coefficient of resistance (α) is equal to:
 (A) $\frac{R_1 + R_0}{R_0 \Delta t}$ (B) $\frac{R_0 - R_1}{R_0 \Delta t}$
 (C) $\frac{R_1 - R_0}{R_0 \Delta t}$ (D) None of these ✓
47. A certain wire has a resistance R , the resistivity of another wire of an identical material with the first, except for its diameter is:
 (A) $\frac{1}{4} R$ (B) $4R$
 (C) $2R$ (D) Same as R ✓
48. The unit of temperature co-efficient of resistivity is:
 (A) K ✓ (B) K^{-1}
 (C) Ω (D) $^{\circ}C$
49. The SI unit of resistivity is:
 (A) Ωm^{-2} (B) m^{-1}
 (C) Ωm ✓ (D) Ω
50. Specific resistance of material depends upon:
 (A) Length (B) Area
 (C) Temperature ✓ (D) Both (A) & (B)
51. If the temperature of a conductor is increased, the product of resistivity and conductivity:
 (A) Increases (B) Decreases
 (C) Remains constant ✓
 (D) May increases or decrease
52. The substance having negative temperature co-efficient is:
 (A) Carbon ✓ (B) Iron
 (C) Tungsten (D) Gold
53. The SI unit of conductance is:
 (A) siemens ✓ (B) ohm
 (C) henry (D) weber
54. On increasing the length of wire specific resistance of the wire:
 (A) Increases (B) Decreases
 (C) Remains unchanged ✓
 (D) First increase then decreases
55. If the length of the conductor is doubled and its cross-sectional area is halved, its conductance will:
 (A) Increase four time (B) Becomes one-fourth ✓
 (C) Becomes one - half (D) Remains unchanged
56. SI unit of conductivity is:
 (A) $S m^{-1}$ ✓ (B) Siemens
 (C) Ωm (D) ΩK^{-1}
57. A wire of length ' l ' and resistance R is cut into three pieces and twisted. Equivalent resistance will be:
 (A) R (B) $R/3$
 (C) $R/9$ ✓ (D) $R/4$
58. Which one is used as temperature sensor in electrical circuit:
 (A) Capacitor (B) Diode
 (C) LDR (D) Thermistor ✓

9.14 ELECTRICAL POWER



23. Define electrical power and prove that; $P = V^2/R$.

Ans. Electrical Power

Definition

Electrical power is the rate at which electrical energy is transferred or converted into another form such as heat, light or mechanical energy in an electric circuit

Explanation

Consider a circuit consisting of a battery of emf ϵ connected in series with a resistance R ; Fig. 19. A steady current I flows through the circuit and a steady potential difference V exists between the terminals A and B of the resistor R . Terminal A, connected to the positive pole of the battery, is at a higher potential than the terminal B. In this circuit the battery is continuously lifting charge uphill through the potential difference V . Using the meaning of potential difference, the work done in moving a charge Q up through the potential difference V is given by

$$\text{Work done} = W = V \times Q \quad \dots\dots (i)$$

This is the energy supplied by the battery.

The rate at which the battery is supplying electrical energy is the power output or electrical power of the battery. Using the definition of power;

$$\text{Electrical power} = \frac{\text{Energy supplied}}{\text{Time taken}} = V \frac{Q}{t}$$

Since $I = \frac{Q}{t}$

The above equation can also be written as:

$$\text{Electrical power } P = VI \quad \dots\dots (ii)$$

Equation 9.42 is a general relation for power delivered from a source of current I operating on a voltage V . In the circuit shown in Fig. 19 the power supplied by the battery is expended or dissipated in the resistor R . The principle of conservation of energy tells us that the power dissipated in the resistor is also given by Eq. 9.42.

$$\text{Power dissipated } P = VI$$

Alternative equation for calculating power can be found by substituting $V = IR$, $I = V/R$ in turn in Eq. 9.42.

$$P = VI = (IR) I = I^2 R$$

$$\text{or } P = VI = V(V/R) = V^2 / R$$

Thus, we have three equations for calculating the power dissipated in a resistor.

$$P = VI, \quad P = I^2 R$$

$$P = V^2 / R \quad \dots\dots (iii)$$

Unit: If V is expressed in volts and I in amperes, the unit of power is watts (W).

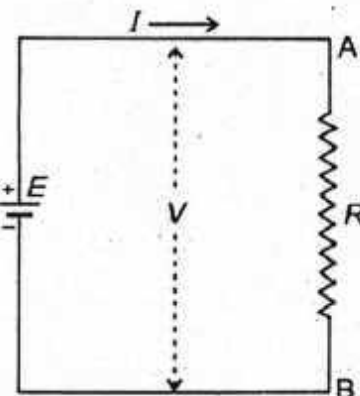


Fig. 19: The power of a battery appears as the power dissipated in the resistance R .

9.15 ELECTROMOTIVE FORCE (EMF) AND POTENTIAL DIFFERENCE



24. Define and explain the terms electromotive force (emf) and potential difference (p.d).

Ans. Electromotive Force

Definition

Electromotive force (emf) is the energy provided by a source (like a battery or generator) per unit charge to move electric charges through a circuit.

Explanation

Suppose when a steady current has been established in the circuit, a charge Q passes through any cross-section of the circuit in time t . During the course of motion, this charge enters the cell at its low potential end and leaves at its high potential end. The source must supply energy W to the positive charge to compel it to go to the point of high potential. The emf E of the source is defined as the energy supplied to unit charge by the cell.

$$\text{i.e., } E = \frac{W}{Q} \quad \dots\dots (i)$$

Unit: The unit of emf is joule per coulomb which is volt (V).

Like other components in a circuit, a cell also offers some resistance. This resistance is due to the electrolyte present between the two electrodes of the cell and is called the internal resistance of the cell.

Thus, a cell of emf E having an internal resistance r is equivalent to a

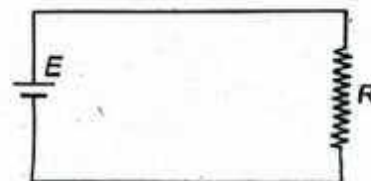


Fig. 20: Electromotive force of a cell

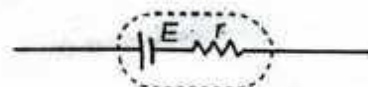


Fig. 21: An equivalent circuit of a cell

source of pure emf E with a resistance r in series; Fig. 21.

of emf E and internal resistance r .

Potential Difference

Definition

It is the amount of work done to move a unit positive charge from one point to another in a electric field.

Explanation

Let us consider the performance of a cell of emf E and internal resistance r as shown in Fig. 22. A voltmeter of infinite resistance measures the potential difference across the external resistance R or the potential difference V across the terminals of the cell. The current I flowing through the circuit is given by

$$I = \frac{E}{R + r}$$

or

$$E = IR + Ir$$

..... (ii)

Here $IR = V$ is the terminal potential difference of the cell in the presence of current I . When the switch S is open, no current passes through the resistance.

In this case, the voltmeter reads the emf E as terminal voltage. Thus, terminal voltage in the presence of the current (switch ON) would be less than the emf E by Ir .

Let us interpret the Eq. (ii) on energy considerations. The left side of this equation is the emf E of the cell which is equal to energy gained by unit charge as it passes through the cell from its negative to positive terminal. The right side of the equation gives an account of the utilization of this energy as the current passes the circuit. It states that, as a unit charge passes through the circuit, a part of this energy equal to Ir is dissipated into the cell and the rest of

the energy is dissipated into the external resistance R . It is given by potential drop IR . Thus, the emf gives the energy supplied to unit charge by the cell and the potential drop across the various elements account for the dissipation of this energy into other forms as the unit charge passes through these elements.

The emf is the "cause" and potential difference is its "effect". The emf is always present even when no current is drawn through the battery or the cell, but the potential difference across the conductor is zero when no current flows through it.

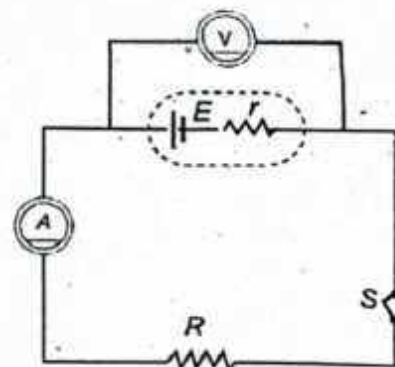
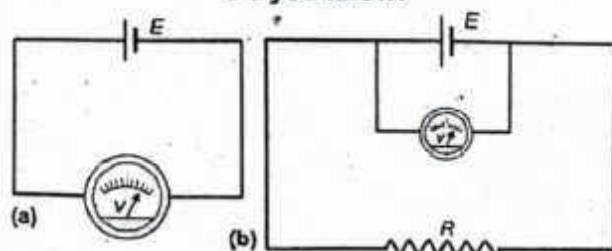


Fig. 22: The terminal potential difference V of a cell is $E - Ir$.

Do you know?



A volt meter connected across the terminals of a cell measures:

- (a) The emf of the cell on open circuit,
- (b) The terminal potential difference on a closed circuit

Example 9.10: The potential difference between the terminals of a battery in open circuit is 2.2 V. When it is connected across a resistance of 5.0Ω , the potential falls to 1.8 V. Calculate the current and the internal resistance of the battery.

Solution:

Given that;

$$E = 2.2 \text{ V}, \quad R = 5.0 \Omega, \quad V = 1.8 \text{ V}$$

To Find:

$$I = ? \text{ and } r = ?$$

Calculations We have to calculate I and r , using the equation:

$$V = IR \quad \text{or} \quad I = \frac{V}{R} = \frac{1.8 \text{ V}}{5.0 \Omega} = 0.36 \text{ A} \quad \text{Ans.}$$

Internal resistance r can be calculated by using

$$E = V + Ir$$

$$2.2 \text{ V} = 1.8 \text{ V} + 0.36 \text{ A} \times r$$

or

$$r = 1.1 \Omega \quad \text{Ans.}$$

1. Power in an electrical circuit is given by
(A) V/I (B) $I^2 R$ ✓
(C) R/I^2 (D) V^2/I
2. The device used to measure electrical power in a circuit is:
(A) Voltmeter (B) Ammeter
(C) Wattmeter ✓ (D) Ohm-meter
3. The power consumed by a 60 W bulb if it is used for 10 hours is:
(A) 600 Wh ✓ (B) 6000 Wh
(C) 60 Wh (D) 600 kWh
4. The unit of electromotive force is:
(A) newton (B) pascal
(C) volt ✓ (D) ampere
5. Which equation represents the maximum output power?
(A) $P = \frac{E^2}{4R}$ (B) $P = \frac{E^2}{4r}$ ✓
(C) $P = \frac{E^2}{4R^2}$ (D) $P = \frac{E^2}{4r^2}$
6. Electrical energy is measured in:
(A) watt (B) horse power
(C) kilowatt (D) kilowatt-hour ✓
7. When the internal resistance of a source is equal to the load, maximum power dissipated is:
(A) $\frac{E}{4r}$ (B) $\frac{E^2}{4r}$ ✓
(C) $\frac{E}{4r^2}$ (D) $\frac{E^2}{4r^2}$
8. For a closed circuit:
(A) $E = V_t$ (B) $E > V_t$ ✓
(C) $E < V_t$ (D) $E = V_t - I_r$
9. The 'emf' even when no current is drawn through the battery or cell is always:
(A) Zero (B) Present ✓
(C) Absent (D) Maximum
10. The maximum power (P_{out}) is delivered to a load resistance R , when the internal resistance of the source is:
(A) $r = \infty$ ✓ (B) $r = R$
(C) $r = 0$ (D) $r = \frac{R}{4}$
11. An ideal current source shall have resistance:
(A) zero (B) finite but not zero ✓
(C) infinite (D) depends upon requirement
12. For an open circuit, terminal potential difference ' V_t ' is:
(A) $V_t = 2 \text{ emf}$ (B) $V_t = \text{emf}$ ✓
(C) $V_t > \text{emf}$ (D) $V_t < \text{emf}$
13. Power of an electric generator of voltage (V) and driving current (I) through an appliance is:
(A) $P = VI$ (B) $P = I^2 R$
(C) $P = \frac{V^2}{R}$ (D) All of these ✓
14. A one farad capacitor is charged to 100V and then discharge through 11 k Ω resistance. The total energy dissipated through resistor is:
(A) 5 kJ (B) 10 kJ ✓
(C) 2 kJ (D) 100 kJ
15. Which factor does not affect the emf of a cell?
(A) Temperature (B) Size of the cell
(C) Type of electrolyte
(D) External circuit resistance ✓

9.16 KIRCHHOFF'S RULES



25. State and explain Kirchhoff's first rule.

Ans. Kirchhoff's First Rule

Statement

It states that the sum of all the currents meeting at a point in the circuit is zero.

i.e., $\Sigma I = 0$ (i)

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

Explanation

Consider a situation where four wires meet at a point A; Fig. 23. The currents flowing into the point A are I_1 and I_2 and currents flowing away from the point are I_3 and I_4 .

For your information

A node is a point in an electric circuit which joins the two or more branches.

According to the convention, currents I_1 and I_2 are positive and currents I_3 and I_4 are negative. Applying Eq. (i), we have

$$I_1 + I_2 + (-I_3) + (-I_4) = 0$$

or $I_1 + I_2 = I_3 + I_4$

Using Eq. (i), Kirchhoff's first rule can be stated in other words as:

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

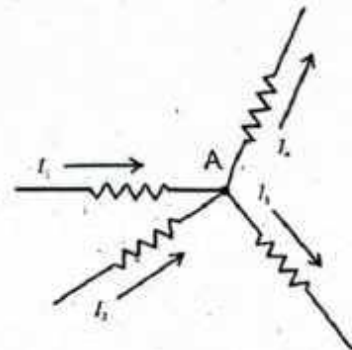


Fig. 23: According to Kirchhoff's 1st rule $I_1 + I_2 = I_3 + I_4$

For Your Information

Kirchhoff's first rule which is also known as Kirchhoff's point rule is a manifestation of law of conservation of charge. If there is no sink or source of charge at a point, the total charge flowing towards the point must be equal to the total charge flowing away from it.

Do you know?

The node at which potential is taken as zero is called datum node or reference node.



26. State and explain Kirchhoff's second rule.

Ans. Kirchhoff's Second Rule

Statement

The algebraic sum of voltage changes in a closed circuit or a loop must be equal to zero.

Explanation

Consider a closed circuit; Fig. 24. The direction of the current I flowing through the circuit depends on the cell having the greater emf. Suppose E_1 is greater than E_2 , so the current flows in counter clockwise direction. We know that a steady current is equivalent to a continuous flow of positive charges through the circuit. A voltage change or potential difference is equal to the work done on a unit positive charge or energy gained or lost by it in moving from one point to the other. Thus, when a positive charge Q due to the current I in the closed circuit, passes through the cell E_1 from low (-ve) to high potential (+ve), it gains energy because work is done on it. Using Eq. (i) the energy gain is E_1Q . When the current passes through the cell E_2 , it loses energy equal to $-E_2Q$ because here the charge passes from high to low potential. In going through the resistor R_1 , the charge Q loses energy equal to $-IR_1Q$ where IR_1 is potential difference across R_1 . The minus sign shows that the charge is passing from high to low potential. Similarly, the loss of energy while passing through the resistor R_2 is $-IR_2Q$. Finally, the charge reaches the negative terminal of the cell E_1 , from where we started. According to the law of conservation of energy, the total change in energy of our system is zero. Therefore, we can write:

$$E_1Q - IR_1Q - E_2Q - IR_2Q = 0 \quad \dots\dots (i)$$

or

$$E_1 - IR_1 - E_2 - IR_2 = 0$$

which is Kirchhoff's second rule and it states that:

The algebraic sum of potential changes in a closed circuit is zero.

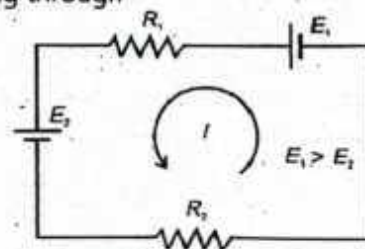
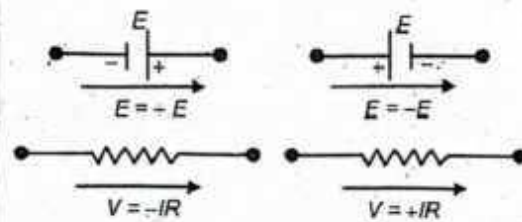


Fig. 24: According to Kirchhoff's 2nd rule $E_1 - IR_1 - E_2 - IR_2 = 0$

Applications

1. This rule is a particular way of stating the law of conservation of energy in electrical problems.
2. It is worthwhile to thoroughly understand the rules for finding the potential changes.
3. If a source of emf is traversed from positive to negative terminal, the potential change is positive. It is negative in the opposite direction.

For your information



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

Example 9.11: Calculate the currents in the three resistances of the circuit shown in the figure.

Calculations: First we select two loops $abcda$ and $ebcfe$. The choice of loops is quite arbitrary, but it should be such that each resistance is included at least once in the selected loops.

After selecting the loops, suppose a current I_1 is flowing in the first loop and I_2 in the second loop, all flowing in the same sense. These currents are

called loop currents. The actual currents will be calculated with their help. It should be noted that the sense of the current flowing in all loops should essentially be the same. It may be clockwise or anticlockwise. Here we have assumed it to be clockwise.

We now apply Kirchhoff's second rule to obtain the equations required to calculate the currents through the resistances. We first consider the loop $abcda$. Starting at point a we follow the loop clockwise. The voltage change while crossing the battery E_1 is $-E_1$ because the current flows through it from positive to negative. The voltage change across R_1 is $-I_1 R_1$. The resistance R_2 is common to both the loops I_1 and I_2 , therefore, the currents I_1 and I_2 simultaneously flow through it. The directions of currents I_1 and I_2 as flowing through R_2 are opposite, so we have to decide that which of these currents is to be assigned a positive sign. The convention regarding the sign of the current is that if we are applying the Kirchhoff's second rule in the first loop, then the current of this loop i.e., I_1 will be assigned a positive sign and all currents flowing opposite to I_1 have a negative sign. Similarly, while applying Kirchhoff's second rule in the second loop, the current I_2 will be considered as positive and I_1 as negative. Using this convention the current flowing through R_2 is $(I_1 - I_2)$ and the voltage change across is $-(I_1 - I_2) R_2$. The voltage change across the battery E_2 is E_2 . Thus, the Kirchhoff's second rule as applied to the loop $abcda$ gives

$$-E_1 - I_1 R_1 - (I_1 - I_2) R_2 + E_2 = 0$$

Substituting the values, we have

$$-40V - I_2 \times 10 \Omega - (I_1 - I_2) \times 30 \Omega + 60V = 0$$

$$20V - 10 \Omega \times [I_1 + 3(I_1 - I_2)] = 0$$

or

$$4I_1 - 3I_2 = 2V \Omega^{-1} = 2A \quad \text{..... (i)}$$

Similarly, applying Kirchhoff's second rule to the loop $ebcfe$, we have

$$-E_2 - (I_2 - I_1) R_2 - I_2 R_3 + E_3 = 0$$

Substituting the values

$$-60V - (I_2 - I_1) \times 30 \Omega - I_2 \times 15 \Omega + 50V = 0$$

$$-10V - 15 \Omega \times [I_2 + 2(I_2 - I_1)] = 0$$

$$6I_1 - 9I_2 = 2V \Omega^{-1} = 2A \quad \text{..... (ii)}$$

Solving Eq.(i) and Eq. (ii) for I_1 and I_2 , we have

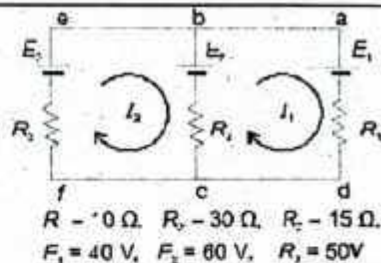
$$I_1 = 0.66A \text{ and } I_2 = 0.22A$$

Knowing the value of loop currents I_1 and I_2 the actual current flowing through each resistance of the circuit can be determined. Figure shows that I_1 and I_2 are the actual currents through the resistances R_1 and R_3 . The actual current through R_2 is the difference of I_1 and I_2 and its direction is along the larger current. Thus,

The current through $R_1 = I_1 = 2/3A = 0.66A$ flowing in the direction of I_1 i.e., from a to d .

The current through $R_2 = I_1 - I_2 = 2/3A - 2/9A = 0.44A$ flowing in the direction of I_1 i.e., from c to b .

The current through $R_3 = I_2 = 2/9A = 0.22A$ flowing in the direction of I_2 i.e., from f to e .



27. Describe the procedure of solving circuit problems.

Ans. Procedures of Solution of Circuit Problems

After solving example 9.11, we are in a position to apply the same procedure to analyse other direct current complex networks. While using Kirchhoff's rules in other problems, it is worthwhile to follow the approach given below:

- (i) Draw the circuit diagram.
- (ii) The choice of loops should be such that each resistance is included at least once in the selected loops.
- (iii) Assume a loop current in each loop. All the loop currents should be in the same sense. It may be either clockwise or anticlockwise.
- (iv) Write the loop equations for all the selected loops. For writing each loop equation, the voltage change across any component is positive if traversed from low to high potential and it is negative if traversed from high to low potential.
- (v) Solve these equations for the unknown quantities.



- | | |
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| <p>1. Kirchhoff's first rule is applicable to:
 (A) Only DC circuits (B) Only AC circuits
 (C) Both AC and DC circuits ✓
 (D) Only resistive circuits</p> <p>2. Kirchhoff's current law implies that at a junction:
 (A) Current accumulates over time
 (B) Net current is always zero ✓
 (C) Voltage is zero
 (D) Power is conserved</p> <p>3. Which of the following is an example of Kirchhoff's first rule:
 (A) $I_1 = I_2 + I_3$ at a junction ✓
 (B) $V = IR$
 (C) $V_1 + V_2 = V_3$ (D) $R_{eq} = R_1 + R_2$</p> <p>4. Kirchhoff's first law is applicable to:
 (A) Series circuits only (B) Parallel circuits only
 (C) Any electrical circuit ✓ (D) Circuits with resistors only</p> <p>5. According to Kirchhoff's voltage law, the algebraic sum of all the p.d. in a closed loop is:
 (A) Equal to the resistance (B) Equal to zero ✓</p> | <p>(C) Maximum (D) Equal to the power</p> <p>6. In Kirchhoff's second law, if you go across a resistor in the direction of current, the voltage:
 (A) Increases (B) Becomes zero
 (C) Decreases ✓ (D) Remains constant</p> <p>7. The sum of emfs and potential drop around a closed loop is:
 (A) Equal to current (B) Equal to resistance
 (C) Infinity (D) Zero ✓</p> <p>8. Kirchhoff's first rule is the manifestation of the law of conservation of:
 (A) Mass (B) Charge ✓
 (C) Energy (D) Momentum</p> <p>9. Kirchhoff's voltage rule is a way of stating conservation of:
 (A) Energy ✓ (B) Momentum
 (C) Charge (D) Angular momentum</p> <p>10. Kirchhoff's second rule is a way of stating conservation of:
 (A) Mass (B) Charge
 (C) Energy ✓ (D) Momentum</p> |
|---|---|

9.17 WHEATSTONE BRIDGE



28. What is Wheatstone bridge? Explain its construction working with the help of a diagram.

Ans. Wheatstone Bridge

The Wheatstone bridge is an electrical circuit used to precisely measure an unknown resistance by balancing two legs of a bridge circuit.

Construction and working

The Wheatstone bridge circuit; Fig. 25 consists of four resistances R_1 , R_2 , R_3 and R_4 connected in such a way so as to form a mesh ABCDA. A battery is connected between points A and C. A sensitive galvanometer of resistance R_g is connected between points B and D. If the switch S is closed, a current will flow through the galvanometer. We have to determine the condition under which no current flows through the galvanometer even after the switch is closed. For this purpose, we analyse this circuit using Kirchhoff's second rule. We consider two loops ABDA and BCDB and assume anticlockwise loop currents I_1 and I_2 through the loops respectively. The Kirchhoff's second rule as applied to loop ABDA gives:

$$-I_1 R_1 - (I_1 - I_2) R_g - I_1 R_3 = 0 \quad \dots (i)$$

Similarly, by applying the Kirchhoff's second rule to loop BCDB, we have

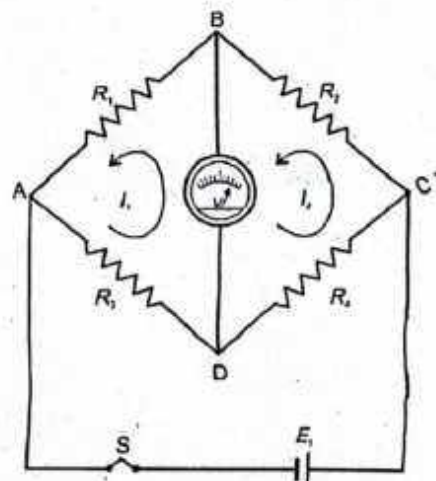


Fig. 25: Wheatstone bridge circuit

$$-I_2 R_2 - I_2 R_4 - (I_2 - I_1) R_g = 0 \quad \dots\dots (ii)$$

The current flowing through the galvanometer will be zero if, $I_1 - I_2 = 0$ or $I_1 = I_2$. With this condition Eqs. (i) and (ii) reduce to:

$$-I_1 R_1 = I_1 R_3 \quad \dots\dots (iii)$$

$$-I_2 R_2 = I_2 R_4 \quad \dots\dots (iv)$$

Dividing Eq. (i) by Eq. (ii):

$$\frac{-I_1 R_1}{-I_2 R_2} = \frac{I_1 R_3}{I_2 R_4} \quad \dots\dots (v)$$

As $I_1 = I_2$, therefore,

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \quad \dots\dots (vi)$$

Thus, whenever the condition of Eq. (vi) is satisfied, no current flows through the galvanometer and it shows no deflection, or conversely when the galvanometer in the Wheatstone bridge circuit shows no deflection, Eq. (vi) is satisfied. If we connect three resistances R_1 , R_2 and R_3 of known adjustable values and a fourth

resistance R_4 of unknown value and the resistances R_1 , R_2 and R_3 are so adjusted that the galvanometer shows no deflection, then from the known resistances R_1 , R_2 and R_3 , the unknown resistance R_4 can be determined by using Eq. (vi).

Point to ponder!

Why is a three-pin plug used in some electric appliances?

Ans. A three-pin plug is used in some electric appliances for safety and proper functioning. In short, three-pin plugs are used for appliances that require earthing for safety, especially those with metal exteriors or higher power ratings.



- | | |
|---|---|
| <p>1. The Wheatstone bridge is used to measure:
 (A) Current (B) Voltage
 (C) Unknown resistance ✓ (D) Capacitance</p> <p>2. In an unbalanced Wheatstone bridge, the p.d. between the two mid-points is:
 (A) Maximum (B) Zero ✓
 (C) Equal to the battery voltage
 (D) Equal to the resistance between the points</p> <p>3. The Wheatstone bridge is said to be balanced when:
 (A) $R_1 + R_2 = R_3 + R_4$ (B) $R_1 + R_3 = R_2 + R_4$
 (C) $R_1 \cdot R_4 = R_2 \cdot R_3$ (D) $\frac{R_1}{R_2} = \frac{R_3}{R_4}$ ✓</p> <p>4. If the Wheatstone bridge is balanced, and one of the resistors is changed, the galvanometer will:
 (A) show zero deflection
 (B) show maximum deflection ✓
 (C) Burn out (D) Act like an open circuit</p> | <p>5. In a Wheatstone bridge, the galvanometer is connected between:
 (A) Battery and ground
 (B) Two opposite corners of the bridge
 (C) Mid-points of the two series branches ✓
 (D) In parallel with a resistor</p> <p>6. The accuracy of a Wheatstone bridge depends on:
 (A) Battery voltage (B) Galvanometer resistance
 (C) Accuracy of known resistors ✓
 (D) Length of connecting wires</p> <p>7. In Wheatstone bridge, if $R_1 = 100 \Omega$, $R_2 = 200 \Omega$ and $R_3 = 150 \Omega$, what must R_4 be for balance?
 (A) 75Ω (B) 300Ω ✓
 (C) 100Ω (D) 200Ω</p> <p>8. The principle of Wheatstone bridge is based on:
 (A) Ohm's law (B) Faraday's law
 (C) Coulomb's law (D) Kirchhoff's law ✓</p> |
|---|---|

9.18 POTENTIOMETER



29. What is a potentiometer? Describe its working and construction.

Ans. Potentiometer

Definition

A very simple instrument which can measure and compare potential differences accurately is a potentiometer.

A potentiometer is mainly used to compare potential differences and to find the value of an unknown resistance.

It works on the principle of Wheatstone bridge.

Construction and Working of Potentiometer

A potentiometer consists of a resistor R in the form of a wire on which a terminal C can slide; Fig. 26(a). The resistance between A and C can be varied from 0 to R as the sliding contact C is moved from A to B . If a battery of emf E is connected across R ; Fig. 26(b) the current flowing through it is $I = E/R$. If we represent the resistance between A and C by r , the potential drop between these points will be $rI = rE/R$. Thus, as C is moved from A to B , r varies from 0 to R and the potential drop between A and C changes from 0 to E .

Such an arrangement also known as potential divider can be used to measure the unknown emf of a source by using the circuit; Fig. 27. Here R is in the form of a straight wire of uniform area of cross-section. A source of potential, a cell whose emf E_x is to be measured, is connected between A and the sliding contact C through a galvanometer G . The positive terminal of E_x and that of the potential

divider are connected to the same point A . If, in the loop $AGCA$, the point C and the negative terminal of E_x are at the same potential, then the two terminals of the galvanometer will be at the same potential and no current will flow through the galvanometer. Therefore, to measure the potential E_x , the position of C is so adjusted that the galvanometer shows no deflection. Under this condition, the emf E_x of the cell is equal to the potential difference between A and C whose value E_r/R is known. In case of a wire of uniform cross-section, the resistance is proportional to the length of the wire. Therefore, the unknown emf is also given by

$$E_x = E \frac{r}{R} = E \frac{l}{L} \quad \dots\dots (i)$$

where L is the total length of the wire AB and l is its length from A to C , after C has been adjusted for no deflection. As the maximum potential that can be obtained between A and C is E , so the unknown emf E_x should not exceed this value, otherwise the null condition will not be obtained. It can be seen that the unknown emf E_x is determined when no current is drawn from it and therefore, potentiometer is one of the most accurate methods for measuring potential.

The method for measuring the emf of a cell as described above can be used to compare the emfs E_1 and E_2 of two cells. The balancing lengths l_1 and l_2 are found separately for the two cells. Then,

$$E_1 = E \frac{l_1}{L} \quad \dots\dots (ii)$$

and
$$E_2 = E \frac{l_2}{L} \quad \dots\dots (iii)$$

Dividing Eq. (ii) by Eq. (iii);

$$\frac{E_1}{E_2} = \frac{l_1}{l_2}$$

So, the ratio of the emfs is equal to ratio of the balancing lengths.

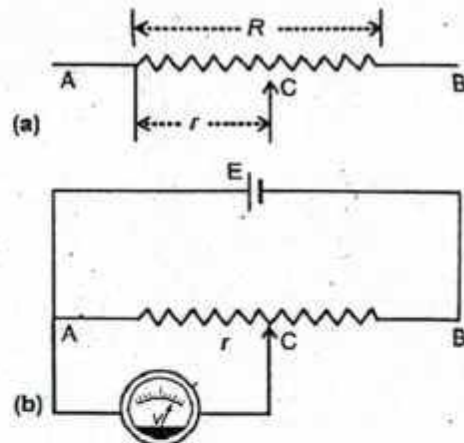


Fig. 9.26

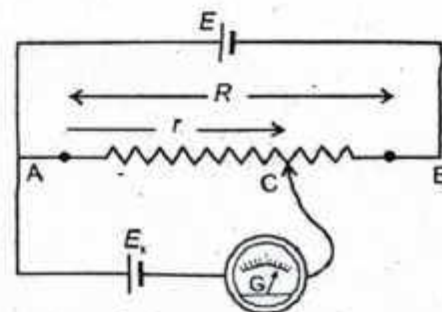


Fig. 9.27

9.19 USE OF A GALVANOMETER



30. What is a galvanometer? Describe null method and advantages of a galvanometer.

Ans. Use of a Galvanometer

A galvanometer is an instrument for detecting a current.

Null Method

A galvanometer is often used in null methods to achieve precise measurements in electrical circuits. The null method involves adjusting the circuit until the galvanometer shows no deflection i.e., a zero reading. This

indicates that certain required conditions are met in the circuit. In this state, the electric potentials at both ends of the galvanometer are the same. Although a galvanometer has its own resistance, but at the null reading, its resistance does not come into play. The reason is that, in this condition no current is passing through it. The null method is widely used in bridge circuits such as Wheatstone and potentiometer setups.

As the null method is used to measure an unknown resistance in the Wheatstone bridge circuits. The galvanometer is connected between the mid-points of opposite sides. The variable resistance is adjusted until the galvanometer shows no deflection. At this point, the bridge is balanced and the unknown resistance can be calculated using the ratio of the known resistances.

In a potentiometer, null method is used to measure an unknown voltage by comparison with a known reference voltage applied across the resistance wire of the potentiometer. A galvanometer and a jockey are used to make contact along the wire. At null point, the potential difference between the jockey and the end of the wire equals the unknown voltage. The position of the jockey gives the measure of the unknown voltage.

Advantages of Using Galvanometer Null Method

There are some advantages of using a galvanometer in null method.

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



- | | |
|---|---|
| <ol style="list-style-type: none"> 1. Potentiometer can be used as:
 (A) Ohm meter (B) Ammeter
 (C) Galvanometer (D) Potential divider ✓ 2. The relation of emfs of two cells $\frac{E_1}{E_2}$ is equal to:
 (A) $\frac{l_2}{l_1}$ (B) $\frac{l_1}{l_2}$ ✓
 (C) $\frac{1}{l_1 l_2}$ (D) $l_1 \times l_2$ 3. Which one of the following is used to determine internal resistance of a cell?
 (A) Potentiometer ✓ (B) Wheat stone bridge
 (C) Ammeter (D) Voltmeter 4. The principle of a potentiometer is based on:
 (A) Ohm's law ✓ (B) Kirchhoff's law
 (C) Magnetic induction (D) Conservation of energy 5. A potentiometer is used to measure:
 (A) Current (B) Resistance
 (C) Power (D) Voltage accurately ✓ 6. The sensitivity of a potentiometer increases if:
 (A) Length of the wire is increased
 (B) Current in the wire is increased
 (C) Wire of high resistivity is used
 (D) Both (A) and (C) ✓ 7. A potentiometer can compare the emf of two cells because:
 (A) It uses a galvanometer (B) It measures current
 (C) It uses variable resistance
 (D) It works without drawing current from the cells ✓ 8. The balancing length in a potentiometer is directly proportional to:
 (A) Square of emf (B) Resistance of the wire
 (C) Emf of the cell ✓
 (D) Current through the galvanometer 9. In a potentiometer experiment, a null deflection means:
 (A) The p.d. is too high | (B) The p.d. across the wire equals the test emf ✓
(C) No voltage exists in the circuit
(D) There is no short circuit
<ol style="list-style-type: none"> 10. In the potentiometer, the null point is found when:
 (A) The galvanometer deflects to the right
 (B) The galvanometer deflects to the left
 (C) The resistance of the wire is zero
 (D) No current flows through the galvanometer ✓ 11. A galvanometer is primarily used to:
 (A) Measure voltage (B) Measure electric current
 (C) Measure resistance directly
 (D) Detect and measure small currents ✓ 12. The device based for the working principle of a galvanometer is:
 (A) Ammeter (B) Voltmeter
 (C) Both (A) and (B) ✓ (D) Ohm meter only 13. A galvanometer can be converted into an ammeter by
 (A) Connecting a high resistance in series
 (B) Connecting a low resistance in parallel ✓
 (C) Connecting a low resistance in series
 (D) Connecting a high resistance in parallel 14. A galvanometer can be converted into a voltmeter by
 (A) Connecting a low resistance in series
 (B) Connecting a high resistance in parallel
 (C) Connecting a high resistance in series ✓
 (D) Removing all resistances 15. The main limitation of a galvanometer is that, it:
 (A) Can only measure large current
 (B) Cannot detect current direction
 (C) Cannot measure voltage directly ✓
 (D) Is very accurate for high voltages 16. The detection of galvanometer is proportional to:
 (A) Voltage (B) Resistance
 (C) Current ✓ (D) Power |
|---|---|



31. What are thermistors? What is the effect of temperature on their resistance and how are they made?

Ans. Thermistor

Definition

A thermistor is a heat sensitive resistor.

Most thermistors have negative temperature coefficient of resistance, i.e., the resistance of such thermistors decreases when their temperature is increased. Thermistors with positive temperature coefficient are also available.

In the thermistors, resistance decreases as temperature increases. This is because increasing temperature provides more energy to the charge carriers (electrons or holes), enabling them to move more freely and thus reducing resistance.

Thermistors are made by heating under high pressure semiconductor ceramic made from mixtures of metallic oxides of manganese, nickel, cobalt, copper, iron, etc. These are pressed into

desired shapes and then baked at high temperature. Different types of thermistors; Fig. 28. They may be in the form of beads, rods or washers.

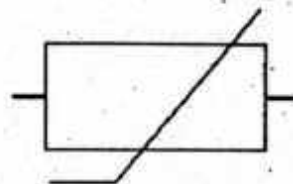


Fig. 28: Thermistors symbols



Fig. 28: Different types of thermistors



32. State some applications of thermistors.

Ans. Applications of Thermistors

1. Temperature Measurement

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

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

Thermistors have wide applications as temperature sensors, i.e. they convert changes of temperature into electrical voltage which is duly processed. For example, these are used in coolant temperature sensors in automobile engines to prevent the engine overheating and in digital thermometers.

2. Temperature Compensation

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

3. Inrush Current Limiting

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

4. Voltage Divider

Thermistors are widely used as voltage divider. As shown in Fig. 29 when temperature of a thermistor increases, its resistance decreases. This decreases the voltage drop across the thermistor. As a result, the potential at point B increases that can be used to trigger a circuit connected to it. In case of a fire alarm, the use of a thermistor turns the NOT gate low when it gets heated. The output of NOT gate goes high and turns the siren ON.

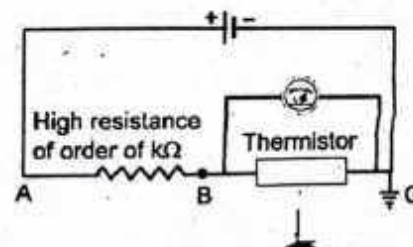


Fig. 29



1. The thermistors convert temperature into:
- | | |
|------------------|------------------------|
| (A) Light energy | (B) Electric voltage ✓ |
| (C) Heat | (D) Sound |

2. A thermistor with positive temperature coefficient is heated and its resistance will:
- | | |
|-----------------|-----------------------|
| (A) Decrease | (B) Increase ✓ |
| (C) Become half | (D) Remain unaffected |

3. **A thermistor is a type of:**
 - (A) Capacitor
 - (B) Diode
 - (C) Inductor
 - (D) Temperature-sensitive resistor ✓
4. **The resistance of a thermistor typically:**
 - (A) Decreases with temperature ✓
 - (B) Increases with temperature
 - (C) Increases with light intensity
 - (D) Remains constant with temperature
5. **A thermistor is commonly used in:**
 - (A) Tuning circuits
 - (B) Light sensors
 - (C) Temperature sensors ✓
 - (D) Audio amplifiers
6. **Which material is typically used to make thermistors?**
 - (A) Copper
 - (B) Insulators
 - (C) Semiconductors ✓
 - (D) Superconductors
7. **The unit of resistance of a thermistor is:**
 - (A) farad
 - (B) ohm
 - (C) kelvin ✓
 - (D) henry
8. **What is the main limitation of thermistors?**
 - (A) They are very large in size
 - (B) They cannot work in a circuit
 - (C) Their response is non-linear ✓
 - (D) They are extremely expensive

9.21 LIGHT DEPENDENT RESISTOR



33. What is a light dependent resistor? Describe its working principle.

Ans. Light Dependent Resistor

Light dependent resistor (LDR) is a resistor whose resistance decreases with increasing light intensity. Due to this property, it is also known as photo resistor. The LDRs are typically made from semiconductor material like cadmium sulphide. The material is deposited in a special pattern on an insulating plate.

Working Principle

The principle used in an LDR is the increase in the conductivity of the material on exposing it to light. In darkness, the semiconductor material has a few free electrons (charge carriers) resulting in high resistance. When light photons hit the material, they transfer energy to electrons in the outer orbits, thus, making them free to conduct electricity. This decreases the resistance of LDR. The amount of light hitting the LDR's surface determines the number of free electrons. Conversely, less light results in lowering the free electrons, thus, making higher resistance. This change in resistance can be measured and used in circuits to sense light levels.



34. State some applications of light dependent resistors.

Ans. Applications of LDRs

1. Light Sensors

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.

2. Camera Exposure Control

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

3. Voltage Divider

In a typical circuit, an LDR can be a part of voltage divider, that converts the resistance change into measurable voltage change. This voltage can then be read by a micro-controller or other control circuitry to perform actions based on light levels. A circuit, Fig. 30 in which an LDR is used as voltage divider. In the dark, the LDR has a very high resistance as compared to the standard resistance ($100\text{ k}\Omega$) in the circuit. Therefore the voltage drop across the LDR is very large as registered by a voltmeter. When the LDR is exposed to light, the resistance of LDR decreases to very low. Now, the voltmeter registers a lower reading. Hence, the change in light intensity gives rise to change in voltage. Therefore, by connecting mid-point B to a NOT gate, LDR can be used as a switch.

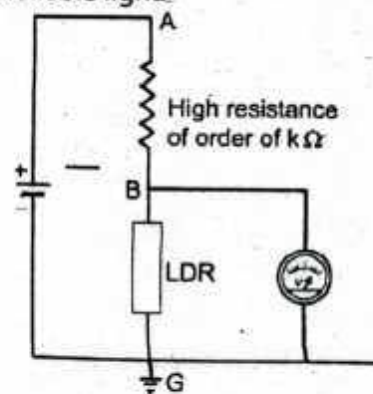


Fig. 30



35. How is reliability of a concrete bridge checked? Explain.

Ans. Reliability of a Concrete Bridge

Inspectors can easily check the reliability of concrete bridge with the help of carbon fibers embedded in its slab. This is possible because of the conducting property of the carbon fibers. Let us know step by step how does it work?

1. First step is to know the electrical properties of carbon fibers. Carbon fibers are known to be good conductors of electricity due to their high carbon content.
2. Secondly, we can embed the carbon fibers within the slab of the concrete bridge during its construction.
Then we can connect them to form a conductor network.
3. Inspectors can check the reliability of the concrete bridge by applying small electric current to the carbon fiber network. They can determine the integrity of the concrete structure by measuring the resistance of the network.
4. The sensor installed into the network can show whether the electric resistance is changing or not. If the resistance remains the same overtime, it indicates that the concrete bridge is maintaining its structural integrity. However, if the resistance increases, it means that the concrete is deteriorating or that the carbon fibers are being damaged.

Some other methods are also used to check the strength of the concrete bridge. For example, a type of sensors continuously monitor strain, vibration and temperature. Internal flaws, such as cracks or voids are detected by using ultrasound waves.



Fig. 31: Carbon fibre sheets



- | | |
|---|---|
| <p>1. As the intensity of light increases, the resistance of an LDR:</p> <p>(A) Decreases ✓ (B) Increases</p> <p>(C) Remains constant (D) Becomes infinite</p> | <p>(A) Increases with increase in light intensity</p> <p>(B) Decreases with decrease in light intensity ✓</p> <p>(C) Remains constant regardless of light</p> <p>(D) First increases then decreases</p> |
| <p>2. In darkness or low light conditions, the resistance of an LDR is:</p> <p>(A) Very low (B) Very high ✓</p> <p>(C) Zero (D) Constant</p> | <p>7. An LDR is most commonly used in:</p> <p>(A) Radio receivers (B) Power converters</p> <p>(C) Voltage amplifiers</p> <p>(D) Light-activated switches ✓</p> |
| <p>3. LDRs are commonly made from:</p> <p>(A) Silicon (B) Germanium</p> <p>(C) Cadmium sulphide (CdS) ✓</p> <p>(D) Copper</p> | <p>8. In an automatic street light system, the LDR is used to:</p> <p>(A) Turn lights on in the morning</p> <p>(B) Increase brightness during the day</p> <p>(C) Turn lights off during the night</p> <p>(D) Switch on light automatically at night ✓</p> |
| <p>4. What happens in a light-sensitive circuit when an LDR is exposed to bright light?</p> <p>(A) LDR resistance decreases ✓</p> <p>(B) Circuit resistance increases</p> <p>(C) Voltage across LDR increases</p> <p>(D) Current flow decreases</p> | <p>9. The working principle of an LDR is based on:</p> <p>(A) Photoemission (B) Thermal conduction</p> <p>(C) Photoconductivity ✓ (D) Hall effect</p> |
| <p>5. A light dependent resistor is a type of:</p> <p>(A) Capacitor (B) Transistor</p> <p>(C) Variable resistor ✓ (D) Diode</p> | <p>10. What is the primary drawback of LDRs in fast-switching applications?</p> <p>(A) High-cost (B) Non-linear response</p> <p>(C) Slow response ✓ (D) Inaccuracy in dark</p> |
| <p>6. The resistance of an LDR:</p> | |

ADDITIONAL SHORT ANSWER QUESTIONS



Q.1 What is the nature of force given by Coulomb's law?

Ans. It is an electrostatic force which can be either attractive or repulsive, depending on the sign of the charges.

Q.2 Can Coulomb's law be applied to large bodies?

Ans. No, it is valid only for point charges or spherically symmetric charge distributions.

Q.3 What is the effect of medium between the charges upon Coulomb's force? Explain.

Ans. In the presence of the dielectric medium the Coulomb's (electrostatic) force decreases.

Explanation:

Vacuum (Free space)	Dielectric Medium
The Coulomb's force is given by $F_{vac} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$	The Coulomb's force is given by $F_{med} = \frac{1}{4\pi\epsilon_0\epsilon_r} \frac{q_1 q_2}{r^2}$ or $F_{med} = \frac{1}{\epsilon_r} \left(\frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} \right)$ or $F_{med} = \frac{1}{\epsilon_r} (F_{vac})$ or $F_{med} = \frac{F_{vac}}{\epsilon_r}$

So,

$$F_{vac} = \epsilon_r F_{med}$$

Since, $\epsilon_r > 1$, for insulators (dielectric), hence

Hence,

$$F_{vac} > F_{med} \text{ or } F_{med} < F_{vac}$$

So, in the presence of a dielectric, the electric force decreases.

Q.4 Distinguish between electric field and electric field intensity.

Ans.

Electric field	Electric field Intensity (Strength)
The space or region around the charge in which it exerts electric force on other charges is known as electric field.	The force experienced per unit charge (q_0) at any required point is known as electric field intensity. Formula: $\vec{E} = \frac{\vec{F}}{q_0}$ Unit: Its SI unit is NC^{-1} .

Q.5 What happens to electric field strength as distance increases?

Ans. As $E \propto \frac{1}{r^2}$, therefore, electric field strength decreases with the square of the distance.

Q.6 How is electric field strength related to P.d?

Ans. In a uniform field; $E = \frac{V}{d}$, where V is potential difference and d is the separation between plates.

Q.7 How do electric field lines appear between two opposite charges?

Ans. They start from the positive charge and curve toward the negative charge, forming a dipole pattern.

Q.8 How do electric field lines behave between two like charges?

Ans. They repel each other, and field lines curve outward without intersecting, showing repulsion.

Q.9 Why are electric field lines useful?

Ans. They visually represent electric field strength and direction, helping us understanding electric force behaviour in space.

Q.10 Differentiate between volt and electron volt.

Ans.

Volt	Electron volt
Volt is a SI unit of potential difference between two points.	Electron volt is a very small unit of energy.
Definition	
If one joule work is done in carrying a unit positive charge from one point to another by keeping in electrostatic equilibrium. Then the potential difference is known as one volt.	The amount of energy acquired or lost by an electron as it traverses a potential difference of one volt.
Mathematically:	
$1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}}$	$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$

Q.11 A particle having a charge of 20 electrons on it falls through a potential difference of 100 V. Calculate the energy acquired by it in electron volt.

Ans. Charge $q = 20$
 Potential difference $V = 100 \text{ V}$
 Energy $\Delta (\text{K.E.}) = ?$
 As $\Delta (\text{K.E.}) = q\Delta V$
 $\therefore \Delta (\text{K.E.}) = (20 \text{ e}) (100 \text{ V})$
 or $\Delta (\text{K.E.}) = 2000 \text{ eV}$

Q.12 What is an electron volt?

Ans. It is the amount of energy gained or lost by an electron when it moves through a potential difference of one volt.

Q.13 How is electron volt related to charge of an electron?

Ans. $1 \text{ eV} = \text{Charge of electron} \times 1 \text{ volt} = (1.6 \times 10^{-19} \text{ C}) \times (1 \text{ V})$

Q.14 How many joules are there in 1 MeV (mega electron volt)?

Ans. $1 \text{ MeV} = 10^6 \times 1.6 \times 10^{-19} = 1.6 \times 10^{-13} \text{ J}$

Q.15 Show that; $\frac{1 \text{ volt}}{1 \text{ meter}} = \frac{1 \text{ newton}}{1 \text{ coulomb}}$

Ans. L.H.S $= \text{Vm}^{-1}$
 $= \frac{\text{J}}{\text{C}} \text{m}^{-1} = \frac{\text{Nm}}{\text{C}} \text{m}^{-1}$
 $= \frac{\text{N}}{\text{C}} = \text{R.H.S}$

Q.16 Prove that; $E = -\frac{\Delta V}{\Delta r}$

Ans. Force experienced by unit +ve charge is given by

$$F = qE \quad \dots\dots (i)$$

Since $q = +1\text{C}$

$$\text{So } F = E \quad \dots\dots (ii)$$

Work done in bringing the charge from point A to B is given by

$$W_{AB} = F.d$$

$$\text{or } W_{AB} = Fd \cos \theta$$

From Eq. (ii) $F = E$, so

$$\text{So, } W_{AB} = Ed \cos \theta \quad \dots\dots (iii)$$

Force and displacement are in opposite direction, so

$$\theta = 180^\circ$$

Eq. (iii) becomes $W_{AB} = -Ed$

..... (iv)

From definition of electric potential:

$$W_{AB} = V_A - V_B$$

$$W_{AB} = \Delta V$$

..... (v)

Equating Eqs. (iv) and (v)

$$\Delta V = -Ed$$

$$E = -\Delta V/\Delta d$$

If distance between two plates is very small, i.e., Δr , then

$$E = -\Delta V/\Delta d$$

Q.17 The potential is constant throughout a given region of space. Is the electric field zero or non-zero in this region? Explain.

Ans. If the potential is constant throughout a given region of space, the electric field will be zero in this region.

Reason:

As $E = -\left(\frac{\Delta V}{\Delta r}\right)$

If potential is constant, $V = \text{constant}$ i.e., $\Delta V = 0$

or $E = -\left(\frac{0}{\Delta r}\right)$

or $E = 0$

Q.18 Suppose that you follow an electric field line due to a positive point charge. Do electric field and the potential increase or decrease?

Ans. If we follow an electric field line due to a positive point charge, both electric field (E) and electric potential (V) will decrease.

Reason:

(i) **For Electric Field**

The electric field at any point due to a point charge is given by:

$$E = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2}$$

or $E \propto \frac{1}{r^2}$

If we follow an electric field line, the distance from the charge increases. So, electric field will decrease.

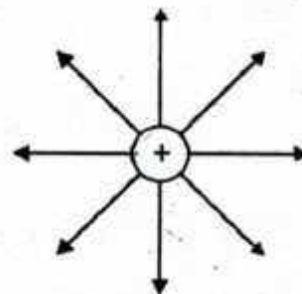
(ii) **For Electric Potential**

The electric potential at any point due to a point charge is given by

$$E = \frac{1}{4\pi\epsilon_0} \frac{q}{r}$$

or $V \propto \frac{1}{r}$

If we follow an electric field line, the distance from the charge increases. So, electric potential will decrease.



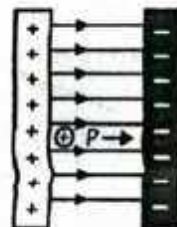
Q.19 How can you identify that which plate is positively charged?

Ans. (i) To identify the positively charged plate, we place a unit positive charge between the plates. The charge moves towards the negatively charged plate. The other plate must be positively charged.

(ii) The positively charged plate can be identified by gold leaf electroscope. The disc of positively charged gold leaf electroscope is brought near the charged plates.

(a) If the divergence of the gold leaf increases, then the plate is positively charged.

(b) If the divergence of the gold leaf decreases, then the plate is negatively charged.



Q.20 Describe the force or forces on a positive point charge when placed between parallel plates.

(a) With similar and equal charges

(b) With opposite and equal charges.

Ans. (a) Net force acting on the positive point charge is zero.

Explanation

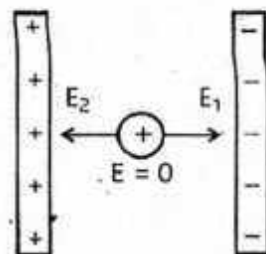
When a positive point charge is placed between parallel plates with similar and equal charges, no force acts on the charge. Because $F = qE$.

The magnitude of E for both plates is equal but opposite in direction, so net value of E is zero.

$$E = E_1$$

$$F = E(0)$$

$$\boxed{F = 0}$$

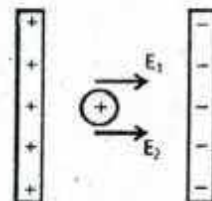


(b) Net force acting on the positive point charge will be maximum.

Explanation

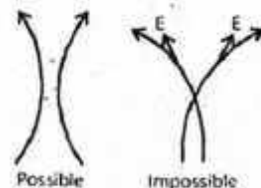
When a positive point charge is placed between parallel plates with opposite and equal charges, force now acts on the charge. Because now the magnitude of E for both plates is equal and in same direction, hence, resultant intensity is maximum so charge experiences a maximum force.

$$\boxed{F = q_0 E}$$



Q.21 Electric lines of force never cross. Why?

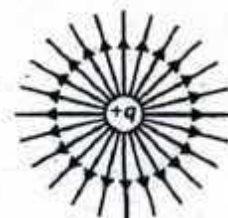
Ans. Electric lines of force never cross each other because electric field has only one direction at any given point. If lines cross each other, electric field should have more than one direction at that point which is not possible.



Q.22 If a point charge q of mass m is released in a non-uniform electric field with lines pointing in the same direction, will it make a rectilinear motion?

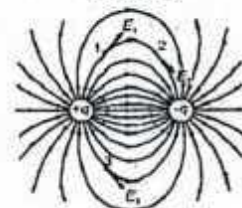
Ans. If a point charge q of mass m is released in a non-uniform electric field with field lines pointing in the same direction, it may or may not make a rectilinear motion.

Case (a): If a point charge ' q ' of mass ' m ' is placed in a non-uniform electric field of an isolated point charge, it will follow straight or rectilinear path along the field line. The charge will follow the path of electric field lines as they are straight, so charge will also follow a straight path.



Case (a)

Case (b): In case of field due to two or more charges, the charge will follow the path of electric field lines as they are curved, so charge will also follow a curved path.



Case (b)

Q.23 Does electric flux depend on the shape of the surface?

Ans. No, it depends only on the amount of charge enclosed, not on the shape of the surface.

Q.24 What does Gauss's law help us to calculate?

Ans. It helps in calculating the electric field due to symmetric charge distribution.

Q.25 What is the electric field inside a uniform charged spherical shell?

Ans. Zero, since no charge is enclosed by a Gaussian surface inside the shell.

Q.26 Is $\vec{E}$ necessarily zero inside a charged rubber balloon if balloon is spherical? Assume that charge is distributed uniformly over the surface.

Ans. Yes, $\vec{E}$ is necessarily zero inside a rubber balloon.

Reason: Imagine a spherical Gaussian surface inside the balloon. The charge enclosed by it is:
 $q = 0$, applying Gauss's law:

$$\phi_e = \frac{q}{\epsilon_0} \quad \dots (i)$$

$$\phi_e = 0 \quad \because (q = 0)$$

The electric flux is given by

$$\phi_e = \vec{E} \cdot \vec{A} \quad \dots (ii)$$

or $\vec{E} \cdot \vec{A} = 0$

From Eqs. (i) and (ii)

or $\boxed{\vec{E} = 0} \quad \because (\vec{A} \neq 0)$



Q.27 Is it true that Gauss's law states that the total number of lines of force crossing any closed surface in the outward direction is proportional to the net positive charge enclosed within the surface?

Ans. Yes, it is a true statement.

Explanation

Total number of lines of forces crossing any closed surface = ϕ

Net positive charge enclosed within surface = Q

According to the statement:

$$\boxed{\phi_e \propto Q}$$

It is Gauss's law.

$$\boxed{\phi_e = \frac{1}{\epsilon_0} \times Q}$$

Q.28 What is electric potential?

Ans. Electric potential at a point is the amount of work done in bringing a unit positive charge from infinity to that point in an electric field.

Q.29 What is the relationship between electric field and electric potential?

Ans. $E = -\frac{\Delta V}{\Delta r}$

Electric field is the negative gradient of electric potential.

The negative sign shows that the electric field points in the direction of decreasing potential.

Q.30 What is potential difference?

Ans. It is the work done in moving a unit positive charge between two points in an electric field.

Q.31 Can electric potential be negative?

Ans. Yes, electric potential can be negative if work is done by the field (e.g. near a negative charge).

Q.32 What is equipotential surface?

Ans. A surface on which all points have the same electric potential. No work is done when moving a charge along this surface.

Q.33 What is meant by zero electric potential?

Ans. A point where no work is needed to bring a unit charge from infinity, or where the net potential due to multiple charge is zero.

Q.34 What is the potential due to a system of charges?

Ans. It is the algebraic sum of potentials due to individual charges at a point.

Q.35 Does higher electric potential mean strong electric field?

Ans. Not necessarily; electric field depends on the rate of change of potential with distance, not just its magnitude.

Q.36 What is meant by electric potential gradient?

Ans. It is the rate of change of electric potential with respect to distance.

Q.37 What is Faraday's cage?

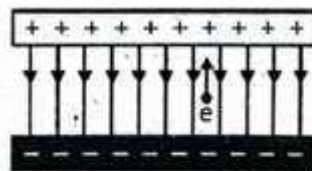
Ans. It is a hollow conducting enclosure that blocks external electric fields.

Q.38 Where is electrostatic shielding used in real life?

Ans. In electronic device, microwave oven, and to protect sensitive equipments from static charges.

Q.39 Do electrons tend to go to region of high potential or of low potential?

Ans. As we know that electron is negatively charge particle so, when it enters in an electric field it goes from region of **low potential** to the region of **high potential** due to the electric force.



Q.40 A potential difference is applied across the ends of a copper wire. What is the effect on the drift velocity of electrons by

(i) **Increasing the potential difference**

(ii) **Decreasing the length and the temperature of the wire.**

Ans. (i) The drift velocity of free electrons increases by increasing the potential difference.

Explanation

The drift velocity of free electrons in the conductor, having length ' l ' and area of cross-section ' A ', is given by

$$V_d = \frac{I}{neA}$$

or $V_d = \frac{V}{neAR} \quad \left(\because I = \frac{V}{R} \right)$

or $V_d \propto V$ (If A and R are constant)

This equation shows that by increasing potential difference, V_d increases.

(ii) The drift velocity of electrons increases by decreasing the length and temperature of the wire.

Explanation

The drift velocity of free electrons in a conductor having length ' l ' and area of cross-section ' A ' is given by

$$V_d = \frac{I}{neA} \quad \left(\because I = \frac{V}{R} \right)$$

or $V_d = \frac{V}{neAR}$

As $R \propto l$ and $R \propto T$

$\therefore V_d \propto \frac{1}{R}$ (If V and A are constant)

When length and temperature decrease, the resistance of the conductor decreases. Hence, drift velocity increases.

Q.41 Do bends in a wire affect its electrical resistance? Explain.

Ans. As, the resistance of a wire depends upon its length " L ", area of cross-section " A " and the resistance of the material of wire R . It is given by

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

Effect of Bends on Resistance:

The bends in a wire may or may not affect its electrical resistance.

Case (a): If the bends in the wire do not change its length and area of cross-section, the resistance of wire will not change.

Case (b): If the bends in the wire change the length or area of cross-section, then the resistance of wire will change with the bends.

Q.42 Why does the resistance of a conductor rise with temperature?

Ans. Actually resistance of a conductor is due to collisions between electrons and lattice atoms. With increase in temperature, vibrational motion of atoms increases and due to greater amplitude of vibration, their collision probability with electrons increases.

Hence, resistance of conductor increases according to the relations;

$$R_t = R_0 (1 + \alpha \Delta t)$$

R_t = resistance at $t^\circ\text{C}$

R_0 = resistance at 0°C

Δt = change in temperature

α = temperature coefficient of resistance

Q.43 What are the difficulties in testing whether the filament of a lighted bulb obeys Ohm's law?

Ans. We know that a current-carrying conductor obeys Ohm's Law only if its temperature of the conductor remains constant. When the current is passed through bulb, the temperature of its filament rises with the time. So, the resistance of the filament also increases with the time. Therefore, it does not obey Ohm's law. Thus, the main difficulties in testing whether the filament of light bulb obey Ohm's law is the increase in the resistance of the filament with the rise in temperature.

Q.44 Is the filament resistance lower or higher in a 500W, 220V light bulb than in a 100 W, 220 V bulb?

Ans.

Bulb - I		Bulb - II	
Data		Data	
$P_1 = 500 \text{ W}$ $V_1 = 220 \text{ V}$ $R_1 = ?$		$P_2 = 100 \text{ W}$ $V_2 = 220 \text{ V}$ $R_2 = ?$	
Formula		Formula	
$P_1 = \frac{V_1^2}{R_1}$		$P_2 = \frac{V_2^2}{R_2}$	
Calculation		Calculation	
$R_1 = \frac{V_1^2}{P_1} = \frac{(220)^2}{500}$ $R_1 = 96.8 \Omega$		$R_2 = \frac{V_2^2}{P_2} = \frac{(220)^2}{100}$ $R_2 = 484 \Omega$	

Result: So the resistance of 500 W, 220 V light bulb is lower than the resistance of 100W, 220V.

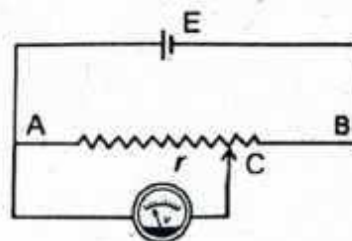
Q.45 Describe a circuit which will give a continuously varying potential.

Ans. A rheostat can provide continuously varying potential. In other words, it can act as a potential divider.

Explanation

It consists of a thin wire AB of high resistance R. A battery of emf is connected to R. The current flowing through it is given by.

$$I = \frac{E}{R}$$



A terminal C slides over the wire AB. The resistance between A and C can be changed from zero to R as terminal C moves from A to B. Let r be the resistance between A and C, then

$$V_{AC} = Ir$$

or

$$V = \frac{E}{R} r$$

As C slides from A to B, r varies from 0 to R and the potential difference between A and C changes from zero to E.

Q.46 Explain why the terminal potential difference of a battery decreases when the current drawn from it is increased?

Ans. Explanation

When the current drawn from the battery is increased, the potential drop across the internal resistance also increases (i.e., the energy dissipation as heat into the battery is increased). Therefore, according to following relation:

$$V_t = E - Ir$$

As Ir factor is increased, so the terminal potential difference ' V_t ' gets decreased.

Q.47 What is Wheatstone bridge? How can it be used to determine an unknown resistance?

Ans. Wheatstone Bridge

It is an electrical circuit that is used to measure the value of an unknown resistance accurately.

Working

Wheatstone bridge consists of four resistances R_1 , R_2 , R_3 and R_4 . When the bridge is electrically balanced, no current flows through the galvanometer. It means the points B and D are at same potential.

According to this condition

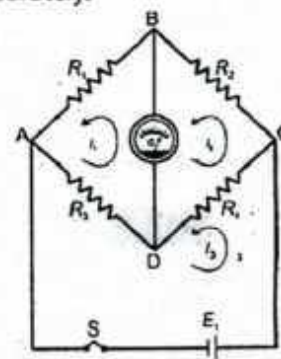
$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

If one of the resistance say $R_4 = X$ is unknown and the other resistances R_1 , R_2 , R_3 are known, then

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

$$X = \frac{R_2}{R_1} \times R_3$$

So, Unknown resistance X can be found.



Q.48 What is conventional current?

Ans. It is the flow of positive charge from the positive terminal to the negative terminal of a power source.

Q.49 Is conventional current the actual flow of electrons?

Ans. No, electrons actually flow from the negative terminal to the positive terminal, but conventional current assumes flow of positive charges.

Q.50 How does conventional current differ from electric current?

Ans. Conventional current flows in the opposite direction to the flow of electrons.

Q.51 State one limitation of Ohm's law.

Ans. It does not apply to non-linear or temperature dependent materials.

Q.52 What is resistivity?

Ans. It is a property of a material that quantifies how strongly it resists the flow of electric current.

Q.53 What factors affect the resistivity of a material?

Ans. Resistivity depends only on the material and its temperature, not on the shape or size.

Q.54 What kind of materials have low resistivity?

Ans. Insulators like rubber, glass and plastic.

Q.55 How is resistivity different from resistance?

Ans. Resistivity is a material property, while resistance depends on the material, length, and cross-sectional area of the conductor.

Q.56 What is electrical power?

Ans. It is the rate at which electrical energy is consumed or produced in a circuit.

$$P = IV$$

$$\text{Or } P = I \left(\frac{V}{I} \right) = I^2 R = \left(\frac{V}{R} \right)^2 \times R = \frac{V^2}{R}$$

The SI unit of electrical power is watt (W). It can be defined as:

A device uses one watt of power when it consumes one joule of energy per second.

Q.57 What is electromotive force?

Ans. It is the total energy supplied by a source per coulomb of charge to move it around a complete circuit.

Q.58 How are emf and p.d different?

Ans. EMF is the total voltage provided by a source; whereas p.d is the voltage drop across components.

Q.59 Can emf do work?

Ans. Yes, it represents the energy source that does work to move charges in a circuit.

Q.60 What happens to terminal p.d when current increases?

Ans. It decreases due to increased voltage drop across internal resistance.

Q.61 What is the purpose of Kirchhoff's rules?

Ans. They help to calculate unknown currents and voltages in complex circuits where simple series/parallel rules are not sufficient.

Q.62 What is Wheatstone bridge?

Ans. It is an electrical circuit used to measure an unknown resistance by balancing two legs of a bridge circuit.

Q.63 What is the condition for balance in a Wheatstone bridge?

Ans. The bridge is balanced when the ratio of resistances in one branch equals the ratio in the other branch:

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

Q.64 What happens when Wheatstone bridge is balanced?

Ans. No current flows through the galvanometer.

Q.65 Where is the Wheatstone bridge commonly used?

Ans. In strain gauges, temperature sensors, and precise resistance measurements.

Q.66 On what principle does a potentiometer work?

Ans. It works on the principle that the potential drop across a uniform wire is directly proportional to its length (where a constant current flows).

Q.67 Why is a potentiometer more accurate than a voltmeter?

Ans. Because it draws no current from the circuit while measuring voltage.

Q.68 What is a balancing length?

Ans. The length of the potentiometer wire at which the galvanometer shows zero deflection.

Q.69 What happens at the null point in a galvanometer?

Ans. The p.d. across the wire segment equals the emf or voltage being measured, and no current flows through the galvanometer.

Q.70 What type of wire is used in a potentiometer?

Ans. A long uniform resistance wire, usually made of manganin or constantan.

Q.71 Why should the potentiometer wire be long and uniform?

Ans. To increase accuracy and ensure a constant potential gradient.

Q.72 What is the basic principle of a galvanometer?

Ans. It works on the principle that a current-carrying coil placed in a magnetic field experiences a torque.

Q.73 How a galvanometer is converted into:

(i) an ammeter

(ii) a Voltmeter

Ans. (i) By connecting a low resistance (shunt) in parallel with the galvanometer.

(ii) By connecting a high resistance in series with the galvanometer

Q.74 What is a thermistor?

Ans. It is a temperature-sensitive resistor whose resistance changes significantly with temperature.

Q.75 What is the primary use of thermistor?

Ans. They are used to measure temperature and in temperature control circuits.

Q.76 Where are thermistors commonly used?

Ans. In electronic thermostats, battery protection circuits, and digital thermometers.

Q.77 What is a light dependent resistor (LDR)?

Ans. It is a resistor whose resistance decreases when the intensity of light falling on it increases.

Q.78 What are some common applications of LDR?

Ans. Used in light sensors, automatic street lights, alarm systems, and camera light meters.

Q.79 What is the principle of an LDR?

Ans. Its resistance changes with the amount of incident light; more light means less resistance.

SOLVED EXERCISE

MULTIPLE CHOICE QUESTIONS

Tick (✓) the correct answer.

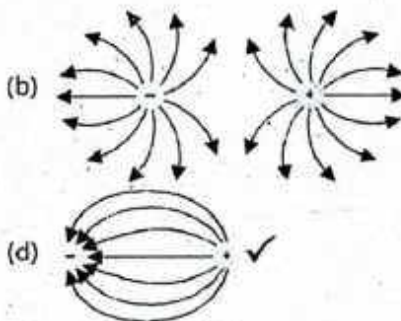
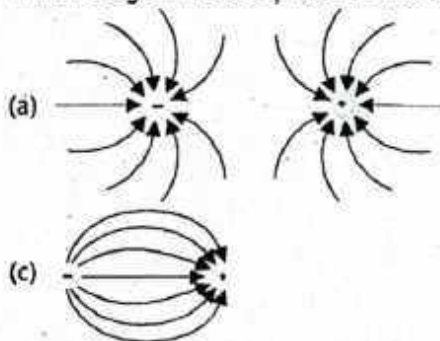
9.1 Two point charges A and B are separated by 10 m. If the distance between them is reduced to 5m, the force exerted on each:

- (a) decreases to half its original value
(b) increases to twice the original value
(c) decreases to one quarter of its original value
(d) increases four times to its original value ✓

9.2 Which electric charge is possible on a particle?

- (a) 2.5×10^{-19} C
(b) 3.2×10^{-19} C ✓
(c) 1.6×10^{-19} C
(d) 6.02×10^{23} C

9.3 Which diagram best represents the electric field lines around two oppositely charged particles?



9.4 What is the work done on an electron by potential difference of 100 volts?

- (a) 1.6×10^{-19} eV
(b) 1.6×10^{-17} eV
(c) 6.25×10^{-17} eV
(d) 100 eV ✓

9.5 The potential at a point situated at a distance of 50 cm from a charge of $50 \mu\text{C}$ is:

- (a) 9×10^{-4} volts
(b) 18×10^{-4} volts
(c) 9×10^5 volts ✓
(d) 18×10^4 volts

9.6 A ball of weight 0.1 N having a charge of $100 \mu\text{C}$ remained suspended between two oppositely charged horizontal metal plates. The electric intensity between the plates is:

- (a) 10 N C^{-1}
(b) 100 N C^{-1}
(c) 1000 N C^{-1} ✓
(d) 10000 N C^{-1}

9.7 A piece of wire has resistance of 4Ω . It is doubled on itself so that its length becomes half but area of cross-section is doubled. Its resistance now will be:

- (a) 8Ω
(b) 4Ω
(c) 2Ω
(d) 1Ω ✓

9.8 The current through a conductor is 3.0 A when it is attached across a potential difference of 6.0 V. How much power is used?

- (a) 0.5 W
(b) 2.0 W
(c) 9.0 W
(d) 18 W ✓

9.9 The algebraic sum of potential changes for a complete circuit is zero. It is the statement of:

- (a) Ohm's law
(b) Gauss's law
(c) Kirchhoff's first law
(d) Kirchhoff's second law ✓

9.10 The radius of curvature of the path of a charged particle in a uniform magnetic field is directly proportional to:

- (a) the particle's charge
(b) the particle's momentum ✓
(c) the particle's energy
(d) the flux density of the field

9.1 How does a moving conductor like an aeroplane acquire charge as it flies through the air? Describe briefly.

Ans. A moving conductor, like an aeroplane, acquires charge as it flies through the air due to a process called frictional charging and electrostatic induction. Let us see how does it happen:

1. Friction with Air Molecules:

As the aeroplane moves at high speeds, it continuously collides with air molecules, dust particles, and ice crystals. These collisions strip electrons from the aeroplane's surface or deposit them, depending on the relative properties of the materials involved. This process is similar to how rubbing a balloon against hair causes static electricity.

2. Induction by the Earth's Electric Field:

The Earth has a natural electric field, which can induce charge imbalances on the aeroplane. As the aeroplane moves through different regions of this field, variations can cause redistribution of charge on its surface.

3. Charging by Precipitation (Precipitation Static):

If the aeroplane flies through rain, snow, or clouds with charged droplets, these particles can transfer charge upon contact with the aeroplane's surface.

4. Interaction with Thunderstorms:

When an aeroplane flies near or through a thunderstorm, it can be exposed to intense electric fields and charged particles, leading to significant static charge buildup.

How does Aeroplane Handle This Charge

Aeroplane are equipped with static dischargers (small rods usually mounted on the trailing edges of wings and other surfaces). These devices help dissipate excess charge safely back into the atmosphere, preventing radio communication interference and reducing the risk of sudden electrostatic discharges.

9.2 Define electric intensity and electric potential.

Ans. Electric Intensity

"Electric intensity at a point in space is the force experienced by a unit positive charge placed at that point."

It is a vector quantity and is denoted by $\vec{E}$.

Mathematically,

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

The SI unit of electric intensity is NC^{-1} or Vm^{-1} .

Electric Potential

"Electric potential at a point is the work done in bringing a unit positive charge from infinity to that point, without any acceleration."

It is a scalar quantity and is denoted by V .

Mathematically,

$$V = \frac{W}{q}$$

Its SI unit is volt (V).

9.3 A battery is rated at 100 A h (ampere-hour). How much charge can this battery supply?

Ans. To find the total charge, a battery can supply, we can use the relationship between charge Q , current I and time t . Thus

$$Q = I \times t$$

The battery is rated at 100 Ah. First convert ampere-hour to ampere-seconds (coulombs).

$$1 \text{ Ah} = 3600 \text{ C}$$

So $100 \text{ Ah} = 360,000 \text{ C}$

The battery can supply 360,000 coulombs of charge.

9.4 Is electron-volt a unit of potential difference or energy? Explain.

Ans. The electron volt (eV) is a unit of energy, not potential difference.

Explanation: An electron volt is defined as the amount of energy gained or lost by an electron when it moves through an electric potential difference of 1 volt.

Mathematically,

$$1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$$

This comes from the formula for energy in an electric field:

$$E = qV$$

For an electron, $q = 1.602 \times 10^{-19} \text{ C}$, so when it moves through 1 volt, it gains $1.602 \times 10^{-19} \text{ J}$ of energy.

Thus, the electron volt (eV) is a unit of energy, while volt (V) is a unit of potential difference.

9.5 A copper wire of length L has resistance R . It is stretched to double of its length. What will be the resistance of the new length of wire?

Ans. Given that:

Original length = L

Original resistance = R

New length = $2L$

Volume of the wire remains constant during stretching.

Using the formula:

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

where ρ is the resistivity, L is the length, and A is the cross-sectional area.

Volume remains constant:

Original volume = $A \times L$

New volume = $A' \times 2L$

By equating

$$A \times L = A' \times 2L$$

or
$$A' = \frac{A}{2}$$

New resistance

$$R' = \rho \frac{2L}{A'} = \rho \frac{2L}{A/2} = \rho \frac{4L}{A} = 4R$$

So, the new resistance is 4 times the original resistance.

9.6 Why does the resistance of a conductor rise with increase in temperature?

Ans. The resistance of a conductor increases with temperature due to the increased scattering of charge carriers (typically electrons) as they move through the material. Let us know, why does, this happen.

1. Increased Lattice Vibrations (Phonon Scattering)

As temperature rises, the atoms in the conductor vibrate more intensely. This increases the chances of electrons colliding with these vibrating atoms, which disrupts their flow and increases resistance.

2. Reduced Electron Mobility

More frequent collisions mean that electrons have a harder time travelling through the conductor without interruptions, effectively reducing their drift velocity and increasing resistance.

3. Minimal Impact from Charge Carrier Density

In most metallic conductors, the number of free electrons does not significantly increase with temperature. Instead, the dominant effect is the increase in scattering, which raises resistance.

This relationship is often expressed using the temperature coefficient of resistance:

$$R_T = R_0 (1 + \alpha \Delta T)$$

For most metals, α is positive, i.e., resistance increases with temperature. However, for some materials like semiconductors, resistance decreases with temperature due to an increase in charge carriers.

9.7 Is the filament resistance lower or higher in a 500W-220V light bulb than in a 100 W-220V bulb?

Ans. The filament resistance is lower in the 500W-220V bulb compared to the 100W-220V bulb.

Explanation: The resistance R of a bulb can be calculated using Ohm's law and the power formula:

$$P = \frac{V^2}{R}$$

Rearranging for resistance:

$$R = \frac{V^2}{P}$$

Since both bulbs operate at the same voltage (220V), we can compare their resistances:

For the 100W bulb:

$$R_{100} = \frac{220^2}{100} = 484 \, \Omega$$

For the 500W bulb:

$$R_{500} = \frac{220^2}{500} = 96.8 \, \Omega$$

Since $96.8 \, \Omega < 484 \, \Omega$, the 500 W bulb has a lower filament resistance than the 100W bulb. This makes sense because a higher power bulb needs to allow more current to flow, requiring a lower resistance.

9.8 Why does resistance of a thermistor changes as temperature increases?

Ans. A thermistor is a type of temperature-sensitive resistor, and in the case of a Negative Temperature Coefficient, its resistance decreases as temperature increases. This happens due to the intrinsic semiconductor properties of the thermistor material. Do you know why?

1. Semiconductor Behaviour

- (i) Thermistors are made from ceramic materials that are semiconductors, such as oxides of manganese, nickel, or cobalt.
- (ii) In semiconductors, electrical conduction is primarily due to charge carriers (electrons and holes).

2. Increase in Charge Carriers

- (i) At low temperatures, there are fewer free electrons in the conduction band, so the material has high resistance.
- (ii) As temperature increases, thermal energy excites more electrons from the valence band to the conduction band.
- (iii) More free electrons (and holes) mean increased conductivity, which corresponds to lower resistance.

9.9 Which materials can be used to construct Faraday's cage and why?

Ans. A Faraday cage is designed to block electric fields and electromagnetic waves from reaching the inside. To do this effectively, it needs matter that conducts electricity well.

Here are some common materials used to construct a Faraday cage:

Copper, aluminium, steel, nickel, silver and metal meshes.

Reason: All these materials conduct electricity. When an external electromagnetic field hits the conductive surface, the free electrons rearrange themselves to cancel out the field's effect inside the cage.

CONSTRUCTED RESPONSE QUESTIONS

9.1 Electric lines of force never cross each other. Why?

Ans. Electric lines of force never cross each other because at any given point in space, the electric field has a unique direction. If two lines were to cross, it would imply that the electric field has two different directions at the same point, which is physically impossible.

Mathematically, the electric field at any point is represented by a single vector, which defines a unique direction and magnitude. Since electric field lines are simply a visual representation of these vectors, they must never intersect.

9.2 Is E necessarily zero inside a charged rubber balloon if the balloon is spherical? Assume that charge is distributed uniformly over the surface.

Ans. No, the electric field E inside the charged rubber balloon is not necessarily zero, even if the balloon is spherical and the charge is uniformly distributed over the surface.

Do you know why?

1. Gauss's Law and Conductors

- (i) If the balloon were a conducting sphere, then the electric field inside would be zero because free charges in a conductor redistribute themselves to ensure there is no electric field within the conductor's material or inside the cavity.

(ii) However, a rubber balloon is an insulator, meaning the charge does not freely move to cancel internal fields.

2. Gauss's Law for a Spherical Shell of Charge

(i) Gauss's law states that the electric flux through a Gaussian surface depends on the enclosed charge:

$$\phi_e = \frac{1}{\epsilon_0} \times Q_{\text{(total charge)}}$$

(ii) If we place a Gaussian surface inside the balloon (within the cavity), it encloses no charge because all charge is on the outer surface.

(iii) This suggests that the net electric flux through the Gaussian surface is zero, which often means the electric field is zero.

3. Electrostatics of a Thin Spherical Shell

(i) A uniformly charged spherical shell produces an electric field outside as if all charge were concentrated at a point at the center.

(ii) Inside, however, the electric field cancels out at every point due to the symmetry of the problem.

(iii) This is a well-known result from electrostatics: the electric field inside a charged spherical shell is zero everywhere.

Conclusion: Yes, the electric field inside the charged rubber balloon is zero, provided that the charge is uniformly distributed over the surface. This follows directly from the symmetry-based argument using Gauss's law. The fact that rubber is an insulator does not affect this result, as long as the charge remains on the outer surface.

9.3 Electrostatic force is 10^{38} times stronger than gravitational force. Argue that our galaxy should be almost electrically neutral.

Ans. The electrostatic force is indeed about 10^{38} times stronger than the gravitational force. If there were even a slight imbalance of charge in our galaxy, the consequences would be drastic. Let us see why our galaxy must be nearly electrically neutral:

1. Strength Comparison

The electrostatic force between two elementary charges follows Coulomb's law:

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

The gravitational force between two masses follows Newton's law:

$$F_g = G \frac{m_1 m_2}{r^2}$$

The ratio of these forces for a proton and an electron is:

$$\frac{F_e}{F_g} = \frac{ke^2}{G m_p m_e} = 10^{38}$$

This means even a minuscule net charge would generate an enormous electrostatic force compared to gravity.

2. Large-Scale Stability

(i) If the galaxy had a significant net charge, the repulsive or attractive electrostatic forces would far exceed gravitational attraction.

(ii) Since the Milky Way is held together by gravity, any significant charge imbalance would cause charged components to repel or attract violently, disrupting the structure of the galaxy.

3. Charge Cancellation in Matter

(i) Atoms and macroscopic objects are generally neutral because they contain equal numbers of protons and electrons.

(ii) While ionized particles exist (such as in plasma), they tend to recombine over time, restoring charge neutrality.

(iii) Large-scale astrophysical objects, like stars and galaxies, are composed of vast numbers of particles that statistically neutralize any significant charge imbalance.

4. Observational Evidence

(i) If the galaxy were not electrically neutral, we would observe strong electrostatic interactions affecting the motion of stars and interstellar gas, which we do not.

(ii) The cosmic microwave background, galactic magnetic fields, and plasma physics observations indicate that any net charge imbalance is negligible.

Conclusion: Since electrostatic forces are overwhelmingly stronger than gravity, even a tiny charge imbalance would dominate galactic dynamics, preventing the stable structure we observe. The fact that our galaxy remains gravitationally bound and stable suggests that it is almost perfectly electrically neutral.

9.4 An uncharged conducting hollow sphere is placed in the field of a positive charge q . What will be the net flux through the shell?

Ans. The net flux through the shell will be zero.

According to Gauss's law, the net electric flux through a closed surface is given by

$$\phi_e = \frac{1}{\epsilon_0} \times Q$$

- Since the sphere is hollow and uncharged, it does not contain any charge inside it. The external charge will induce charges on the outer surface of the shell, but these induced charges do not contribute to any net charge enclosed within the shell.

9.5 A potential difference is applied across the ends of a copper wire. What is the effect on the drift velocity of free electrons by

- increasing the potential difference?**
- decreasing the length and the temperature of the wire?**

Ans. The drift velocity (v_d) of free electrons in a conductor is given by the equation:

$$v_d = \frac{I}{nAe}$$

where:

I is the current, n is the number density of free electrons, A is the cross-sectional area of the wire, and e is the elementary charge.

Using Ohm's law ($V = IR$) and the relation $R = \rho \frac{L}{A}$, we can express drift velocity as:

$$v_d = \frac{V}{L} \times \frac{1}{nep}$$

where V is the applied potential difference, L is the length of the wire, and p is the resistivity of the material.

(i) Increasing the potential difference (V)

From the equation, increasing V increases V_d directly, since drift velocity is proportional to the electric field $E = \frac{V}{L}$.

- A higher potential difference increases the electric field strength, causing electrons to accelerate more, thereby increasing their drift velocity.

(ii) Decreasing the length and temperature of the wire

Decreasing the length (L): The electric field $E = \frac{V}{L}$ increases if L decreases (for the same V), leading to an increase in v_d .

Decreasing the temperature: Lowering the temperature reduces the resistivity (p) of copper because there are fewer lattice vibrations obstructing electron flow. Since $V_d \propto \frac{1}{p}$, a lower resistivity increases drift velocity.

9.6 Why the terminal potential difference of a battery decreases when the current drawn from it is increased?

Ans. The terminal potential difference (p.d.) of a battery decreases when the current drawn from it increases due to the internal resistance of the battery.

A battery consists of an electromotive force (emf), E , and an internal resistance, r . When a current I flows through the battery, a voltage drop occurs across the internal resistance, given by Ohm's law:

$$V = E - I_r$$

Explanation

1. When no current is drawn ($I = 0$), the terminal voltage is equal to the emf: $V = E$.
2. As the current increases, the voltage drop across the internal resistance (I_r) also increases.
3. This causes the terminal voltage to decrease. Since

$$V = E - I_r$$

4. If the current is very high, the voltage drop I_r can become significant, leading to a noticeable reduction in the terminal p.d.
This effect is more pronounced in batteries with higher internal resistance, older batteries, or when supplying high-power loads.

COMPREHENSIVE QUESTIONS

- 9.1 Explain the electric potential and prove that electric field intensity is equal to the negative of potential gradient.**
Ans. See Q. 12 and Q. 13.
- 9.2 State and explain Kirchhoff's rules.**
Ans. See Q. 26 and Q. 27.
- 9.3 What is a Wheatstone bridge? Explain its working with the help of a diagram.**
Ans. See Q. 29.
- 9.4 What is a light dependent resistor (LDR)? How can this be used as ON-OFF switch for lighting?**
Ans. See Q. 34 and Q. 35.
- 9.5 What is a potentiometer? Describe its working.**
Ans. See Q. 30.

NUMERICAL PROBLEMS

- 9.1 Two unequal point charges repel each other with a force of 0.4 N when they are 5.0 cm apart. Find the force which each charge exerts on the other when they are (a) 2.5 cm apart (b) 15.0 cm apart.**

Solution:

Using Coulomb's law:

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

where F is the force between the charges.
 $k = 9 \times 10^9 \text{ Nm}^2 \text{ C}^{-2}$ is Coulomb's constant.
 q_1 and q_2 are the magnitude of the charges.
 r is the distance between the charges.

We are told that the force is 0.4 N when the charges are 5.0 cm apart.

Because the force depends on the inverse square of the distance, we can compare the force at a new distance ' r ' using:

$$\frac{F'}{F} = \left(\frac{r}{r_1}\right)^2$$

- (a) When distance is 2.5 cm:

$$\frac{F'}{0.4} = \left(\frac{5.0}{2.5}\right)^2 = 2^2 = 4$$

or $F' = 4 \times 0.4 = 1.6 \text{ N}$ **Ans.**

- (b) When distance is 15.0 cm:

$$\frac{F'}{0.4} = \left(\frac{5.0}{15.0}\right)^2 = \left(\frac{1}{3}\right)^2 = \frac{1}{9}$$

or $F' = \frac{1}{9} \times 0.4 = 0.04 \text{ N}$ **Ans.**

- 9.2 A particle of charge $+20 \mu\text{C}$ is placed between two parallel plates, 10 cm apart and having a potential difference of 0.5 kV between them. Calculate the electric field between the plates, and the electric force exerted on the charged particle.**

Solution:

Given data:

Charge = $q = +2 \mu\text{C} = 2 \times 10^{-6} \text{ C}$

Distance between plates = $d = 10 \text{ cm} = 0.1 \text{ m}$

Potential difference = $V = 0.5 \text{ kV} = 500 \text{ V}$

To Find:

- (i) Electric field = $E = ?$
 (ii) Force exerted = $F = ?$

Calculations:

- (i) Electric field between parallel plates is given by

$$E = \frac{V}{d} = \frac{500 \text{ V}}{0.1 \text{ m}} = 5000 \text{ Vm}^{-1} = 5 \text{ k NC}^{-1} \text{ Ans.}$$

- (ii) Electric force on the particle is given by

$$F = qE$$

$$F = 2 \times 10^{-6} \text{ C} \times 5 \text{ kNC}^{-1} = 0.1 \text{ N} \text{ Ans.}$$

- 9.3 The electron and proton in a hydrogen atom are separated (on the average) by a distance of approximately $5.3 \times 10^{-11} \text{ m}$. Find the ratio of the electric force and the gravitational force between the electron and proton in this state.**

Solution:

To find the ratio of electric force to gravitational force between an electron and a proton, we can use the formulae for Coulomb's law and Newton's law of gravitation.

1. Coulomb's law (Electric force):

$$F_e = \frac{k \times e^2}{r^2} \quad \dots\dots (i)$$

where $k = 9 \times 10^9 \text{ Nm}^2 \text{ C}^{-2}$ (Coulomb's constant)

$e = 1.6 \times 10^{-19} \text{ C}$ (Charge on an electron or proton)

$r = 5.3 \times 10^{-11} \text{ m}$ (Average separation)

2. Gravitational force:

$$F_g = \frac{G m_e m_p}{r^2} \quad \dots\dots (ii)$$

where $G = 6.67 \times 10^{-11} \text{ Nm}^2 \text{ kg}^{-2}$ (Gravitational constant)

$m_e = 9.11 \times 10^{-31} \text{ kg}$ (Mass of an electron)

$m_p = 1.67 \times 10^{-27} \text{ kg}$ (Mass of proton)

$r = 5.3 \times 10^{-11} \text{ m}$ (Same distance)

Taking the ratio of Eqs. (i) and (ii)

$$\frac{F_e}{F_g} = \frac{\frac{k e^2}{r^2}}{\frac{G m_e m_p}{r^2}} = \frac{k e^2}{G m_e m_p}$$

Putting the values

$$\frac{F_e}{F_g} = \frac{(9 \times 10^9) (1.6 \times 10^{-19})^2}{(6.67 \times 10^{-11}) (9.1 \times 10^{-31}) (1.67 \times 10^{-27})}$$

Calculating numerators:

$$(9 \times 10^9) (2.56 \times 10^{-38}) = 2.30 \times 10^{-28}$$

Calculating denominators:

$$(6.67 \times 10^{-11}) (9.1 \times 10^{-31}) (1.67 \times 10^{-27}) \approx 1.01 \times 10^{-67}$$

$$\text{Now } \frac{F_e}{F_g} = \frac{2.30 \times 10^{-28}}{1.01 \times 10^{-67}} = 2.28 \times 10^{39}$$

$$\text{or } \frac{F_e}{F_g} \approx 2.3 \times 10^{39} \text{ Ans.}$$

So, the electric force is about 2.3×10^{39} times stronger than the gravitational force between the electron and proton in a hydrogen atom.

9.4 After a pleasant showering, a water droplet of mass $1.2 \times 10^{-11} \text{ kg}$ is located in the air near the ground. An atmospheric electric field of magnitude $6.0 \times 10^3 \text{ N C}^{-1}$ points vertically downward in the vicinity of the water droplet. The droplet remains suspended at rest in the air. Find the electric charge on the droplet.

Solution:

Given data:

Mass of water droplet = $m = 1.2 \times 10^{-11} \text{ kg}$

Magnitude of electric field = $E = 6.0 \times 10^3 \text{ NC}^{-1}$

To Find:

Electric charge on the droplet = $q = ?$

Calculations: To find the electric charge on the water droplet, we need to apply Newton's second law and consider the forces acting on the droplet. Since the droplet is suspended at rest, the net force is zero. This means the gravitational force is exactly balanced by the electric force.

Force acting on the droplet:

Gravitational force = $F_g = mg$

Electric force = $F_e = qE$

Since the droplet is suspended and not moving, therefore,

$$F_e = F_g$$

$$\text{or } qE = mg$$

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

Putting the values

$$q = \frac{(1.2 \times 10^{-11} \text{ kg}) (9.8 \text{ ms}^{-2})}{6.0 \times 10^3 \text{ NC}^{-1}}$$

$$q = 1.96 \times 10^{-14} \text{ C}$$

This is the magnitude of electric charge on the water droplet required to keep it suspended in the given electric field.

The droplet contains negative charge i.e., opposite to the atmospheric field, therefore,

$$q = -1.96 \times 10^{-14} \text{ C} \text{ Ans.}$$

9.5 An electron enters the region of a uniform electric field, with $v = 2.99 \times 10^6 \text{ m s}^{-1}$ and $E = 300 \text{ N C}^{-1}$. The horizontal length of the plates is 10.0 cm. Find the acceleration of the electron while it is in the electric field. How long will it take to pass through the field?

Solution:

Given data:

Initial velocity of the electron = $v_i = 2.99 \times 10^6 \text{ ms}^{-1}$

Electric field = $E = 300 \text{ NC}^{-1}$

Length of the plates (distance along x-axis) $d = 10 \text{ cm} = 0.1 \text{ m}$

Calculations: To solve it, we break it into two parts.

1. Acceleration of the Electron in the electric field:

$$F = eE$$

$$e = 1.6 \times 10^{-19} \text{ C}$$

$$m = 9.1 \times 10^{-31} \text{ kg}$$

Using Newton's 2nd law:

$$a = \frac{F}{m} = \frac{eE}{m}$$

Putting the values

$$a = \frac{1.6 \times 10^{-19} \text{ C} \times 300 \text{ NC}^{-1}}{9.1 \times 10^{-31} \text{ kg}}$$

$$= \frac{4.8 \times 10^{-17} \text{ N}}{9.1 \times 10^{-31} \text{ kg}}$$

$$a = 5.27 \times 10^{13} \text{ ms}^{-2} \text{ Ans.}$$

2. Time to pass through the field:

Since there is no acceleration in the horizontal direction, time is just:

$$t = \frac{d}{v_i}$$

Putting the values

$$t = \frac{0.1 \text{ m}}{2.99 \times 10^6 \text{ ms}^{-1}}$$

$$t = 3.34 \times 10^{-8} \text{ s} \text{ Ans.}$$

- 9.6 A disc of 10 cm^2 area is placed in a vertical electric field $E = 5 \times 10^5 \text{ N C}^{-1}$. If the plane of the disc makes an angle of 30° with the horizontal, determine the electric flux through the disc.

Solution:

Given data:

$$\text{Area of disc} = A = 10 \text{ cm}^2 = 10 \times 10^{-4} \text{ m}^2 \\ = 1 \times 10^{-3} \text{ m}^2$$

$$\text{Electric intensity} = E = 5 \times 10^5 \text{ NC}^{-1}$$

$$\text{Angle} = \theta = 30^\circ$$

To Find:

$$\text{Electric flux} = \phi = ?$$

Calculations: To find the electric flux through the disc, we use the formula:

$$\phi = \vec{E} \cdot \vec{A} = EA \cos \theta$$

Putting the values

$$\phi = 5 \times 10^5 \text{ NC}^{-1} \times 1 \times 10^{-3} \text{ m}^2 \cos 30^\circ \\ = 5 \times 10^2 \text{ Nm}^2 \text{ C}^{-1} \left(\frac{\sqrt{3}}{2} \right) \\ \phi = 250 \sqrt{3} \text{ Nm}^2 \text{ C}^{-1} \text{ Ans.}$$

- 9.7 A circular copper rod is 50 cm long and has 1 cm diameter. Find the resistance across its ends. What should be the side of square cross-section of a 50 cm long tungsten rod if its resistance is the same? [Resistivity of copper is $1.69 \times 10^{-8} \Omega \text{ m}$ and that of tungsten is $5.0 \times 10^{-8} \Omega \text{ m}$.]

Solution:

Given data:

$$\text{Length} = L = 50 \text{ cm} = 0.5 \text{ m}$$

$$\text{Diameter} = d = 1 \text{ cm} = 0.01 \text{ m}$$

$$\text{Radius} = r = \frac{0.01 \text{ m}}{2} = 0.005 \text{ m}$$

$$\text{Resistivity of copper} = \rho = 1.69 \times 10^{-8} \Omega \text{ m}$$

$$\text{Resistivity of tungsten} = \rho = 5.0 \times 10^{-8} \Omega \text{ m}$$

To Find:

- (i) Resistance of copper rod = ?
(ii) Side of square tungsten rod = ?

Calculations:

Area of circular cross-section:

$$A = \pi r^2 = 3.14 (0.005 \text{ m})^2 = 3.14 (25 \times 10^{-6} \text{ m}^2) \\ = 78.54 \times 10^{-6} \text{ m}^2$$

- (i) Resistance of copper rod

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

Putting the values

$$R = \frac{1.69 \times 10^{-8} \Omega \text{ m} \times 0.5 \text{ m}}{78.54 \times 10^{-6} \text{ m}^2} = \frac{8.45 \times 10^{-9} \Omega}{78.54 \times 10^{-6}}$$

$$R = 1.08 \times 10^{-4} \Omega \text{ Ans.}$$

- (ii) Side of square cross-section of tungsten rod with same resistance:

$$\text{Using } R = \rho \frac{L}{A}$$

$$\text{or } A = \rho \frac{L}{R}$$

Let side of square cross-section be 'a', then area:

$$A = a^2$$

$$\text{or } a^2 = \rho \frac{L}{R}$$

Putting the values

$$a^2 = \frac{5.0 \times 10^{-8} \Omega \text{ m} \times 0.5 \text{ m}}{1.08 \times 10^{-4} \Omega} = \frac{2.5 \times 10^{-8} \text{ m}^2}{1.08 \times 10^{-4}}$$

$$a^2 = 2.323 \times 10^{-4} \text{ m}^2$$

$$a^2 = \sqrt{2.323 \times 10^{-4} \text{ m}^2} = 0.01523 \text{ m}$$

$$a = 1.52 \text{ cm} \text{ Ans.}$$

- 9.8 The copper winding of an electric fan has a resistance of 50Ω at 30°C . After running for some time, the resistance becomes 52Ω . How much is the increase in temperature of the winding? [For copper $\alpha = 0.0039 \text{ K}^{-1}$]

Solution:

Given data:

$$\text{Initial resistance} = R_0 = 50 \Omega$$

$$\text{Initial temperature} = T_0 = 30^\circ \text{C}$$

$$\text{Final temperature} = R_t = 52 \Omega$$

$$\text{Temperature coefficient of copper } \alpha = 0.0039 \text{ K}^{-1}$$

To Find:

$$\text{Final temperature} = T = ?$$

Calculations:

Using the formula:

$$R_t = R_0 [1 + \alpha (T - T_0)]$$

Putting the values

$$52 \Omega = 50 \Omega [1 + 0.0039 \text{ K}^{-1} (T - 30^\circ \text{C})]$$

$$\text{or } 0.04 = 0.0039 (T - 30)$$

$$\text{or } T - 30 = \frac{0.04}{0.0039}$$

$$\text{or } T = 10.3^{\circ}\text{C} \text{ Ans.}$$

Thus, increase in temperature is 10.3°C .

- 9.9** During an experiment, a copper wire of 50 m long and $150 \mu\text{m}$ thick is hung vertically. Then a current of 1 A is passed across its ends for 50 s. Find the resistance of the wire and the heat dissipated during this process. [Resistivity of copper is $1.69 \times 10^{-8} \Omega \text{ m}$.]

Solution:

Given data:

Length of wire = $L = 50 \text{ m}$

$$\begin{aligned} \text{Thickness} = \text{Diameter of wire } d &= 150 \mu\text{m} \\ &= 150 \times 10^{-6} \text{ m} \\ &= \frac{150 \times 10^{-6} \text{ m}}{2} \\ &= 75 \times 10^{-6} \text{ m} \end{aligned}$$

Radius time = 50 s

Resistivity of copper $\rho = 1.69 \times 10^{-8} \Omega \text{ m}$

Electric current = $I = 1 \text{ A}$

To Find:

- (i) Resistance of wire = $R = ?$
(ii) Heat dissipated = $H = ?$

Calculations:

- (i) Using the formula:

$$R = \rho \frac{L}{A} \quad \dots\dots (i)$$

$$\begin{aligned} \text{As } L &= \pi r^2 = 3.14 \times (75 \times 10^{-6} \text{ m})^2 \\ &= 1.767 \times 10^{-8} \text{ m}^2 \end{aligned}$$

Putting the values in eq. (i)

$$R = 1.69 \times 10^{-8} \Omega \text{ m} \times \frac{50 \text{ m}}{1.767 \times 10^{-8} \text{ m}^2}$$

$$R = 47.8 \Omega \text{ Ans.}$$

- (ii) The heat dissipated by a resistor over time is given by

$$H = I^2 R t$$

Putting the values

$$H = (1 \text{ A})^2 \times 47.8 \Omega \times 50 \text{ s}$$

$$H = 2390 \text{ J} \text{ Ans.}$$

- 9.10** The emf of a battery is 12 V. It is connected to a 3.6Ω resistor. If the internal resistance of the battery is 0.2Ω , what will be the terminal voltage across the battery?

Solution:

Given data:

End of battery = $\epsilon = 12 \text{ V}$

External resistance = $R = 3.6 \Omega$

Internal resistance = $r = 0.2 \Omega$

To Find:

Terminal voltage = $V = ?$

Calculations:

First, we calculate the current in the circuit by using Ohm's law:

$$I = \frac{\epsilon}{R + r} = \frac{12 \text{ V}}{3.6 \Omega + 0.2 \Omega} = \frac{12 \text{ V}}{3.8 \Omega} = 3.16 \text{ A}$$

$$I = 3.16 \text{ A}$$

Now, we calculate terminal voltage V , which is the voltage across the external resistance.

$$V = \epsilon - Ir = 12 \text{ V} - (3.16 \text{ A} \times 0.2 \Omega)$$

$$V = 12 - 0.632 = 11.368 \text{ V}$$

$$V = 11.4 \text{ V} \text{ Ans.}$$