COMPLETE BOOK NOTES

F.Sc. Physics

(GRADE-12)

by MUHAMMAD ALI MALIK

HOUSE OF PHYSICS PUBLICATIONS

F.Sc. Physics (2^{nd} Year) COMPLETE BOOK NOTES

IMPORTANT QUESTIONS WITH ANSWERS

Q # 1. What do you know about electrostatics?

Ans. The branch of Physics which deals with the charges at rest is called electrostatics.

Q # 2. State the coulomb's law.

Ans. Statement.

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

If two point charges 'q_1' and 'q_2' are separated by a distance 'r', then the electrostatic force 'F' between them is expressed as:

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

where k is the constant of proportionality, which can be expressed as

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

where ε_0 is the permittivity of free space and its value in SI unit is $8.85 \times 10^{-12}\ C^2 N^{-1}\ m^{-2}$.

Q # 3. Write down the vector form of Coulomb's law.

Ans. The electrostatic force '**F**' between two point charges 'q_1' to 'q_2' is expressed as:

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

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

Q # 4. Show that Coulomb force is a mutual force

Ans. Coulomb's force is a mutual force, it means that if a charge 'q_1' exerts a force on charge 'q_2', then 'q_2' also exerts an equal and opposite force on 'q_1'. If charge 'q_1' exerts an electrostatic force '$\mathbf{F_{12}}$' due to charge 'q_2' and 'q_2' exerts electrical force '$\mathbf{F_{21}}$' on charge 'q_1' and, then

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

Proof.

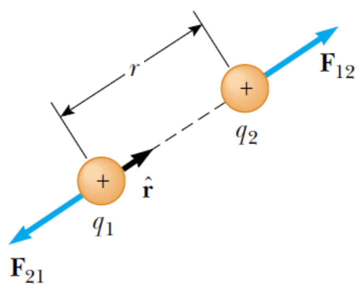
If $\hat{\mathbf{r}}_{12}$ represents the direction of force from charge 'q_1' to 'q_2' and $\hat{\mathbf{r}}_{21}$ is the unit vector which represent the direction of force from charge 'q_2' to 'q_1', then

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

$$\mathbf{F}_{12} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\hat{\mathbf{r}}_{12} \quad \text{----------------} \quad (2)$$

As $\hat{\mathbf{r}}_{21} = -\,\hat{\mathbf{r}}_{12}$, so the eq. (1) becomes

$$\mathbf{F}_{21} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}(-\,\hat{\mathbf{r}}_{12})$$



$$\mathbf{F}_{21} = -\frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\hat{\mathbf{r}}_{\mathbf{12}}$$

By eq. (2)

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

This expression shows that Coulomb force is a mutual force.

Q # 5. What is the effect of dielectric medium on electrical force, when it is placed between two point charges?

Ans. If the dielectric medium having relative permittivity 'ε_r' is placed between two point charges, then the electrical force will reduced by ε_r-times. The expression of coulomb's force between two point charges, when the dielectric medium is placed between them, is expressed as:

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

(*Definition*) Dielectric

An insulator, placed between two point charges, is referred as dielectric.

(*Definition*) Point Charges

The charges whose sizes are very small as compared to the distance between them are called point charges.

(*Definition*) Electric Field

The space or region around any charge, in which it exerts forces of attraction or repulsion on other charges, is called its electric field.

Q # 6. What do you know about 'Electric Field Intensity'? Also derive its expression.

Ans. The electrostatic force per unit test charge, at a specific point in the electric field, is called electric field intensity.

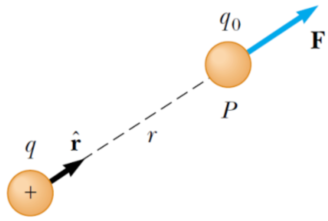
If '**F**' is the electrostatic force acting on a test charge 'q_0' at a point 'P', then electric field intensity '**E**' is expressed as

$$\mathbf{E} = \frac{\mathbf{F}}{q_0}$$

Electric field intensity is a vector quantity and its direction is same as the direction of the force.

Q # 7. Find out the expression of Electric Field Intensity due to Point Charge.

Ans. Consider a point charge 'q' as shown in the figure below



If '**F**' is the electrostatic force acting on a test charge 'q_0' at a point 'P', then electric field intensity '**E**' is expressed as:

$$\mathbf{E} = \frac{\mathbf{F}}{q_0} \quad \text{----------------} \quad (1)$$

By Coulomb's law, the electrostatic force '**F**' between point charges 'q' and 'q_0' is expressed as:

$$\mathbf{F} = \frac{1}{4\pi\,\varepsilon_0}\frac{qq_0}{r^2}\hat{\mathbf{r}}$$

Putting value of '**F**' in eq. (1), we get

$$\mathbf{E} = \frac{\left(\frac{1}{4\pi\,\varepsilon_0}\frac{qq_0}{r^2}\hat{\mathbf{r}}\right)}{q_0} = \left(\frac{1}{q_0}\right)\left(\frac{1}{4\pi\,\varepsilon_0}\frac{qq_0}{r^2}\hat{\mathbf{r}}\right)$$

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

This is the expression of electric field intensity due to a point charge.

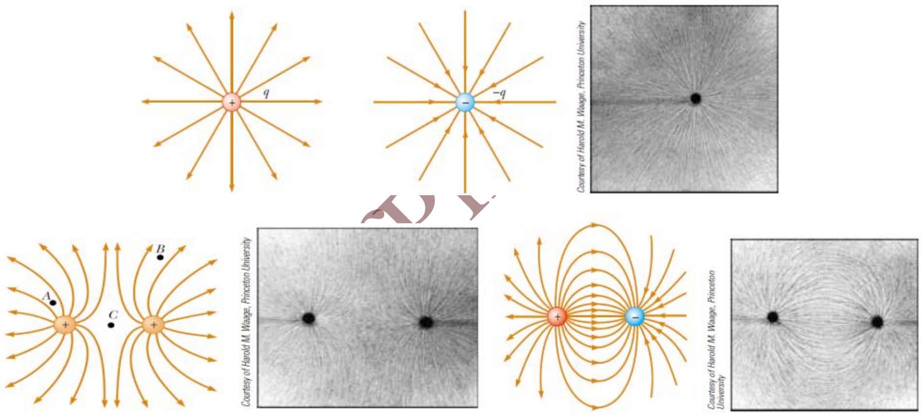
Q # 8. Write down the properties of electric lines of force.

i) Electric field lines originate from positive charges and end on negative charges.

ii) The tangent to a field line at any point gives the direction of the electric field intensity at that point.

iii) The lines are closer where the field is strong, the lines are farther apart where the field is weak.

iv) No two lines cross each other.



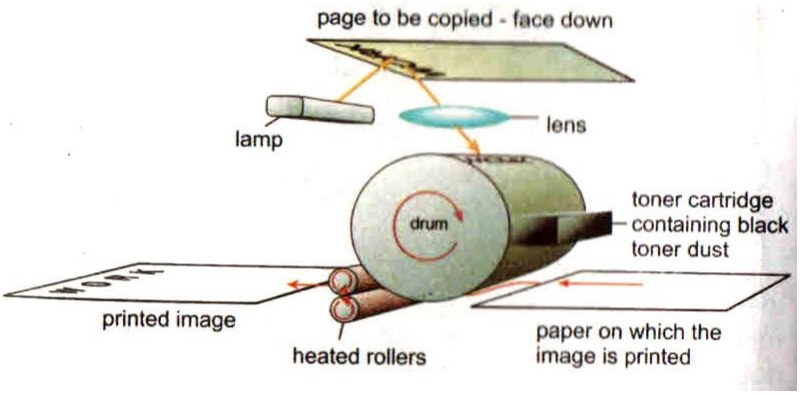
Q # 9. Write a note on following.

i) Xerography

The copying process is called xerography. The main component of photocopying machine is a drum which is an aluminum cylinder coated with layer of selenium.

Aluminum is a good conductor but selenium is a photoconductor. The positive charge is spread over the selenium. The charge will remain on the surface of drum as long as it remains in dark. When light falls on the drum, the electrons from aluminum pass through the conducting selenium and neutralize the positive charge.

The light from lamp transfers an image of the page to the drum. The dark areas retain their positive charge, but light area becomes conducting, lose their positive charge and become neutral. The drum collects negatively charged dry ink from toner where it sticks to the positive charged areas. The ink from the drum is transferred on to a sheet of paper on which the document is to be copied. Heated pressure rollers then melt the ink on to the paper to produce the permanent print of the document.

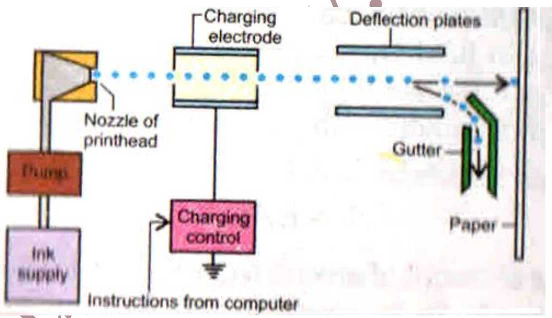


ii) Inkjet Printer

The inkjet printer uses electric charge in its working. The ink is forced out of a small nozzle and breaks up into extremely small droplets. During their flight, the droplets pass thorough two electrical components, which are the "charging electrode" and "deflecting plates"

The charging electrodes are used to charge the ink droplets that are not needed on the paper. The charged ink droplets are deflected in to the gutter (closed surface) by the deflecting plates.

The uncharged ink droplets pass through deflecting plates and strike the paper. When the print head moves over the paper which is to be inked, the charging control turns off the charging electrodes.



Q # 10. What do you know about electric flux? Describe its different cases.

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

OR

The dot product of electric field intensity and vector area element is called electric flux. It is a scalar quantity and it is denoted by a Greek letter Φ_e. Mathematically, it can be expressed as

$\Phi_e = \mathbf{E}.\mathbf{A}$ ------------------- **(1)**

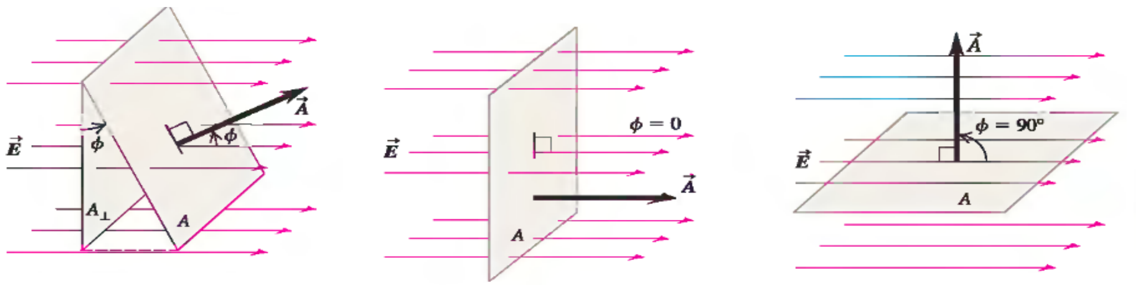
Where **E** = Electric Field Intensity

A = Vector Area

Eq. (1) can be written as

$\Phi_e = EA\cos\theta$

$\because$ θ is the angle between **E** and **A.**



Case 1. If the vector area **A** is taken parallel to the field lines **E** then the electric flux will be

$$\Phi_e = EA\cos 0 \quad = EA \qquad \text{(Since } \cos 0° = 1)$$

Thus the electric flux through an area element will be maximum, when the **E** is parallel to **A**.

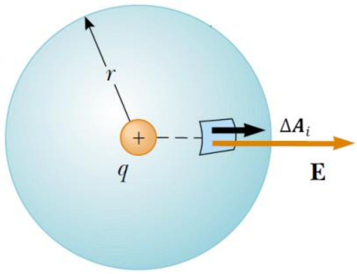
Case 2. If the vector area **A** is taken perpendicular to the field lines **E** then the electric flux passing through the body is given by

$$\Phi_e = EA\cos 90° = 0 \qquad \text{(Since cos90 =0)}$$

Thus the electric flux through an area element will be zero, when the **E** and **A** are perpendicular to each other.

Q # 11. Find out the expression of the electric flux passing through a surface enclosing a charge.

Ans. Consider a closed surface in the form of a sphere of radius 'r' which has a point charge 'q' at its centre, as shown in the figure below:



We want to find out the value of electric flux through this close surface. For this, we divide the total surface area of the sphere into n small area elements $\Delta\mathbf{A}_1, \Delta\mathbf{A}_2, \ldots\ldots\ldots \Delta\mathbf{A}_n$. The electric intensities corresponding to the area elements $\Delta\mathbf{A}_1, \Delta\mathbf{A}_2, \ldots\ldots\ldots \Delta\mathbf{A}_n$ are $\mathbf{E_1}, \mathbf{E_2}, \ldots\ldots \mathbf{E_n}$ respectively. Total flux passing through a closed surface of sphere is

$$\Phi_e = \mathbf{E_1}.\Delta\mathbf{A}_1 + \mathbf{E_2}.\Delta\mathbf{A}_2 + \ \ldots\ldots\ldots + \mathbf{E_n}.\Delta\mathbf{A}_n \text{ ------------------- } \mathbf{(1)}$$

The direction of electric field intensity and the vector area is same at each patch. Moreover, because of spherical symmetry, at the surface of sphere,

$$|\mathbf{E_1}| = |\mathbf{E_2}| = \ \ldots\ldots\ldots = |\mathbf{E_n}| = E = \frac{1}{4\pi\,\varepsilon_0}\frac{q}{r^2} \text{ ------------------- } \mathbf{(2)}$$

Equation (1) will become

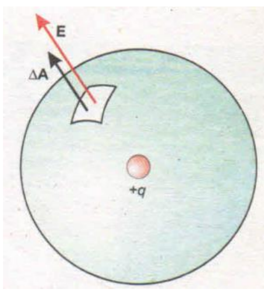
$$\Phi_e = E\Delta A_1 + E\Delta A_2 + \ \ldots\ldots\ldots + E\Delta A_n$$

$$= E \times (\Delta A_1 + \Delta A_2 + \ \ldots\ldots\ldots + \Delta A_n)$$

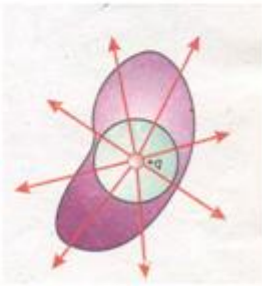
$$= E \times (\text{ Total spherical surface area})$$

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

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



Q # 12. Describe the dependence of shape of close surface on electric flux passing through it.



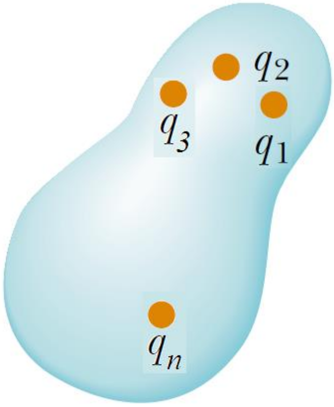
Ans. Consider an arbitrary shaped close surface enclosing a sphere which contain '$+q$' on its center, as shown in the figure below

It can be seen that the flux through arbitrary shaped close surface is same as that through the sphere. Hence the total flux through a close surface does not depend on the shape and geometry of closed surface.

Q # 13. State and explain the Gauss's law.

Statement. It states that the total electric flux through any closed surface is equal to the product of $\frac{1}{\varepsilon_0}$ times the total charge enclosed in it.

Explanation: Consider point charges $q_1, q_2, q_3, \dots\dots\dots q_n$ are spread in a closed surface S as shown in figure:



Electric flux due to charge $q_1 = \Phi_1 = \frac{q_1}{\varepsilon_0}$

Electric flux due to charge, $q_2 = \Phi_2 = \frac{q_2}{\varepsilon_0}$

Electric flux due to charge, $q_3 = \Phi_3 = \frac{q_3}{\varepsilon_0}$

⋮ ⋮ ⋮ ⋮

⋮ ⋮ ⋮ ⋮

Electric flux due to charge $q_n = \Phi_n = \frac{q_n}{\varepsilon_0}$

Total flux passing through the closed surface is

$$\Phi_e = \Phi_1 + \Phi_2 + \Phi_3 + \dots\dots\dots \Phi_n$$

$$\Phi_e = \frac{q_1}{\varepsilon_0} + \frac{q_2}{\varepsilon_0} + \frac{q_3}{\varepsilon_0} + \dots\dots\dots \frac{q_n}{\varepsilon_0}$$

$$\Phi_e = \frac{1}{\varepsilon_0} \times (q_1 + q_2 + q_3 + \dots\dots\dots + q_n)$$

$$\Phi_e = \frac{1}{\varepsilon_0} \times (\text{total charge enclosed by the closed surface})$$

$$\Phi_e = \frac{1}{\varepsilon_0} \times Q \quad \text{------------------- (1)}$$

Where $Q = q_1 + q_2 + q_3 + \dots\dots\dots + q_n$, is the total charge enclosed by the close surface. Equation (1) is the mathematical form of Gauss's law.

Q # 14. How the Gauss's law is applied to find out electric field intensity due symmetrical charge distribution.

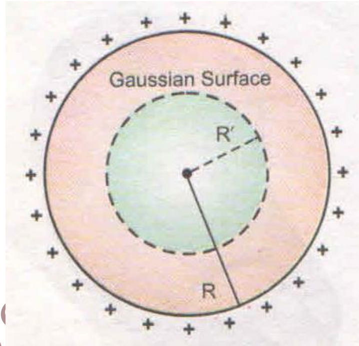
Ans. In order to find out electric field intensity due to different charge distributions, a Gaussian surface is considered which passes through the point at which the electric intensity is to be evaluated. Next the charge enclosed by the close surface is calculated and finally the electric intensity is computed by applying the Gauss's law.

Q # 15. Calculate the electric field intensity due to a hollow charged sphere.

Ans. Consider a hollow charged conducting sphere of radius 'R' is given a positive charge 'Q', as shown in the figure below:

We want to find out electric field intensity at point 'P' inside the hollow charged sphere. For this, we consider a spherical Gaussian surface which passes through the point P.

It can be seen that the charge enclosed by the Gaussian surface is zero. Then by applying the Gauss's law, we have



$$\Phi_e = \frac{q}{\varepsilon_0} = 0 \quad \text{------------------- (1)}$$

Also

$$\Phi_e = \mathbf{E}.\mathbf{A} \quad \text{------------------- (2)}$$

Comparing eq. (1) and (2), we get

$$\Phi_e = \mathbf{E}.\mathbf{A} = 0$$

As $\mathbf{A} \neq 0$,

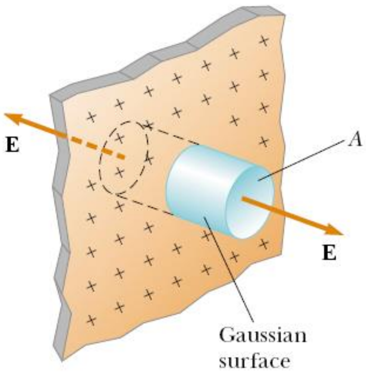
Therefore $\mathbf{E} = 0$

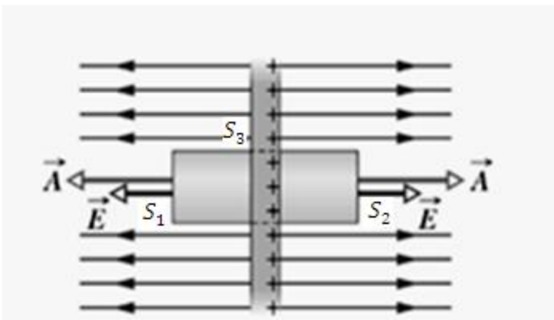
Thus the interior of a hollow charge sphere is a field free region.

Q # 16. Calculate the electric field intensity due to an infinite sheet of charge.

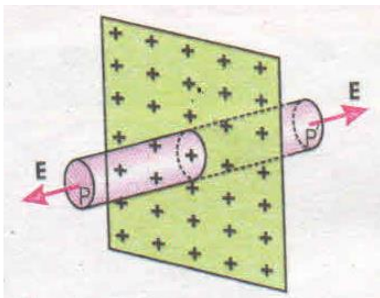
Ans. Consider an infinite sheet charges as shown in the figure below. Let the uniform surface charge density is 'σ'.

We want to find out electric field intensity at point 'P' due to this charge distribution. For this we consider a cylindrical Gaussian surface.





We divide the cylindrical Gaussian surface into three parts i.e., S_1, S_2 and S_3, where



S_1 = Left cross sectional area of cylindrical Gaussian surface

S_2 = Right cross sectional area of cylindrical Gaussian surface

S_3 = Area of curved of cylindrical Gaussian surface

Since $\mathbf{E}$ is parallel to the surface S_3, so there is no contribution to the flux from the curved wall of cylinder. While the flux through the two flat ends of the closed cylindrical surface is

$$\Phi_e = EA + EA = 2EA \text{ ------------------- } \mathbf{(1)}$$

where A is the surface area of flat surface.

The charge enclosed by the Gaussian surface 'q' can be find out by using the expression:

$$\sigma = \frac{q}{A} \Longrightarrow q = \sigma A$$

Applying the Gauss's law,

$$\Phi_e = \frac{1}{\varepsilon_0} \times (\text{total charge enclosed by the closed surface})$$

$$\Phi_e = \frac{1}{\varepsilon_0} \times (\sigma A) \text{ ------------------- } \mathbf{(2)}$$

Comparing eq. (1) and (2)

$$2EA = \frac{1}{\varepsilon_0} \times \sigma A$$

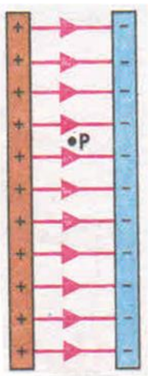
$$E = \frac{\sigma}{2\varepsilon_0}$$

This is the expression of electric field intensity due to infinite sheet of charge.

In vector form

$$\mathbf{E} = \frac{\sigma}{2\varepsilon_0}\,\hat{\mathbf{r}}$$

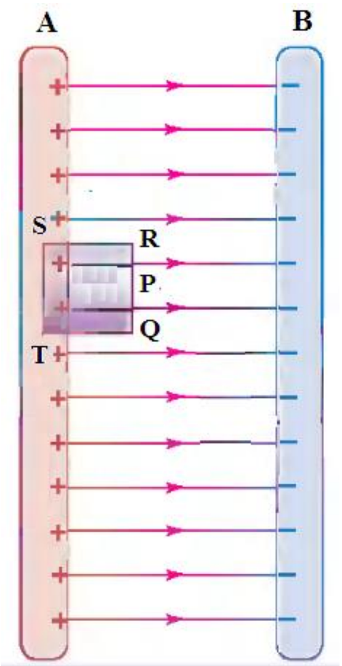
where '$\hat{\mathbf{r}}$' is a unit vector normal to the sheet directed away from it.



Q # 17. Calculate the electric field intensity between two oppositely charged plates.

Ans. Consider two oppositely charged plates 'A' and 'B' are placed at a very small distance as shown in the figure below. Suppose σ is the magnitude of surface charge density on each plate.

We want to find out electric field intensity at point 'P' due to oppositely charged plates. For this we consider a Gaussian surface in the form of a hollow box represented as QRST.



As the field lines are parallel to RS and TQ sides of Gaussian surface, so the flux through these will be zero. Thus the total electric flux through the Gaussian surface is the flux passing through the side QR, i.e.,

$$\Phi_e = EA \qquad \text{------------------- } \mathbf{(1)}$$

The charge enclosed by the Gaussian surface 'q' can be find out by using the expression:

$$\sigma = \frac{q}{A} \Longrightarrow q = \sigma A$$

Applying the Gauss's law,

$$\Phi_e = \frac{1}{\varepsilon_0} \times (\text{total charge enclosed by the closed surface })$$

$$\Phi_e = \frac{1}{\varepsilon_0} \times (\sigma A) \quad \text{------------------- (2)}$$

Comparing eq. (1) and (2)

$$EA = \frac{1}{\varepsilon_0} \times \sigma A$$

$$E = \frac{\sigma}{\varepsilon_0}$$

This is the expression of electric field intensity due to oppositely charged parallel plates.

In vector form

$$\mathbf{E} = \frac{\sigma}{\varepsilon_0}\,\hat{\mathbf{r}}$$

where '$\hat{\mathbf{r}}$' is a unit vector directed from positive to the negative plate.

Q # 18. Define following

i. Electric Potential Difference ii. Absolute Electric Potential

Ans.

i. Electric Potential Difference

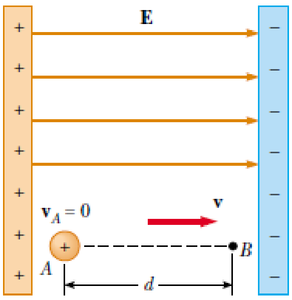
The work done per unit charge in moving it from one point to another point in an electric field is called electric potential difference. The SI unit of electric potential difference is joule/coulomb, called volt.

If W_{AB} is the work done in moving a test charge q_0 from point A to B in an electric field, then work done per unit charge from point A to point B is described as:

$$\text{Electric Potential Difference } \Delta V = \frac{W_{AB}}{q_0}$$

ii. Absolute Electric Potential

Work done per unit charge in moving it from infinity to a specific point in the field is known electric potential or absolute electric potential. The SI unit of electric potential is joule/coulomb, called volt.



Q # 19. Show that electric potential is the negative gradient of electric potential.

Ans. Consider a positive charge q_0 is placed in a uniform electric field, between two oppositely charged plates. The potential difference between A and B is expressed as:

$$V_A - V_B = \frac{W_{AB}}{q_0} \quad \text{------------------- (1)}$$

Where W_{AB} is the work done in displacing a test charge from point A to point B, against the electric field.

$$W_{AB} = \mathbf{F}.\mathbf{d} = Fd\cos 180° = -Fd$$

$\because F = q_0 E$ and d is the displacement between point A and B.

$$W_{AB} = -q_0 E d$$

The equation (1) will become

$$\Delta V = V_A - V_B = \frac{-q_0 E d}{q_0}$$

$$\Delta V = -Ed$$

$$E = -\frac{\Delta V}{d} \quad \text{-------------------- (2)}$$

If the plates A & B are separated by infinitesimally small distance Δr, then the equation (2) will become

$$E = -\frac{\Delta V}{\Delta r} \quad \text{-------------------- (3)}$$

The quantity $\frac{\Delta V}{\Delta r}$ gives the maximum rate of change of potential with respect to distance which is called the potential gradient. Hence, the electric field intensity is the negative gradient of electric potential. The negative sign indicate that the direction of E is along the decreasing potential. From equation (3) indicated that the unit of electric field intensity is Vm^{-1}.

Q # 20. Prove that $\quad 1\,\frac{volt}{meter} = 1\,\frac{newton}{coulomb}$

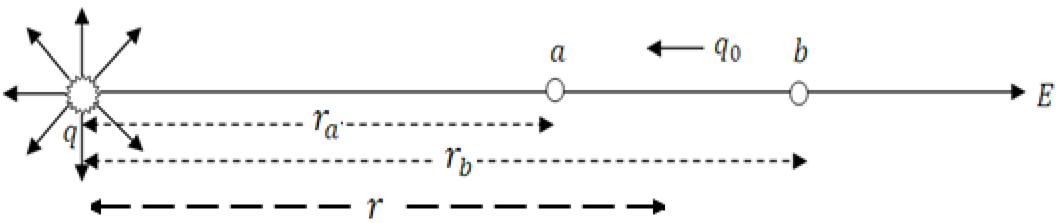
Ans. $L.H.S. = 1\,\frac{volt}{meter} = 1\,\frac{joule/coulomb}{meter}$

$$= 1\,\frac{joule}{meter \times coulomb} = 1\,\frac{newton \times meter}{meter \times coulomb}$$

$$= 1\,\frac{newton}{coulomb} = R.H.S.$$

Q # 21. Calculate the electric potential at a point due to a point charge.

Ans. Consider two points A and B in the electric field of a point charge q as shown in the figure below. The distance of points A and B from point charge q are r_a and r_b, respectively.



We want to find out electric field intensity at point P which is at the distance r from point charge. The magnitude of electric field intensity at point P is

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2} \quad \text{-------------------- (1)}$$

Consider $\Delta r = r_b - r_a$

$\Rightarrow r_b = r_a + \Delta r$

As r represents midpoint of interval between A and B, so

$$r = \frac{r_a + r_b}{2} = \frac{r_a + r_a + \Delta r}{2} = \frac{2r_a + \Delta r}{2}$$

$$r^2 = \left(\frac{2r_a+\Delta r}{2}\right)^2 = \frac{4r_a{}^2+\Delta r^2+4r_a\Delta r}{4}$$

As Δr is very small so neglecting Δr^2, we have

$$r^2 = \left(\frac{2r_a+\Delta r}{2}\right)^2 = \frac{4r_a{}^2+4r_a\Delta r}{4} = r_a{}^2 + r_a\Delta r$$

Substituting the value of Δr

$$r^2 = r_a{}^2 + r_a(r_b - r_a) = r_a{}^2 + r_a r_b - r_a{}^2 = r_a r_b$$

Substituting values in equation (1)

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r_a r_b} \qquad \text{------------------- (2)}$$

As electric field intensity is the negative gradient of electric potential, therefore

$$E = -\frac{\Delta V}{\Delta r} = \frac{-(V_b - V_a)}{(r_b - r_a)} = \frac{(V_a - V_b)}{(r_b - r_a)}$$

Putting values of equation (2)

$$\frac{(V_a - V_b)}{(r_b - r_a)} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r_a r_b}$$

$$V_a - V_b = \frac{q}{4\pi\varepsilon_0}\frac{r_b - r_a}{r_a r_b}$$

$$V_a - V_b = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{r_a} - \frac{1}{r_b}\right] \qquad \text{------------------- (3)}$$

This is the expression of electric potential difference between two points A and B. to calculate the absolute electric potential due to a point charge at point A, the point B is assume to be at infinity (i.e., $V_b = 0$, and $r_b = \infty$). Thus, the equation (3) will become

$$V_a - 0 = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{r_a} - \frac{1}{\infty}\right]$$

$$V_a = \frac{q}{4\pi\varepsilon_0}\frac{1}{r_a} \qquad \text{------------------- (4)}$$

The equation (4) gives the value of absolute electric potential at point A. the absolute electric potential at point P, which is at the distance r from point charge will be:

$$V = \frac{q}{4\pi\varepsilon_0}\frac{1}{r}$$

Q # 22. What do you know about electron volt? Also prove that 1eV $= 1.6 \times 10^{-19}$J.

Ans. The electron volt is the unit of energy which is defined as

"*the amount of energy acquired or lost by an electron when it is displaced across two points having a potential difference of one volt*". It is denoted by eV.

Proof: If the charge is free to move along the direction of field, it will acquire kinetic energy. In the present case, the loss of potential energy (ΔU) is equal to the gain in kinetic energy ($\Delta K.E$).

$$\Delta K.E = \Delta U$$

$$\Delta K.E = q\Delta V$$

If $q = 1.6 \times 10^{-19}\ C$ and $\Delta V = 1\ V$, therefore,

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

As the kinetic energy acquired by the electron will acquire the kinetic energy of one electron as it move through a potential difference of one volt, is called electron volt. Therefore

$1\ eV = 1.6 \times 10^{-19}\ CV$

Or $1\ eV = 1.6 \times 10^{-19}\ J$ $\because CV = J$

Hence proved.

Q # 23. Describe the similarities and difference among electrical and gravitational force.

Ans. The electrical force between two charges is directly proportional to the product of their charges and inversely proportional to the square of the distance between them:

$F = k\frac{q_1 q_2}{r^2}$ **------------------- (1)**

The gravitational force between two masses is directly proportional to the product of their masses and inversely proportional to the square of the distance between them:

$F = G\frac{m_1 m_2}{r^2}$ **------------------- (2)**

Similarities among the Electrical and Gravitational Force

(i) Both forces are the conservative forces.

(ii) Both forces obey the inverse square law.

Differences among the Electrical and Gravitational Force

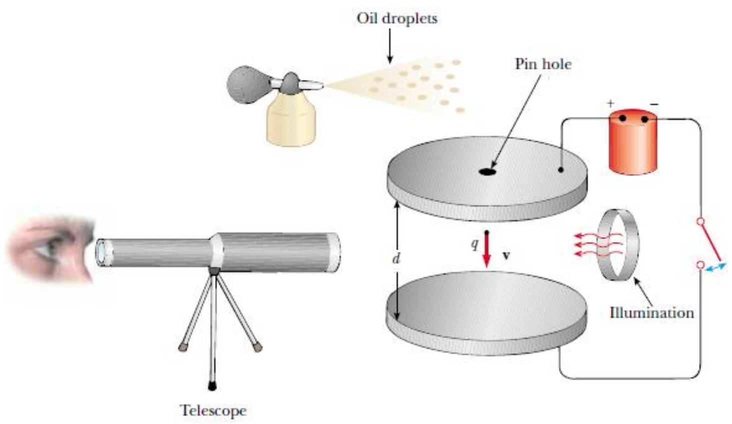
(i) Electrical force is might be attractive as well as repulsive while the gravitational force is only attractive.

(ii) Electrostatic force is medium dependent and can be shielded while the gravitational force lack this property.

(iii) The value of gravitational constant is very small while the electrical constant is very large. It is because of the fact that gravitational force is very weak as compared to electrical force.

Q # 24. Calculate the charge on an electron by Millikan's method.

Ans. In 1909, R.A Millikan's devised a technique that resulted in precise measurement of the charge on an electron. The experimental set up of Millikan's oil drop experiment is shown in figure below:



The setup consist of parallel plates separated by a distance d. The upper plate has a small hole. A voltage V is applied to the plates and so an electric field between the plates is set up. The magnitude of **E** is given by

$$\mathrm{E} = \frac{\mathrm{V}}{d} \quad \text{………………….. } \mathbf{(1)}$$

An atomizer is used for spraying oil drop through a nozzle. The oil drop gets charged due to friction with the walls of atomizer. Some of these drops will pass through the hole in the upper plate. A telescope is used to observe the path of motion of one of these charged droplets.

A given droplet between the two plates could be suspended in air if the gravitational force $F_g = mg$ acting on the drop is equal to the electrical force $F_e = qE$. The F_e can be adjusted equal to F_g by adjusting the voltage. In this case we can write:

$$F_e = F_g$$

$$qE = mg$$

By using equation (1), we get

$$q\,\frac{\mathrm{V}}{d} = mg$$

$$\Rightarrow q = \frac{mgd}{V} \quad \text{………………….. } \mathbf{(2)}$$

In order to determine the mass of the droplet, the electric field between the plates is switched off. The droplet falls under the action of gravity through air. Its terminal velocity v_t is determined by timing the fall of droplet over measured distance. The drag force on the droplet can be find out using Stokes's law:

$$F = 6\pi\eta r v_t = mg \quad \text{………………….. } \mathbf{(3)}$$

where r is the radius of the droplet and η is the coefficient of viscosity of air. If ρ is the density of droplet, then

$$m = \frac{4}{3}\pi r^3 \rho \quad \text{………………….. } \mathbf{(4)}$$

Hence the equation (3) will become,

$$6\pi\eta r v_t = \left(\frac{4}{3}\pi r^3 \rho\right) g$$

$$r^2 = \frac{9\eta v_t}{2\rho g}$$

Knowing the value of r, the mass can be calculated using equation (4). This value of m is substituted in equation (2) to get value of charge q on the droplet.

Millikan measured the charge on many drops and found that each charge was an integral multiple of minimum value of charge equal to $1.6 \times 10^{-19}C$. He, therefore, concluded that this minimum value of charge is the charge on electron.

Q # 25. What do you about a capacitor?

Ans. A capacitor is a device that can store charge. It consists of two metal plates placed near one another separated by air, vacuum or any other insulator. When plates of a capacitor are connected with a battery of voltage V, the battery places a charge $+Q$ on the plate connected with its positive terminal and a charge $-Q$ on the other plate which is connected to its negative terminal. It is found that amount of charge on one plate of capacitor Q is directly proportional to the potential difference

$$Q \propto C$$

$$Q = CV$$

where C is the constant of proportionality and is called capacitance of the capacitor. Its value depends upon the geometry and medium between them.

Q # 26. What do you know about the capacitance of a capacitor?

Ans. The ability of a capacitor to store charge is called capacitance of a capacitor. It can also be defined as

" *The amount of charge on one plate necessary to raise the potential of the plate by one volt with respect to the other*".

Q # 27. Derive a relation for the capacitance of a parallel plate capacitor

Ans. Consider a parallel plate capacitor consists of two plane metal plates, each of area A, separated by a distance d as shown in figure below:

We want to find out the expression of capacitance for a parallel plate capacitor, whose plates are separated by air.

By definition, the capacitance is

$$C_{vac} = \frac{Q}{V} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where Q is the charge on the capacitor and V is the potential difference between the parallel plates. The magnitude E of electric intensity is given by

$$E = \frac{V}{d} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The electric intensity between two oppositely charged plates is given by

$$E = \frac{\sigma}{\varepsilon_0} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where $\sigma = \frac{Q}{A}$ is the surface charge density on each plate. Hence, equation (3) will become

$$E = \frac{Q}{A\varepsilon_0} \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

By comparing (2) and (4), we get

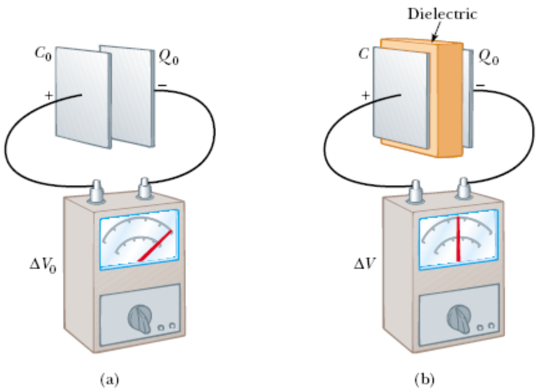
$$\frac{V}{d} = \frac{Q}{A\varepsilon_0}$$

Or $$\frac{Q}{V} = \frac{A\varepsilon_0}{d}$$

Putting values in equation (1)

$$C_{vac} = \frac{A\varepsilon_0}{d} \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

This is the expression of capacitance of a parallel plate capacitor, whose plates are separated by vacuum.

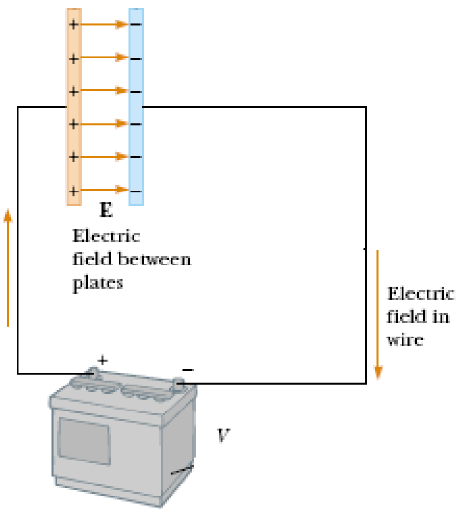


Q # 28. Describe the effect on the capacitance of a parallel plate capacitor, when a dielectric medium is place between its plates.

Ans. The presence of a dielectric medium of dielectric constant ε_r has resulted in decrease in the potential difference between the plates as shown in the figure below:

Since Q remains constant, therefore the capacitance C increased as we placed the dielectric medium between the plates of a capacitor. Thus, the expression of capacitance of capacitor when a dielectric medium of dielectric constant ε_r is placed between the plates of capacitor will be:

$$C_{med} = \frac{A\varepsilon_0\varepsilon_r}{d}$$



Q # 29. Define dielectric constant of a substance.

Ans. The dielectric constant of a substance is defined as "*The ratio of the capacitance of a parallel plate capacitor with an insulating substance as medium between the plates to its capacitance with vacuum as medium between them*"

Mathematically, it is described as:

$$C_{med} = \frac{A\varepsilon_0\varepsilon_r}{d}$$

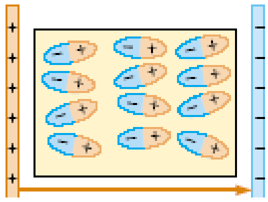
$$C_{med} = \varepsilon_r C_{vac}$$

Or $\varepsilon_r = \frac{C_{med}}{C_{vac}}$

Q # 30. Write a short note on electric polarization of dielectric.

Ans. The dielectric consists of atoms and molecules which are electrically neutral. The centers of positive and negative charges coincide in the absence of an electric field. When a dielectric is placed in an electric field between the plates of a capacitor, the centers of positive and negative charges now no longer coincide with each other. Thus the molecules of the dielectric under the action of electric field become dipoles and the dielectric is said to be polarized.

Q # 31. How the electric polarization of dielectric result in the enhancement of capacitance of capacitor?



Ans. The positively charged plate attracts the negative end of the molecular dipoles and negatively charged plate attracts the positive end. Thus the surface of the dielectric which is in contact with the positively charged plate places a layer of negative charges on the plate. Similarly the surface of the dielectric in contact with the negatively charged plate places a layer of positive charges. It decreases the surface density of the charge σ on the plates, which result in decrease in electric intensity $E = \frac{\sigma}{\varepsilon_0}$. This decrease of potential difference between the plates. As the capacitance is inversely proportional to the potential difference between plates. Therefore, the capacitance of capacitor increased due to electric polarization of a dielectric.

Q # 32. Find out the expression of energy stored in the electric field of a capacitor.

Ans. Consider a capacitor having capacitance C is connected with a battery having a terminal potential difference V.

We want to find out the expression of energy stored in electric field of a charged capacitor. The charge on the plate possesses electrical potential energy which arises work is to be done to deposit the charge on the plate. With each small increment of charge, the potential difference between the plates increases. This is due to the fact that a larger amount of work is needed to bring up next increment of charge.

Initially, when the capacitor is uncharged, the potential difference between the plates is zero and finally it becomes V when charge q is deposited on each plate. Thus average potential difference is $\frac{0+V}{2} = \frac{1}{2}V$.

Therefore the energy stored in the capacitor is:

$$E = \frac{1}{2}qV$$

$$\because q = CV \; for \; a \; capacitor$$

$$E = \frac{1}{2}CV^2$$

Substituting $V = Ed$ an d $C = \frac{A\varepsilon_0\varepsilon_r}{d}$, we get:

$$E = \frac{1}{2}\left(\frac{A\varepsilon_0\varepsilon_r}{d}\right)\ (Ed)^2$$

$$E = \frac{1}{2}\left(\frac{A\varepsilon_0\varepsilon_r}{d}\right)\ E^2\ d^2$$

$$E = \frac{1}{2}\ \varepsilon_0\varepsilon_r E^2\ (Ad)$$

Where Ad is the volume between the plates.

Energy Density

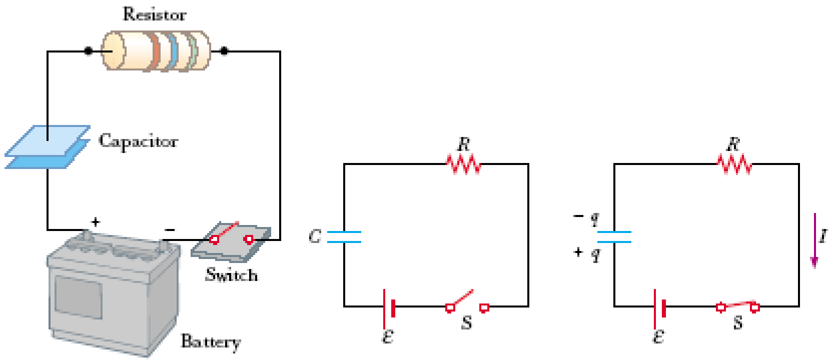
The energy density can be find out by dividing the energy stored in the capacitor by volume of the capacitor:

$$Energy\ Density = \frac{E}{Volume} = \frac{E}{Ad}$$

$$Energy\ Density = \frac{1}{2}\ \varepsilon_0\varepsilon_r E^2$$

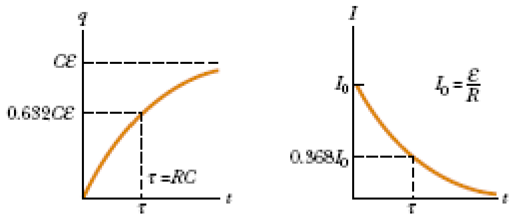
Q # 33. Describe the phenomenon of charging and discharging of a capacitor

Ans. The electrical circuits consist of both capacitor and resistors are called RC circuit. When the RC circuit is connected to a battery, it starts charging the capacitor through resistor R.



(a) (b) $t < 0$ (c) $t > 0$

The capacitor is not charged immediately, rather charges built up gradually to the equilibrium value $q_0 = CV_0$. The growth of charge with time is shown in the graph (a). According to the graph, $q = 0$ at $t = 0$ and increases gradually with time till it reaches the equilibrium value $q_0 = CV_0$.



(a) (b)

Graph (b) shows the discharging of a capacitor through resistor. The graph shows that discharging begins at $t = 0$ when $q = CV_0$ and decreases gradually to zero.

RC Time Constant

How fast or how slow the capacitor is charging or discharging, depends upon the product of the resistance and the capacitance. As the unit of the product RC is that of time, so this product is known as the time constant and is defined as the time required by "*the capacitor to deposit 0.63 times the equilibrium charge*".

The charge reaches its equilibrium value sooner when the time constant is small. Similarly, smaller values of time constant RC leads to a more rapid discharge.

EXERCISE SHORT QUESTIONS

Q # 1. The potential is constant throughout a given region of space. Is the electric field zero or non zero in this region? Explain.

Ans. The electric field intensity is described by the relation:

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

According to the relation, the electric field is negative gradient of electric potential. If the electric potential is constant throughout given region of space, then change in electric potential $\Delta V = 0$, hence $E = 0$.

Q # 2. Suppose that you follow an electric field line due to a positive point charge. Do electric field and the potential increases or decreases.

Ans. If we follow an electric field line due to a positive point charge, then it means that we are moving await from point charge. Thus the distance from the charge increases. Due to increase of distance from positive charge, both electric field intensity and electric potential decreases as:

$E \propto \frac{1}{r^2}$ and $V \propto \frac{1}{r}$

Q # 3. How can you identify that which plate of capacitor is positively charged?

Ans. The presence of charge on a body is detected by a device called gold leaf electroscope. The leaves of gold leaf electroscope are diverged by giving them negative charge.

- If the disc is touched with any plate of the charged capacitor and the divergence of the leaves increases, the plate of capacitor is negatively charged
- If the divergence of leaves decreases, then that plate of capacitor is positively charged.

Q # 4. Describe the force or forces on a positive point charge when placed between parallel plates:

i. **With similar and equal charges**
ii. **With opposite and equal charges**

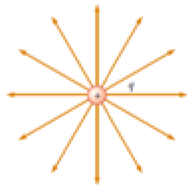
Ans. When a positive point charge is placed between parallel plates with similar and equal charges, then the electric field intensity due to one plate is equal in magnitude but opposite in direction of electric intensity due to other plate. So the value of resultant electric field intensity E is zero. Hence the net force on the positive point charge is zero. Thus it will remain at rest.

When a positive point charge is placed between parallel plates with opposite but equal amount of charge, then electric field intensity due to one plate is equal in magnitude but in same direction of the electric field intensity due to other plate. So the value of resultant electric field intensity is non zero. Hence the point charge will be accelerated towards negative plate.

Q # 5. Electric lines of force never cross. Why?

Electric lines of force never cross each other. This is because of the reason that electric field intensity has only one direction at any given pint. If the lines cross, electric intensity could have more than one direction which is physically not correct.

Q # 6. If a point charge of mass m is released in a non-uniform electric field with field lines in the same direction pointing, will it make a rectilinear motion.



Ans. A non-uniform field of a positive point charge is shown in the figure:

If a point charge q of mass m is placed at any point in the field, it will follow straight or rectilinear path along the field line due to repulsive force.

Q # 7. Is E necessarily zero inside a charged rubber balloon if the balloon is spherical. Assume that charge is distributed uniformly over the surface.

Ans. Yes, E is necessarily zero inside a charged rubber balloon if balloon is spherical. If the Gaussian surface is imagined inside charged balloon, then it does not contain any charge i.e., q=0.

Applying Gausses law:

$$\Phi_e = \frac{q}{\varepsilon_0} = 0 \quad ---------- \quad (1)$$

Also,

$$\Phi_e = E.A \quad ----------- \quad (2)$$

Comparing (1) and (2), we have:

$$E.A = 0$$

As $A \neq 0$, therefore, $E = 0$

Hence electric field intensity will be zero inside a spherical balloon.

Q # 8. 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 surface?

Ans. Yes, the above statement is true.

Electric flux is defined as the measure of number of electric lines of force passing through a certain area. According to Gauss's law, the flux through any close surface is $\frac{1}{\varepsilon_0}$ times the total charged enclosed in it.

Electric flux = $\frac{1}{\varepsilon_0}$ (Total Charge Enclosed)

Electric flux = constant (Total Charge Enclosed)

Electric flux $\propto$ (Total Charge Enclosed)

Q # 9. Do electrons tends to go to region of high potential or of low potential?

Ans. The electrons being negatively charge particle when released in electric field moves from a region of lower potential (negative end) to a region of high potential (positive end).

CURRENT ELECTRICITY

Q # 1. What do you know about electric current?

Ans. Electric Current

The amount of electric charge that flows through a cross section of a conductor per unit time is known as electric current.

If ΔQ is the amount of charge flow through a cross-section in time Δt , then the electric current I is described mathematically as:

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

It is a base quantity and its unit is ampere.

Ampere

If one coulomb charge flows through a cross-section of a conductor in one second then the current will be one ampere.

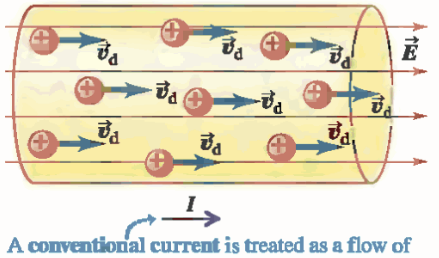
$$1\text{ Ampere} = \frac{1\text{ Coulomb}}{1\text{ second}}$$

Q # 2. Write down a note on the direction of flow of current through any conductor.

Ans. Current direction

Earlier, it was thought that the current flow through a conductor due to positive charges from higher potential to lower potential in any external circuit. But later on, it was found that the flow of current in metallic conductor is due to the flow of electrons from the point of lower potential to the point of higher potential.

But still we also take the direction of flow of current along the flow of positive charges. The reason is that it has been found experimentally that positive charge moving in one direction is equivalent in all external effects to a negative charge moving in opposite direction.



A conventional current is treated as a flow of positive charges, regardless of whether the free charges in the conductor are positive, negative, or both.

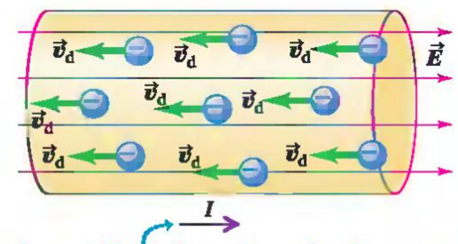
Conventional current

The current flow due to positive charges from a point at higher potential to a point at lower potential is called conventional current.

Q # 3. Describe the effect of electric field on the motion of free electrons.

Ans. All atoms contain free electrons. In the absence of any external electric field, the free electrons are in random motion just like the molecules of gas in a container and the net current through wire is zero.

If the ends of the wire are connected to a battery, an electric field (**E**) will setup at every point with in the wire. Due to electric effect of the battery the electrons will experience a force in the direction opposite to **E**.



In a metallic conductor, the moving charges are electrons — but the *current* still points in the direction positive charges would flow.

Muhammad Ali Malik (M. Phil. Physics), Govt. Degree College, Naushera, www.fb.com/HomeOfPhysics

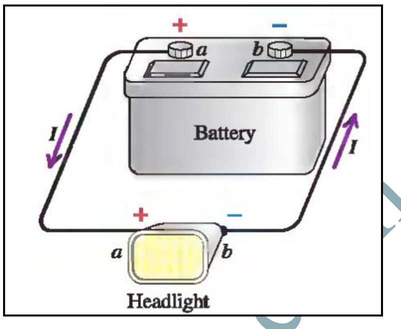
Drift velocity

When electric field is established across the ends of a conductor, the free electrons modify their random motion and drift slowly with a constant velocity in the direction opposite to E. This constant velocity is known as drift velocity.

Q # 4. Write down a note on the sources of current?

Ans. Sources of current

A source which maintains constant potential difference between the ends of the conductor is called sources of current. Source of current converts some non electrical energy (chemical, mechanical, heat or solar energy) to electrical energy.



Examples

i) Cells which convert chemical energy into electrical energy.
ii) Electric generators convert mechanical energy into electrical energy.
iii) Thermo couples convert heat energy into electrical energy.
iv) Solar cells convert light energy into electrical energy.

Q # 5. Describe the effects of current?

Ans. Effects of Current.

The presence of current produces various effects through which it can be detected. Its some effects are given below

i) Heating effect.
ii) Magnetic effect.
iii) Chemical effect.

i) Heating Effect

Current flow through a metallic conductor due to the motion of free electrons. During their motion they frequently collide with one another. On each collision they transfer some of their kinetic energy to the atom with which they collide. And these collisions produce heating effect in the wire.

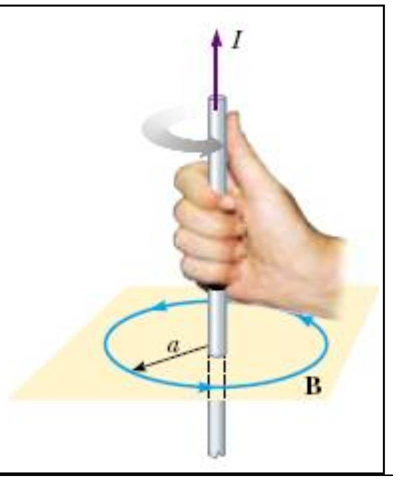
It is found that the heat H produced by the current I in the wire of resistance R during time interval y is given by the expression:

$$H = I^2RT$$

The heating effect of the current is utilized in electric heaters, kettle, toaster and electric iron etc.

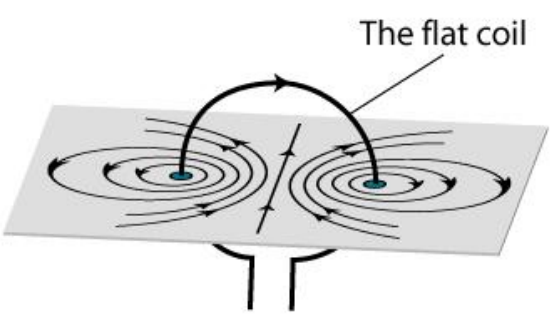
ii) Magnetic Effect

The flow of current always carries magnetic field surrounding it in space. The strength of magnetic field depends upon the value of current and the distance from the element. The pattern of the field produced by a current carrying straight wore, a coil and a solenoid is shown in the figure.

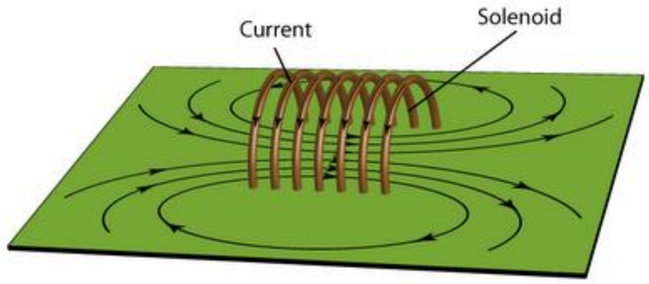


Magnetic effect is used to detect the presence of current.

Moreover, all the machines involving electric motors also use the magnetic effect of current.



Magnetic field pattern generated by a flat coil



Magnetic field generated by a solenoid. The field pattern is resemble a long bar magnet.

iii) Chemical Effect

Certain liquids (such as copper sulphate solution) conduct electricity due to some chemical reaction takes place within them. The study of this process is known as electrolysis. The chemical reaction produced during electrolysis of a liquid are due to chemical effects of current. It depends upon the nature of the liquid and quantity of electricity passed through the liquid.

Example

When $CuSO_4$ dissolved in water it dissociates into Cu^{++} and SO_4^{--}. On passing the current the following reaction takes place due to chemical effect of electric current.

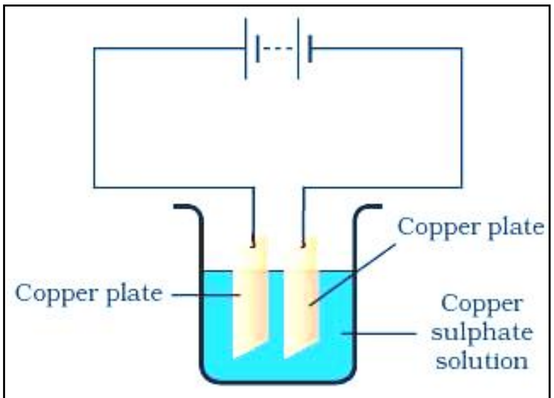
At cathode

$$Cu^{++} + 2e^{-1} \rightarrow \quad Cu$$

The copper atoms thus formed are deposited at the cathode plate. While copper is being deposited at the cathode, the SO_4^{--} ions move towards the anode. Copper atoms from anode go into the solution as copper atoms combine with sulphate ions to form copper sulphate:

$$Cu^{++} + SO_4^{--} \rightarrow CuSO_4$$

As the electrolysis proceeds, copper is continuously deposited on the cathode, while an equal amount of copper dissolved into the solution and the density of copper sulphate solution remains unaltered.



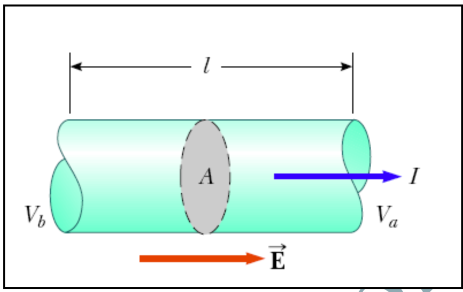
Electroplating

A process of coating a thin layer of some expensive metal (gold, silver etc) on an article of some cheap metal is called electroplating.

Q # 6. State Ohm's law.

Ans. Ohm's law

It states that "the current flowing through a conductor is directly proportional to the applied potential difference if all physical states remain same."



Mathematically it is expressed as

$$V \propto I$$

$$V = R\,I$$

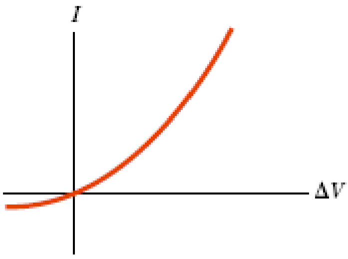
Where R(resistance) is the constant of proportionality.

Resistance

The opposition against the flow of current is known as resistance. The SI unit of resistance is Ohm. Mathematically, it is described as:

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

Q # 7. What do you know about the Non-Ohmic devices?

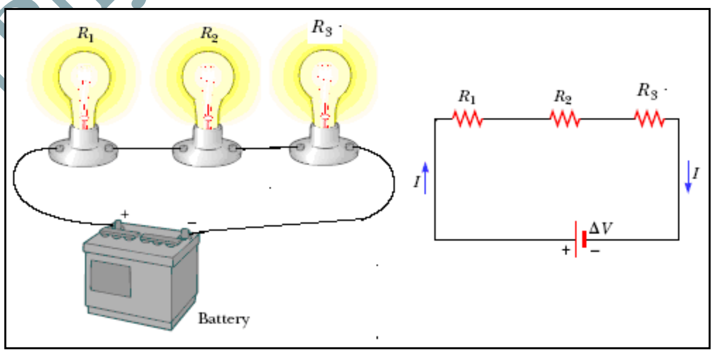


Ans. Those devices which don't the Ohm's law are called non Ohmic devices. The current-voltage graph of non-ohmic devices is not a straight line. The example of non ohmic devices are filament bulb and semi-conductor diodes.

Q # 8. Write down a short note on series and parallel combination of resistances?

Series combination of resistances

If the resistances are connected end to end this kind of combination of resistances is known as series combination of resistances.



In this type of combination the voltage divides itself but current through each resistance remain same.

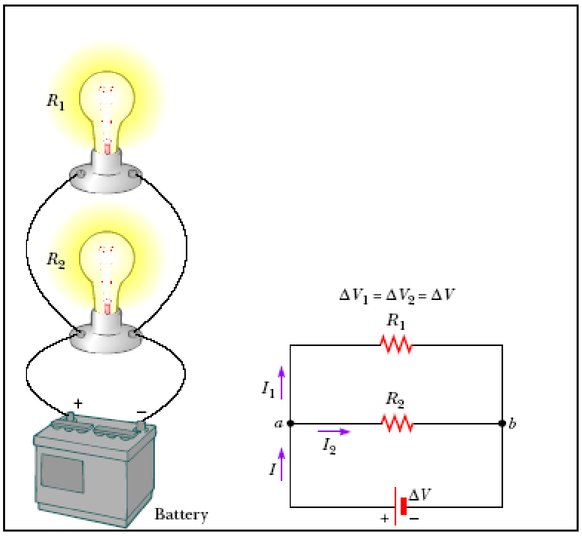
And the equivalent resistance is given by

$$R_e = R_1 + R_2 + R_3$$

Parallel Combination of Resistances

If resistances are connected in such a way that their ends are joined at two points this kind of combination is known as parallel combination of resistances.

In this type of combination the voltage across each resistance remain same but current divides it self.



And the equivalent resistance R_e can be find out by using expression:

$$\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2}$$

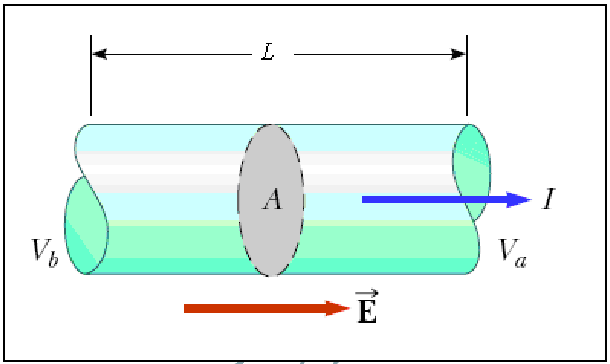
Q # 9. Define resistivity and derive its expression? Also describe the effect of temperature on the resistivity of conductor.

Ans. Resistivity

The resistance of a meter cube of material is called its resistivity.

Expression

The resistance of the wire is directly proportional to the length of the wire (L) and inversely proportional to the cross sectional area (A).



Mathematically, it is described as:

$R \propto L$ ---------- (1)

$R \propto \frac{1}{A}$ ---------- (2)

Combining (1) & (2), we get:

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

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

And the value of ρ is

Where ρ is constant of proportionality known as Resistivity.

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

Its unit is Ohm meter.

Effect of temperature on resistivity of conductor

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 atoms increases and hence the probability of their collision with free electrons also increases which result increase of resistance of conductor.

Q # 10. Write a note on

- **i) Temperature Coefficient of Resistance**
- **ii) Temperature Coefficient of Resistivity**

Ans. Temperature Coefficient of Resistance

The fractional change in resistance per Kelvin is known as the temperature coefficient of resistance. It is denoted by symbol α and is described mathematically as:

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

where R_0 is the resistance of the conductor at 0^0C and R_t is the resistance at t^0C.

Temperature Coefficient of Resistivity.

The fractional change in resistivity per Kelvin is known as the temperature coefficient of resistivity.

Temperature coefficient of resistivity $\alpha = \frac{\rho_t - \rho_0}{\rho_0 t}$

ρ_o = resistance of conductor at 0^oc

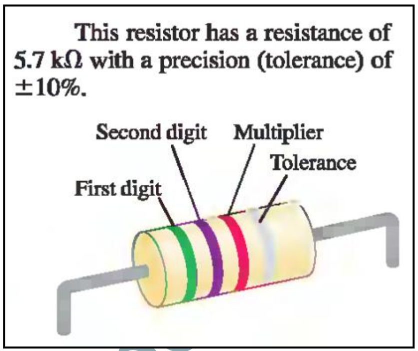
ρ_t = resistance of conductor at t^oc

Q # 11. Write a note on carbon resistor?

Ans.

Carbon resistors

Carbons resistors consist of high grade ceramic rod, on which a thin resistive film of carbon is deposited. The numerical value of their resistance is indicated by the color code which consist of bands of different colors printed on the body of the conductor.



Usually, the code consist of four bands, which are interpreted as:

- The first band indicates the first digit in the numerical value of the resistance.
- The second band gives the second digit of numerical value.
- The third band is decimal multiplier i.e., it gives the number of zeros after the first two digits.
- The fourth band gives resistance tolerance.

Q # 12. What do you know about rheostat. Also describe its construction.

Ans. It is wire wounded variable resistor. It is consist of an insulating cylinder on which a manganin wire is wounded over an insulating cylinder. The ends of the wire are connected to two fixed terminals (A and B). A third terminal is attached to a sliding contact which can which can be moved over the wire.

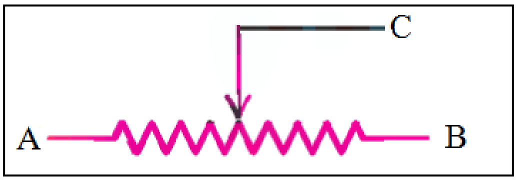
Q # 13. Describe the working of a Rheostat as

i) Variable Resistor

ii) Potential Divider

Ans.

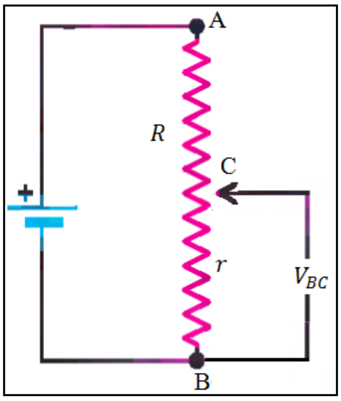
Rheostat as variable resistor



Rheostat can be used as a variable resistor. For this purpose, one of its fixed terminal A and the sliding terminal C is inserted in the circuit. If sliding contact C move towards terminal A then the resistance involved in the circuit decreases, if it moves towards B then the resistance involved in the circuit increases.

Rheostat as potential divider

To use rheostat as potential divider, potential difference V is applied across the fixed ends A and B of rheostat with the help of a battery. If R is the resistance of the wire AB, the current I passing through is given by:



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

The potential difference between the portion BC of the wire AB is given by:

$$V_{BC} = current \ \times resistance$$

$$V_{BC} = \frac{V}{R} \times r = \frac{r}{R} V$$

Where r is the resistance of the portion BC of wire. The equation shows that this circuit can provide potential difference at output terminal varying from zero to the full potential difference of the battery depending on the position of sliding contact. As the sliding contact moves towards the end B, the resistance r of portion of the wire decreases which result in decrease of output voltage V_{BC}. On the other hand if the sliding contact C is moved towards the end A, the output voltage V_{BC} increases.

Q # 14. Write a note on thermistors.

Ans. Thermistors

Thermistors are heat sensitive resistors. These are made up by heating under high pressure ceramic, from mixture of metallic oxides of nickel, cobalt, copper, iron etc. These are pressed into desired shapes and then baked at high temperature.

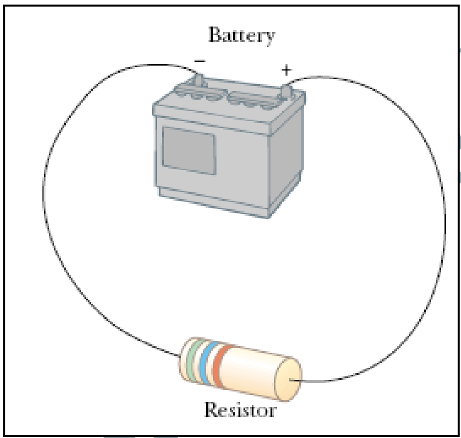
Termisters with positive temperature coefficient of resistance as well as negative temperature of resistance are available. The thermistors having high negative coefficient of temperature are used for accurate measuring of temperature up to 10K.

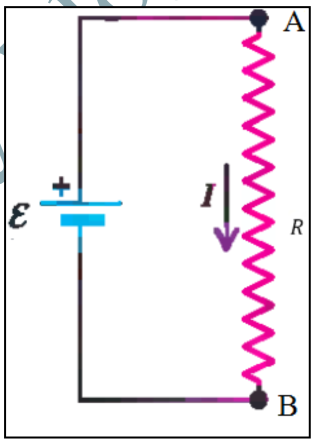
Q # 15. Define electrical power and derive its expression?

Ans. Electrical power

"The rate at which battery is supplying electrical energy is called its electrical power."

Consider a circuit consisting of a battery E connected in series with resistance R as shown in the figure:





A steady current I flows through the circuit and steady potential difference V exist between the terminals A and B of the resistor R. Using the meaning of potential difference, the work done ΔW in moving ΔQ up through the potential difference V is:

$$\Delta W = V \times \Delta Q$$

This is the energy supplied by the battery. The rate at which the battery is supplying electrical energy is called the electrical power of the battery.

$$Electrical\ Power = \frac{Energy\ Supplied}{Time\ Taken} = V\ \frac{\Delta Q}{\Delta t}$$

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

$$Electrical\ Power = VI$$

By the principal of conservation of energy, the electrical power of the battery is dissipated in the resistor R. Therefore,

$$Power\ Dissipated\ (P) = VI$$

From Ohm's law, substituting $V = IR$ and $I = \frac{V}{R}$

$$Power\ Dissipated\ (P) = VI = IR * I = I^2R$$

$$Power\ Dissipated\ (P) = VI = V * \frac{V}{R} = \frac{V^2}{R}$$

Q # 16. Differentiate between emf of a battery and potential difference?

Ans.

Electromotive Force	Potential Difference
i. Energy supplied by a battery to the charge carriers to move in circuit is called electromotive force (emf).	i. Work done per unit charge in moving it from one point to another is called potential difference.
ii. emf is the cause	ii. Potential difference is the effect of emf
iii. the emf is always present even when no current is drawn through battery.	iii. The potential difference across the conductor is zero when no current flows through it.

Q # 17. Describe the relationship between the emf of a battery and terminal potential difference. Explain this relationship on the basis of energy consideration.

Ans. Consider a battery of emf E having internal resistance r. The current I flowing through the circuit is given by:

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

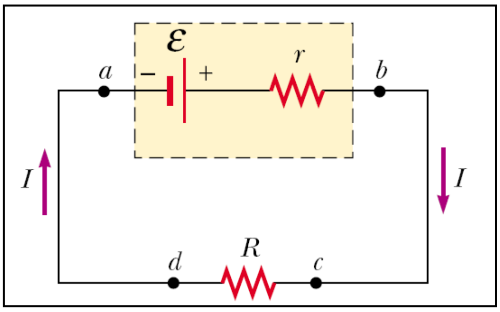
Or

$$E = IR + Ir \quad \text{-----------------} \quad (1)$$

Here $IR = V$ is the terminal potential difference of the battery in the presence of current I and Ir is the voltage drop on internal resistance of the battery.

Explanation

The left side of equation (1) is the emf of the battery, which is equal to the energy gained by unit charge (electron) to move from its negative to positive terminal. The right side of the equation gives an account of the utilization of this energy. It states that, as a unit charge passes through a circuit, a part of its 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 the potential drop IR.



Q # 18. Derive the expression for maximum power output?

Ans. Maximum power output.

As the current I is flows through the of resistance R, the charges flow from a point of higher potential to a point of lower potential and as such, they loose potential energy. Then power delivered by the battery of resistance R will be:

$$Power\ delivered\ to\ R = P_{out} = VI$$

$$P_{out} = I^2R$$

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$$\because V = IR$$

As the current flowing through the circuit is $I = \frac{E}{R+r}$, therefore

$$P_{out} = \left(\frac{E}{R+r}\right)^2 R$$

$$= \frac{E^2R}{(R+r)^2} = \frac{E^2R}{R^2+r^2+2Rr}$$

$$P_{out} = \frac{E^2R}{R^2+r^2-2Rr+2Rr+2Rr}$$

$$P_{out} = \frac{E^2R}{(R-r)^2+4Rr} \quad \text{---------------} \quad (1)$$

When $R = r$, the denominator of the expression of P_{out} is least and so P_{out} is then maximum.

Thus the maximum power is delivered to the resistance (load), when internal resistance of the source equals the load resistance. For $R = r$, the equation (1) becomes:

$$P_{out} = \frac{E^2R}{(R-R)^2+4R*R} = \frac{E^2R}{4R^2} = \frac{E^2}{4R}$$

Q # 19. Explain the Kirchhoff's Rules.

Ans. Kirchhoff's 1st Rule

It states that

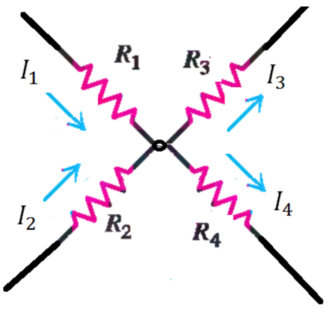
"The sum of all the current flowing towards point is equal to sum of all the currents flowing away from the point"

Or

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

It is described mathematically as:

$$\sum I = 0$$



Explanation

Consider a section where four wires meet at a point A. I_1 and I_2 are flowing towards the point where I_3 and I_4 flowing away from the point A. Mathematically represented as

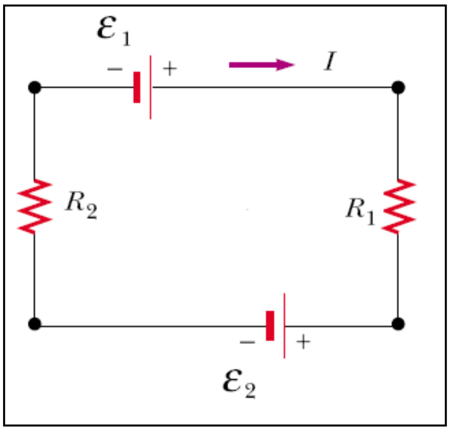
$$I_1 + I_2 + (-I_3) + (-I_4) = 0,$$

$$\Rightarrow I_1 + I_2 = I_3 + I_4$$

Kirchhoff's 2nd Rule

It states that

"The algebraic sum of all the potential changes in closed circuit is zero".



Explanation

Consider a closed circuit shown in the figure below:

Suppose E_1 is greater than E_2 .

- When a positive charge ΔQ passes through the cell E_1 from low $(-ve)$ to high potential $(+ve)$, it gained energy because the work is done on it. The energy gained by charge is $E_1\Delta Q$.

- When the current passes through the cell E_2, it loses energy equal to $-E_2\Delta Q$ because here the charge passes from high to low potential.
- In going through the resistor R_1, the charge ΔQ loses energy equal to $-IR_1\Delta Q$ where IR_1 is potential difference across R_1.
- Similarly the loss of energy while passing through the resistor R_2 is $-IR_2\Delta Q$.

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 is zero. Therefore, we can write:

$$E_1\Delta Q - IR_1\Delta Q - E_2\Delta Q - IR_2\Delta Q = 0$$

Or

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

This is mathematical form of Kirchhoff's rule.

Q # 20. Write a note on Wheatstone Bridge.

Ans. Wheatstone Bridge

Wheatstone Bridge is the combination of four resistances, arranged in the form of mesh, used to find out unknown resistance.

Explanation

Consider four resistances R_1, R_2, R_3, R_4 connected in such a way so as to form a mesh ABCDA. A battery of emf is connected between points A and C. A sensitive galvanometer of resistance R_g is connected between points B and D.

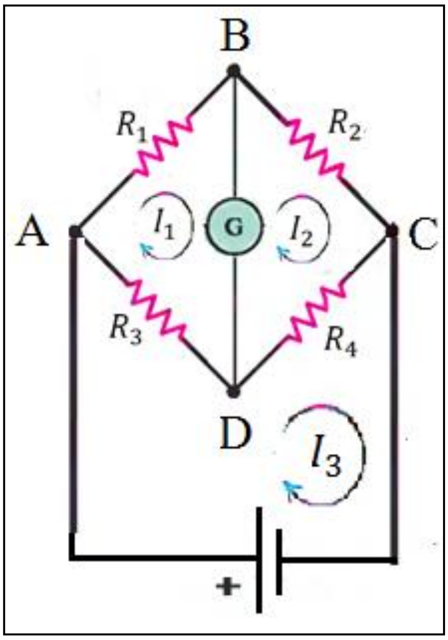
Let the current I_1, I_2, I_3 flows through the loops ABDA, BCDB, ADCA respectively.

The Kirchhoff's 2nd Rule as applied to loop ABDA gives:

$$-I_1R_1 - (I_1 - I_2)R_g - (I_1 - I_3)R_3 = 0 \quad \text{----------} \quad (1)$$

Similarly by applying the Kirchhoff's 2nd Rule to the loop BCDB, we have:

$$-I_2R_2 - (I_2 - I_3)R_4 - (I_2 - I_1)R_g = 0 \quad \text{----------} \quad (2)$$



The current through the galvanometer will be zero if $I_1 - I_2 = 0$ or $I_1 = I_2$. With this condition, the equation (1) and (2) reduces to:

$$-I_1R_1 = (I_1 - I_3)R_3 \quad \text{----------} \quad (3)$$

$$-I_1R_2 = (I_1 - I_3)R_4 \quad \text{----------} \quad (4)$$

Dividing equation (3) and (4), we get:

$$\frac{-I_1R_1}{-I_1R_2} = \frac{(I_1 - I_3)R_3}{(I_1 - I_3)R_4}$$

$$\Rightarrow \frac{R_1}{R_2} = \frac{R_3}{R_4} \quad \text{----------} \quad (5)$$

If we connect three resistance R_1, R_2, R_3 of known adjustable values and unknown resistance R_4 in such a way that no current pass through galvanometer, then the unknown resistance can be find out easily by equation (5).

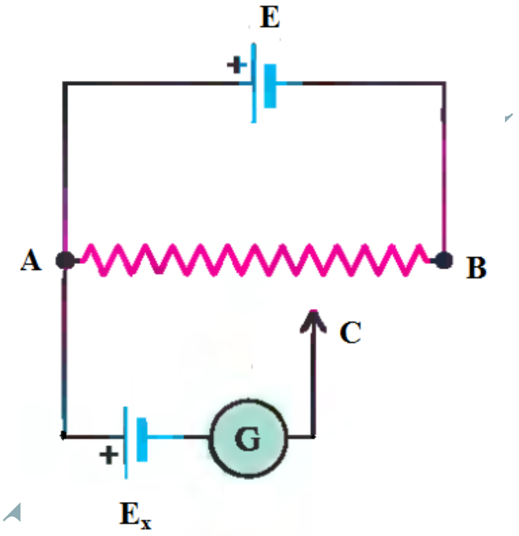
Q # 21. What do you know about potentiometer? Also describe the advantage of potentiometer over voltmeter.

Ans.

Potentiometer

It is a device that is used to measure potential difference between two points without drawing any current from original circuit.

Advantage of Potentiometer over Voltmeter



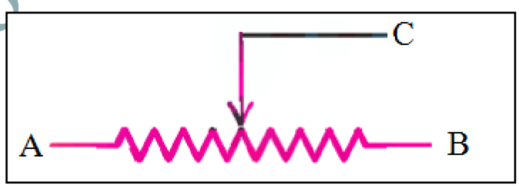
Potential difference is usually measured by an instrument called voltmeter. The voltmeter is connected across the two points in a circuit between which the potential difference is to be measured. It is necessary that the resistance of the voltmeter be large compared to the circuit resistance across which the voltmeter is connected. Otherwise an appreciable current will flow through the voltmeter which will alter the circuit current and the potential difference measured. Thus the voltmeter can read the correct potential difference only when it does not draw any current from the circuit across which it is connected.

On the other hand, potentiometer is a very simple instrument which can measure and compare potential difference accurately without drawing any circuit current.

Q # 22. Explain the construction and working of Potentiometer?

Construction

It is consist of a wire which has resistance R between its two fixed terminals A and B while a sliding terminal C can slide over the wire. The resistance r between A & C can be varies from 0 to R by moving sliding contact C from A to B.



If a battery of emf E is connected across R .Then current flowing through it is

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

If we represent the resistance between A and C by r. Then potential drop across r will be:

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

Thus the potential drop can be varied from 0 to V across A & C terminals by sliding the terminal C from A to B.

A source of potential difference whose emf is E_x is to be measured is connected A and sliding contact C through a galvanometer G. The potential divider is connected at point A. After adjusting the circuit

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the sliding contact is so adjusted that galvanometer show no deflection. At this condition the emf E_x is equal to potential difference across A and C, whose value is known, i.e.,

$$E_x = r\,\frac{E}{R} \quad ---------- \quad (1)$$

In case of a wire if uniform cross sectional area, the resistance is proportional to length.

So $r \propto l$ & $R \propto L$

Therefore, unknown emf E_x is given by :

$$E_x = r\,\frac{E}{R}$$

Comparison of different emfs

We can compare different emfs E_1 & E_2 of two cells easily by finding the balancing condition. If l_1 is the balancing length corresponding the E_1, then:

$$E_1 = E\,\frac{l_1}{L} \quad ---------- \quad (2)$$

Similarly, if l_2 is the balancing length corresponding the E_2, then:

$$E_2 = E\,\frac{l_2}{L} \quad ---------- \quad (3)$$

Dividing equation (2) and (3), we get:

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

This expression tells that the ratio of two emfs is equal to ratio of their balancing lengths.

EXERCISE SHORT QUESTIONS

Q # 1. A potential difference is applied across the ends of a copper wire. What is the effect on the drift velocity of free electrons by

i. Increasing the potential difference

ii. Decreasing the length and the temperature of the wire.

Ans. The drift velocity V_d of electrons in a conductor is described by the formula:

$$V_d = \frac{\Delta V}{ne\rho L}$$

Where ΔV is the potential difference between the ends of conductor, L is the length of conductor and ρ is the resistivity of wire. From equation, it is clear that

i. Drift velocity of electron increases with increase in potential difference

ii. Drift velocity of electron also increases by decreasing the length and temperature of wire.

Q # 2. Do bends in a wire affect its electrical resistance? Explain.

Ans. The resistance of the conductor is described by the formula:

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

Where L is the length and A is the cross-section area of conductor. ρ the electrical resistivity of the material which depends upon the nature of conductor.

Hence the resistance of conductor depends upon the geometry and nature of conductor. Hence the bends in conducting wires don't affect its electrical resistance.

Q # 3. What are the resistances of the resistors given in the figure A and B. What is the tolerance of each? Explain what is meant by the tolerance.

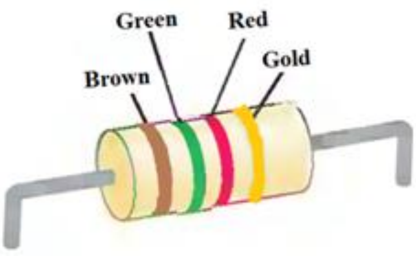


Fig. A

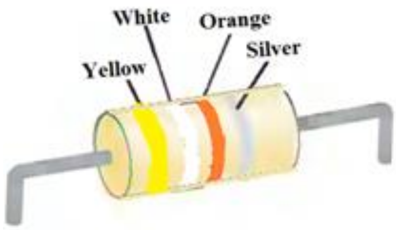


Fig. B

For figure A. The color codes for figure A are as follows: Brown 1 (First Digit) Green 5 (Second Digit) Red 2 (Number of Zero) Therefore Resistance = 1500 Ω And Tolerance = T = 5%	For figure B. The color codes for figure B are as follows: Yellow 4 (First Digit) White 9 (Second Digit) Orange 3 (Number of Zero) Therefore Resistance = 49000 Ω And Tolerance = T = 10%

Tolerance

Tolerance means the possible variation in the value of resistance from the marked value. For example, a 1000 Ω resistance with a tolerance of 10% can have an actual resistance between 900 Ω and 1100 Ω.

Q # 4. Why does the resistance of conductor rise with temperature?

Ans. 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 atoms increases and hence the probability of their collision with free electrons also increases which result increase of resistance of conductor.

Q # 5. What are the difficulties in testing whether the filament of a lighted bulb obeys ohm's law?

Ans. Ohm's law states that the current flowing through the conductor is directly proportional to the potential difference applied across its ends provided that the temperature of the conductor remains constant. In case of a lighted bulb, the temperature of the filament increases with the passage of current through it. Hence the Ohm's law can't be applied to filament bulb.

Thus the main difficulty in testing whether the filament of a lighted bulb obeys ohm's law is the change in temperature with the flow of current in it.

Q # 6. Is the filament resistance lower or higher in a 500 W, 220 V bulb than in a 100 W, 220 V bulb?

Ans. We know that

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

The resistance of filament of 500 W, 220 V bulb is:

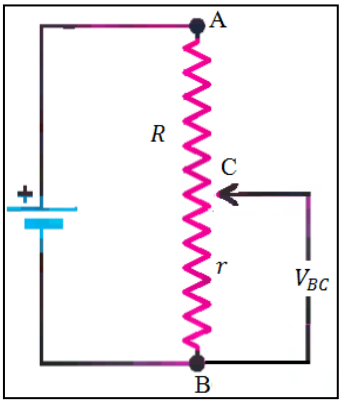
$$R = \frac{V^2}{P} = \frac{(220)^2}{500} = 98.6\ \Omega$$

The resistance of filament of 100 W, 220 V bulb is:

$$R = \frac{V^2}{P} = \frac{(220)^2}{100} = 484\ \Omega$$

It is clear that the filament resistance is lowered in a 500 W, 220 V bulb than 100 W, 220 V bulb.

Q # 7. Describe a circuit which will give a continuously varying potential.



Ans. To use rheostat as potential divider, potential difference V is applied across the fixed ends A and B of rheostat with the help of a battery. If R is the resistance of the wire AB, the current I passing through is given by:

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

The potential difference between the portion BC of the wire AB is given by:

$$V_{BC} = current\ \times resistance$$

$$V_{BC} = \frac{V}{R} \times r = \frac{r}{R} V$$

Where r is the resistance of the portion BC of wire. The equation shows that this circuit can provide potential difference at output terminal varying from zero to the full potential difference of the battery depending on the position of sliding contact. As the sliding contact moves towards the end B, the resistance r of portion of the wire decreases which result in decrease of output voltage V_{BC}. On the other hand if the sliding contact C is moved towards the end A, the output voltage V_{BC} increases.

Q # 8. Explain why the terminal potential difference of a battery decreases when current drawn from it is increases.

Ans. The terminal potential difference V_t of the battery of emf ε is described by the formula:

$$V_t = \varepsilon - Ir$$

Where r is the internal resistance of the battery and I is the current flowing through outer circuit.

It is clear from equation that when I is large, the factor Ir becomes large and V_t becomes small. Hence terminal potential difference of a battery decreases when current drawn from it is increased.

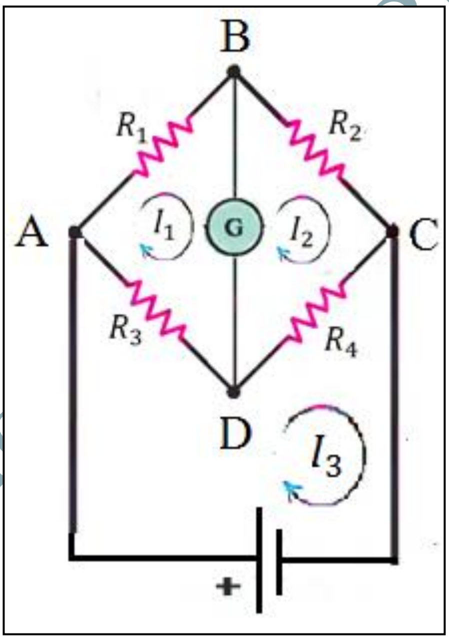
Q # 9. What is Wheatstone bridge? How can it be used to determine an unknown resistance?

Ans. It is an electrical circuit which can be used to find the unknown resistance of a wire. The circuit of Wheatstone bridge is shown in the figure.

It consist of four resistance connected in the form of a mesh, galvanometer, battery and a switch. When the bridge is balanced, it satisfies the following relation:

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

If the values of R_1, R_2, R_3 are known, then R_4 can be calculated, provided the bridge is balanced.



ELECTROMAGNETISM

Q # 1. Describe the properties of magnetic field due to current in a long straight conductor.

Ans. When the heavy current is passed through a straight conductor:

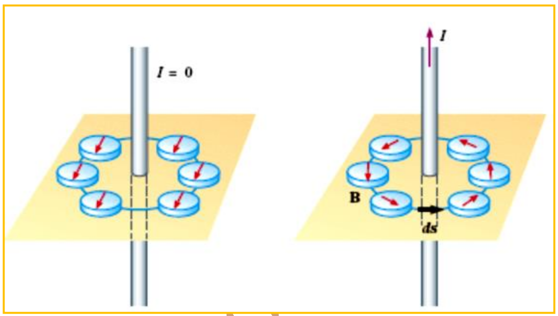
A magnetic field is set up in the region surrounding a current carrying wire.

i. The lines of force are circular and their direction depends upon the direction of current.

ii. The magnetic field lasts only as long as the current is flowing through the wire.

iii. The direction of magnetic lines of force can be find out by right hand rule described below:

"*If the wire is grasped in fist of right hand with the thumb pointing in the direction of current, the finger of the hand will circle the wire in the direction of magnetic field.*"



Q # 2. Derive the expression of force on a current carrying conductor in a uniform magnetic force.

Ans. If a current carrying conductor is placed in an external magnetic field, the magnetic field of conductor will interact with the external magnetic field, as the result of which the conductor may experience a force.

Consider a rod of copper of length L that is capable of moving on the pair of copper rails. The whole arrangement is placed between the poles pieces of a horseshoe magnet so that the copper rod is subjected to a magnetic field B directed vertically upward.

When a current I is passed through the copper rod from battery, the current carrying conductor will experience magnetic force and moves on the rails. The magnitude of magnetic force depends upon the following factors:

i. The magnetic force is directly proportional to the current flowing through conductor.

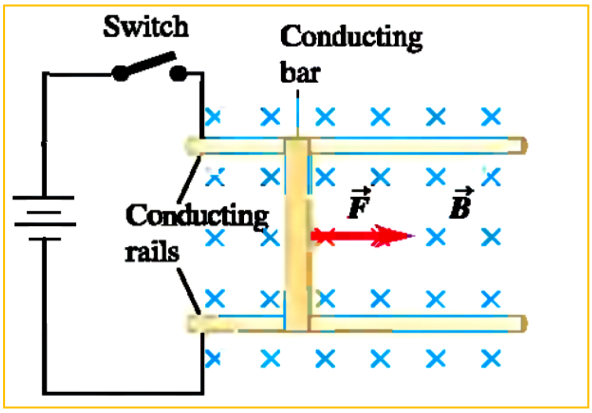
$$F \propto I$$

ii. The force is directly proportional to the length of the conductor inside the magnetic field.

$$F \propto L$$

iii. The force is directly proportional to the strength of applied magnetic field.

$$F \propto B$$



iv. The magnetic force on current carrying conductor is directly proportional to $\sin\theta$, where θ is the angle between conductor and the field.

$$F \propto \sin\theta$$

Combining all these factors,

$$F \propto ILB\sin\theta$$

$$F = k\,ILB\sin\theta$$

Where k is the constant of proportionality. If we follow SI units, the value of k is 1. Thus in SI units

$$F = ILB\sin\theta$$

If L vector is in the direction f current flow, then in vector form:

$\mathbf{F} = I\,(\mathbf{L} \times \mathbf{B})$

This is expression of magnetic force on a current carrying conductor in a uniform magnetic field.

Q # 3. Define the term Magnetic Field Strength.

Ans. The force acting on one meter length of conductor placed at right angle to the magnetic field when 1 A current is passing through it. In SI units the unit of magnetic field strength is tesla ($1\text{T} = 1\,\text{NA}^{-1}\text{m}^{-1}$).

Q # 4. What do you know about magnetic flux?

Ans. The number of magnetic lines of force passing through certain area element is called magnetic flux. The magnetic flux Φ_B through the plane element of vector area **A** in the uniform magnetic field **B** is given by the dot product of **B** and **A**.

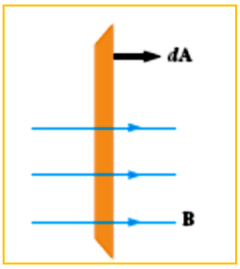
$$\Phi_B = \mathbf{B}.\mathbf{A}$$

$$\Phi_B = BA\cos\theta$$

Where θ is the angle between the magnetic field strength **B** and vector area **A**. Magnetic flux is a scalar quantity and its SI unit is NmA^{-1} which is called weber (Wb).

Special cases

Case 1. When the field is directed along the normal to the area, so θ is zero and the flux is maximum:



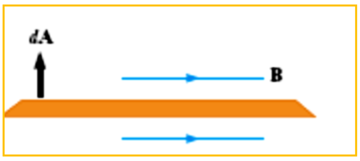
$$\Phi_B = \mathbf{B}.\mathbf{A} = BA\cos 0 = BA$$

Case 2. When the field is parallel t the plane of the area, the angle between the field and normal to the area is 90^0, i.e., $\theta = 90^0$, so the flux through the area in this position is zero.

$$\Phi_B = \mathbf{B}.\mathbf{A} = BA\cos 90^0 = 0$$

Case 3. For the case of curved surface placed in a non-uniform magnetic field, the curved surface is divided into small surface elements. Each element being assumed plane and the flux through the whole curved surface is calculated by the sum of the contributions from all the elements of the surface.

Q # 5. Define the term flux density.



Ans. The magnetic induction B is the flux per unit area of a surface perpendicular to B, hence it is also called as flux density. Its unit is $Wb\,m^{-2}$.

Q # 6. State the Ampere's Law. Apply it to find out the magnetic field strength inside a current carrying solenoid.

Ans. Consider a close circular path enclosing a current carrying conductor. This closed path is referred as Amperean path. Divide this path into small elements of length like $\Delta\mathbf{L}$. Let **B** be the value of flux density at the site of $\Delta\mathbf{L}$. If θ is the angle between **B** and $\Delta\mathbf{L}$, then $B\cos\theta$ represents the component of **B** along $\Delta\mathbf{L}$. Thus $\mathbf{B}.\Delta\mathbf{L}$ represents product of length of element $\Delta\mathbf{L}$ and the component of **B** along $\Delta\mathbf{L}$. Ampere's law states that

"*The sum of the quantities $\mathbf{B}.\Delta\mathbf{L}$ for all path elements into which the complete loop has been divided equals μ_0 times the total current enclosed by the loop*"

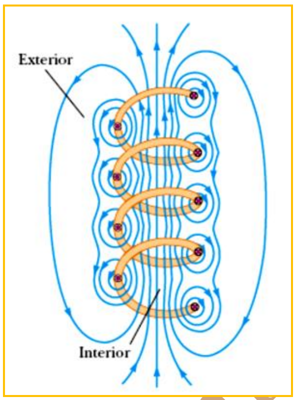
The Ampere's law can be described mathematically as:

$$(\mathbf{B}.\Delta\mathbf{L})_1 + (\mathbf{B}.\Delta\mathbf{L})_2 + (\mathbf{B}.\Delta\mathbf{L})_3 + \dots\dots + (\mathbf{B}.\Delta\mathbf{L})_r + \dots\dots (\mathbf{B}.\Delta\mathbf{L})_N = \mu_0 I$$

Or

$$\sum_{r=1}^{N} (\mathbf{B}.\Delta\mathbf{L})_r = \mu_0 I$$

Where $(\mathbf{B}.\Delta\mathbf{L})_r$ is the value of $\mathbf{B}.\Delta\mathbf{L}$ along the **r th** element and N is the total number of elements into which loop has been divided.



Magnetic Field Strength Due To Current Carrying Solenoid

When current passes through a solenoid, it behaves like bar magnet. Suppose that the magnetic field inside a long solenoid is uniform and much strong whereas outside the solenoid.

We want to find out the magnetic field strength B inside the solenoid by applying Ampere circuital law. For this we consider a rectangular Amperean loop. We divide the loop into four elements of lengths $ab = l_1$, $bc = l_2$, $cd = l_3$ and $da = l_4$.

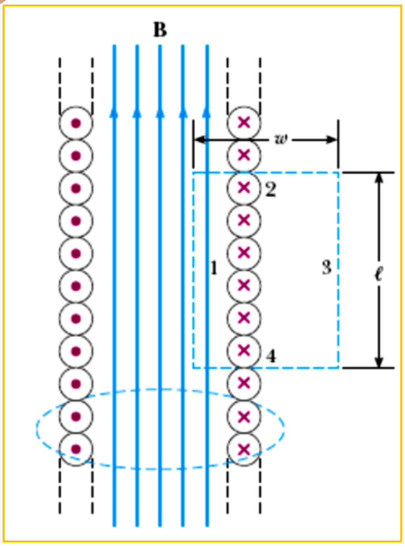
Applying Ampere's law, we have:

$$\sum_{r=1}^{4}(\mathbf{B}.\Delta\mathbf{L})_r = \mu_0 \times current\ enclosed$$

$$(\mathbf{B}.\Delta\mathbf{L})_1 + (\mathbf{B}.\Delta\mathbf{L})_2 + (\mathbf{B}.\Delta\mathbf{L})_3 + (\mathbf{B}.\Delta\mathbf{L})_4 = \mu_0 \times current\ enclosed \quad \text{-------} \quad (1)$$

- The length element $ab = l_1$ lies inside the solenoid, where the field is uniform and is parallel to l_1:

  $(\mathbf{B}.\Delta\mathbf{L})_1 = B\, l_1 \cos 0^0 = B\, l_1$



- For the element $cd = l_3$, that lies outside the solenoid, the field **B** is zero, so

  $(\mathbf{B}.\Delta\mathbf{L})_3 = 0$

- For elements $bc = l_2$ and $da = l_4$, **B** is perpendicular to length elements, so

  $(\mathbf{B}.\Delta\mathbf{L})_2 = (\mathbf{B}.\Delta\mathbf{L})_4 = 0$

The equation (1) becomes:

$B\, l_1 = \mu_0 \times current\ enclosed$

If n is the number of turns per unit length of the solenoid, the rectangular surface will intercept nl_1 turns, each carrying current I. So the current enclosed by the loop is nl_1I. Thus Ampere's law gives

$B\, l_1 = \mu_0 \times nl_1I$

$B = \mu_0 nI$

Direction of Magnetic field strength inside Solenoid

The direction of magnetic field strength B can be find out by right hand rule which states:

Hold the solenoid in the right hand with figures curling in the direction of current, the thumb will point in the direction of the field.

Q # 7. Find out the expression of magnetic force on a moving charge in a magnetic field.

Ans. Consider the portion of wire, carrying current I, is placed in an external magnetic field of strength **B**. The magnetic force on the current carrying conductor is given by the expression:

$$\mathbf{F}_L = I\,(\mathbf{L} \times \mathbf{B}) \quad \text{---------- } \mathbf{(1)}$$

Let

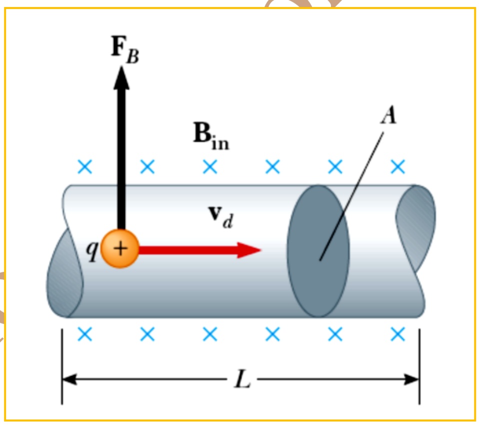
n = Number of free electrons per unit

AL = Volume of the conductor

nAL = Number of free electrons in the conductor

v = Speed of the charge carrier

Then the carrier entering the left face of the segment takes the time $\Delta t = {}^{L}/_{v}$ to reach the right face. If



q = Charge on a charge carrier

Then $nALq = \Delta Q$ = Total charge flowing in conductor in time $\Delta t = {}^{L}/_{v}$

So, the current through conductor is:

$$I = \frac{q}{t} = \frac{nALq}{L/v} = nAqv$$

The equation (1) becomes:

$$\mathbf{F}_L = nAqv\,(\mathbf{L} \times \mathbf{B})$$

$$= nAqv\left(L\hat{L} \times \mathbf{B}\right) \quad \text{---------- } \mathbf{(2)}$$

It is clear from the figure that the direction of the segment **L** is the same as the direction of the velocity of the charge carriers **v**. If $\hat{L}$ is a unit vector along the direction of segment **L** and $\hat{v}$ is along the velocity **v**, then

$$\hat{L} = \hat{v}$$

Substituting the value in equation (2), we have:

$$\mathbf{F}_L = nAqv\,(L\hat{v} \times \mathbf{B})$$

$$= nAqL\,(v\hat{v} \times \mathbf{B})$$

$$= nALq\,(\mathbf{v} \times \mathbf{B})$$

As nAL is the total number of charge carriers in the segment **L,** so the force **F** experienced by a single charge carrier is:

$$\mathbf{F} = \frac{\mathbf{F}_L}{nAL} = q\,(\mathbf{v} \times \mathbf{B})$$

Thus the force experience by a single charge carrier moving with velocity **v** in the magnetic field strength **B** is:

$$\mathbf{F} = q\,(\mathbf{v} \times \mathbf{B})$$

Q # 8. What do you know about the Lorentz force?

When a charge particle q is moving with velocity **v** in a region where there is electric field **E** and magnetic field **B**, then the vector sum of electric force $q\mathbf{E}$ and magnetic force $q\,(\mathbf{v} \times \mathbf{B})$ is called the Lorentz force **F**. Mathematically, it is described as:

$$\mathbf{F} = \mathbf{F}_e + \mathbf{F}_b$$

$$\mathbf{F} = q\mathbf{E} + q\,(\mathbf{v} \times \mathbf{B})$$

It is important to note that only the electric force does work, while no work is done by the magnetic force which is simply a deflecting force.

Q # 9. Derive the expression to find out $^e/_m$ of an electron.

Ans. Let a narrow beam of electrons moving with a constant speed v be projected at right angles to a known magnetic field **B**. The magnetic force experienced by the beam of electron will be:

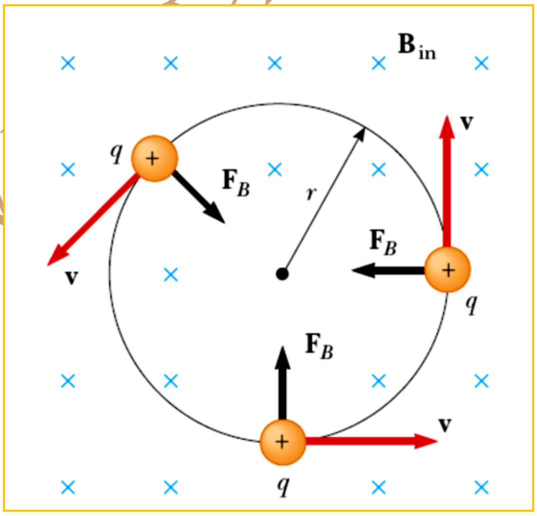
$$\mathbf{F} = -e\,(\mathbf{v} \times \mathbf{B})$$

The direction of the force will be perpendicular to both **v** and **B.** As the electron is experiencing a force that acts at right angle to velocity, so it will change the direction of velocity. Thus the electrons are subjected to a constant force $F = evB$ at the right angle to the direction of motion. Under the action of this force, the electrons will move in the circle as shown in the figure.

As the electron moves in the circle, the necessary magnetic force $\frac{mv^2}{r}$ is provided by the magnetic force $F = evB$. Thus we have:

$$evB = \frac{mv^2}{r}$$

$$\frac{e}{m} = \frac{v}{Br} \quad \text{----------} \quad (1)$$



This equation shows that if the values of v and r is known, $^e/_m$ of the electron is determined.

- To find out the value of r, a glass tube is filled with a gas such as hydrogen at low pressure. The glass tube is placed in a region of uniform magnetic field of known value. As the electrons are shot into this tube, they begin to move along a circle under the action of magnetic force. As the electron move, they collide with the atoms of gas. This excites the atoms due to which they emit light and their path becomes visible as a circular ring of light. The diameter of ring can be easily measured.
- In order to measure the velocity v of electrons, we should know the potential difference through which the electrons are accelerated before entering into magnetic field. If V is this potential difference, the energy gained by the electrons during their acceleration is Ve. This appears as kinetic energy of electrons:

$$\frac{1}{2}mv^2 = Ve$$

$$v = \sqrt{\frac{2Ve}{m}}$$

Substituting the value of v in equation (1), we get:

$$\frac{e}{m} = \frac{1}{Br}\sqrt{\frac{2Ve}{m}}$$

$$\sqrt{\frac{e}{m}} = \frac{1}{Br}\sqrt{2V}$$

Squaring both sides:

$$\frac{e}{m} = \frac{2V}{B^2r^2}$$

This is the required expression to find the e/m of electron.

Q # 10. What do you know about cathode ray oscilloscope (CRO)? Also describe the construction, working and applications of CRO.

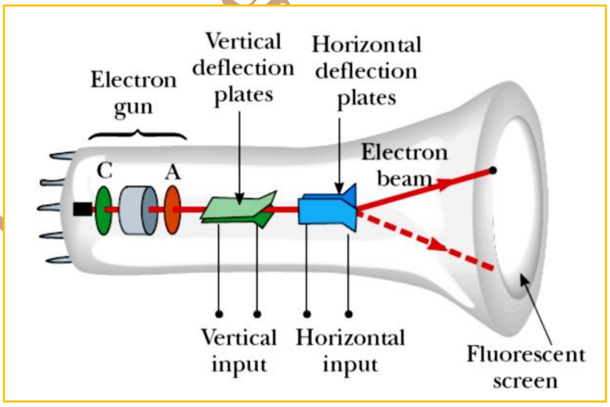
Ans. Cathode ray oscilloscope is a high speed graph plotting device. It is called cathode ray oscilloscope because it traces the desired waveform with a beam of electrons which are also called cathode rays.

Principle

Its works by deflecting the beam of electrons as they pass through uniform electric field between the two sets of parallel plates. The deflected beam then falls on fluorescent screen where it makes a visible spot. It can display the graphs of functions which rapidly vary with time.

Construction

The beam of electrons is provided by an electron gun which consists of an indirectly heated cathode, a grid and anode. The filament heats the cathode C which emits electrons. The anode A which is at high positive potential with respect to cathode, accelerate as well as focus the electronic beam to the fixed spot on the screen.



The two set of defecting plates are usually referred as horizontal and vertical deflection plates. A voltage applied between the horizontal plates deflects the beam horizontally on the screen and the voltage applied across vertical deflects the beam vertically on the screen.

Working

The voltage that is provided across horizontal plates is usually provided by a circuit that is built in the CRO. It is known as sweep or time base generator whose output waveform is a saw tooth voltage of period T.

If a sinusoidal voltage is applied across the y plates when, simultaneously, time base voltage is impressed across horizontal plates, will now spread out and appear as sinusoidal trace on the screen.

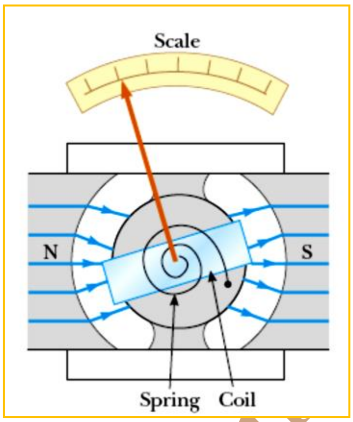
Uses of CRO

The CRO is used for displaying the waveform of a given voltage. Once the waveform is displayed, we can measure the voltage, its frequency and phase. Information about the phase difference between two voltages can be obtained by simultaneously displaying their waveforms.

Q # 11. Find out expression of torque on a current carrying coil.

Ans. Consider a rectangular coil carrying current I. The coil is capable of rotation about an axis XX`. Suppose it is placed in uniform magnetic field **B** with its plane along the field.

The force on current carrying conductor placed in magnetic field is describe by the expression $F = ILB\sin\theta$, where θ is the angle between conductor and the field.

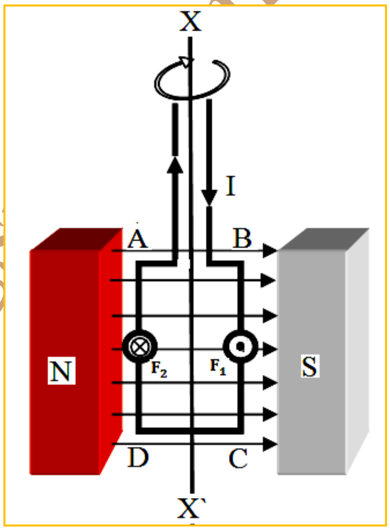


- In case of the sides AB and CD of the coil, the angle θ is zero or 180^0, so the force on these sides will be zero.
- In case of sides DA and BC, the angle θ is 90^0 and the force on these sides will be:

  $$F_1 = F_2 = ILB$$

  Where L is the length of these sides, F_1 is the force on the side DA and F_2 on BC.

Therefore, the forces $\mathbf{F_1}$ and $\mathbf{F_2}$ being equal and opposite form a couple which tends to rotate it about an axis.



The torque τ of the couple is given by the expression:

$$\tau = (Force)(Moment\ Arm)$$

$$\tau = (ILB)(a) = IBLa \quad \text{----------} \quad (1)$$

where a is the moment arm of the couple and is equal to the length of side AB or CD. La is the area of the coil. The equation (1) becomes:

$$\tau = IBA \quad \text{----------} \quad (2)$$

The equation (2) gives the value of torque when the field **B** is in the plane of the coil. However, if the field makes an angle α with the plane of the coil, the moment arm will become $a\cos\alpha$. So,

$$\tau = IBLa\cos\alpha$$

$$\tau = IBA\cos\alpha$$

Q # 12. What do you know about galvanometer? Also describe its construction and working.

Ans. A galvanometer is an electrical instrument used to detect the passage of current.

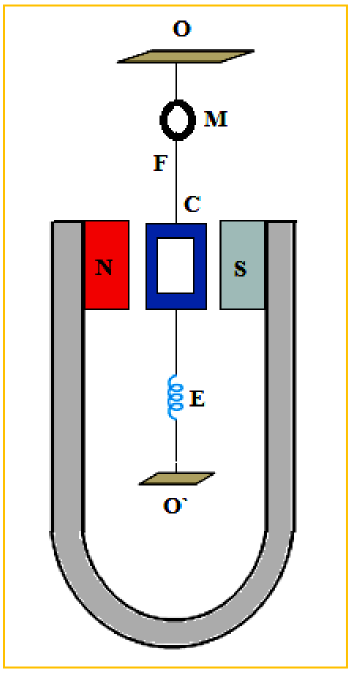
Principle

Its working depends upon the fact that when a current carrying coil is placed in a magnetic field, it experiences a torque which can be described by the formula:

$$\tau = NIAB\cos\alpha$$

Where N is the number of turns in the coil, A is its area, I is the current passing through it, B is the magnetic field in which the coil is placed and α is the angle which the plane of the coil makes with B.

Due to action of the torque, the coil rotates and thus it detects the current.



Construction

A rectangular coil C is suspended between concaved shaped N and S poles of horseshoe magnet with the help of a fine metallic suspension wire. The suspension wire F is also used as one current lead to the coil. The other terminal of the coil is connected to a loosely wound spiral E which serve as the second current lead. The pole pieces of the magnet are made concave to make the field radial and stronger.

Working

When the current is passed through the coil, it is acted upon by a couple which tends to rotate the coil. This couple is known as deflecting couple and is given by $NIAB\cos\alpha$. As the coil is placed in radial magnetic field in which the plane of the coil is always parallel to the firld , so α is always zero. This makes $\cos\alpha = 1$ and thus,

$$Deflecting\ Couple = NIAB$$

As the coil turns under the action of deflecting couple, the suspension wire is twisted which gives rise to a torsional couple. It tends to untwist the suspension and restore the coil to its original position. This couple is known as restoring couple.

The restoring couple of the suspension wire is proportional to the angle of deflection θ as long as the suspension wire obeys Hook's law. Thus

$$Restoring\ Torque = c\theta$$

Where constant c is called torsional couple and is defined as the couple of untwist.

Under the effect of these two couples, coil comes to rest when

$$Deflecting\ Torque = Restoring\ Torque$$

$$NIAB = c\theta$$

$$I = \frac{c}{NAB}\theta \quad \text{----------} \quad (1)$$

Thus $I \ \alpha \ \theta$ since $\frac{c}{NAB} = constant.$

Thus the current passing through the coil is directly proportional to the angle of deflection.

Sensitivity of Galvanometer

Sensitivity of the galvanometer is the measure of the ability of galvanometer to detect small amount of current. It is obvious from equation (1) that a galvanometer can be made more sensitive if $\frac{c}{NAB}$ is made small. Thus, to increase the sensitivity of galvanometer, c may be decreased or B, A and N may be increased.

Dead Beat Galvanometer

The galvanometer in which the coil comes to rest quickly after current passed through it or the current is stopped from flowing through it, is called stable or a dead beat galvanometer.

Q # 13. Describe the working of an ammeter.

Ans. An ammeter is an electrical instrument which is used to measure the current in amperes. An ammeter can be constructed by connecting a low value bypass resistance (called shunt) to a galvanometer.

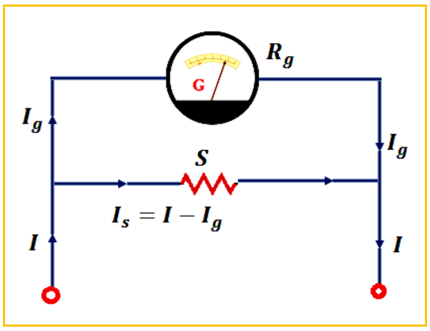
Consider a galvanometer of resistance R_g which gives full scale deflection when current I_g is passed through it. The potential difference V_g that causes the current I_g to pass through galvanometer is given by

$$V_g = I_g R_g$$

We want to find out the expression of shunt (bypass) resistant R_s that is needed to convert the galvanometer to ammeter which can measure maximum current I.

The shunt resistance is of such a value so that the current I_g pass through galvanometer and the remaining current $(I - I_g)$ passes through shunt.

As the shunt resistance is parallel to the galvanometer, the potential difference across the galvanometer is equal to the potential difference across the shunt.



$V_g = V_s$

$I_g R_g = (I - I_g)R_s$

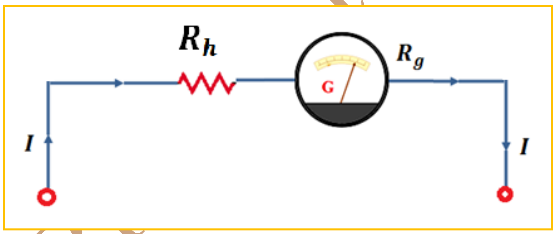
$R_s = \frac{I_g}{I - I_g} R_g$

This is the expression to find out the shunt resistance, that is connected in parallel to convert galvanometer into ammeter.

Q # 14. Find out expression of resistance that is connected in series with galvanometer to convert it into voltmeter.

Ans. A voltmeter is an electrical device which measures the potential difference in volts between two points in an electric circuit.

To construct a voltmeter, a very high resistance is connected in series with galvanometer. Consider a galvanometer of resistance R_g which gives full scale deflection when current I_g is passed through it.



In order to make a voltmeter of the range of V volts, the value of high should be such that full scale deflection is obtained when it is connected across V volts. If the current I_g passes through the circuit, then by applying Ohm's law:

$V = V_g + V_R$

$\Rightarrow V = I_g R_g + I_g R_h$

$\Rightarrow V = I_g (R_g + R_h)$

$\Rightarrow \frac{V}{I_g} = R_g + R_h$

$\Rightarrow \boldsymbol{R_h} = \frac{V}{I_g} - R_g$

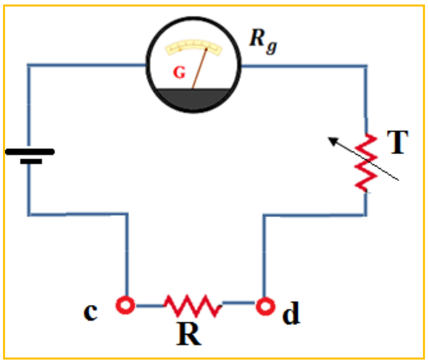
This is the expression to find out the resistance that is connected in series to convert galvanometer into ammeter.

Q # 15. Describe the construction and working of Ohmmeter.

Ans. It is a useful device for rapid measurement of resistance. It consists of a galvanometer, and adjustable resistance of known value and a cell connected in series as shown on the figure.

To convert a galvanometer into ohmmeter, the scale of galvanometer is calibrated using the following procedure:

- The series resistance R_s is so adjusted that when the terminals c and d are short circuited ($R = 0$), the galvanometer gives full scale deflection. So the extreme graduation of the usual scale of the galvanometer is marked 0 for resistance measurement.



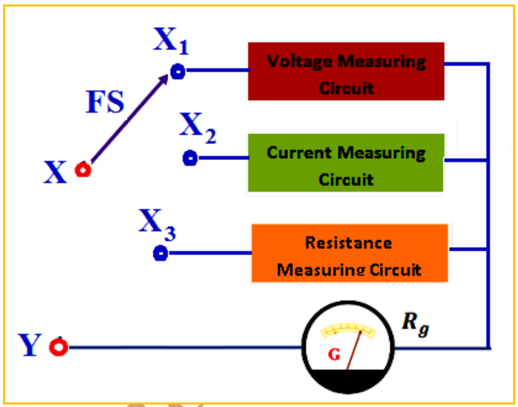
- When the terminals c and d are not joined, no current passes through galvanometer and its deflection is zero. Thus zero of the scale is marked as infinity ohms.
- When R is not infinite, the galvanometer deflects to some intermediate point depending on the value of R and hence the

galvanometer scale can he calibrated to read the resistance directly.

Q # 16. Write down the working of AVO meter in detail.

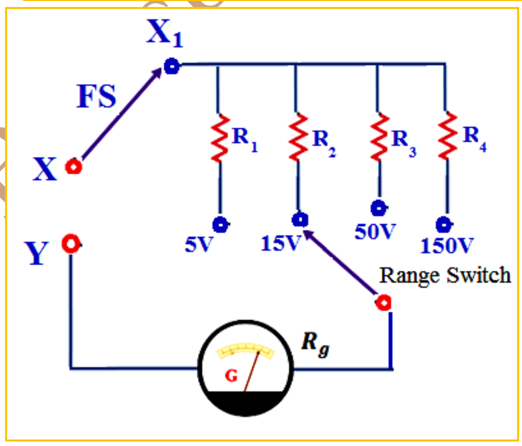
It is an instrument which can measure the current in amperes, potential difference in volts and resistance in ohms. It actually employs a single galvanometer which by the help of a switch is converted into multi-ranged ammeter, voltmeter and ohmmeter according to the requirement of the user.

Here X and Y are the main terminals of AVO meter which is connected with the circuit in which the measurement is required. FS is the function selector switch which connects the galvanometer with relevant measuring circuit.



Voltage Measuring Part of AVO Meter

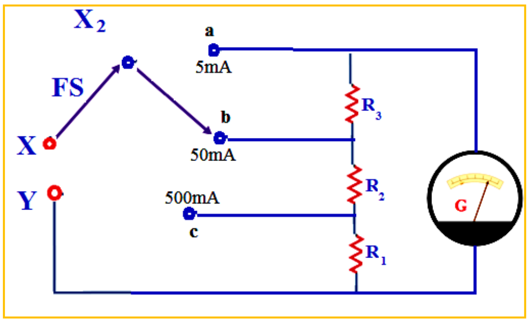
The voltage measuring part of AVO Meter is actually a multi-ranged voltmeter. It consist of a number of resistances each of which can be connected in series with the moving coil galvanometer with the help of a switch called the range switch. The value of each resistance depends upon the range of the voltmeter which it controls.



Current Measuring Part of AVO Meter

The current measuring part of AVO meter is actually is a multi-ranged ammeter. It consist of a number of low resistance connected in parallel with the galvanometer. The values to these resistances depend upon the range of the ammeter.

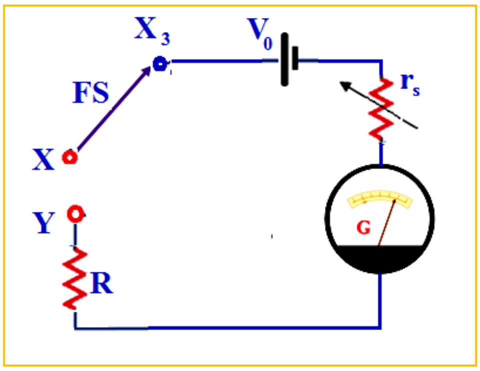
The circuit also has a range selection switch SR which is used to select a particular range of current.



Resistance Measuring Part of AVO Meter

The resistance measuring part of AVO meter is in fact a multi-range ohmmeter. Circuit for each range of this meter consist of a battery of emf V_0 and a variable resistance R_s connected in series with galvanometer of resistance R_g.

Before measuring an unknown resistance by an ohmmeter, it is first zeroed which means that we short circuit the terminals X, Y and adjust to r, to produce full scale deflection.



Digital Multimeter

Another useful device to measure resistance, current and voltage is an electronic instrument called digital multimeter. It is a digital version of an AVO meter. It has become very popular testing device because the digital values are displayed automatically with decimal point, polarity and the unit for V, A or Ω.

These meters are generally easier to use because they eliminate the human error that often occur in reading the dial of an ordinary AVO meter.

EXERCISE SHORT QUESTIONS

Q # 1. A plane conducting loop is located in a uniform magnetic field that is directed along the x-axis. For what orientations of the loop, is the flux maximum? For what orientation, is the flux minimum?

Ans. The magnetic flux through a conducting loop can be find out by the expression:

$$\Delta\varphi = \mathbf{B.A} = BA\cos\theta$$

Here **B** is the magnetic field strength and A is vector area whose direction is perpendicular to the plane of the loop.

Case 1. When vector area of the conducting loop is in the direction of magnetic field strength i.e., $\theta = 0°$, then the magnetic flux:

$$\Delta\varphi = \mathbf{B.A} = BA\cos 0° = BA \qquad \text{as } \cos 0° = 1$$

Thus the magnetic flux through the coil is maximum, when the vector area of the conducting loop is parallel to magnetic field strength.

Case 2. When vector area of the conducting loop is perpendicular to magnetic field strength i.e., $\theta = 90°$, then the magnetic flux:

$$\Delta\varphi = \mathbf{B.A} = BA\cos 90° = BA \qquad \text{as } \cos 90° = 0$$

Thus the magnetic flux through the coil is minimum, when the vector area of the conducting loop is perpendicular to magnetic field strength.

Q # 2. A current in a conductor produce a magnetic field, which can be calculated using Ampere's Law. Since current is defined as the rate of flow of charge. What can you conclude about the magnetic field due to stationary charges? What about moving charges?

Ans. A stationary charges cannot produce any magnetic field. In case of stationary charges, the rate of flow of charges is zero(i.e. current $= 0$), so there will be no magnetic field.

As the moving charges produce current, so the magnetic field produced around the path of its motion similar to the magnetic field produced around a current carrying conductor.

Q # 3. Describe the charge in the magnetic field inside a solenoid carrying steady current I, if (a) the length of the solenoid is doubled but the number of turns remains the same and (b) the number of turns are doubled, but the length remains the same.

Ans. The magnetic field strength **B** inside a current carrying conductor can be find out by the expression:

$$B = \mu_0 nI \quad \text{-----------} \quad (1)$$

Where I is the current flowing through conductor and n is the number of turns per unit length i.e., $n = \frac{N}{L}$. Thus

$$B = \frac{\mu_0 NI}{L}$$

(a) When Length of solenoid is doubled by keeping the number of turns constant, then magnetic field strength:

$$B' = \frac{\mu_0 NI}{2L} \Rightarrow B' = \frac{B}{2}$$

Thus on doubling the length of solenoid by keeping the turns constant, the magnetic field strength becomes one half of its original value.

(b) When number of turns of solenoid is doubled by keeping the length of solenoid constant, then magnetic field strength:

$$B'' = \frac{\mu_0(2N)I}{L} \Longrightarrow B'' = 2B$$

Thus on doubling the number of turns of solenoid by keeping its length constant, the magnetic field strength becomes doubled of its original value.

Q # 4. At a given instant, a proton moves in the positive x-direction in the region where there is magnetic field in the negative z-direction. What is the direction of the magnetic force? Will the proton continue to move in the positive x-direction? Explain.

Ans. As the proton is moving in the positive x-direction and magnetic field is directed into the plane of paper, then the magnetic force on proton can be find out using expression:

$$\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$$

According to right hand rule, the magnetic force is directed along y-axis.

No, the proton will not continue to move in the positive x-direction. Since the magnetic force is acting at the right angle to motion of conductor, therefore it will move along a circular path in xy-plane.

Q # 5. Two charged particles are projected into a region where there is a magnetic field perpendicular to their velocities. If the charge are deflected in opposite directions, what can you say about them?

Ans. When a charge particle is projected in a magnetic field, it will experience the magnetic force given by:

$$\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$$

The magnetic force is a deflecting force. Thus if the charged particles are deflected in opposite direction, then particles are oppositely charged. i.e., one particle is positively charged and the other is negatively charged.

Q # 6. Suppose that a charge q is moving in a uniform magnetic field with a velocity v. Why is there no work done by the magnetic force that acts on the charge?

Ans. The magnetic force on a charge particle will act normal to the direction of motion of the particle, so the work done by the force is given by:

$$W = \mathbf{F}.\mathbf{d} = Fd\cos\theta$$

Where θ is the angle between the magnetic force and displacement of charge particle. For present case: $\theta = 90°$. Therefore:

$$W = Fd\cos 90° = 0$$

Thus we can say that magnetic force is a deflecting force and it cannot do any work.

Q # 7. If a charge particle moves in a straight line through some region of space, can you say that the magnetic field in the region is zero.

Ans. The magnitude of magnetic force on a charge particle can be expressed as:

$$F = qvB\sin\theta$$

Where θ is the angle between **B** and **v**. So if the particle moves in a straight line through some region of space then it means that the charge particle is not experiencing magnetic force which might be due to one of the following reasons:

i. Magnetic field strength B in the region is zero

ii. Magnetic field is parallel or anti-parallel to the direction of motion.

Q # 8. Why does the picture on a TV screen become distorted when a magnet is brought near the screen?

Ans. The picture on a TV is formed when moving electrons strike the florescent screen. As magnet is brought close to the TV screen, the path of electrons is distorted due to the magnetic force on them. So the picture on the screen of TV is distorted.

Q # 9. Is it possible to orient a current loop in a uniform magnetic field such that the loop will not tend to rotate? Explain.

Ans. A current carrying loop when placed in magnetic field will experience a torque given by:

$$\tau = BINA\cos\alpha$$

Where B is the magnetic field strength, I is current flowing through coil, N is number of turns in a coil, A is the area of the coil and α is the angle between plane of the coil and magnetic field.

It is clear from expression that when plane of the coil makes and angle of 90° with magnetic field, the torque on the coil will be zero. In this condition, the coil will not tend to rotate.

Q # 10. How can a current loop be used to determine the presence of a magnetic field in a given region of space?

Ans. When a current carrying loop is placed in a uniform magnetic field, a torque is produced in the loop is given by:

$$\tau = BINA\cos\alpha$$

If the loop is deflected in a given region, then it confirms the presence of magnetic field, otherwise not.

Q # 11. How can you use a magnetic field to separate isotopes of chemical element?

Ans. If the ions of isotopes of an element are projected in a magnetic field of known strength B, the ions move in circular path of radius r. The e/m of the ion is given by the expression:

$$\frac{e}{m} = \frac{v}{Br} \Rightarrow r = \frac{v}{B} \times \frac{m}{e}$$

If v, B and e of the ions are constant, then

$$r \propto m$$

So the ions of different mass will have different radii of curvature and hence they can be separated in magnetic field.

Q # 12. What should be the orientation of a current carrying coil in a magnetic field so that torque acting upon the coil is (a) maximum (b) minimum?

Ans. A current carrying loop when placed in magnetic field will experience a torque given by:

$$\tau = BINA\cos\alpha$$

Where B is the magnetic field strength, I is current flowing through coil, N is number of turns in a coil, A is the area of the coil and α is the angle between plane of the coil and magnetic field.

(a) When plane of the coil is parallel to magnetic field, $\alpha = 0$ and the torque acting on the coil will be maximum given by: $\tau = BINA\cos 0° = BINA$

(b) When plane of the coil is perpendicular to magnetic field, $\alpha = 90°$ and the torque acting on the coil will be minimum, given by: $\tau = BINA\cos 90° = 0$.

Q # 13. A loop of wire is suspended between the pools of a magnet with its plane parallel to the pole faces. What happens if a direct current is put through the coil? What happens if an alternating current is used instead?

Ans. When direct current is passed through he coil of wire, a torque acts on the coil which rotates the coil.

However, when alternating current is passed through the coil, the direction of current is reversed after every half cycle of the coil. So the coil oscillates in the magnetic field instead of rotating.

Q # 14. Why the resistance of an ammeter should be very low?

Ans. An ammeter is connected in series with a circuit to measure the current. It is connected in series so that total current passing through the circuit should pass through it. If the resistance of the ammeter will be large, it will alter the current of the circuit to great extent and the measurement of current will not be accurate.

Q # 15. Why the voltmeter should have a very high resistance?

Ans. A voltmeter is connected in parallel to the resistor to measure potential difference across it. It should have very high resistance so that practically, a very little current should pass through it and the current of the circuit should almost remain constant, so that it might measure the potential difference across a resistor accurately.

ELECTROMAGNETIC INDUCTION

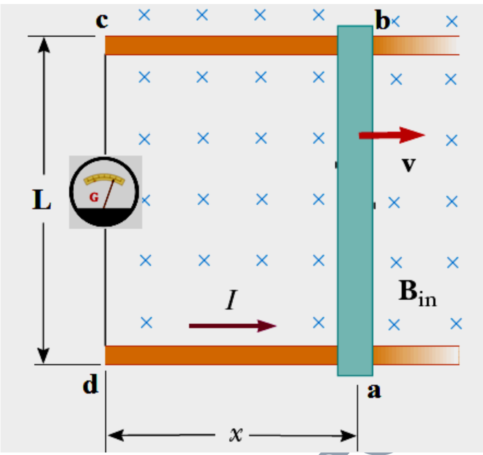
Q # 1. What do you know about electromagnetic induction?

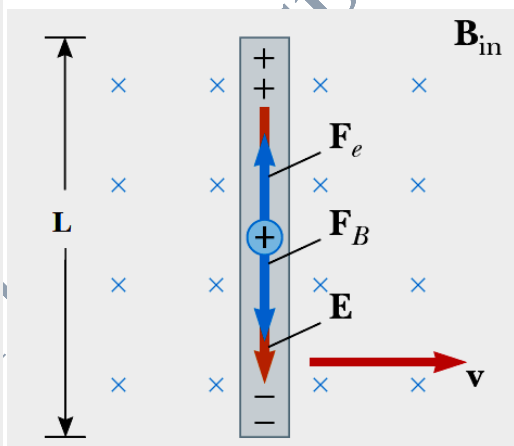
Ans. When a conductor that is moved through a magnetic field, the electric current flow through the circuit. The emf produced in the conductor is called induced emf, and the current generated is called induced current. This phenomenon is known as electromagnetic induction.

Q # 2. Define the term motional emf. Also derive its expression.

Ans. The emf induced by the motion of a conductor across the magnetic field is called motional emf.

Consider a conducting rod of length L placed on two parallel metal rails separated by a distance L. A galvanometer is connected between the ends c and d of rails. This forms complete conducting loop abcd. A uniform magnetic field B is applied directed into the paper.





Initially, when the rod is stationary, galvanometer indicates no current in the loop. If the rod is pulled to the right with constant velocity **v**, the galvanometer indicates current flowing through the loop.

Obviously, the current is induced due to the motion of the conducting rod across the magnetic field. The rod is acting as a source of emf $\varepsilon = V_b - V_a = \Delta V$.

When the rod moves, a charge q within the rod also moves with same velocity v in the magnetic field B and experience a force that is given by:

$$\bar{F} = q(\bar{v} \times \bar{B})$$

The magnitude of force is

$$F = q\,v\,B\sin\theta$$

Since the angle between v and B is 90^o, so

$$F = q\,v\,B$$

Applying the right hand rule, we see that **F** is directed from a to b of the rod. Under the action of this force, the positive charge carriers inside rod accumulate on side b of the rod, due to which deficiency of positive charges occurs at side a of rod and equivalent negative charge appear on this side. This results in establishment of electric field $\mathbf{E_o}$ inside the rod from b to a.

The system quickly reaches an equilibrium state in which these two forces on the charge are balanced. If $\mathbf{E_o}$ is the electric intensity in this state then:

$$q\,E_o = q\,v\,B$$
$$\Rightarrow E_o = v\,B \quad \text{----------} \quad (1)$$

As the electric field intensity is the negative gradient of electric potential, therefore

$$E_o = -\frac{\Delta V}{L} \quad \text{----------} \quad (2)$$

Where L is the length of the conductor and ΔV is the potential difference, which is equal to induced emf due to motion of conductor in magnetic field. Comparing equation (1) and (2), we get:

$$-\frac{\Delta V}{L} = v\,B$$
$$\Rightarrow \Delta V = -\,v\,BL$$

Therefore, the magnitude of the motional emf is given as:

$$\varepsilon = \Delta V = -\,v\,BL$$

If the angle between 'v' and 'B' is θ, then

$$\varepsilon = \Delta V = -\,v\,BL\sin\theta$$

This is the expression of motional emf.

Q # 3. State and prove the Faraday's law of electromagnetic induction.

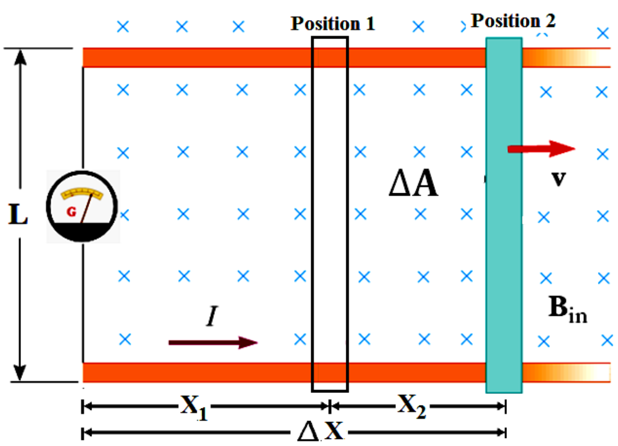
Ans.

Statement

The average emf induced in a conducting coil of N loop is equal to the negative of the rate at which the magnetic flux through the coil is changing with time.

Proof

Consider a conducting rod of length L placed on two parallel metal rails separated by a distance L. A galvanometer is connected between the ends c and d of rails. This forms complete conducting loop abcd. A uniform magnetic field B is applied directed into the paper.



Let the conducting rod L moves from position 1 to position 2 in small interval of time Δt. The distance traveled by the rod in time Δt is $x_2 - x_1 = \Delta x$. The motional emf induced in a rod mobbing perpendicular to magnetic field is $\varepsilon = -vBL$

Since the rod is moving with constant velocity **v**, therefore

$$v = \frac{\Delta x}{\Delta t}$$

The expression of motional emf becomes:

$$\varepsilon = -vBL = -\left(\frac{\Delta x}{\Delta t}\right)BL = -\frac{\Delta x.B.L}{\Delta t} \quad \text{----------} \quad (1)$$

As the rod moves through the distance Δx, the increase in the area of the loop is given by:

$$\Delta A = \Delta x.\,L$$

This increases the flux through the loop by

$$\Delta\phi = \Delta x.L.B$$

Thus equation (1) becomes:

$$\varepsilon = -\frac{\Delta\phi}{\Delta t}$$

If there is a coil of N loops instead of a single loop, then induced emf will become N times, i.e.,

$$\varepsilon = -N\frac{\Delta\phi}{\Delta t}$$

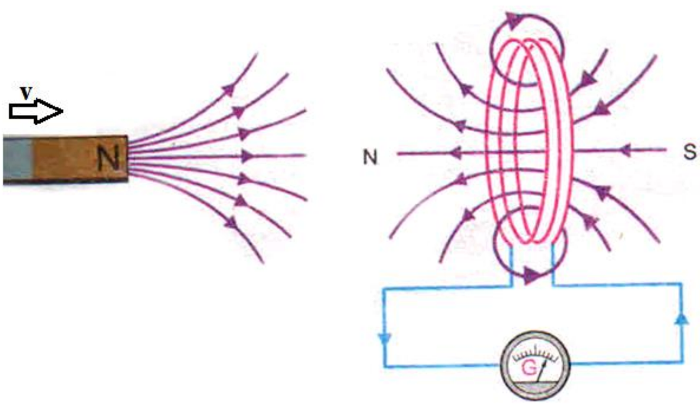
The minus sign indicates that the direction of induced emf is such that it opposes the change in flux. This expression tells that the emf induced in a conducting coil of N loop is equal to the negative of the rate at which the magnetic flux through the coil is changing with time.

Q # 4. State and explain the Lenz's law.

Ans.

Statement

The direction of the induced current is always so as to oppose the change which causes the current.



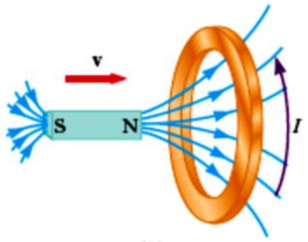
Explanation

The mathematical expression of the Faraday's law of electromagnetic induction is:

$$\varepsilon = -N\frac{\Delta\phi}{\Delta t}$$

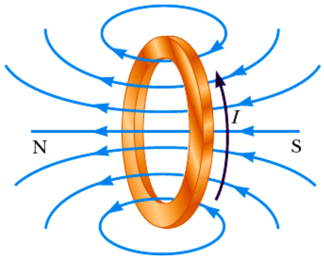
The minus sign in the expression is very important. It has to do with the direction of induced emf. Consider a coil in which the current is induce by the movement of a bar magnet.

a) When the magnet is moved toward the stationary conducting loop, a current is induced in the direction shown. The magnetic field lines shown are those due to the bar magnet.



(a)

b) This induced current produces its own magnetic field directed to the left that counteracts the increasing external flux. The magnetic field lines shown are those due to the induced current in the ring.



(b)

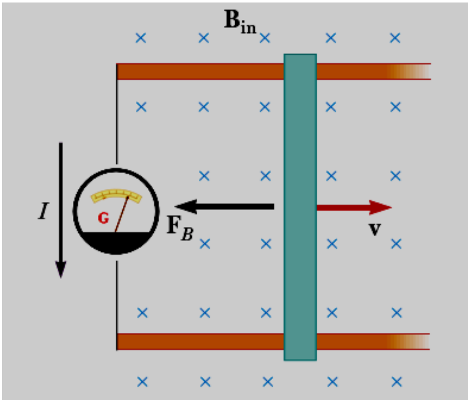
According to Lenz's law, the push of the magnet is the "change" that produces the induced current and current acts to oppose the push.

Q # 5. Describe the Lenz's law as a statement of Law of conservation of energy.

Ans. Consider a conducting rod of length L placed on two parallel metal rails separated by a distance L. A galvanometer is connected between the ends of rails. This forms complete conducting loop. A uniform magnetic field B is applied directed into the paper.

- When the rod moves towards right, emf is induced in it and current flows through loop in anti-clockwise direction.
- Since the current carrying current is moving in magnetic field, it experiences a magnetic force F having magnitude $F_m = ILB\sin 90^0 = ILB$.

By the right hand rule, the direction of magnetic force F_m is opposite to that of **v**, so it tends to stop the rod.



(a)

An external dragging force equal to F_m in magnitude but opposite in direction must be applied to keep the rod moving with constant velocity.

The dragging force provides the energy for the induce current to flow. This energy is the source of induced current. Thus electromagnetic induction is exactly according to low of conservation of energy.

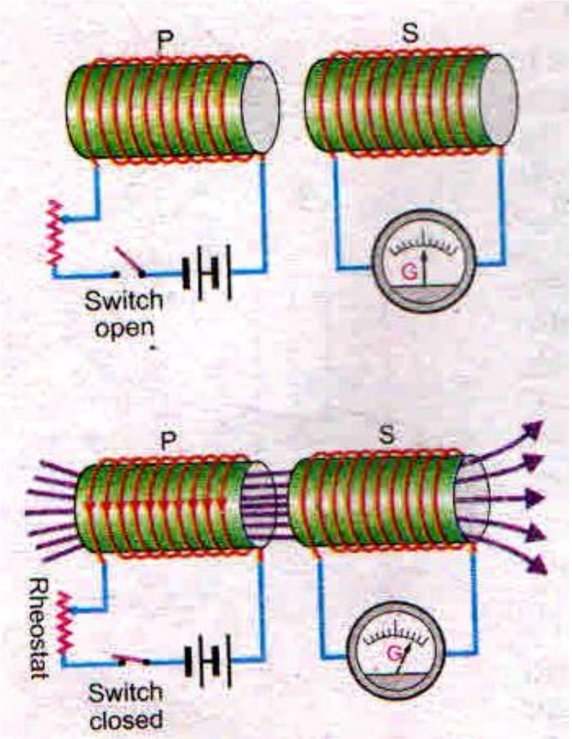
Q # 5. What do you know about mutual induction? Derive the expression of mutual induction.

The phenomenon in which the changing current in one coil induces an emf in another coil is called the mutual induction.

It is denoted by the symbol M and the SI unit of the mutual inductance is VsA^{-1}, which is called henry.

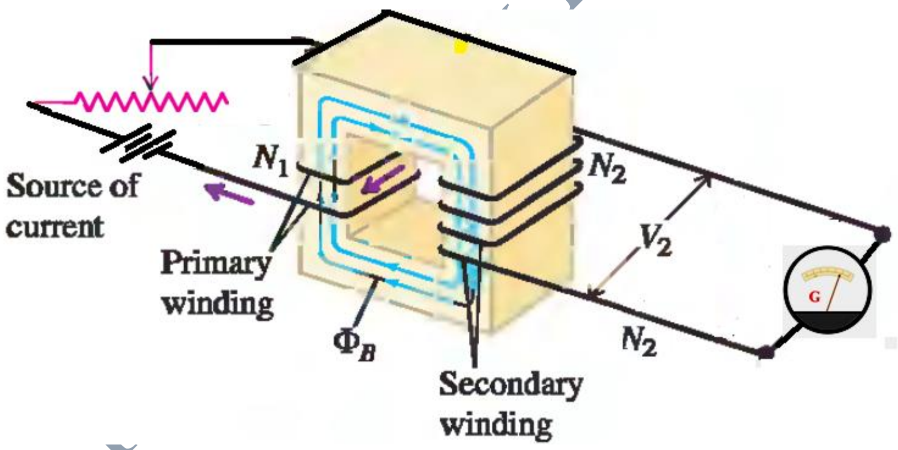
Derivation

Consider two coils placed close to each other. One coil is connected with a current source is called "primary" and the other one connected to the galvanometer is called the "secondary". If the current in the primary is changed by varying the resistance of the rheostat, the magnetic flux in the surrounding regions changes. Since the secondary coil is magnetically linked with primary, the changing flux in primary also changes flux through secondary.



According to Faraday's law, the emf induced in secondary is directly proportional to the rate of change of flux through it and is given by the expression:

$$\varepsilon_S = -N_S \frac{\Delta\phi_S}{\Delta t} \quad ---------- \quad (1)$$



As the flux through secondary coil $N_S\phi_S$ is directly proportional to the current I_P in primary coil, therefore

$$N_S\phi_S \propto I_P$$

$$\Rightarrow N_S\phi_S = M I_P$$

Where M is the constant of proportionality and is called the mutual inductance of two coils.

The equation (1) becomes:

$$\varepsilon_S = -N_S \frac{\Delta\phi_S}{\Delta t} = -\frac{\Delta(N_S\phi_S)}{\Delta t} = -\frac{\Delta(MI_P)}{\Delta t} = -M\frac{\Delta I_P}{\Delta t}$$

$$\varepsilon_S = -M\frac{\Delta I_P}{\Delta t} \quad ---------- \quad (2)$$

The negative sign indicates the fact that the induced emf is in such a direction that it opposes the change of current in the primary coil. The equation (2) can be written as:

$$M = -\frac{\varepsilon_S}{\left(\frac{\Delta I_P}{\Delta t}\right)}$$

This is expression of mutual induction which may also be described as the ratio of average emf induced in the secondary coil to the time rate of change of current in the primary.

Q # 6. What do you know about self induction? Derive the expression of self induction.

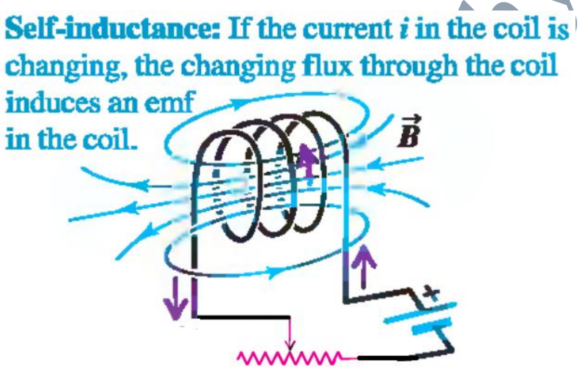
Ans. Self Induction

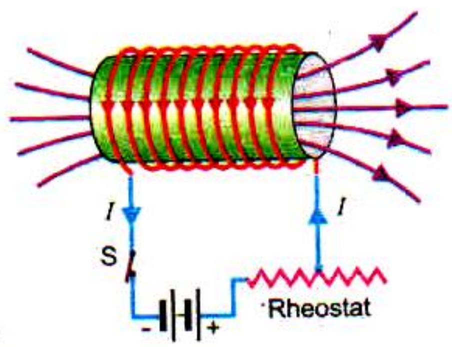
The phenomenon in which the changing current in a coil induces an emf in itself is called the self induction.

It is denoted by the symbol L and the SI unit of the self inductance is VsA^{-1}, which is called henry.

Derivation

Consider the circuit shown in the figure. A coil is connected in series with a battery and a rheostat. Magnetic flux is produced through the coil due to the current it. If the current is changed by varying the rheostat quickly, magnetic flux through the coil changes that causes an induced emf in the coil. Such an emf is called self induced emf.





According to Faraday's law, the emf induced in a coil is directly proportional to the rate of change of flux through it and is given by the expression:

$$\varepsilon_L = -N\frac{\Delta\phi}{\Delta t} \text{ ---------- } (1)$$

If the flux through one loop of the coil is ϕ, then the total flux through the coil of N loops would be $N\phi$. As ϕ is proportional to magnetic field which is in turn proportional to the current I, therefore:

$$N\phi \propto I$$

$$\Rightarrow N\phi = L\,I$$

Where L is the constant of proportionality and is called the self inductance of the coil.

The equation (1) becomes:

$$\varepsilon_L = -N\frac{\Delta\phi}{\Delta t} = -\frac{\Delta(N\phi)}{\Delta t} = -\frac{\Delta(LI)}{\Delta t} = -L\frac{\Delta I}{\Delta t}$$

$$\varepsilon_L = -L\frac{\Delta I}{\Delta t} \quad \text{----------} \quad (2)$$

The negative sign indicates the fact that the self induced emf must oppose the change that produced it. That's why the self induced emf is sometimes called back emf. The equation (2) can be written as:

$$L = -\frac{\varepsilon_L}{\left(\frac{\Delta I}{\Delta t}\right)}$$

This is expression of self induction which may also be described as the ratio of induced emf to the time rate of change of current in the coil.

Q # 7. Find out the expression of energy stored in the magnetic field of current carrying inductor.

Ans. Energy can be stored in the electric field between the plates of capacitor. In a similar manner, energy can be stored in the magnetic field of an inductor.

Consider a coil connected to a battery and a switch in series. When the switch is turned on voltage V is applied across the ends of the coil and current through it rises from zero to its maximum value I. Due to change of current, an emf is induced, which is opposite to that of battery. Work is done by the battery top move charges against the induced emf.

Work done by the battery in moving a small charged Δq is:

$$W = \Delta q \varepsilon_L \quad \text{----------} \quad (1)$$

Where ε_L is the magnitude of induced emf, given by:

$$\varepsilon_L = L\frac{\Delta I}{\Delta t}$$

Putting the value of ε_L in equation (1), we get:

$$W = \Delta q L\frac{\Delta I}{\Delta t} = \frac{\Delta q}{\Delta t}L\Delta I \quad \text{----------} \quad (2)$$

Total work done in establishing the current from 0 to I is found by inserting for $\frac{\Delta q}{\Delta t}$, the average current, and the value of ΔI.

Average Current $= \frac{\Delta q}{\Delta t} = \frac{0+I}{2} = \frac{1}{2}I$

Change in current $\Delta I = I - 0 = I$

The equation (2) will become:

$$W = \left(\frac{1}{2}I\right)L(I)$$

$$W = \frac{1}{2}LI^2$$

This work is stored as potential energy in the inductor. Hence the energy stored in an inductor is:

$$U_m = \frac{1}{2}LI^2 \qquad \text{----------} \quad (3)$$

This equation can be expressed in terms of the magnetic field strength **B** of a solenoid.

If the flux through one loop of the coil isΦ, then the total flux through the coil of N loops would be $N\Phi$. As the magnetic flux $\Phi = BA$ is proportional to magnetic field which is in turn proportional to the current I, therefore:

$$N\Phi \propto I$$

$$N\Phi = LI$$

$$L = \frac{N\Phi}{I} = \frac{NBA}{I} \qquad \text{----------} \quad (4)$$

The magnetic field strength inside solenoid is $B = \mu_0 nI$. Therefore the equation (4) becomes:

$$L = \frac{N\mu_0 nIA}{I} = N\mu_0 nA$$

If l is the length of solenoid, then putting $N = nl$ in the above equation, we get:

$$L = (nl)\mu_0 nA$$

$$L = \mu_0 n^2 Al$$

Thus the equation (3) becomes:

$$U_m = \frac{1}{2}(\mu_0 n^2 Al)I^2$$

Since for a solenoid is $B = \mu_0 nI \Longrightarrow I = \frac{B}{\mu_0 n}$. Substituting for I, the above equation becomes:

$$U_m = \frac{1}{2}(\mu_0 n^2 Al)\left(\frac{B}{\mu_0 n}\right)^2 = \frac{1}{2}(\mu_0 n^2 Al)\frac{B^2}{\mu_0^2\ n^2}$$

$$U_m = \frac{1}{2}\frac{B^2}{\mu_0}(Al) \qquad \text{----------} \quad (5)$$

Now the energy density can be defined as the energy stored per unit volume insider the solenoid, so dividing equation (5) by volume (Al), we get energy density:

$$u_m = \frac{1}{2}\frac{B^2}{\mu_0}$$

Q # 8. What do you know about alternating current generator? Also describe its principle, construction and working.

A current generator is a device that converts mechanical energy into electrical energy.

Principle

The principle of an electric generator is based on Faraday's law of electromagnetic induction. When a coil is rotated in a magnetic field by some mechanical means, magnetic flux through the coil changes, and consequently an emf is induced in the coil.

Construction

A rectangular loop of wire of area A be placed in uniform magnetic field **B**. the loop is rotated about an axis through its center with constant angular velocity ω. One end of the loop is attached to a metal ring R and the other end to the ring R'. These rings, called slip rings are concentric with the axis of the loop and rotate with it. Rings RR' slide against stationary carbon brushes to which external circuit is connected.

Working

To calculate the induced emf in the loop, consider its position while it is moving in anticlockwise. The vertical side ab of the loop is moving with velocity **v** in the magnetic field **B**. if the angle between **v** and **B** is θ, the motional emf induced in the side ab has the magnitude,

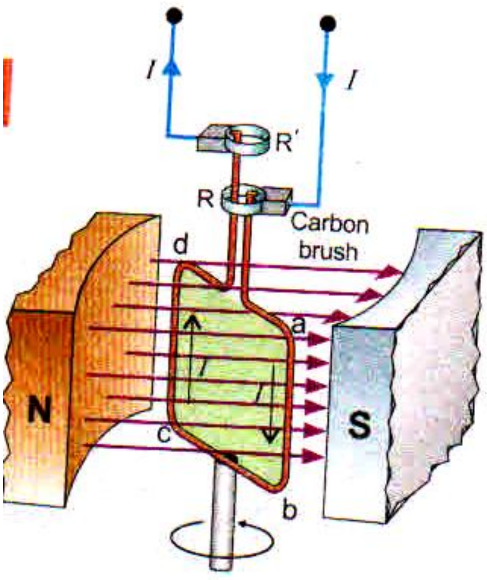
$$\varepsilon_{ab} = \text{vBL}\sin\theta$$

The same amount of emf is induced in the side cd. Therefore,

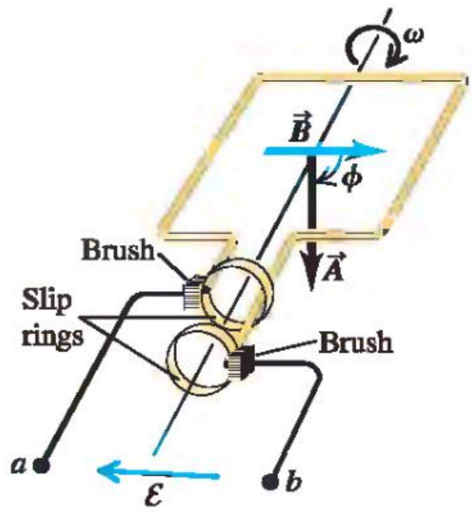
$$\varepsilon_{cd} = \text{vBL}\sin\theta$$

The net contribution to emf by the side ab and da is zero because the orce acting on the charges inside bc and da is not along the wire. Thus

$$\varepsilon_{bc} = \varepsilon_{da} = 0$$



(Front view)



The total emf is the loop is

$$\varepsilon = \varepsilon_{ab} + \varepsilon_{cd}$$

$$\varepsilon = \text{vBL}\sin\theta + \text{vBL}\sin\theta$$

$$\varepsilon = 2\text{vBL}\sin\theta$$

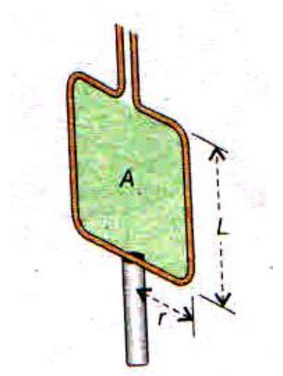
If the coil is replaced by a coil of N turns, the total emf in the coil will be:

$$\varepsilon = 2\text{NvBL}\sin\theta \quad \text{---------} \quad (1)$$

The linear speed v of the vertical wire is related to the angular speed ω by the relation:

$$v = r\omega$$

Where r is the distance of the vertical wires from the center of the coil. Substituting this value in equation (1), we get:



$$\varepsilon = 2N(r\omega)BL\sin\theta$$

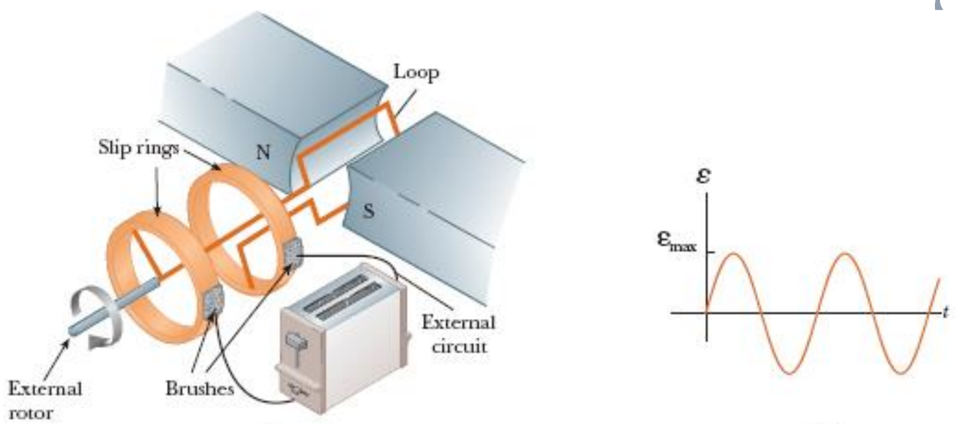
$$\Rightarrow \varepsilon = N\omega(2rL)B\sin\theta$$

$$\Rightarrow \varepsilon = N\omega AB\sin\theta \qquad \text{---------} \quad (2)$$

Where $2rL = A$ = area of the coil

As the angular displacement $\theta = \omega t$, so the equation (2) becomes:

$$\varepsilon = N\omega AB\sin(\omega t) \qquad \text{---------} \quad (3)$$



(a) (b)

The equation (3) shows that the induced emf varies sinusoidally with time. It has the maximum value ε_0 when $\sin(\omega t)$ is equal to 1. Thus

$$\varepsilon_0 = N\omega AB$$

Thus the equation (3) can be written as:

$$\varepsilon = \varepsilon_0 \sin(\omega t)$$

If R is the resistance of the coil, then by Ohm's law, induced current in the coil will be:

$$I = \frac{\varepsilon}{R} = \frac{\varepsilon_0 \sin(\omega t)}{R} = \frac{\varepsilon_0}{R}\sin(\omega t)$$

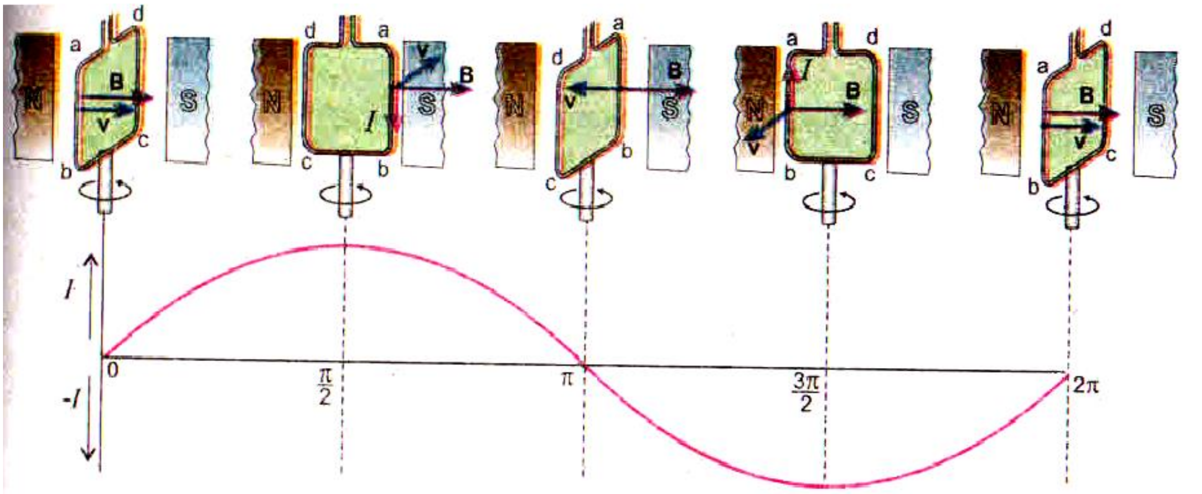
$$\Rightarrow I = I_0 \sin(\omega t)$$

Variation of Current as a Function of θ

- When the angle between v and B is $\theta = 0^0$, the current is zero.
- As θ increases, current also increases. At $\theta = 90^0$, the maximum current flows through the coil, directed along abcda.
- On further increase in θ, the current decreases. At $\theta = 180^0$, the current becomes zero.
- For $180^0 < \theta < 270^0$, current increases but in reverses the direction i.e., dcbad. At $\theta = 270^0$, the maximum current flows through the coil.

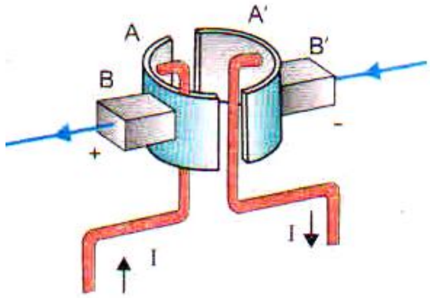
- At $\theta = 360^0$, one rotation is completed and the current decrease to zero. After one rotation, the cycle repeats itself.

The current alternates in direction once in one cycle. Therefore, such a current is called alternating current. It reverses its direction f times per second.

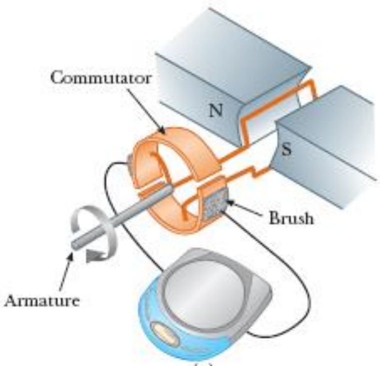


Q # 9. Write a note on DC Generator.

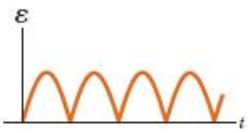
AC Generators are not suitable for many applications, for example to run a DC motor. In 1834, William Sturgeon invented a simple device called commutator that prevents the direction of current from changing.



DC Generator is similar to the AC generator in construction with the difference that "slip rings" are replaced by "split rings". The "split rings" are two halves of a ring that act as commutator.



(a)



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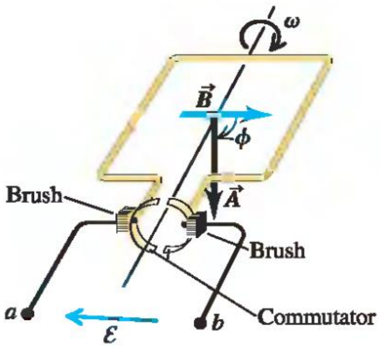
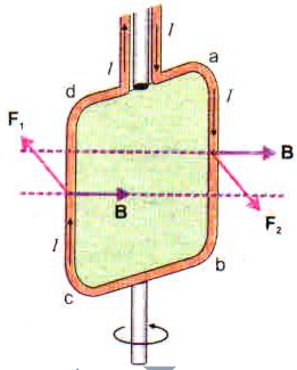


When the current in the coil is zero and is about to change direction, the split rings also changes the contacts with the carbon brushes BB'. Therefore, the output from BB' remains in the same direction although the current is not constant in magnitude. The fluctuations of the output can be significantly reduced by using many coils rather than a single one.

Muhammad Ali Malik (M. Phil. Physics), Whatsapp # +923016775811, www.fb.com/HomeOfPhysics

Q # 10. Describe the back emf effects in generators.

Ans. A generator is a source of electricity production that converts the mechanical energy into electrical energy. For this purpose, a large turbine is turned by high pressure or waterfall. The shaft of the turbine is attached to the coil which rotates in the magnetic field.



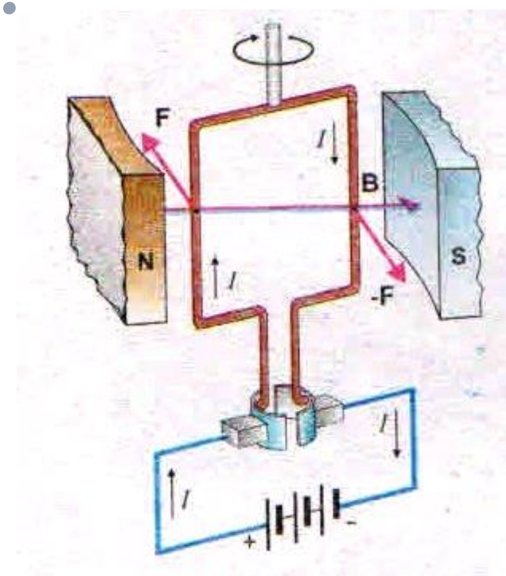
When the circuit is open, the generator does not supply electrical energy, and a very little force is needed to rotate the coil. As soon as the circuit is closed, a current is drawn through the coil. The magnetic field exerts force on the current carrying coil.

Force F_1 is acting on the left side of the coil whereas an equal but opposite force F_2 acts on the right side of the coil. These forces are such that they produce a counter torque that opposes the rotational motion of the coil. This effect is sometimes referred to as back motor effect in the generator.

Q # 11. Write a note on DC motor?

Ans. A motor is a device which converts electrical energy into mechanical energy. The basic principle of electric motor is that "a wire carrying current placed in magnetic field experience a force".

In construction a DC motor is similar to a DC generator, having a magnetic field, a commutator and an armature.



In DC motor, the brushes are connected to DC supply or battery. When the current flows through the armature coil, the force on the conductor produces a torque that rotates the armature. The amount to the torque depends upon the current, the strength to the magnetic field, the area of the coil ant the number of turns of the coil.

Q # 12. What do you know about back emf effect in motors? Also describe the relation between back emf and current.

Ans. When the coil motor rotates across the magnetic field by the applied potential difference V, an emf is induced in it. The induced emf is in such a direction that opposes the emf running motor. Due to this reason, the induced emf is called back emf of the motor. The magnitude of the back emf increases with the speed of motor.

Relation between Back Emf and Current

Since V and ε are opposite in polarity, the net emf in the circuit is $V-\varepsilon$. If R is the resistance of the coil and I the current drawn by the motor, then by Ohm's law:

$$I = \frac{V-\varepsilon}{R} \Rightarrow V = \varepsilon + IR$$

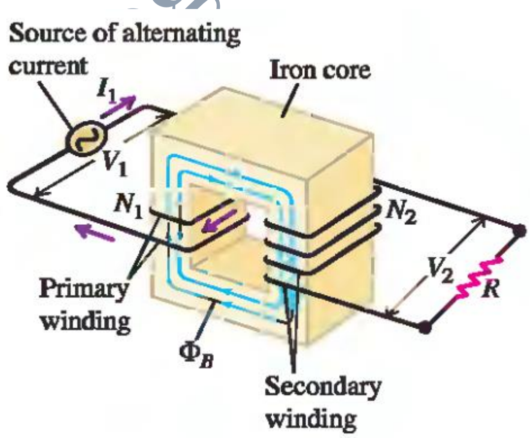
- When the motor is just started, back emf is almost zero and hence a large current passes through the coil.
- As the motor speeds up, the back emf increases and current becomes smaller and smaller. However, the current is sufficient to provide the torque on the coil drive the load and overcome losses due to friction.
- If the motor is overloaded, it slows down. Consequently, the back emf decreases and allows motor to draw more current.
- If the motor is overloaded beyond its limits, the current could be so high that it may burn out the motor.

Q # 13. What is transformer? Describe its construction, principle and working.

A transformer is an electrical device used to change a given alternating emf into a larger or smaller alternating emf.

Principle

The transformer works on the principle of mutual induction between two coils. The transformer consists of two coils of copper electrically insulated from each other, wound on the same iron core. The coil to which AC power is supplied is called primary and that from which power is delivered to the circuit is called secondary.



Working

Suppose that an alternating emf is applied to the primary. if at some instant t, the flux is changing at the rate of $\frac{\Delta\phi}{\Delta t}$, then there will back emf induced in the primary, which will oppose the applied voltage. The instantaneous value of the self induced emf is given by:

$$\text{Self induced emf} = -N_P\left[\frac{\Delta\phi}{\Delta t}\right]$$

Where N_P is the number of turns in the primary. If the resistance of the coil is negligible then the back emf is equal and opposite to applied voltage V_P.

$$V_P = -back\ emf = N_P\left[\frac{\Delta\phi}{\Delta t}\right] \quad \text{---------} \quad (1)$$

Assuming that the two coils are tightly coupled and the flux through the primary also passes through the secondary. Therefore, the rate of change of flux through secondary will be $\frac{\Delta\phi}{\Delta t}$ and the magnitude of induced emf across the secondary is given by:

$$V_S = N_S\left[\frac{\Delta\phi}{\Delta t}\right] \quad \text{---------} \quad (2)$$

Where N_S is the number of turns in the secondary.

Dividing equation (1) and (2), we get:

$$\frac{V_P}{V_S} = \frac{N_P}{N_S} \quad \text{---------} \quad (3)$$

Q # 14. Differentiate among step-up transformer and step-down transformer.

Step-up Transformer

A transformer in which voltage across secondary is greater than the primary voltage is called step up transformer. For the case of a step up transformer $V_S > V_P$, then according to the equation (3) we have: $N_S > N_P$.

Step-Down Transformer

A transformer in which voltage across secondary is less than the primary voltage is called step up transformer. For the case of a step down transformer $V_S < V_P$, then according to the equation (3) we have: $N_S < N_P$.

Q # 15. What is the difference between an ideal transformer and an actual transformer?

Ans. Electrical power in a transformer is transformed from its primary to the secondary coil by means of changing flux. For an ideal case the power input to the primary is nearly equal to the power output from secondary i.e.,

Power Input =Power Output

$$V_P I_P = V_S I_S$$

But in actual transformer, the output is always less than input due to power losses. There are two main causes of power losses, namely eddy currents and magnetic hysteresis.

Due to power losses, a transformer is far from being an ideal. The efficiency of the transformer is defined as:

$$E = \frac{Output\ Power}{Input\ Power} \times 100$$

Q # 16. Describe the different causes of power loss.

There are two main causes of power loss, which are given below

Eddy Current

The induced currents that are set up in the core of transformer in the direction perpendicular to the flux are known as eddy currents. It results in power dissipation and heating of the core material.

Hysteresis Losses

Hysteresis losses are the energy expended to magnetize and demagnetize the core material in each cycle of AC.

Q # 16. How the efficiency of the transformer can be improved?

Following step should be executed in order to improve the efficiency of transformer:

- Core should be assembled from the laminated sheet of a material whose hysteresis loop area is very small.
- The insulation between lamination sheets should be perfect so as to stop the flow of eddy currents.
- The resistance of the primary and secondary coils should be kept minimum.

EXERCISE SHORT QUESTIONS

Q # 1. Does the inducted emf in circuit depend on the resistance of the circuit? Does the induced current depend on the resistance of the circuit?

Ans. The expression for induced emf is given by

$$\boldsymbol{\varepsilon = -N\frac{\Delta\phi}{\Delta t}}$$

The relation shows that the induced emf in a coil only depend upon the rate of change of magnetic flux and number of turns but does not depend upon the resistance of the coil.

As the induced current flowing through a coil is given by:

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

this expression shows that the value of current depends upon the resistance of the coil. The smaller the value of the resistance of the coil, greater will he the value of current.

Q # 2. A square loop of wire is moving through a uniform magnetic field. The normal to the loop is oriented parallel to the magnetic field. Is a emf induced in the loop? Give a reason for your answer.

Ans. The induce emf in a wire is given by:

$$\varepsilon = vBL\sin\theta$$

Where θ the angle between "v" and "B".

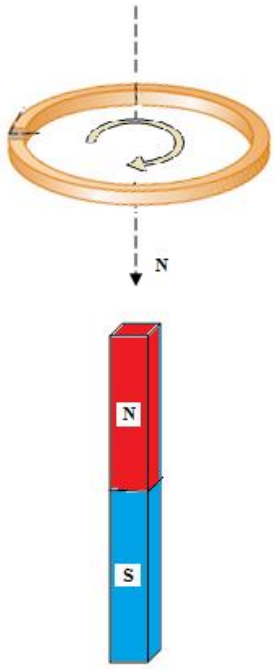
When normal to the loop is parallel to the field, the velocity vector "v" of side of loop is also parallel to field "B", so $\theta = 0$. Therefore,

$$\varepsilon = vBL\sin 0$$

$$\Longrightarrow \varepsilon = vBL(0)$$

$$\Longrightarrow \varepsilon = 0$$

Thus, emf induced in the loop is zero.

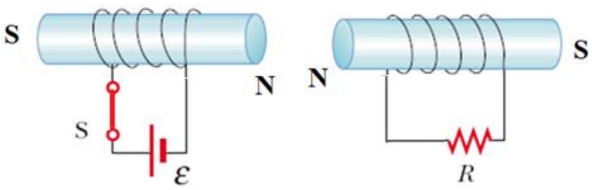


Q # 3. A light metallic ring is released from above into a vertical bar magnet as shown in the figure. Viewed from above, does the current flow clockwise or anti-clockwise in the ring?

Ans. According to Lenz's law, the direction of the induced current is opposite to the cause which produces it. So, the side of the ring facing north pole of magnet must be north pole of the induced magnetic field.

When viewed from above, the current in the ring is clockwise.

Q # 4. What is the direction of the current through resistor R as shown in the figure? As the switch S is (a) closed (b) open.



Ans. When switch S is closed, then the current in the primary coil increases from zero to maximum. During this time interval, magnetic flux through the secondary coil increases from zero to maximum and induced current produce in it. According to Lenz's law, the current through the secondary should flow in anti-clockwise direction. And current through resistor will be from left to right.

(b) However, if the switch is opened, the induced current through secondary should flow in clockwise direction. So the current through resistor R will flow from right to left.

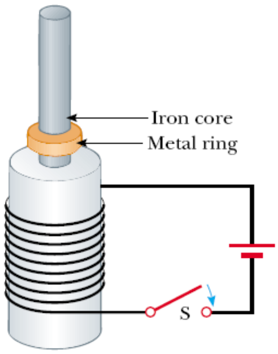
Q # 5. Does the induced emf always act to decrease the magnetic flux through a circuit?

Ans. The induced emf always opposes the cause that produces it.

- If the magnetic flux through the circuit through the circuit is increasing, then induced emf acts to decrease the magnetic flux.
- If the magnetic flux through the circuit through the circuit is decreasing, then induced emf acts to increase the magnetic flux.

Hence, the induced emf does not always act to decrease the magnetic flux through the circuit.

Q # 6. When the switch in the circuit is closed, a current is established in the coil and the metal ring jumps upward. Why? Describe what would happen to the ring if the battery polarity were reversed?



Ans. When the switch in the circuit is closed, the current is set up in the coil which establish magnetic field in it.

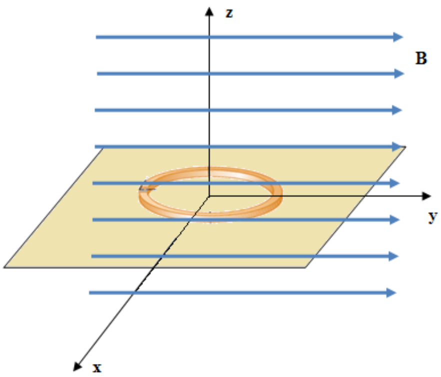
This result in change of magnetic flux through the metallic ring and hence an induced emf is produced in it.

The induced magnetic field in the ring opposes the magnetic field of the coil (according to Lenz's law). Therefore the ring experience a force of repulsion and jumps up.

The same event occurs even if the polarity of the battery is reversed.

Q # 7. Figure shows a coil of wire in the xy-plane with a magnetic field directed along the y-axis. Around which of the three coordinate axes should the coil be rotated in order to generate an emf and a current in the coil?

Ans.



- The coil must be rotated along x-axis to get change of magnetic flux and an induced current through it.
- If the coil is rotated about y-axis, the flux passing through the coil zero because plane of the coil remains parallel to magnetic field B all the times.
- If the coil is rotated about z-axis then no change of magnetic flux takes place through coil.

Hence if the coil is rotated about x-axis, then there is a change of magnetic flux passing through a coil. So only in this case, an emf is induced in the coil.

Q # 8. How would you position a flat loop of wire in a changing magnetic field so that there is no emf induced in the loop?

Ans. If the plane of loop of wire is placed parallel to changing magnetic field i.e., $\theta = 0$, then no flux through it will change. Hence no emf will be induced through the loop as:

$$\varepsilon = \omega AB \sin\theta$$

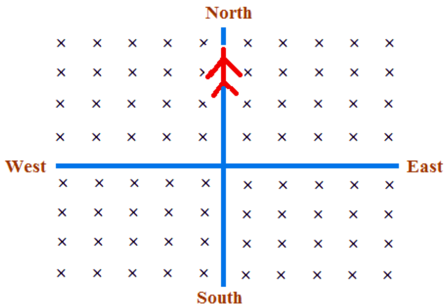
$$\varepsilon = \omega AB \sin 0 = \omega AB(0)$$

$$\varepsilon = 0$$

Q # 9. In a certain region, the earth's magnetic field point vertically down. When a plane flies due north, which wing tip is positively charged?

Ans. The magnetic force on electrons in the wing is given by:

$$\mathbf{F} = -e(\mathbf{v} \times \mathbf{B})$$



When the plane flies due north in the earth magnetic field directed vertically downward, then electrons will experience force in east direction.

Thus west wingtip of the plane is positively charged.

Q # 10. Show that ε and $\frac{\Delta\varphi}{\Delta t}$ have the same units.

Ans. As we know that:

- $\varepsilon = \frac{W}{q}$

$$\Rightarrow unit\ of\ \varepsilon = \frac{unit\ of\ Work}{unit\ of\ charge} = \frac{joule}{coulomb} = volt \quad ---------- \quad (1)$$

- $\frac{\Delta\varphi}{\Delta t} = \frac{B\Delta A}{\Delta t}$

$$\Rightarrow unit\ of\ \frac{\Delta\varphi}{\Delta t} = \frac{(unit\ of\ B)(unit\ of\ \Delta A)}{unit\ of\ \Delta t} = \frac{(NA^{-1}m^{-1})(m^2)}{s}$$

$$\Rightarrow unit\ of\ \frac{\Delta\varphi}{\Delta t} = \frac{N \times m}{A \times s}$$

As $N \times m = J\ (joule)$ and $A \times s = C\ (coulomb)$

$$\Rightarrow unit\ of\ \frac{\Delta\varphi}{\Delta t} = \frac{joule}{coulomb} = volt \quad ---------- \quad (2)$$

Hence from (1) and (2), it is proved that both $\boldsymbol{\varepsilon}$ and $\frac{\Delta\varphi}{\Delta t}$ have the same units.

Q # 11. When an electric motor, such as an electric drill, is being used, does it also act as a generator? If so what is the consequences of this?

Ans. When an electric motor is running, its armature is rotating in a magnetic field. A torque acts on the armature and at the same time, magnetic flux is changing through the armature which produces an induced emf. The induced emf opposes the rotation of armature. This means that motor also acts as generator when it is running.

consequences

- When the motor is just started, back emf is almost zero and hence a large current passes through the coil.
- As the motor speeds up, the back emf increases and current becomes smaller and smaller. However, the current is sufficient to provide the torque on the coil drive the load and overcome losses due to friction.
- If the motor is overloaded, it slows down. Consequently, the back emf decreases and allows motor to draw more current.
- If the motor is overloaded beyond its limits, the current could be so high that it may burn out the motor.

Q # 12. Can a DC motor be turned into a DC generator? What changes are required to be done?

Ans. Yes, a DC motor be turned into a DC generator.

In order to convert DC motor into a DC generator, two changes are to be done:

- The magnetic field must be supplied by the permanent magnet and not by electromagnet.
- An arrangement to rotate the coil armature should be provided.

Q # 13. Is it possible to change both the area of the loop and the magnetic field passing through the loop and still not have an induced emf in the loop?

Ans. If both area of the loop A and magnetic field strength B are changed such that change is magnetic flux is zero i.e., $\Delta\phi = 0$. Then by Faraday's law:

$$\varepsilon = -\frac{\Delta\phi}{\Delta t} = 0$$

Hence no induced emf in the loop will be produced.

Q # 14. Can an electric motor be used to drive an electric generator with output from the generator being used to operate the motor?

Ans. No it is not possible. Because if it is possible, it will be a self operating system without getting energy from some external source and this is against the law of conservation of energy.

Q # 15. A suspended magnet is oscillating freely in a horizontal plane. The oscillations are strongly damped when a metal plate is placed under the magnet. Explain why this occurs?

Ans. the oscillating magnet produces change of magnetic flux close to it. The metal plate placed below it experiences the change of magnetic flux. As the result, eddy current are produced inside metal. According to Lenz's law, these eddy current oppose the cause which produce it. So, the oscillations of magnet are strongly damped.

Q # 16. Four unmarked wires emerge from a transformer. What steps would you take to determine the turn ratio?

Ans. By checking continuity of the coils, the coils are separated as primary and secondary coils. An alternating voltage of known value V_P is connected to one coil (primary coil), the output voltage V_S across the ends of the other coil (secondary coil) is measured. The turn ratio of the coil is determined by using relation:

$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

Q # 17. (a) Can a step-up transformer increase the power level?

(b) In a transformer, there is no transfer of charge from the primary to the secondary. How is, then the power transferred?

Ans.

(a). In case of an ideal transformer, the power output is equal to the power input. In actual transformer, due of dissipation of energy in the coil, the output power is always less than input power. Therefore, a step-up transformer can't increase power level.

(b). The two coils of transformer are magnetically linked i.e., the change of flux through one coil is linked with the other coil.

Q # 18. When the primary of a transformer is connected to AC mains, the current in it

(a) Is very small if the secondary circuit is open, but

(b) Increases when the secondary circuit is closed. Explain these facts.

Ans. (a). If the secondary circuit is open, then output power will be zero. Because output power is always slightly smaller than the output power, therefore a very small value of current is being drawn by a primary coil of transformer form AC mains.

(b). When the secondary circuit is closed, the output power will be increased. As we know that output power is equal to input power, therefore the transformer will draw large current from the AC mains to increase the primary power. Hence, greater current is needed in primary to equalize power in secondary coil.

ALTERNATING CURRENT

Q # 1. What do you know about alternating current?

Ans. The current that is produced by a voltage source whose polarity keeps on reversing with time is called alternating current.

Q # 2. Define following for an alternating quantity:

- i. **Instantaneous value**
- ii. **Peak Value**
- iii. **Peak to Peak Value**
- iv. **Phase of AC**

Ans. Instantaneous Value

The value of the voltage or current that exist in a circuit at any instant of time t measured from some reference point is known as its instantaneous value. Mathematically, it is given by:

$$V = V_0 \sin\theta = V_0 \sin(\omega t)$$

$$V = V_0 \sin\left(\frac{2\pi}{T} \times t\right) = V_0 \sin(2\pi ft)$$

Peak Value

It is the highest value reached by the voltage or current in one cycle. It is denoted by the symbol V_0.

Peak to Peak Value

It is the sum of the positive and negative peak values usually written as p-p value.

Phase of AC

The instantaneous value of the alternating voltage is given by:

$$V = V_0 \sin\theta$$

$$V = V_0 \sin(\omega t)$$

The angle $\theta = \omega t$ specifies the instantaneous value of the instantaneous value voltage or current known as its phase.

Q # 3. What do you mean by Root Mean Square (rms) Value of an alternating quantity? Describe its significance. Also derive an expression to calculate the rms value of an alternating quantity.

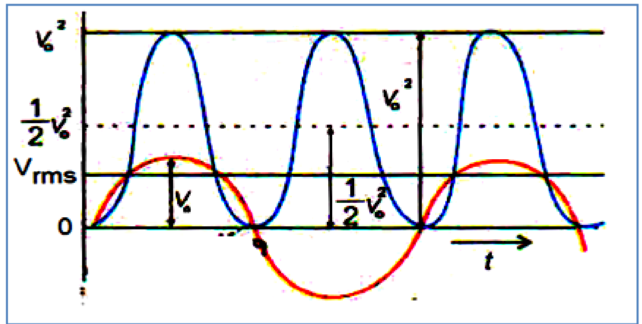
Ans. The alternating current (or voltage) measure by square root of its mean square value is known as root mean square (rms) value.

Significance of RMS Value

The average value of current and voltage over a cycle is zero but the power delivered during a cycle is not zero because power is I^2R and the values of I^2 are positive even for negative values of I. Thus the average value of I^2 is not zero and is called mean square current. The alternating current or voltage is actually measured by square root of its mean square value known as root mean square (rms) value.

RMS Value of Alternating Signal

As the graph of V^2 is symmetrical about the line $\frac{1}{2}V_0^2$, so from this figure, the mean or average value of V^2 is $\frac{1}{2}V_0^2$. The root mean square value of V is obtained by taking the square root of $\frac{1}{2}V_0^2$ (mean square value). Therefore,



$$V_{rms} = \sqrt{\frac{1}{2}V_0^2} = \frac{V_0}{\sqrt{2}} = 0.7\ V_0$$

Similarly, $I_{rms} = \sqrt{\frac{1}{2}I_0^2} = \frac{I_0}{\sqrt{2}} = 0.7\ I_0$

Q # 4. What do you know about AC Circuits?

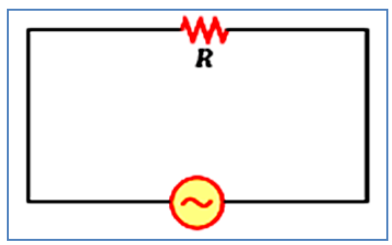
Ans. The basic element of a direct current circuit is resistor R which controls the current or voltage and the relation between them is given by the Ohm's law:

V=IR

In AC circuits, in addition to resistors R, two new circuit elements such as inductor L and capacitor C are used. The current and voltage in AC circuits is controlled by the three elements R, L and C.

Q # 5. Describe the relationship between instantaneous voltage and current when AC passes through resistor.

A resistor of resistance R is connected with the alternating voltage source is shown in the figure. The potential difference V across the terminals of the resistor is given by the expression:



$$V = V_0 \sin(\omega t) \text{ ------- } (1)$$

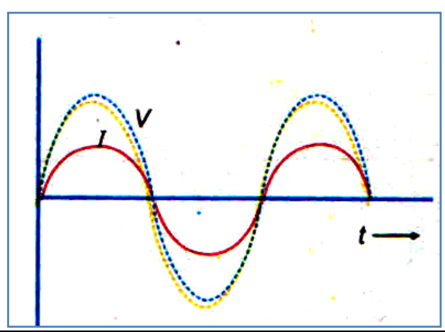
Where V is the instantaneous value of alternating voltage and V_0 is the peak value of the alternating voltage.

Dividing both sides by R, we get:

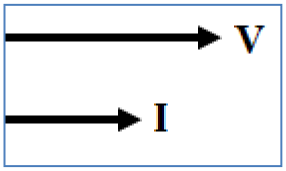
$$\frac{V}{R} = \frac{V_0}{R}\sin(\omega t)$$

$$\Rightarrow I = I_0 \sin(\omega t)$$

Where I is the instantaneous current and I0 is the peak value of the current. The graph of I and V verses time describe



that both I and V are proportional to $\sin \omega t$.



Both I and V across the resistor oscillate at the same frequency. Furthermore, both I and V go to zero at the same time, and both reach their peak value at the same time. The current and voltage are in phase.

In phase diagram of resistive circuit, the voltage V and current I are drawn parallel because there is no phase difference between them.

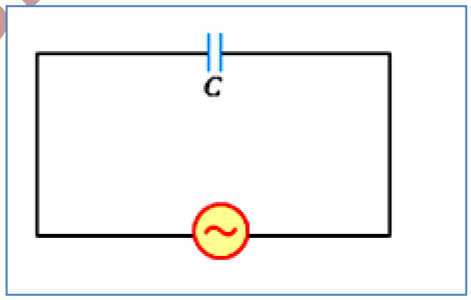
The opposition to the AC which the circuit presents in the resistance is given by:

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

Q # 6. Describe the relationship between instantaneous voltage and current when AC passes through capacitor.

Ans. Direct current flows through a capacitor continuously because of presence of insulating medium between the plates of capacitor.

While the alternating current flow through AC circuit containing capacitor, because the capacitor plates are continuously charged, discharged and charged the other way round by the alternating voltage.



The applied voltage between the plates of the capacitor is given by:

$$V = V_0 \sin \omega t$$

The charge stored on the plates of the capacitor at any instant is given by expression:

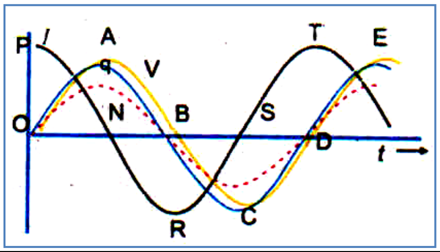
$$q = CV$$

$$\Rightarrow q = CV_0 \sin \omega t$$

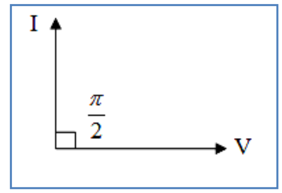
Since C and V_0 are constants, it is obvious that q will vary the same way as applied voltage i.e., V and q are in phase. The current I flowing through the connecting wires is equal to the rate of change of q i.e.,

$$I = \frac{\Delta q}{\Delta t}$$

So the value of I at any instant is the corresponding slope of q-t curve or v-t curve. Initially, when q = 0, the slope is maximum, so I is then maximum. From O to A, slop of q-t curve decreases to zero. So I is zero at N. from A to B, the slope to the q-t curve is negative and so I is negative from N to R. In this way, the curve PNRST gives the variation of current with time.



It can be seen from figure, that phase of V and I at O is zero and $\frac{\pi}{2}$, respectively. It means that current leads the voltage by $\frac{\pi}{2}$. This is vectorically, represented as:



Capacitive Reactance

It is the measure of opposition offered by the capacitor to the flow of alternating current. It is usually represented by X_C. Its value is given by the expression:

$$X_C = \frac{V_{rms}}{I_{rms}}$$

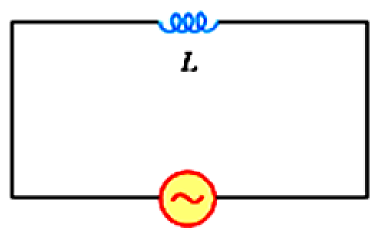
Where V_{rms} is the value of the alternating voltage across the capacitor and I_{rms} is the rms value of the alternating current passing through capacitor. The SI unit of the reactance is Ohm.

The capacitive reactance is inversely proportional to the frequency of the source, i.e.,

$$X_C = \frac{1}{2\pi fC} = \frac{1}{\omega C}$$

Q # 7. Describe the relationship between instantaneous voltage and current when AC passes through inductor.

Ans. Consider an a.c. circuit consisting of an inductor connected across the terminals of an a.c. source. Assume that the resistance of the coil is negligible. Suppose the current flowing at any instant in the circuit is:

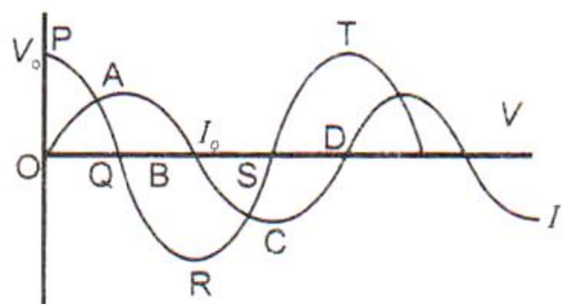


$$I = I_0 \sin(\omega t) = I_0 \sin(2\pi ft)$$

If L is the inductance of the coil, the changing current set up a back emf in the coil and its magnitude is given as:

$$\varepsilon_L = L\frac{\Delta I}{\Delta t}$$

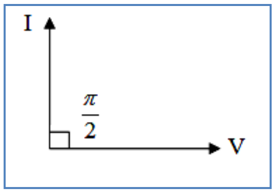
Since there is no resistance in the circuit, the applied voltage V must be equal to the back emf:



$$V = L\frac{\Delta I}{\Delta t}$$

As L is the constant of the circuit, therefore, voltage at any instant will be proportional to the rate of change of current.

The value of $\frac{\Delta I}{\Delta t}$ is given by the slop of I-t curve. At O, the value of the slop is maximum, so the maximum value of V (equal to V_0) . From O to A, the slop of I-t graph decreases to zero so the voltage decreases from V_0 to zero at Q. From A to B, the slop of I-t graph is negative, so the voltage goes from



Q to R. In this way the voltage is represented by the curve PQRST corresponding to current curve OABCD is obtained.

Inductive Reactance

It is the measure of opposition offered by the inductance coil to the flow of AC. It is represented by the symbol X_L. By definition

$$X_L = \frac{V_{rms}}{I_{rms}}$$

Where is the rms value of the alternating voltage across the capacitor and I_{rms} is the rms value of the alternating current passing through inductor. The SI unit of the reactance is Ohm. The reactance of the inductor is usually represented by the expression:

$$X_C = 2\pi fL = \omega L$$

Q # 8. Define the term impedance.

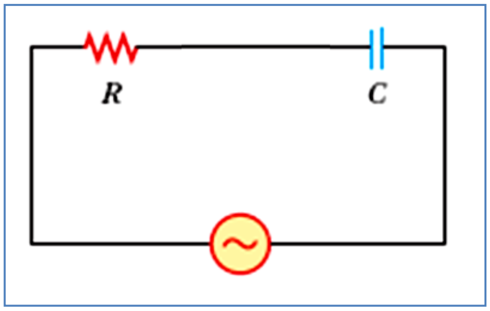
Ans. A measure of the opposition to the flow of charges in an AC circuit is called impedance.

An AC circuit may be composed of a resistance, inductance and capacitance or a combination of these elements. The combined effect of resistance and reactances in such circuit is known as impedance and is denoted by Z. The SI unit of impedance is ohm.

It measured by the ratio of the rms value of the applied voltage to the rms value of resulting current.

$$Z = \frac{V_{rms}}{I_{rms}}$$

Q # 9. What do you mean by RC Series Circuit? Calculate the impedance of the circuit by drawing their impedance diagram.



Ans. Such a circuit in which resistor R and capacitor C are connected in series is called RC series circuit.

Figure shows an RC series circuit excited by an AC source. The potential difference across resistor 'IR' would be in phase with current I.

Taking the current as the reference, the potential difference across the resistor is represented by the line along the current line because the potential difference is in phase with current.

The potential difference across the capacitor $V_C = \frac{I_{RMS}}{\omega C}$. As the current leads the voltage by 90°, so the line representing vector $\frac{1}{\omega C}$ is drawn at right angle to the current line.

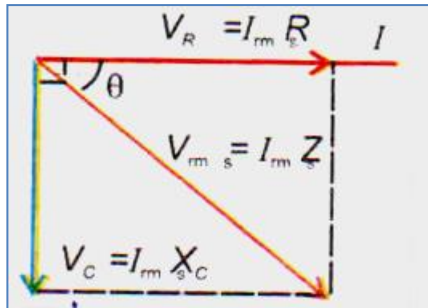
Calculation of Impedance

The value of applied voltage V is obtained by the resultant of vectors $I_{RMS}R$ and $\frac{I_{RMS}}{\omega C}$.

$$V_{RMS} = \sqrt{(I_{RMS}R)^2 + \left(\frac{I_{RMS}}{\omega C}\right)^2}$$

$$\Rightarrow V_{RMS} = I_{RMS}\sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2}$$

$$\Rightarrow \frac{V_{RMS}}{I_{RMS}} = \sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2}$$



We know that $Z = \frac{V_{RMS}}{I_{RMS}}$, therefore

$$Z = \sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2}$$

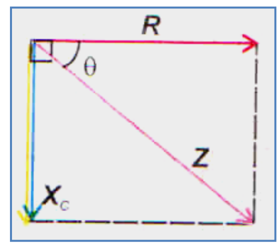


Figure shows that the current and the applied voltage are not in phase. The phase θ by which the current leads the voltage is given by the expression:

$$\theta = \tan^{-1}\left(\frac{1}{\omega CR}\right)$$

Q # 10. What do you mean by RL Series Circuit? Calculate the impedance of the circuit by drawing their impedance diagram.

Ans. A circuit in which resistor R and inductor L are connected in series is called RL series circuit.

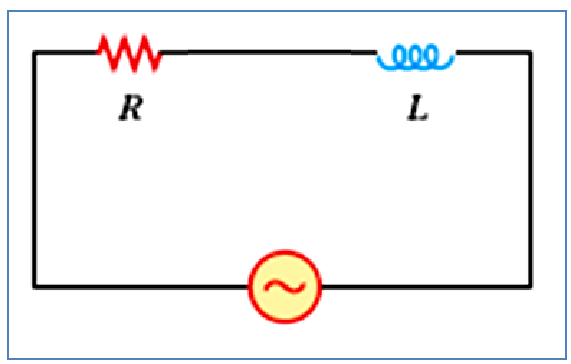


Figure shows an RL series circuit excited by an AC source. The potential difference across resistor 'IR' would be in phase with current I.

Taking the current as the reference, the potential difference across the resistor is represented by the line along the current line because the potential difference is in phase with current.

The potential difference across the inductor $V_L = I_{RMS}(\omega L)$. As the current lags the voltage by 90°, so the line representing vector ωL is drawn at right angle to the current line.

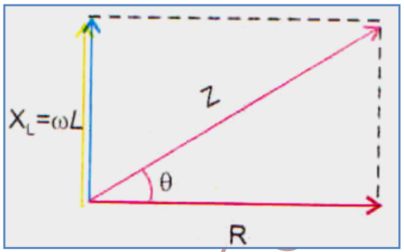
Calculation of Impedance

The value of applied voltage V is obtained by the resultant of vectors $I_{RMS}R$ and $I_{RMS}\omega L$.

$$V_{RMS} = \sqrt{(I_{RMS}R)^2 + (I_{RMS}\omega L)^2}$$

$$\Rightarrow V_{RMS} = I_{RMS}\sqrt{R^2 + (\omega L)^2}$$

$$\Rightarrow \frac{V_{RMS}}{I_{RMS}} = \sqrt{R^2 + (\omega L)^2}$$



We know that $Z = \frac{V_{RMS}}{I_{RMS}}$, therefore

$$Z = \sqrt{R^2 + (\omega L)^2}$$

Figure shows that the current and the applied voltage are not in phase. The phase θ by which the current leads the voltage is given by the expression:

$$\theta = \tan^{-1}\left(\frac{\omega L}{R}\right)$$

Q # 11. Describe the power dissipation in AC circuits.

Ans. The expression for power is $P = V_{RMS} I_{RMS}$. This exprfession is true in case of AC circuits, only when V and I are in phase as in case of purely resistive circuits.

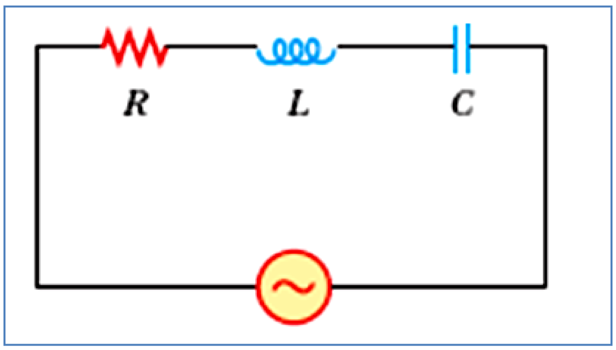
In AC circuits, the potential difference between the applied voltage and the current is θ. The component of V along current I_{RMS} is $V_{RMS}\cos\theta$. Actually, it is this component of the voltage vector which is in phase with current. So power dissipated in AC circuit is:

$$P = I_{RMS}(V_{RMS}\cos\theta)$$

The factor $\cos\theta$ is known as power factor.

Q # 12. Find out expression for resonance frequency for the case of series resonance circuit. Also describe its properties.

Ans. Consider RLC series circuit which is excited by an alternating voltage source whose frequency can be varied. It can be seen from the impedance diagram, that the inductive reactance $X_L = \omega L$ and capacitive reactance $X_C = \frac{1}{\omega C}$ are directed opposite to each other.



- When the frequency of the source is very small, $X_C = \frac{1}{\omega C}$ is much greater than $X_L = \omega L$. So the capacitance dominates at low frequencies and circuit behaves like an RC circuit.

- When the frequency of the source is high, $X_L = \omega L$ is much greater than $X_C = \frac{1}{\omega C}$. So the inductance dominates at high frequencies and circuit behaves like an RL circuit.
- In between low and high frequencies, there will be a frequency ω_R at which $X_L = X_C$. This condition is called resonance.

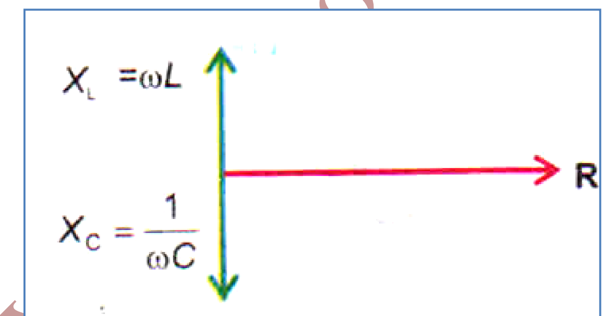
Thus at resonance, the inductive reactance being equal and opposite to capacitive reactance, cancel each other. The value of resonance frequency can be find out by putting value in equation $X_L = X_C$:

$$\omega_R L = \frac{1}{\omega_R C}$$

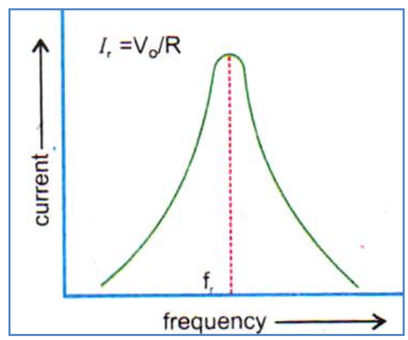
$$\Rightarrow (\omega_R)^2 = \frac{1}{LC}$$

$$\Rightarrow \omega_R = \frac{1}{\sqrt{LC}}$$

$$\Rightarrow f_R = \frac{1}{2\pi\sqrt{LC}}$$



Properties of series resonance circuit

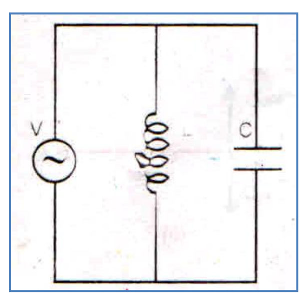


- ➢ The resonance frequency is given by the expression:

$$f_R = \frac{1}{2\pi\sqrt{LC}}$$

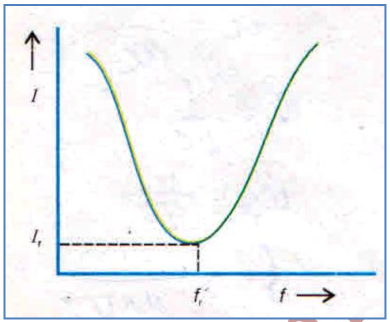
- ➢ The impedance of the circuit is minimum at this frequency and is equal to R.
- ➢ The impedance of the circuit at resonance is resistive so the current and the voltage are in phase and power factor is 1.
- ➢ If the amplitude of the source voltage V_0 is constant, the current is maximum at the resonant frequency and its value is $\frac{V_0}{R}$.

Q # 13. What is parallel resonance circuit? Also describe the properties of this circuit.



Ans. The LC-parallel circuit connected to alternating voltage source is shown in the figure. The inductance coil L has negligibly small resistance. The circuit resonates at frequency ω_r for which capacitive reactance becomes equal to inductive reactance i.e., $X_C = X_L$

Properties of Parallel Resonance Circuit



- The resonance frequency of parallel resonance circuit can be determined by using expression:

$$f_R = \frac{1}{2\pi\sqrt{LC}}$$

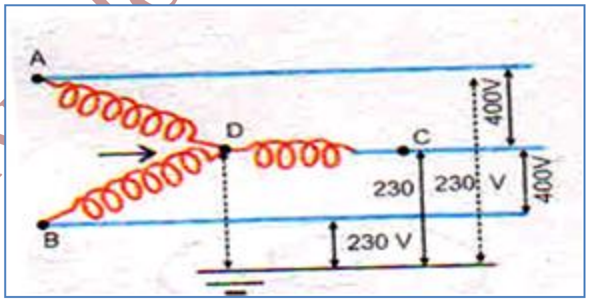
- At resonance frequency, the circuit impedance is maximum.
- At resonance, the circuit current is minimum and is in phase with the applied voltage.

Q # 14. What do you know about choke.

Ans. It is a coil of thick copper wire wound closely over a soft iron laminated cores. It is used in AC circuits to limit current with extremely small wastage of energy as compared to a resistance or a rheostat.

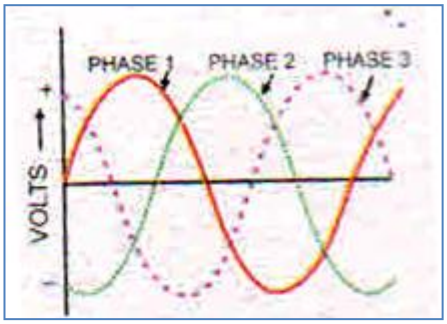
The choke uses the induction phenomenon to limit the current of the circuit. As its resistance is very small, therefore, it consumes extremely small power.

Q # 15. Write a note on three phase AC supply.



Ans. In three phase AC supply (generator), there are three coils inclined at an angle 120° to each other. Each coil is connected to its own part of slip rings. As the coils rotate in the magnetic field, an alternating voltage is generated across all slip rings.

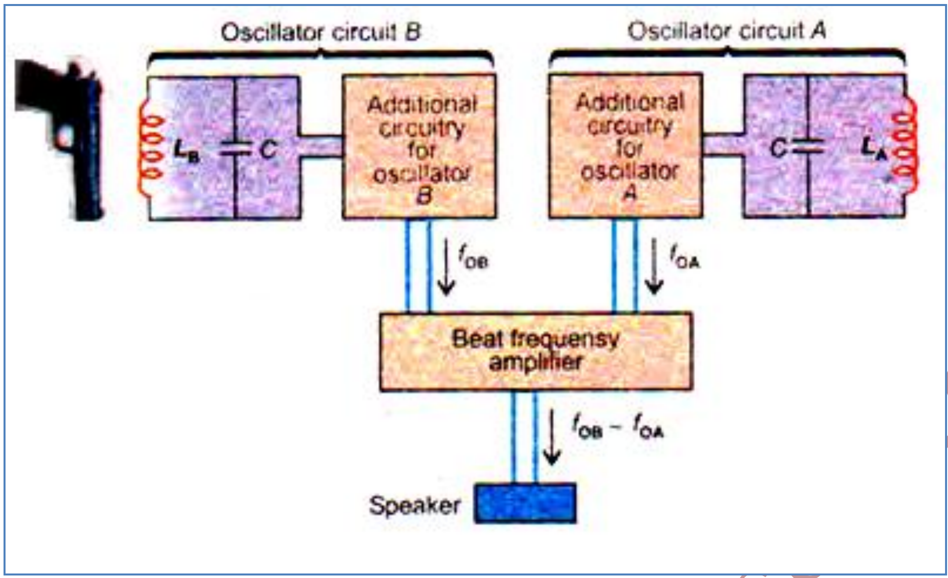
The phase difference between the alternating voltages are 120°. It means that when the voltage between the first pair of slip rings is zero, the voltage across the second pair of slip rings 120°. Similarly, the voltage generated across the third pair will have a phase difference of 240°.



The main advantage of having a three phase supply is that the total load of the house or a factory is divided in three parts, so that none of the line is overloaded.

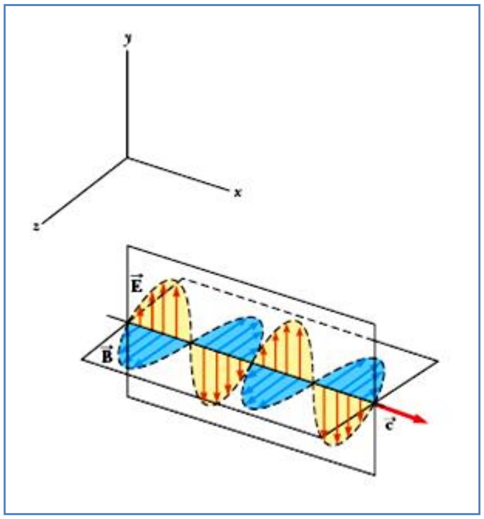
Q # 16. Describe the basic principle of metal detectors.

Ans. metal detectors are the electrical instruments that are used for detection and security purposes. A metal detector consist of LC-circuits, which behave just like an oscillating mass-spring system. This circuit is called electrical oscillator. Two such electrical oscillators are used in the operation of a metal detector. The schematic diagram of a metal detector is shown in the figure below:



In the absence of any nearby metal object, the inductances L_A and L_B are the same and hence the resonant frequency of the two circuits is also same. Ehen the inductor B comes near a metal object, its inductance L_B decreases and corresponding oscillator frequency increases and thus a beat note is heard in the attached speaker.

Metal detectors are used for security purposes and to locate buried objects.



Q # 17. Write a note on electromagnetic waves.

Ans. The waves which don't require any material medium for their propagation are called electromagnetic waves. It consists of vibrating electric and magnetic fields which move at the speed of light and are at right angle to each other and to the direction of propagation.

These waves are periodic waves, hence they have wavelength λ, which is given by:

$$\lambda = \frac{c}{f}$$

Where c and f are is the speed and frequency of wave respectively.

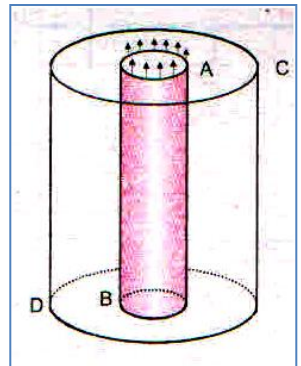
Depending upon the values of wavelength and frequency, the electromagnetic waves are classified into different types such as

- Radio waves
- Microwaves
- Infrared Waves
- Visible light rays etc.

Principle of Generation of Electromagnetic Waves

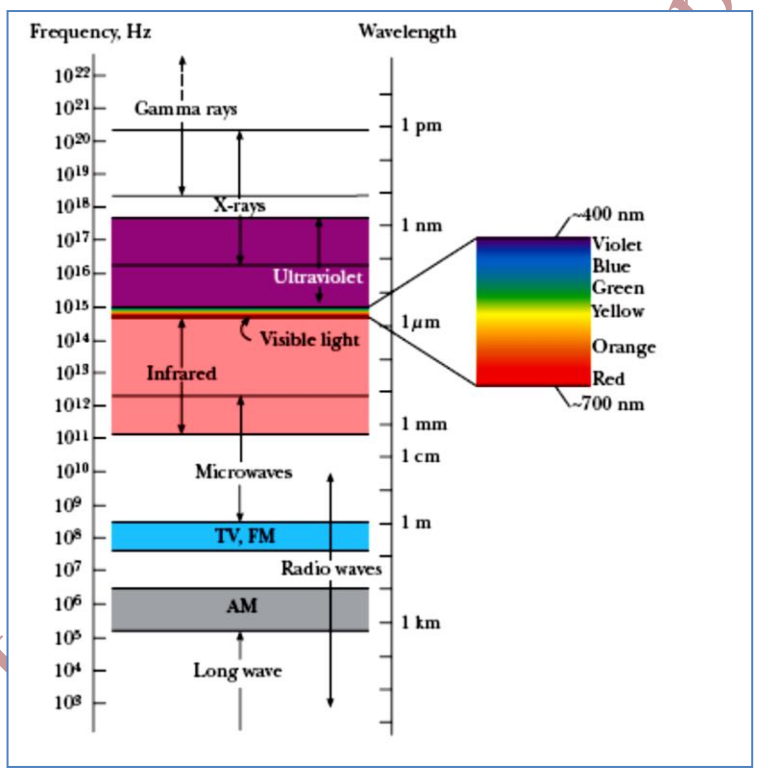
The basic principle of generation of electromagnetic waves is:

"A changing magnetic flux creates an electric field and a changing electric flux creates magnetic field"



For example, if the change of magnetic flux takes place in region of space AB. This change of magnetic flux will set up an electric field in the surrounding region CD. The creation of the electric field in the region CD will cause a change of electric flux through it due to which a magnetic field will be set up in the space surrounding CD and so on.

Thus each field will generate the other and the whole package of electric and magnetic fields will move along propelling itself through space.



Q # 18. Define the term modulation. Describe its different types.

Ans. The process of combining the low frequency signal with a high frequency

Amplitude Modulation

In this type of modulation, the amplitude of the carrier wave is increased or diminished as the amplitude of the superposing modulating signal increases or decreases.

Frequency Modulation

In this type of modulation, the frequency of the carrier wave is increased or diminished as the amplitude of the superposing modulating signal increases or decreases. But the carrier wave amplitude remains constant.

EXERCISE SHORT QUESTIONS

Q # 1. A sinusoidal current has rms value of 10 A. What is the maximum or peak value?

Ans.

$$RMS\ value\ of\ current\ = I_{rms} = 10\ A$$

$$Peak\ Value\ (maximum\ value) = I_0 = ?$$

Using formula:

$$I_{rms} = \frac{I_0}{\sqrt{2}}$$

$$\Rightarrow I_0 = \sqrt{2}\ \ I_{rms}$$

$$\Rightarrow I_0 = \sqrt{2}(10\ A)$$

$$\Rightarrow I_0 = 14.14\ A$$

Thus, the maximum value of the current is 14.14 A.

Q # 2. Name the devices that will

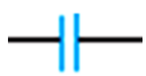
(a) Permit flow of direct current but oppose the flow of alternating current

(b) Permit flow of alternating current but not the direct current.

Ans.

(a) An inductor (choke) is a device which permits flow of direct current but opposes the flow of alternating current. It is represented by the following symbol:

(b) A capacitor is a device which permits flow of alternating current but not the direct current. It is represented by the symbol given below:



Q # 3. How many times per second will an incandescent lamp reaches maximum brilliance when connected to a 50 Hz source?

Ans. The brilliance of the lamp will become maximum twice in one AC cycle because the current also becomes maximum two times in a cycle (i.e., for +ve half cycle and –ve half cycle).

As the frequency "f" of AC cycle is 50 Hz.

$$So\ maximum\ brilliance\ shown\ by\ lamp\ per\ second\ = Twice\ the\ frequency\ of\ AC\ source$$

$$So\ maximum\ brilliance\ shown\ by\ lamp\ per\ second\ = 2f = 2 \times 50 = 100\ times$$

Hence, the brilliance will be maximum 100 time in one second.

Q # 4. A circuit contains an iron-cored inductor, a switch and a DC sources arranged in series. The switch is closed and after an interval reopened. Explain why a spark jumps across the switch contacts?

Ans. When a switch of circuit containing iron cored inductor is closed, current increases from zero to maximum value. This changing current produce change of magnetic flux and hence emf is produced.

After an interval, when switch is reopened, the current changes from maximum to zero. Again emf is developed across the coil. This is back emf. This produces spark across the switch contacts.

Q # 5. How does doubling the frequency affect the reactance of (a) an inductor (b) capacitor?

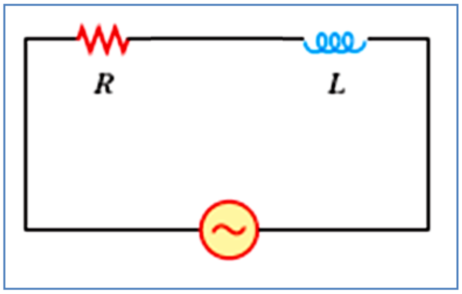
Ans.

	Formula for Reactance	**Doubling frequency**	**Result**
Inductor	$X_L = \omega L$	$X_L' = 2\omega L = 2X_L$	Inductive Reactance will become double
Capacitor	$X_C = \frac{1}{\omega C}$	$X_C' = \frac{1}{2\omega C} = \frac{1}{2}X_C$	Capacitive Reactance will becomes half

Hence by doubling the frequency, the inductive reactance will become double, while capacitive reaction remains half.

Q # 6. In a RL circuit, will the current lag or lead the voltage? Illustrate your answer by a vector diagram.

Figure shows an RL series circuit excited by an AC source. The potential difference across resistor 'IR' would be in phase with current I.

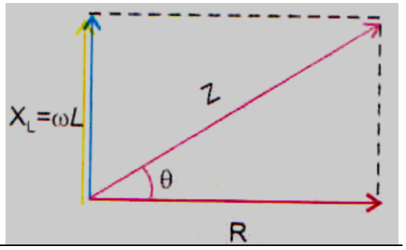


Taking the current as the reference, the potential difference across the resistor is represented by the line along the current line because the potential difference is in phase with current.

The potential difference across the inductor $V_L = I_{RMS}(\omega L)$. As the current lags the voltage by 90°, so the line representing vector ωL is drawn at right angle to the current line.

Figure shows that the current and the applied voltage are not in phase. The phase θ by which the current leads the voltage is given by the expression:

$$\theta = \tan^{-1}\left(\frac{\omega L}{R}\right)$$



Q # 7. A choke coil placed in series with an electric lamp in an AC circuit causes the lamp to become dim. Why is it so? A variable capacitor added in series in this circuit may be adjusted until the lamp glows with normal brilliance. Explain, how this is possible?

Ans. Let an electric lamp connected to a source of alternating voltage V in AC circuit. When there is no inductance or capacitance in the circuit, the impedance is equal to the resistance of the circuit, say R. it means that the current flowing through the lamp is

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

(a) When a choke coil is connected in series with an electric lamp

If, now, a choke coil of inductive reactance X_L is placed in series with the electric lamp, the new impedance of the circuit will be:

$$Z_1 = \sqrt{R^2 + X_L^2}$$

Therefore, the current flowing through the circuit in this case will be:

$$I_1 = \frac{V}{Z_1} = \frac{V}{\sqrt{R^2 + X_L^2}}$$

From the comparison of both currents, we see that I_1 is smaller than I and that is why the electric lamp is dimmed on placing a choke coil in the circuit.

(b) A Variable capacitor added in series with an electric lamp

When a variable capacitor also is in series with the circuit, its capacitive reactance X_C opposes X_L and thus the impedance of the circuit is

$$Z_2 = \sqrt{R^2 + (X_L - X_C)^2}$$

Therefore, the current flowing through the circuit in this case will be:

$$I_2 = \frac{V}{Z_2} = \frac{V}{\sqrt{R^2 + (X_L - X_C)^2}}$$

If the $X_L = X_C$, then $I_2 = \frac{V}{Z_2} = \frac{V}{\sqrt{R^2+(0)^2}} = \frac{V}{R} = I$

Hence, the current I_2 becomes equal to the current I for $X_L = X_C$, as if there is no reactance in the circuit and hence the lamp glow with normal brilliance.

Q # 8. Explain the condition under which electromagnetic waves are produced from a source.

Ans. When alternating voltage is applied across the ends of a metallic antenna, and oscillating electric field comes into existence which accelerates the electrons again and again as the polarities of the antenna changes after half a cycle.

The accelerated electrons radiate energy carried by changing electric field. A changing electric field creates a magnetic field and a changing magnetic field creates electric field. Thus each field will generate the other and the whole package of electric and magnetic fields will move along propelling itself through space.

Q # 9. How the reception of a particular radio station is selected on your radio set?

Ans. A particular radio station can be selected on a radio set by tuning it. When the frequency of the LC-oscillator in the radio set is equal to the frequency of the radio wave from a particular radio station, a resonance is produced. The current of this signal becomes maximum and can detected and amplified. The resonance frequency:

$$f_R = \frac{1}{2\pi\sqrt{LC}}$$

Q # 10. What is meant by A.M and F.M?

Ans. Amplitude Modulation

In this type of modulation, the amplitude of the carrier wave is increased or diminished as the amplitude of the superposing modulating signal increases or decreases.

Frequency Modulation

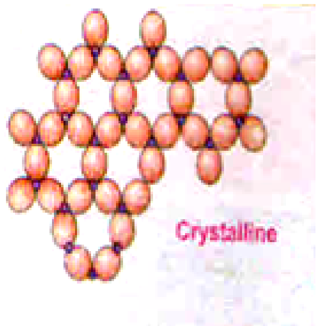
In this type of modulation, the frequency of the carrier wave is increased or diminished as the amplitude of the superposing modulating signal increases or decreases. But the carrier wave amplitude remains constant.

Muhammad Ali Malik (M. Phil. Physics), Whatsapp # +923016775811, www.fb.com/HomeOfPhysics

IMPORTANT QUESTIONS WITH ANSWERS

Q # 1. What do you know about crystalline solids? Describe its properties.

Ans. The solids in which the atoms, ions and molecules are arranged periodically are called crystalline solids.



Examples:

- Metals such as copper, zinc, iron etc.
- Ionic compounds such as sodium chloride
- Ceramics such as zirconia

are the examples of crystalline solids.

Properties of Crystalline Solids

1. The crystalline solids show the phenomenon of X-ray diffraction.
2. Every crystalline solid has sharp melting point i.e., for every crystal there is a temperature at which the thermal vibrations becomes so great that the structure suddenly breaks up, and the solid melts.

Q # 2. Write a note on amorphous or glassy solids?

Ans. The word amorphous means shapeless. Thus in amorphous solids, there is no regular arrangement of molecules like that in crystalline solids.

Examples:

The ordinary glass is an example of amorphous solids.

Properties of Amorphous Solids

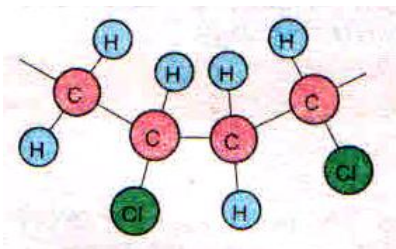
1. As the atom, ions and molecules are not arranged periodically in amorphous solids, so these solids don't show the phenomenon of X-ray diffraction.
2. The amorphous solids don't have sharp melting point. For example, a glass passes through a paste like state on heating and becomes a very viscous liquid at almost 800^0C.

Q # 3. What are Polymeric Solids? Describe its properties.

Ans. Polymeric solids are formed by polymerization reaction in which relatively simple molecules are chemically combined into massive long chain molecules. Polymers may be said to be more or less solid materials with a structure that is intermediate between order and disorder.

Example:

Plastics, synthetic rubber, polythene and nylon etc. are the examples of polymers.



Properties of Polymeric Solids

Polymeric solids have low specific gravity, but yet they exhibit good strength to weight ratio.

Q # 4. Define following:

i) Unit Cell

ii) Crystal Lattice

Ans.

Unit Cell

A crystalline solid consists of three dimensional pattern that repeat itself over and over again. This smallest three dimensional basic structure is called unit cell.

Crystal Lattice

The whole structure obtained by the repetition of unit cell is known as crystal lattice.

Q # 5. What do you know about deformation? Also describe the phenomenon of deformation in crystalline solids.

Ans. Deformation

Any change in shape, volume and length of an object when it is subjected to some external force is called deformation.

Deformation in Crystalline Solids

In crystalline solids atoms are arranged in a certain order. When external force is applied on such a body, a distortion results because of displacement of the atoms from their equilibrium position and the body is said to be in state of deformation.

In deformed crystalline solid, the atoms return to their equilibrium position after the removal of external force. This ability of the body to return to its original shape is called elasticity.

Q # 6. What do you know about mechanical properties of solids?

Ans. The properties shown by the solid material under the action of external force are called mechanical properties. Physical quantities such as stress, strain and modulus of elasticity are used to describe the mechanical properties of solids.

Q # 7. Define the term Stress. Also describe its different types.

The force applied on unit area to produce any change in the shape, volume or length of a body is called stress. Mathematically, it is described as:

$$Stress\,(\sigma) = \frac{Force\ (F)}{Area\ \ (A)}$$

The SI unit of stress is newton per square meter, which is given the name pascal (Pa).

Types of Stress

Tensile Stress: A stress that causes the change in length of an object is called tensile stress.

Shear Stress: A stress that causes the change in shape of an object is called shear stress.

Volume Stress: A stress that causes the change in volume of an object is called volume stress.

Q # 8. Define the term Strain. Also describe its different types.

Ans. Strain is the measure of deformation of a solid when stress is applied to it. For the case of one dimensional deformation, strain is defined as the fractional change in length.

If Δl is the change in length and l is the original length, then the strain is given by:

$$Strain\ (\varepsilon) = \frac{\Delta l}{l}$$

Since strain is the ration of lengths, it is dimensionless, and therefore, has no units.

Types of Strain

Tensile Strain: If the strain is due to tensile stress, it is called tensile strain.

Shear Strain: A strain produced in the object when it is subjected to shear stress is called shear strain. When the opposite faces of a rigid body are subjected to shear stress, the shear strain produced is given by:

$$Shear\ Strain = \frac{\Delta a}{a} = \tan\theta$$

Volumetric Strain: When the applied stress changes the volume, then the change in volume per unit volume is called volumetric strain. Thus

$$Volumetric\ Strain = \frac{\Delta V}{V}$$

Q # 9. What do you know about Modulus of Elasticity? Describe its different types.

Ans. Modulus of Elasticity The ratio of stress to strain is a constant for a given material, provided the external applied force is not too great, called modulus of elasticity. Mathematically, it is described as:

$$Modulus\ of\ Elasticity = \frac{Stress}{Strain}$$

Since the strain is a dimensionless quantity, the units of modulus of elasticity are the same as that of stress, i.e., Nm^{-2} or Pa.

Types of Elastic Constants

Young Modulus: For the case of linear deformation, the ration of tensile stress to tensile strain is called Young Modulus (Y):

$$Y = \frac{F/A}{\Delta l/l}$$

Shear Modulus: When the shear stress **τ =(F/A)** and shear strain **($\gamma = \tan\theta$)** are involved, then their ratio is called shear modulus (G):

$$G = \frac{F/A}{\tan\theta}$$

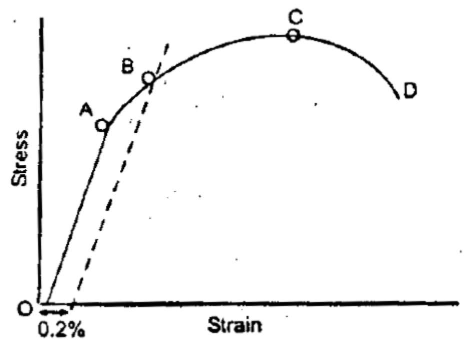
Bulk Modulus: For three dimensional deformations, when volume is involved, then the ratio of applied stress to volumetric strain is called bulk modulus (K):

$$K = \frac{F/A}{\Delta V/V}$$

Where ΔV is the change in original volume V.

Q # 10. How the mechanical properties of a wire are determine in Tensile Test.

In tensile test, metal wire is extended at a specified deformation rate. The stresses generated in the wire during deformation are continuously measured by a suitable electronic device fitted in the mechanical testing machine. Stress-strain curve is plotted automatically on XY chart recorder. A typical stress strain curve for a ductile material is shown in the figure:



In the initial stages of deformation, stress is increased linearly with strain till point A on stress-strain curve. This is called proportional limit.

Proportional Limit (Definition):

Proportional limit is the greatest stress that a material can endure without losing straight line proportionality between stress and strain.

From A to B, the stress and strain are not proportional, but nevertheless, if the load is removed at any point between O and B, the curve will be retraced and the material will return to its original length. The point B is called yield point and the value of stress at this point is known as yield stress or elastic limit.

Yield Stress or Elastic Limit (Definition):

Elastic limit is the greatest stress that a material can endure without any permanent deformation.

If the stress is increased beyond elastic limit, the specimen becomes permanently deformed. This kind of behavior is called plasticity. The region of plasticity is represented by the portion of the curve from B to C. The point C represents ultimate tensile strength (UTS).

Ultimate Tensile Stress (UTS), (Definition):

Ultimate tensile stress is the maximum stress that a material can withstand.

Once point C corresponding to UTS is crossed, the material breaks at point D, responding to fracture stress.

Q # 11. Describe the classification of solids on the basis of plastic deformation of solids.

Ductile Substances

Substances that undergo plastic deformation until they break are called ductile substances. Lead, copper and wrought iron are ductile.

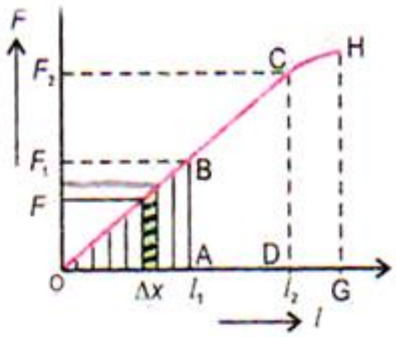
Brittle Substance

The substances which break just after the elastic limit is reached, are known as brittle substances. Glass and high carbon steel are brittle.

Q # 12. Define the term Strain Energy. Also derive its expression of strain energy by considering force-elongation graph obtained during the tensile test of a wire.

Ans. Strain Energy. The amount of P.E stored in a material due to displacement of its molecule from its equilibrium position, under the action of stress, is called strain energy.

Derivation of the expression of Strain Energy



Energy in stretched wire

Ans. Consider a wire whose one end is attached to a fixed support, is stretched vertically by connecting a weight at its lower end. The suspended weight acts as a stretching force. The extension in the wire is increased by increasing the stretching force. The graph plotted between extension l for the different value of stretching force is shown in the figure:

It is clear from the figure that the force is constant in producing extension l_1 but is changing linearly from 0 to F_1. In order to calculate the work done for extension l_1 by a certain force F_1, it is convenient to find the work done by graphical method.

The work done for extension l_1 by a certain force F_1 will be equal to the area under force – extension curve, which is equal to the area of triangle OAB. Therefore,

$$\text{Work Done} = \text{Area of triangle OAB}$$

$$\text{Work Done} = \frac{1}{2}(\text{base})(\text{altitude})$$

$$\text{Work Done} = \frac{1}{2}(\overline{OA})(\overline{AB})$$

$$\text{Work Done} = \frac{1}{2}(l_1)(F_1)$$

This work done is appeared as strain energy inside the wire. So

$$\text{Strain Energy} = \frac{1}{2}(l_1)(F_1) \quad \text{----------} \quad (1)$$

Expression of Strain Energy in terms of Elastic Modulus

If A is the cross-sectional area of the wire of length L, then the modulus of elasticity E of the wire can be described as:

$$Modulus\ of\ Elasticity = \frac{Stress}{Strain}$$

$$E = \frac{F_1/A}{l_1/L}$$

$$E = \frac{F_1 L}{A l_1} \Rightarrow F_1 = \frac{E A l_1}{L}$$

Putting value in equation (1), we get:

$$\text{Strain Energy} = \frac{1}{2}(l_1)\left(\frac{EAl_1}{L}\right)$$

$$\Rightarrow \text{Strain Energy} = \frac{1}{2}\left(\frac{EAl_1^2}{L}\right)$$

Q # 12. What do you mean by electrical properties of solids? Also write a short note on energy band theory of solids.

Ans. The electrical properties of solids determine its ability to conduct electric current. The conventional free electron theory based on Bohr Model failed to explain completely the vast diversity in the electrical behavior of solids. On the other hand, the energy based on wave mechanical model has been found successful in resolving this problem.

Q # 13. Define following:

i. **Energy Band**
ii. **Forbidden Band**
iii. **Valance Band**
iv. **Conduction Band**

Ans.

Energy Band

When the numbers of atoms are brought together, as in a crystal, they interact with one another. As the result, each energy level splits up into several sub-levels. A group of such energy sub-levels are called an energy band.

Forbidden Bands

The energy bands are separated by gaps in which there is no energy level. Such energy gaps are called forbidden bands.

Valence Bands

The electrons in the outermost shell of an atom are called valance electrons. Therefore, the energy band occupied by valance electrons is called the valance band. The valance band may be either completely filled or partially filled with the electrons but can never be empty.

Conduction Band

The energy band next to the valance band is called the conduction band. The valance and conduction bands are separated by forbidden energy gaps. The conduction band may be empty or partially filled. The electrons in the conduction band can drift freely in the materials and are called free or conduction electrons.

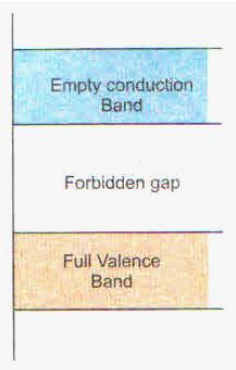
Q # 14. Differentiate among conductors, insulators and semiconductors on the basis of band theory of solids.

Ans. The width of forbidden energy gap between valance and conduction band decide whether a material is a conductor, insulator or a semiconductor.

Insulators

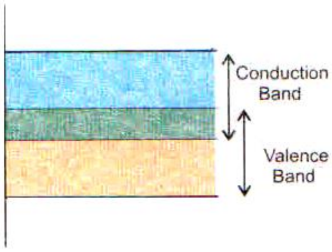
Insulators are those materials in which valance electrons are bound very tightly to their atoms and are not free. In terms of energy bands, it means that an insulator has:

a) An empty conduction band (no free electron)
b) A full valence band
c) A large energy gap (several eV) between them.



Conductor

Conductors are those which have plenty of free electrons for electrical conduction. In terms of energy bands, conductors are those materials in which valence and conduction band largely overlap each other. There is no physical distinction between the two band which ensures the availability of free electrons. That is why, the conductions are good conductors of electricity.



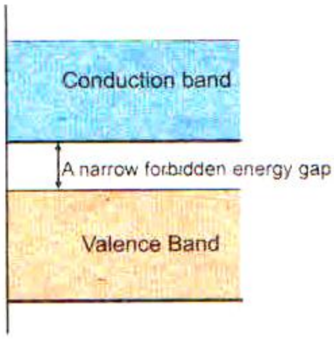
Semiconductors

In terms of energy bands, semiconductors are those materials which at room temperature have

i) A partially filled conduction band

ii) A partially filled valence band

iii) A very narrow forbidden energy gap (of the order of 1 eV) between the conduction and valence bands.



Q # 15. Describe the variation in conductivity of semi-conductors due to effect of temperature.

Ans. At 0 K, there are no electrons in the conduction band and their valence band is completely filled. It means at 0 K a piece of Ge or Si is a perfect insulator.

However, with the increase of temperature, some electrons posses sufficient energy to jump across the small energy gap from the valance band to conduction band. This transfers some free electrons in the conduction band and create some holes in the valance band. The vacancy of electron in the valence band is known as a hole. It behave like a positive charge. Thus at room temperature, Ge or Si crystals becomes a semiconductor.

Q # 16. Differentiate among intrinsic and extrinsic semi-conductor materials.

Intrinsic Semiconductor

A semiconductor in its extremely pure form is known as intrinsic semiconductors.

Extrinsic Semi-conductors

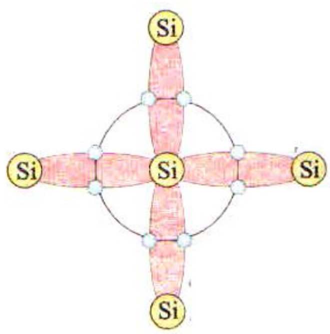
The doped semi-conducting materials are called extrinsic semi-conductors.

Q # 17. Define the term Doping.

Ans. The electrical behavior of semiconductors is extremely sensitive to the purity of the material. It is substantially changed on introducing a small impurity into pure semi-conductor. This process is called doping.

Q # 18. Write a note on Crystal Structure of Intrinsic Semi-conductors.

Ans. Pure elements of silicon and germanium are intrinsic semi-conductors. These semi-conductor elements have atoms with four valence electrons. In solid crystalline form, the atoms of these elements arrange themselves in such a pattern that each atom has



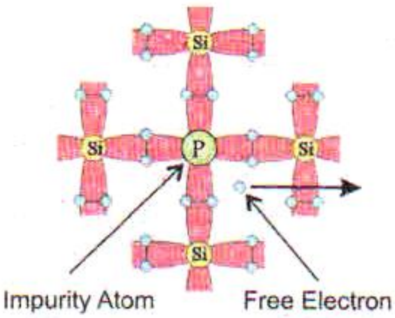
four equidistant neighbors. Each atom with its four valence electrons, shares an electrons from its neighbors. This effectively allocates eight electrons in the outermost shell of each atom, which is a stable state.

Q # 19. Describe the different types of extrinsic semi-conducting materials.

The conductivity of silicon and germanium can be drastically increased by the controlled addition of impurities to the intrinsic (pure) semiconductive material.

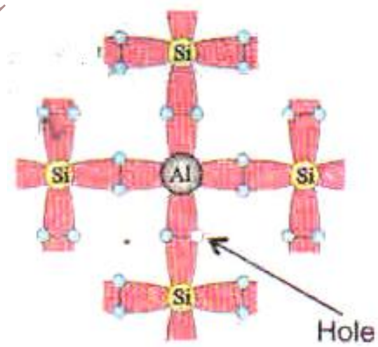
N-Type Semi-conductors

When a silicon crystal is doped with a pentavalent element, e.g., arsenic, antimony or phosphorous etc., four valance electrons of impurity atom form covalent bond with the four neighboring Si atoms, while the fifth valence electron provides a free electron in the crystal. This extra electron becomes a conduction electron because it is not attached to any atom. Such a doped extrinsic semi-conductor is N-type semi-conductor.



P-Type Semi-conductors

When a silicon crystal is doped with the trivalent element, e.g., aluminum, boron, gallium or indium etc., three valence electrons of the impurity atom form covalent bond with three neighboring Si atoms, while the one missing electron in the covalent bond with the forth neighboring Si atom, is called a hole which in fact is vacancy where an electron is accommodated. Such a semi-conductor is called P-Type Semi-conductor.



Q # 20. What is effect of battery on the motion of charge carrier in a semi-conductor crystal?

Ans. When a battery is connected to a semi-conductor, it establishes an electric field across it due to which a directed flow of electrons and holes takes place. The electrons drift towards the positive end whereas the holes drift towards the negative end of the semi conductor. The current flowing through the semi-conductor is carried by both electrons and holes. It may be noted that the electronic current and charge the hole current add up together to give the current I.

Q # 21. Define following:

i. **Superconductors**
ii. **Critical Temperature**
iii. **High Temperature Superconductors**

Superconductors

The materials whose resistivity becomes zero below a certain temperature are called superconductors.

Critical Temperature

The temperature at which the resistivity of a material falls to zero is called critical temperature.

High Temperature Superconductors

Any superconductor having a critical temperature above 77K (the boiling point of liquid nitrogen) is referred as high temperature superconductor.

Q # 22. Describe the applications of superconductors.

Superconductors can be used in

a) Magnetic Resonance Imaging (MRI)
b) Magnetic Levitation Trains
c) Powerful but small electric motors
d) Fast computer chips

Q # 23. What is the reason of magnetic behavior of solids?

The magnetism produced by electrons within an atom can arise from two motions:

i) Electron orbiting the nucleus behaves like an atom sized loop of current that generate small magnetic field.

ii) The spin motion of electron also gives rise to a magnetic field.

The net magnetic field generated by the electrons within an atom is due to combined field created by their orbital and spin motion.

Q # 24. Differentiate among the paramagnetic and diamagnetic substances.

Paramagnetic Substances

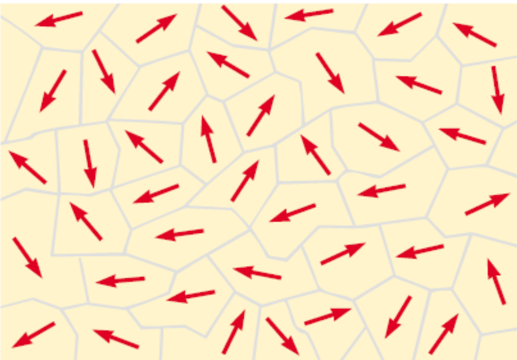
The solids in which the orbital and spin axes of the electrons in an atom are so oriented that their fields support each other are called paramagnetic substances. In these solids, each atom behaves like a tiny magnet.

Diamagnetic Substance

In diamagnetic substance, there is no resultant field as the magnetic field produced by both orbital and spin motions of the electron might add up to zero. For example, the atoms of water copper, bismuth and antimony are diamagnetic.

Q # 25. Write a note on Ferromagnetic Substances. Also describe its different types.

In ferromagnetic substances, e.g., Fe, Co, Ni, Chromium dioxide and Alnico, the atoms cooperate with each other in such a way so as to exhibit a strong magnetic effect. In ferromagnetic substance, there exist small regions called domains (contain 10^{12} to 10^{16} atoms). Within each domain, the magnetic fields of all spinning electrons are parallel to one another, i.e., each domain is magnetized to saturation. Each domain behaves as a small magnet with its own north and south poles.



Types of Ferromagnetic Substances

Soft Ferromagnetic Substances

In soft ferromagnetic substances, the domains are easily oriented on applying an external field and also readily return to random positions when the field is removed. This is desirable in an electromagnet and also in transformers. Iron is a soft magnetic material.

Hard Ferromagnetic Substances

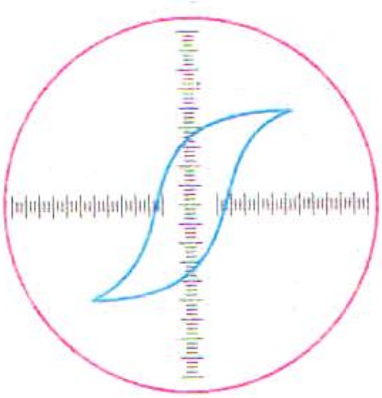
In hard ferromagnetic materials, domains are no so easily oriented to order. They required very strong external fields, but once oriented, retain the alignment. These solids are used to make permanent magnet. Steel is an example of hard ferromagnetic material.

Q # 26. What do you know about the Curie temperature in Ferromagnetic Substances?

The thermal vibrations in ferromagnetic solids tends to disturb the orderliness of domains. Ferromagnetic materials preserve the orderliness at ordinary temperatures. When heated, they begin to lose their orderliness due to increased thermal motion. This process begins to occur at a particular temperature called Curie temperature. Above the Curie temperature iron is paramagnetic but not ferromagnetic. The curie temperature of iron is about 750^0C.

Q # 27. How the Hysteresis Loop of a magnetic material is obtained?

To investigate a ferromagnetic material, a bar of that material such as iron is placed in an alternating current solenoid. When the alternating current is at the positive peak value, it fully magnetizes the specimen in one direction and when the current is at its negative peak, it fully magnetized it in opposite direction. Thus an alternating current changes from its positive peak value to its negative peak value and then back to its positive peak value, the specimen undergoes a complete cycle of magnetization, called hysteresis loop.



Q # 28. Define the following properties of Hysteresis Loop:

i. **Hysteresis**
ii. **Saturation**
iii. **Remanence or Retaintivity**
iv. **Coercivity**
v. **Area of Hysteresis Loop**

Hysteresis

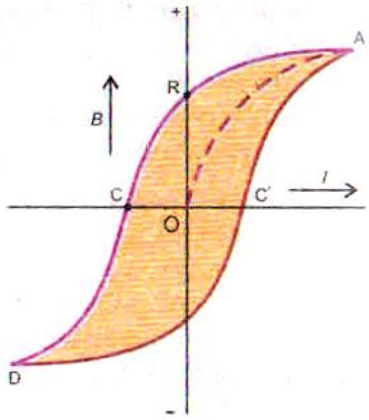
The value of flux density for any value of current is always greater when the current is decreasing, then when it is increasing, i.e., magnetism lags behind the magnetizing current. This phenomenon is known as hysteresis.

Saturation

The alignment of all domains of magnetic materials under the influence of external magnetic field is called saturation. The magnetic flux density increases from zero and reaches a maximum value. At this stage, the material is said to be magnetically saturated.

Remanence or Retaintivity

When the current is reduced to zero, the material still remain strongly magnetized represented by point R on the curve. It is due to the tendency of domains to stay partially in line, once they have been aligned.



(a) Hysteresis loop of steel

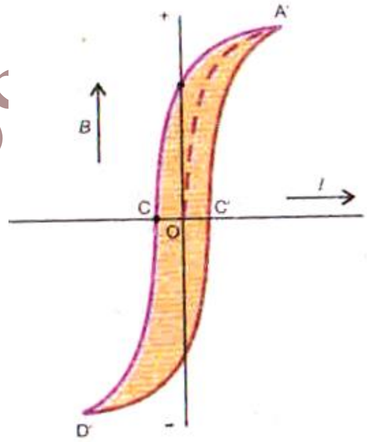
Coercivity

To demagnetize the material, the magnetizing current is reversed and increased to reduce the magnetization to zero. This is known as coercive current, represented by C on curve. The Coercivity of steel is more than that of iron, as more current is needed to demagnetize it.

Area of the loop (Measure of Hysteresis Loss)

The area of the loop is the measure of the energy needed to magnetize and demagnetize the specimen during each cycle of the magnetizing current. This is the energy required to do work against internal friction of the domains. This work is dissipated as heat. It is called hysteresis loss.

Hard magnetic material like steel cannot be easily magnetized and demagnetized, so they have large loop area as compared to soft magnetic materials such as iron which can easily be magnetized. The energy dissipated per cycle, thus, for iron is less than for steel.



(b) Hysteresis loop of soft iron

OR = Retentivity
OC = Coercivity

Q # 29. Describe the advantages of Hysteresis Loop.

Suitability of magnetic material for different purposes can be studied by taking the specimen through a complete cycle and drawing the hysteresis loop.

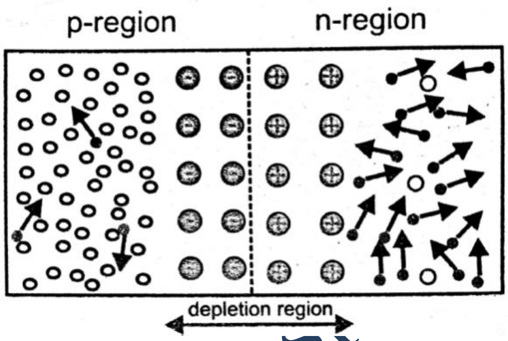
- A material with high Retaintivity and large coercive force would be most suitable to make a permanent magnet.
- The cores of electromagnets used for alternating current where the specimen repeatedly undergoes magnetization and demagnetization should have narrow hysteresis curve of small area to minimize the waste of energy.

Chapter # 18: Electronics

It is branch of Physics which deals with the controlled flow of charge carriers through semiconductors.

PN-Junction

If a piece of intrinsic silicon is doped so that a part is n-type and the other part isp-type, then the boundary between the p-type and n-type is called PN-junction.



The p region has many holes (majority carriers) from the impurity atoms and only a few thermally generated free electrons (minority carriers). The n region has many free electrons (majority carriers) from the impurity atoms and only a few thermally generated holes (minority carriers).

Formation of the Depletion Region

When a p-type semiconductor is brought close an n-type to form a PN-junction, then the free electrons near the junction in the n region begin to diffuse across the junction into the p-type region where they combine with holes near the junction.

As a result of this diffusion, a chargeless region is formed around the junction in which charge carriers are not present. This region is known as depletion region.

Barrier Potential

Due to formation of depletion region, a potential difference develops across the junction which stop further diffusion of electrons in p-type region. This potential difference is called potential barrier. Its value is 0.7V in case of silicon and for the case of germanium, its value is 0.3V.

EXERCISE SHORT QUESTION

Q # 1: How does the motion of an electron in n-type substance differ from the motion in a p-type substance?

Ans. In n-type material, the electrons are the majority carriers. They move from lower potential to higher potential. In p-type materials, the holes are the majority carriers. They move from higher potential to lower potential.

Q # 2: What is the net charge on an n-type or p-type substance?

Ans. The pentavalent or trivalent impurity atoms bombard on intrinsic semiconductor, to form it n-type or p-type material, are neutral. Therefore, an n-type or p-type substance is an electrically neutral substance.

Q # 4: Why charge carries are not present in the depletion region?

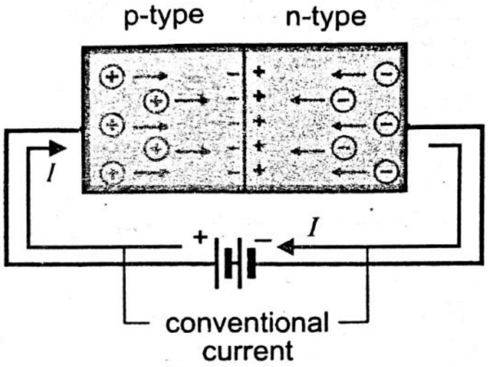
Ans. When a p-type semiconductor is brought close an n-type to form a PN-junction, and then the free electrons near the junction in the n region begin to diffuse across the junction into the p-type region where they combine with holes near the junction, and neutralize holes in p-type. As a result, a charge less region is formed across the junction in which charge carriers are not present. This region is known as depletion region.

Biasing

Application of an external voltage to the PN-junction is called biasing. There are two types of biasing:

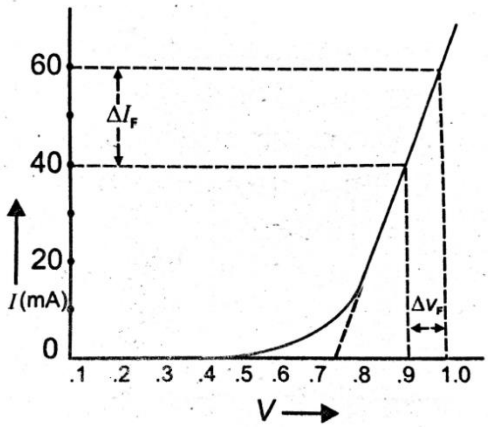
- Forward Biasing
- Reverse Biasing

Forward Biasing



A junction diode is said to be forward biased if its P-type region is connected to the positive terminal and N-type region is connected to the negative terminal of the battery.

The external potential difference supplies energy to free electrons in the n-regions and to hole in p-region. When this energy is sufficient to overcome the potential barrier, a current of the order of few milli-amperes begins to flow across the junction.



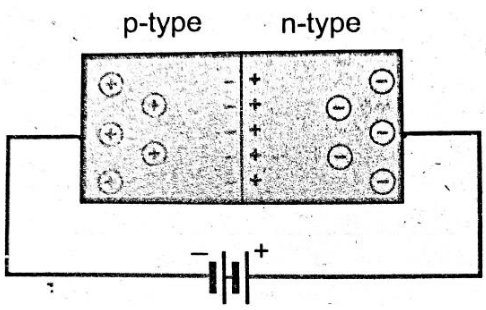
The variation of current through the junction with the bias voltage is described by the VI-diagram. If the forward biased voltage is increased by ΔV_F, the current is ΔI_F. The ratio $\Delta V_F / \Delta I_F$ is known as forward resistance r_f of p-n junction, i.e.,

$$r_f = \frac{\Delta V_F}{\Delta I_F}$$

Reverse Biasing

A junction diode is said to be reversed biased, if its P-type region in connected with the negative terminal and N-type region with positive terminal of the battery.

In reverse biasing, the negative terminal attracts the holes and the positive terminal attracts the electrons away from the junction, so that the depletion region is widened. There is no possibility of majority charge carriers to flow across the junction. However a very small current (of the order of a few micro-amperes) flow in the circuit due to minority charges carriers, which is called a reverse current.



The reverse characteristics of the p-n junction diode describes that as the reverse voltage is increase from 0, the reverse the reverse current quickly rises to its saturation value I_0. As the reverse voltage is further increased, the reverse current remains constant.

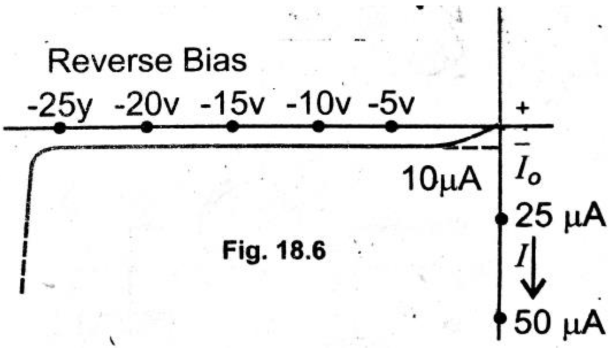


Fig. 18.6

As the reverse voltage is increased, the kinetic energy of the minority charge carriers with which they cross the depletion region also increases till it is sufficient to break a covalent bond. As the covalent bond breaks, more electron-hole pairs are created. Thus the reverse current begin to increase till a point reached when the junction breaks down and reverse current rise sharply. After breakdown the reverse current will rise to very high value which will damage the circuit.

EXERCISE SHORT QUESTION

Q # 3: The anode of a diode is 0.2 V positive with respect to its cathode. Is it forward biased?

Ans. A junction diode is said to be forward biased if its P-type region is connected to the positive terminal and N-type region is connected to the negative terminal of the battery. Since anode (p-type) is at positive potential 0.2 V with respect to its cathode (n-type), so it satisfied the condition of forward biased.

But the potential barrier of Ge and Si are 0.3 V and 0.7 V respectively, so such small value of voltage can't produce forward current.

Q # 5: What is the effect of forward and reverse biasing of diode on the width of depletion region?

Ans. When the diode is forward biased, the width of depletion region is decreased. When the diode is reversed biased, the width of depletion region is increased.

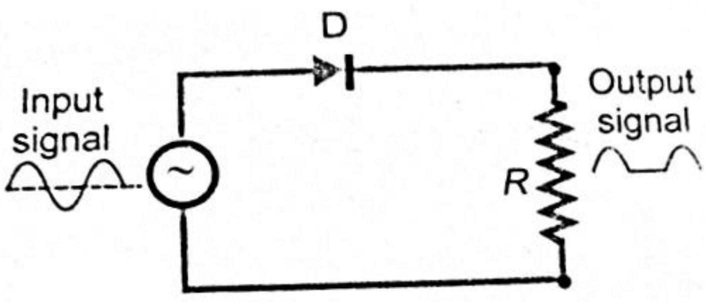
Rectification

The process of conversion of alternating current into direct current is called rectification. There are two very common types of rectification

i) Half wave rectification
ii) Full wave rectification

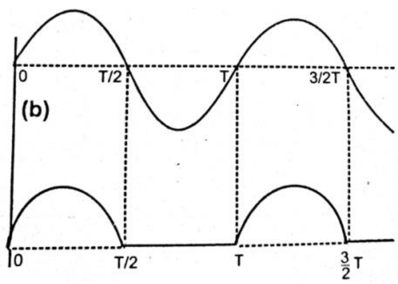
Half Wave Rectification

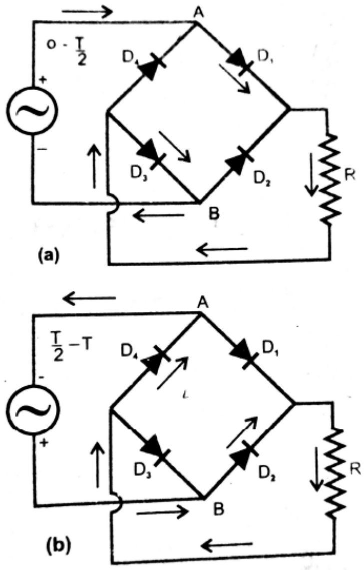
A half-wave rectifier allow current through the load only during one-half of the cycle. A diode is connected to an ac source and to a load resistor R_L forming a half-wave rectifier. When the sinusoidal input voltage (V_{in}) goes positive, the diode is forward-biased and conducts current through the load resistor. The current produces an output voltage across the load R_L which has the same shape as the positive half-cycle of the input voltage as shown in figure below:

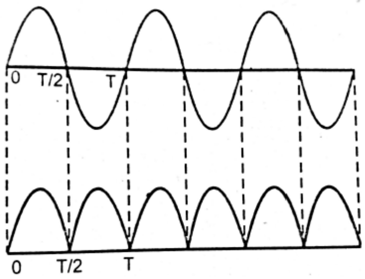


When the input voltage goes negative during the second half of its cycle, the diode is reverse-biased. There is no current, so the voltage across the load resistor is 0 V.

The net result is that only the positive ha]f-cycles of the ac input voltage appear across the load. Since the output does not change polarity, it is a pulsating dc voltage with a certain frequency as shown in the figure.







Full-Wave Rectifiers

A full-wave rectifier allows unidirectional (one-way) current through the load during the entire 360° of the input cycle.

The Bridge Full-Wave Rectifier

The bridge rectifier uses four diodes connected as shown in Figure. When the input cycle is positive as in part (a), diodes D_1 and D_2 are forward-biased and conduct current in the direction shown. A voltage is developed across R_L that looks like the positive half of the input cycle. During this time, diodes D_3 and D_4 are reverse-biased.

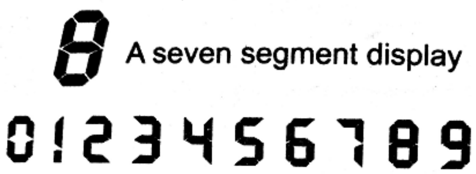
When the input cycle is negative as in Figure (b), diodes D_3 and D_4 are forward-biased and conduct current in the same direction through R_L as during the positive half-cycle. During the negative half-cycle, D_1 and D_2 are reverse-biased. A full-wave rectified output voltage appears across R_L as a result of this action.

Specially Designed p-n Junctions

There are many types of p-n junctions diodes that have been developed for special purposes. Three most commonly used such diode are:

1. Light Emitting Diode
2. Photo Diode
3. Photo Voltaic Cell

Light Emitting Diode



Light emitting diode (LED) are made from special semi-conductors such as gallium arsenide and gallium arsenide phosphide. In these diodes, the potential barrier between p and n sides is such that when an electron combines with the hole during forward biased conduction, a photon of visible light is emitted. These diodes are commonly used as small light sources e.g., indicators etc.

EXERCISE SHORT QUESTION

Q # 6: Why ordinary silicon diodes don't emit light?

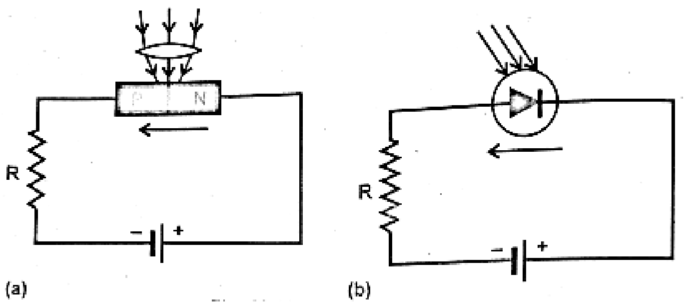
Ans. The potential barrier across the pan-junction of Si is 0.7 V. so in forward biased condition, when electron recombine with the hole, a photon of light having 0.7 eV energy is released. As the energy of emitted photon lies in infrared region of electromagnetic spectrum. That's why we don't observe light emission from Si diode.

Photo Diode

Photo diode is used for the detection of light. It is operated in reverse biased condition. When no light is incident on the junction, the reverse current I is almost negligible but when its p-n junction is exposed to light, the reverse current increases with the intensity of light.

A photo diode can turn its current ON and OFF in nano-seconds. Hence it is one of the fastest photo detection devices. Application f photo diodes includes:

- **i.** Detection-both visible and invisible
- **ii.** Automatic switching
- **iii.** Logic circuits
- **iv.** Optical communication equipment etc.



EXERCISE SHORT QUESTION

Q # 7: Why a photo diode is operated in reverse biased state?

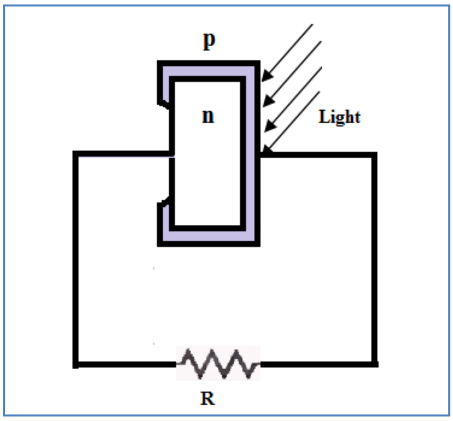
Ans. Photo diode is used for detection of light. It is operated in the reverse biased condition.

- When no light is incident on the junction, the reverse current is almost negligible.
- When a photo diode is exposed to light, the reverse current increases with intensity of light.

Thus the reverse biased condition of a photo diode is useful to detection of light.

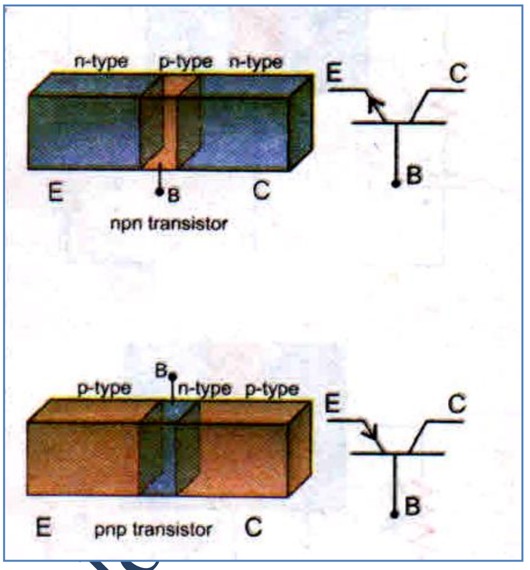
Photo-Voltaic Cell

It consists of a thick n-type region covered by a thin p-type layer. When such a p-n junction having no external bias is exposed to light, absorbed photons generate electron-hole pairs. It results into an increase percentage of minority charge carriers in both p and n-regions. When these charge carriers diffuse close to the junction, the electric field due to junction potential barrier sweeps them across the junction. It causes a current flow through the external circuit R. The current is proportional to the intensity of light.



Transistor

The transistor is constructed with three doped semiconductor regions separated by two pn junctions. The three regions of transistor are termed as emitter, base, and collector and the two p-n junctions are called base-emitter junctions and collector-base junctions.



For the normal operation of p-n junction transistor, the base-emitter junction is forward biased and collector-base junction is reversed biased.

There are two types of transistors:

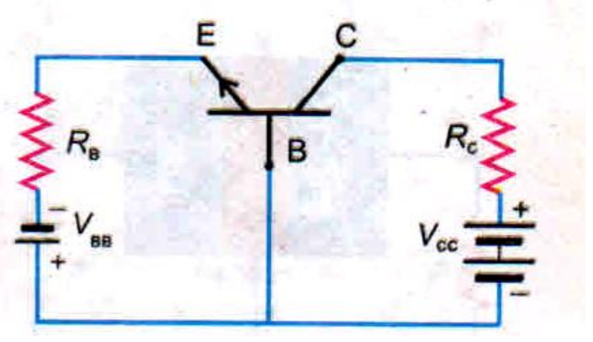
npn-Transistor: If a p-type region is sandwiched between two n type regions, then the transistor is called npn-transistor.

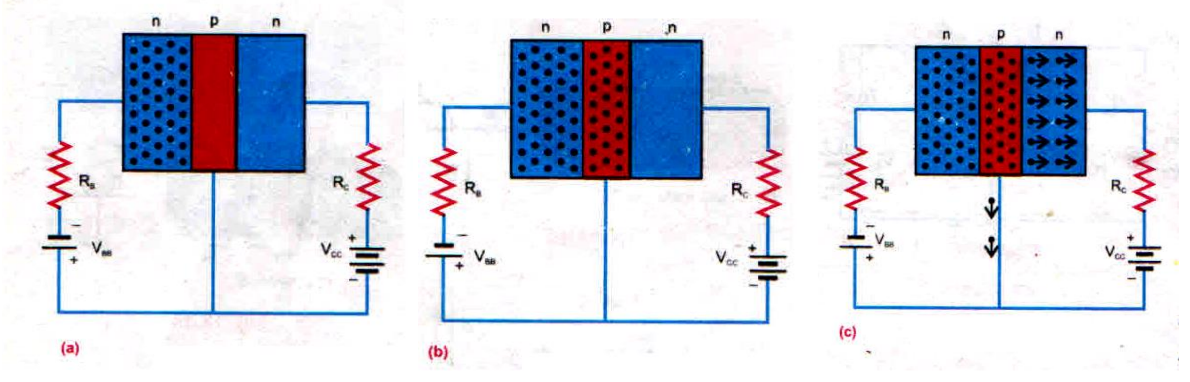
pnp-Transistor: If a n-type region is sandwiched between two p type regions, then the transistor is called npn-transistor.

Working

In normal operation of a transistor, the batteries V_{BB} and V_{CC} connected in such way that its emitter-base junction is forward biased and its collector-base junction is reversed biased.

When the biasing voltage is applied, the emitter injects a large number of electrons in the base region. These free electrons in the base can flow in either of the two directions. They can either flow out of the base to the positive terminal of V_{BB} or they can be attracted towards the collector because of battery V_{CC}. Since the base is extremely thin, very few electron manage to recombine with holes and escape out of the base. Almost all of the free electrons injected from the emitter into the base are attached into the collector by the large positive V_{CC}.





Thus, in a normally biased transistor, an electronic current I_E flows from the emitter into the base. A very small part of it I_B flows out of the base, the rest current I_C flows out of the collector i.e.,

$$I_E = I_C + I_B$$

It is found that for a given transistor, the ratio of collector current I_C to base current I_B is nearly constant i.e.,

$$\beta = \frac{I_C}{I_B}$$

EXERCISE SHORT QUESTION

Q # 8: Why is the base current in a transistor very small?

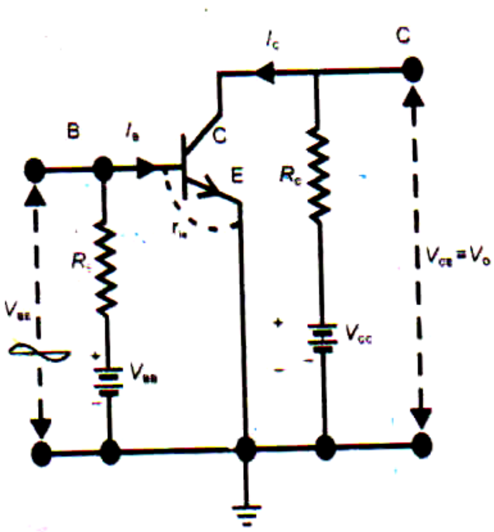
Ans. The base of a transistor is kept thin so that a very few charge carriers (electrons or holes)from emitter may combine with electrons or holes of base. This result in larger collector current, hence larger current and power gain to transistor become possible.

Transistor as an Amplifier

Amplification is the process of linearly increasing the amplitude of an electrical signal. In majority of the electronic circuits, transistors are basically used as amplifiers. An amplifier is thus the building block of every complex electronic circuit.

Consider an npn transistor in common emitter mode. The common emitter mode is widely used, since it provides much greater power gain as compare to common base or common collector mode.

The input signal is applied between the emitter-base junction and output is taken across the load R_C connected in the collector circuit. The common emitter transistor as an amplifier is shown in the figure:



DC Analysis

The battery V_{BB} forward biases the base emitter junction and V_{CC} reverse biases the collector base junction. V_{BE} and V_{CE} are the input and output voltages respectively. The base current I_B current flowing through the input circuit is given by the relation:

$$I_B = \frac{V_{BE}}{r_{ie}}$$

Where r_{ie} is the base emitter resistance of the transistor.

The transistor amplifies the base current β −times. So the current passes through the output circuit is given by the expression:

$$I_C = \beta I_B = \beta \frac{V_{BE}}{r_{ie}}$$

The output voltage $V_0 = V_{CE}$ is determined by the applying the Kirchhoff Voltage Rule on the output loop:

$$V_{CC} - I_C R_C - V_{CE} = 0$$

$$\Longrightarrow V_{CE} = V_{CC} - I_C R_C$$

$$\Longrightarrow V_0 = V_{CC} - \beta \frac{V_{BE}}{r_{ie}} R_C - - - - - - - - - \quad (1)$$

AC Analysis

When small signal voltage ΔV_{in} is applied at the input, the input voltage changes from $V_{BE}$to $V_{BE} + \Delta V_{in}$. This causes a little changes in base from I_B to $I_B + \Delta I_B$ due to which the collector current changes from $I_C$to $I_C + \Delta I_C$. As the collector current changes, the voltage drop across R_C i.e., $I_C R_C$ also changes due to which the output voltage V_0 changes by ΔV_0. Substituting the changed values in equation (1), we get:

$$V_0 + \Delta V_0 = V_{CC} - \beta \left(\frac{V_{BE} + \Delta V_{in}}{r_{ie}} \right) R_C - - - - - - - \quad (2)$$

Subtracting equation (1) and (2), we get:

$$\Delta V_0 = -\beta \left(\frac{\Delta V_{in}}{r_{ie}} \right) R_C$$

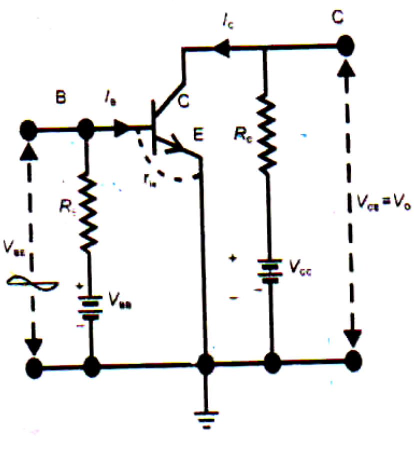
$$\Longrightarrow \frac{\Delta V_0}{\Delta V_{in}} = -\frac{\beta R_C}{r_{ie}} \qquad \textit{where } \frac{\Delta V_0}{\Delta V_{in}} = A_v \textit{ is the voltage gain.}$$

$$\Longrightarrow A_v = -\frac{\beta R_C}{r_{ie}}$$

The factor $\frac{\beta R_C}{r_{ie}}$ is of the order of hundred, so the input signal is amplified. The negative sign shows that there is a phase shift of 180^0 between the input and output signals.

EXERCISE SHORT QUESTION

Q # 9: What are the biasing requirements of the junction of a transistor for its normal operation? Explain how these requirements are met in a common emitter amplifier?



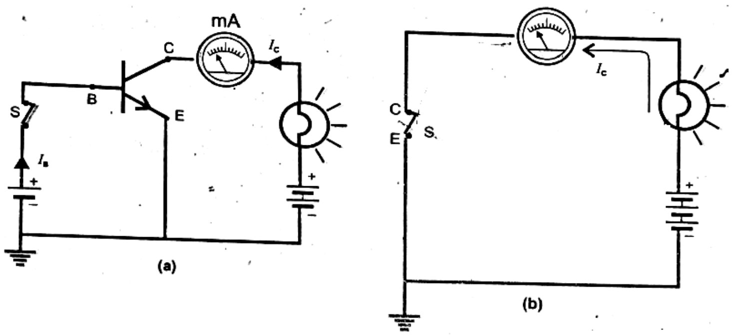
Ans. For the normal operation of transistor, the EB (emitter-base) junction of transistor is forward biased and CB (collector-base) junction of transistor is reversed.

In npn-transistor in common emitter configuration, the EB-junction is forward biased by V_{BB}battery and CB-junction is reversed biased by V_{CC} battery, as shown in the figure.

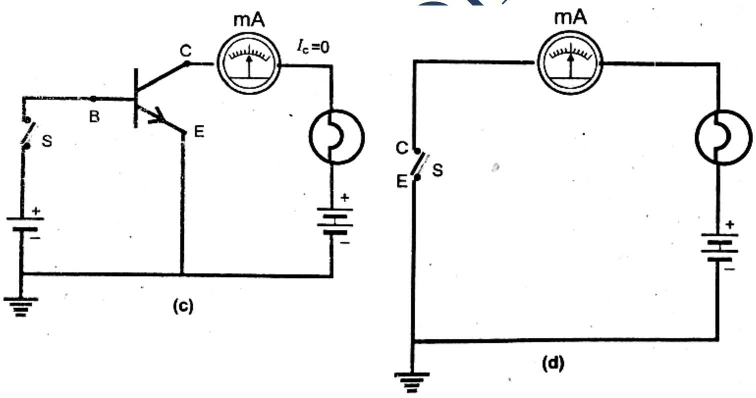
Transistor as a Switch

The circuit in which a transistor is used as a switch is shown in the figure. The base B and emitter E act as input terminals, which are also called the control terminals. The collectors C and emitter E behave as the output terminals of the switch.

In order to turn on the switch, a potential V_B is applied between control terminals. This injects a large current I_B into the base circuit due to which a very heavy current I_C begins to flow in the CE circuit which will turn the bulb ON.



To turn the switch OFF, the base current I_B is set zero by opening the base circuit. As $I_C = \beta I_B$, so I_C becomes zero and CE circuit becomes open.

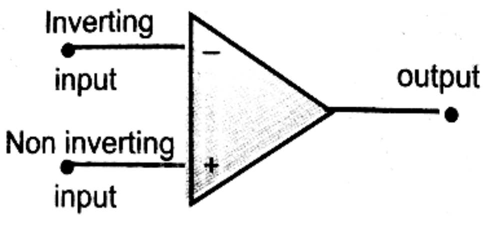


An electronic computer is basically a vast arrangement electronic switches which are made from transistors.

Operational Amplifiers

The enclosed circuit of the amplifier that is integrated on a small silicon chip is called operational amplifier (OP-AMP). Operational amplifier is used by making requisite connections (such as input, output and power supply) with pins projected outside the capsule. used by making requisite connections with these pins. OP-AMP sometimes used to perform mathematical operations electronically.

The op-amp is usually represented by its symbol shown in Fig. It has two input terminals. One is known as inverting input (-) and the other non-inventing input (+).



- A signal that is applied at the inverting (-) input, appears after amplification, at the output terminal with a phase shift of 180°.
- If the signal is applied at non-inverting input (+).it is amplified at the output without any change of phase.

Characteristics of Op-Amp

Input Resistance

It is the resistance between the (+) and (-) inputs of the amplifier. Its value is very high --of the order of several mega ohms. Due to high value of the input resistance R_{in}, practically no current flows between the two input terminals.

Output Resistance

It is the resistance between the output terminal and ground. Its value is only a few ohms.

Open Loop Gain

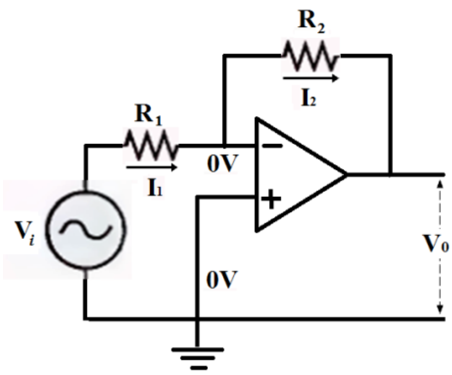
It is the ratio of output voltage V_o, to the voltage difference between non-inverting and inverting inputs when there is no external connection between the output and the inputs i.e.,

$$A_{OL} = \frac{V_o}{V_+ - V_-} = \frac{V_o}{V_i}$$

The open loop gain of the amplifier is very high. It is of the order of 10^5.

OP-AMP as Inverting Amplifier

For the use of OP-AMP as inverting amplifier, the input signal V_{in}, is applied at inverting terminal (-) through a resistance R_1. V_0 is its output. The non-inverting terminal (+) is grounded, i.e., $V_+ = 0$. We know that open loop gain A_{OL} is very high:



$$V_+ - V_- \approx 0$$

$$\Rightarrow V_- \approx V_+$$

$$\Rightarrow V_- \approx 0$$

Now

$$\text{Current through} R_1 = I_1 = \frac{V_{in} - V_-}{R_1} = \frac{V_{in} - 0}{R_1} = \frac{V_{in}}{R_1}$$

$$\text{Current through } R_2 = I_2 = \frac{V_- - V_o}{R_2} = \frac{0 - V_o}{R_2} = \frac{-V_o}{R_2}$$

As practically no current flows between (-) and (+) terminals, so according to Kirchhoff's current rule:

$$I_1 = I_2$$

$$\Rightarrow \frac{V_{in}}{R_1} = \frac{-V_o}{R_2}$$

$$\Rightarrow \frac{V_o}{V_{in}} = \frac{-R_2}{R_1}$$

As $\frac{V_o}{V_{in}}$ is defined as gain G of the inverting amplifier, so

$$G = -\frac{R_2}{R_1}$$

The negative sign indicates that the output signal is 180° out of phase with respect to input signal.

Important Note: It is interesting to note that the closed loop gain depends upon the two externally connected resistances R_1 and R_2. The gain is independent of what is happening inside the amplifier.

Op-Amp as Non-Inverting Amplifier

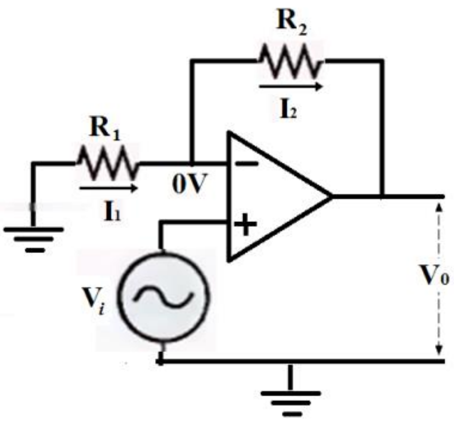
To use OP-AMP as non-inverting amplifier, the input signal V_{in} is applied at the non-inverting terminal (+). Due to high open loop gain of amplifier:

$$\boldsymbol{V_+ \approx V_- \approx V_{in}}$$

Also, from figure:

$$\text{Current through} R_1 = I_1 = \frac{0 - V_-}{R_1} = \frac{0 - V_{in}}{R_1} = \frac{-V_{in}}{R_1}$$

$$\text{Current through } R_2 = I_2 = \frac{V_- - V_o}{R_2} = \frac{V_{in} - V_o}{R_2}$$



As practically no current flows between (-) and (+) terminals, so according to Kirchhoff's current rule:

$$I_1 = I_2$$

$$\Rightarrow \frac{-V_{in}}{R_1} = \frac{V_{in} - V_o}{R_2}$$

$$\Rightarrow \frac{-V_{in}}{R_1} = \frac{V_{in}}{R_2} - \frac{V_o}{R_2}$$

$$\Rightarrow \frac{V_o}{R_2} = V_{in}\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

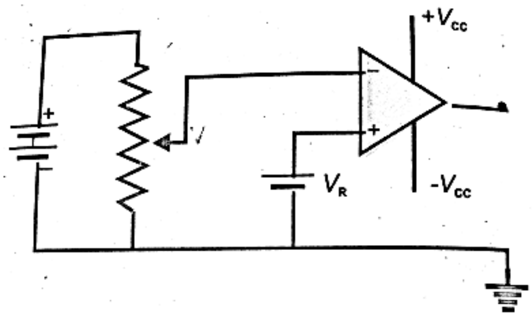
$$\Rightarrow \frac{V_o}{V_{in}} = R_2\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

As $\frac{V_o}{V_{in}}$ is defined as gain G of the inverting amplifier, so

$$G = 1 + \frac{R_2}{R_1}$$

Again the gain of the amplifier is independent of the internal structure of the op-amp. The positive sign of gain indicates that the input and output signals are in phase.

Op-Amp as a Comparator

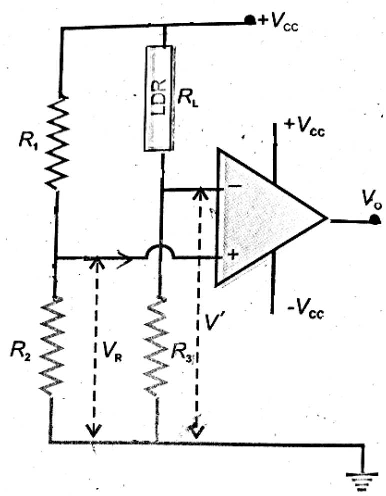


As the open loop gain of the op-amp is very high (10^5), even a very small potential difference between the inverting and non-inverting inputs is amplified to such a large extent that amplifier gets saturated. This feature of op-amp is used to compare two voltages. Fig. shows the circuit of an op-amp used comparator. V_R is reference voltage which is connected with (+) terminal and V is the voltage which is to be compared with the reference V_R. It is connected with (-) terminal.

When $V_- > V_+ \quad or \quad V > V_R, \quad then\ V_o = -V_{CC}$

and if $V_- < V_+ \quad or \quad V < V_R, \quad then\ V_o = +V_{CC}$

Comparator as a Night Switch



Suppose it is required that when intensity of light falls below a certain level, the street light is automatically switched on. This can be accomplished by using op-amp as a comparator. The output of the op-amp is connected with a relay system which energizes only when $V_0 = +V_{CC}$ and then it turns on the street lights.

In figure, resistances R_1 and R_2 form a potential divider. The potential drop across R_2 provides the reference voltage V_R to the (+) input of the op-amp. Thus:

$$V_R = \frac{R_2}{R_1 + R_2} \times V_{CC} \quad ------ \quad (1)$$

LDR is a light dependent resistance. The value of its resistance R_L depends upon the intensity of light falling upon it. R_L and R_3 form another potential divider. The potential drop across R_3 is V' which is given by:

$$V' = \frac{R_3}{R_L + R_3} \times V_{CC} \quad ------ \quad (2)$$

V' provides the voltage to (-) input of the op-amp. V' will not be a constant voltage but it will vary with the intensity of light.

- During day time, when light is falling upon LDR, R_L is small. According to Eq. (2), V' will be large such that $V' > V_R$ so that $V_0 = -V_{CC}$. Thus when $V_0 = -V_{CC}$, the light will not be switched ON.
- As it gets darker, R_L becomes larger and V' decreases. When V' becomes just less than V_R, the output of op-amp switches to $+V_{CC}$ which energizes the relay system and the street lights are turned ON.

Digital Systems

A system which deals with quantities and variables having two discrete values or states are called is called digital system. In these circuits, the input and output can have any one of the two values "1" or "0". Following are the examples of such quantities:

- A switch can either open or closed.
- The answer of a question can be either yes or no.
- A certain statement can be either true or false.
- A bulb can be either on or off.

In all these situations, one of the states is represented by "1" and the other state by "0".

- 1 represents:
  - **i.** ON circuit
  - **ii.** High voltage
  - **iii.** True statement
- 0 represents:
  - **i.** OFF circuit
  - **ii.** Low voltage
  - **iii.** False statement

Logic gates solve problems by using a special algebra, known as "Boolean Algebra". Boolean algebra is based upon three basic operations namely:

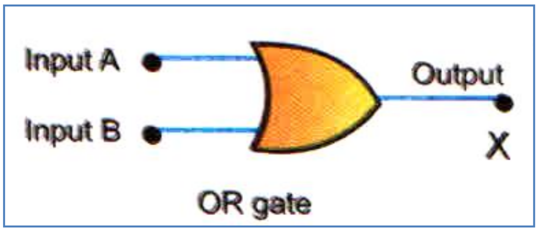
i. AND operation
ii. OR operation
iii. NOT operation

Logic Gates

The electronic circuits which implement the various logic operations are known as logic gates. There are three basic types of logic gates: (i) AND Gate, (ii) OR Gate, (iii) NOT Gate

OR Gate

OR gate implements the logic of OR operation. It has two or more inputs and a single output. The symbolic representation of an OR gate is shown in the figure.



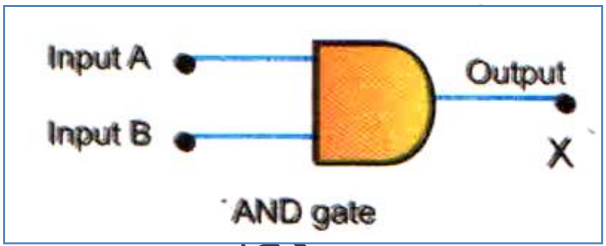
The output of the OR gate has a value "0" when both of its inputs A and B is at 0. For all other operations of inputs [(1,0), (0,1), (1,1)], the output is "1". It is also called "Any or All Gate". Thus it implements the truth table of OR operation. The mathematical notation of OR operation is:

$$C = A + B$$

Truth Table of OR Operation		
A	**B**	**Output**
0	0	0
0	1	1
1	0	1
1	1	1

AND Gate

AND gate implements the logic of AND operation. It has two or more inputs and a single output. The symbolic representation of an AND gate is shown in the figure.



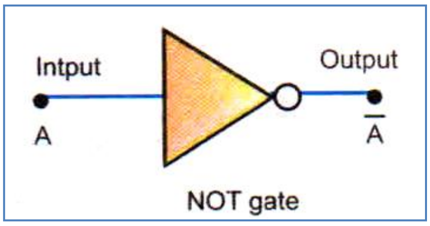
The output of the AND gate has a value "1" when all inputs are "1" and "0" for all other combinations of inputs. This gate is also called "All or Nothing Gate". Thus it implements the truth table of AND operation. The mathematical notation of OR operation is:

$$C = A.B$$

Truth Table of AND Operation		
A	**B**	**Output**
0	0	0
0	1	0
1	0	0
1	1	1

NOT Gate

It performs the operation of inversion or complementation. That is why it is also known as inverter. It changes a logic level to its opposite level, i.e., it changes 1 to 0 and 0 to 1. The symbolic representation of NOT gate is shown in the figure. The Boolean equation corresponding to NOT operation is described as:

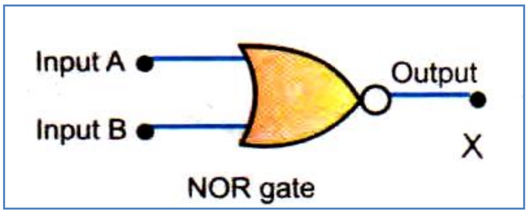


$$B = \bar{A}$$

Truth Table of NOT Operation	
Input	**Output**
0	1
1	0

NOR Gate

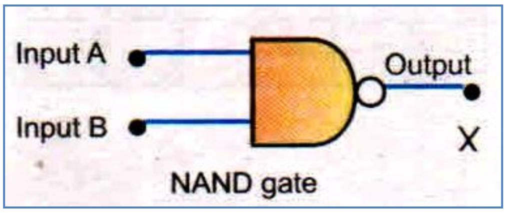
If a NOT Gate is connected at the output of an OR gate, then the combination acts as NOR Gate i.e., in NOR gate the output of the OR Gate is inverted. The symbolic representation of a NOR gate is shown in the figure. The output of the NOR gate is "1" when both inputs A and B are "0". And the output is "0" for all other combinations of inputs. Its Boolean equation is:



$$C = \overline{A + B}$$

Truth Table of NOR Operation			
Input		A + B	**Output**
A	**B**		$\overline{A + B}$
0	0	0	1
0	1	1	0
1	0	1	0
1	1	1	0

NAND Gate

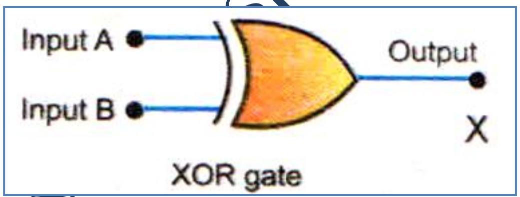


If a NOT Gate is connected at the output of an AND gate, then the combination acts as NAND Gate i.e., in NAND gate the output of the AND Gate is inverted. The symbolic representation of a NAND gate is shown in the figure. The output of the NAND gate is "0" when both inputs A and B are "1". And the output is "1" for all other combinations of inputs. Its Boolean equation is:

$$C = \overline{A\,.\,B}$$

Truth Table of NAND Operation			
Input		A. B	Output
A	B		$\overline{A.B}$
0	0	0	1
0	1	0	1
1	0	0	1
1	1	1	0

Exclusive OR Gate (XOR Gate)



This gate has two inputs A, B and one output C. the output of XOR gate is "0" when both inputs are same i.e., $(A, B) = \{(0,0), (1,1)\}$and the output is "1" when the inputs are different. The symolic representation of XOR gate is shown in the figure.

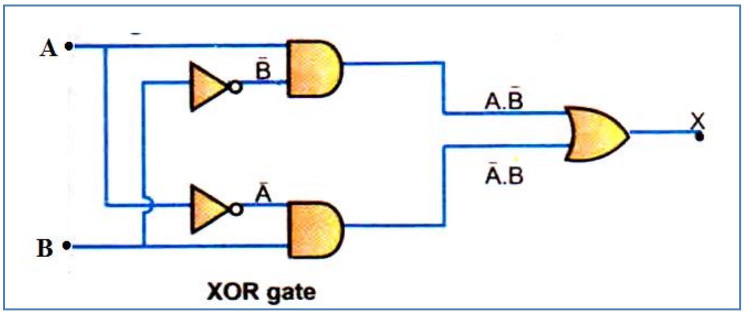
Its Boolean equation is:

$$C = A \oplus B = A.\overline{B} + \overline{A}.B$$

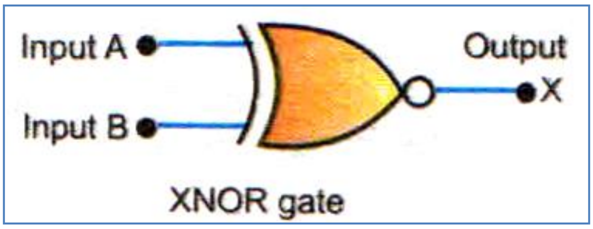
Truth Table of XOR Operation		
A	B	Output
0	0	0
0	1	1
1	0	1
1	1	0

The circuit which acts as XOR gate consist of combinations of gates as shown in the figure:

In XOR gate, A and $\overline{B}$ (Complement of B) are applied to the inputs 1st AND gate and 2nd AND gate is gets the inputs $\bar{A}$ (Complement of A) and B as shown in the figure. The outputs from two AND gates are fed to OR gates. This circuit verifies the truth table of XOR operation.



Exclusive NOR Gate (XNOR Gate)

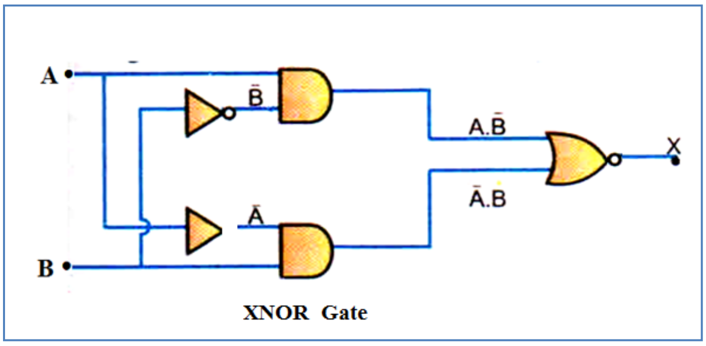


If an inverter is connected in the output of and XOR gate, then the combination is called XNOR gate. It has two inputs A, B and one output C. The output of XNOR gate is "1" when both inputs are same i.e.,

$(A, B) = \{(0,0), (1,1)\}$and the output is "0" when the inputs are different. The symolic representation of XNOR gate is shown in the figure.Its Boolean equation is:

$$C = \overline{A \oplus B} = \overline{A.\overline{B} + \overline{A}.B}$$

The circuit which acts as XNOR gate consist of combinations of gates as shown in the figure:

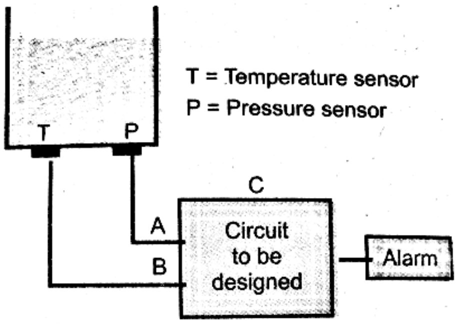


Truth Table of XNOR Operation			
A	**B**	$A \oplus B$	**Output**
0	0	0	1
0	1	1	0
1	0	1	0
1	1	0	1

In XNOR gate, A and $\bar{B}$ (Complement of B) are applied to the inputs 1st AND gateand 2nd AND gate is gets the inputs $\bar{A}$(Complement of A) and B as shown in the figure. The outputs from two AND gates are fed to NOR gates. This circuit verifies the truth table of XNOR operation.

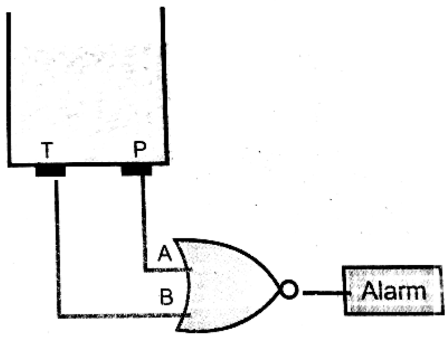
Application of Gates in Control Systems

Gates are widely used in control systems. They control the function of the system by monitoring some physical parameter such as temperature, pressure or some other physical quantity of the system.



A circuit is to be designed which will ring an alarm when either the temperature or pressure or both cross the maximum specified limit. The alarm requires a LOW (0) voltage for its activation.

The block diagram of the problem is shown in Fig. in which C is the circuit to be designed. Its inputs A and B are fed by the temperature and pressure sensors T and P fitted into the vet. Whenever output of the circuit C is LOW, the alarm is activated. So the circuit C should be such that its output is 0 as soon as the limit for temperature or pressure is exceeded, i.e., when A=0, B = 1 or when A= 1, B = 0 or when A= B = 1. The output of C should be HIGH when temperature and pressure are within the specified limit, i.e., when A = B = 0. This gives the truth table of NOR gate. So the circuit C in Fig. should be a NOR gate.



EXERCISE SHORT QUESTIONS

Q # 1. What are the measurements on which two observers in relative motion will always agree upon?

Ans. The measurement on which two observers in relative motion will always agree upon is speed of light.

Q # 2. Does the dilation means that time really passes more slowing in moving system or that it only seems to pass more slowly?

Ans. According to the time dilation formula $= \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$, time is not constant. It is relative.

- Time passes normally for any observer within his own system.
- Time seems to pass more slowly when an observer in one system in relativistic motion takes the time measurement of the other system.

Q # 3. If you are moving in a space ship at very high speed relative to the earth, would you notice a difference (a) in your pulse rate (b) in pulse rate of people on earth?

Ans. The pulse rate of a person who is travelling in a spaceship is not changed with respect to clock inside the spaceship.

But the person in spaceship will experience the change in pulse rate of the people on earth, according to the relation $t = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$.

Q # 4. If the speed of light were infinite, what would the equations of special theory of relativity reduce to?

Ans. If we take speed of light c as infinity, then the equations of special theory of relativity reduce to:

- **Time dilation formula:** $t = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{t_0}{\sqrt{1-\frac{v^2}{\infty^2}}} = \frac{t_0}{\sqrt{1-0}} = t_0$, i.e., Time in motion=Proper Time
- **Length contraction formula:** $L = L_0\sqrt{1-\frac{v^2}{c^2}} = L_0\sqrt{1-\frac{v^2}{\infty^2}} = L_0\sqrt{1-0} = L_0$, i.e., Length in motion = Proper Length
- **Mass increment formula:** $m = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{m_0}{\sqrt{1-\frac{v^2}{\infty^2}}} = \frac{m_0}{\sqrt{1-0}} = m_0$, i.e., Mass in motion=Rest Mass
- $E = mc^2 = m\infty^2 = \infty$

Q # 5. Since mass is form of energy, can we conclude that a compressed spring has more mass than the same spring when it is not compressed?

Ans. Mass is form of energy. According to the theory of relativity, there would be increase in mass of compressed spring. However, this increase in mass is slightly greater than original mass (negligibly small) according to the relation:

$$\Delta m = \frac{\Delta E}{c^2}$$

Q # 6. As a solid is heated and begins to glow, why does it first appear red.

Ans. At lower temperature, a body emits radiation of low energy (longer wavelength). Since longest visible wavelength is red, so it appears red first.

Q # 7. What happens to total radiation from a black body if its absolute temperature is doubled?

Ans. According to Stephen Boltzmann law: $E = \sigma T^4$

- When absolute temperature is doubled, then: $E' = \sigma (2T)^4 = 16\sigma T^4 = 16E$

Thus if absolute temperature is doubled, the total radiation emitted by black body increases 16 times.

Q # 8. Which photon, red, green or blue carry the most (a) energy and (b) momentum?

Energy: According to relation: $E = hf = \frac{hc}{\lambda}$, the photons of blue light having shorter wavelength must have larger energy as compared to photons of red or green color light.

Momentum: According to relation: $p = \frac{h}{\lambda}$, the photons of blue light having shorter wavelength must have larger momentum as compared to photons of red or green color light.

Q # 9. Which have the low energy quanta? Radio waves or X-rays.

Ans. According to relation: $E = hf = \frac{hc}{\lambda}$, the quanta of X-rays having shorter wavelength must have larger energy as compared to quanta of radio waves.

Q # 10. A beam of red light and a beam of blue light have exactly the same energy. Which beam contains the greater number of photons?

Ans. As $(Energy\ of\ a\ photon\ of\ blue\ light) > (Energy\ of\ a\ photon\ of\ red\ light)$

Therefore, two color beams having same energy will contain different number of photons.

- The blue light, having photon of comparatively larger energy contains less number of photons
- The red light, having photon of comparatively smaller energy contains greater number of photons

Q # 11. Does the brightness of a beam of light primarily depend on the frequency of photons or the number of photons?

Ans. The brightness of a beam depends upon intensity (number of photons) and not on the frequency of light. Thus brightness increases with intensity of light.

Q # 12. When ultrayoilot light falls on certain dyes, visible light is emitted. Why does this not happens when infrared light falls on these dyes?

Ans. UV light consists of photons having energy greater than energy of visible light photons. When UV light falls on dyes, atoms initially become excited and then de-excited by emitting lower energy photons, which may be detectable by normal human eyes.

Infrared light consists of photons having energy lower than energy of visible light photons. When Infrared light falls on dyes, atoms initially become excited and then de-excited by emitting lower energy photons which couldn't lie in visible spectrum of electromagnetic radiation.

Q # 13. Will bright light eject more electrons from metal surface than dimmer light of same color?

Ans. Since "number of electrons" ejected from metal surface depend upon the intensity of light (number of photons). Therefore, bright light being more intense will eject more electrons from a metal surface than dimmer light of same color.

Q # 14. Will higher frequency light eject greater number of electrons than lower frequency light?

Ans. No, the higher frequency light will not eject greater number of electrons than low frequency light. It is because of the reason that number of electrons emitted from metal surface depends upon intensity of light (number of photons) and not frequency of light.

Q # 15. When light shines on a surface, is momentum transferred to the metal surface?

Ans. When light falls on the surface, about 20% of incident light energy is absorbed in each reflection. So both energy and momentum is transferred to the metal surface.

Q # 16. Why can red light be used in photographic dark room when developing films but a blue or white light cannot?

Ans. Since the frequency of red light is less as compared to blue light, so red light has less energy as compared to blue light. Therefore, photographic films an the material concerned are less affected in the presence of red light.

Q # 17. Photon A has twice the energy of photon B. what is the ratio of the momentum to A to that of B.

Ans. Given that the energy of photon A is twice the energy of photon B i.e.,

$$E_A = 2E_B$$

The momentum of photon A = $P_A = \frac{E_A}{c}$

The momentum of photon B = $P_B = \frac{E_B}{c}$

Now, $\frac{P_A}{P_B} = \frac{\left(\frac{E_A}{c}\right)}{\left(\frac{E_B}{c}\right)} = \frac{E_A}{E_B} = \frac{2E_B}{E_B} = 2$

So, photon A has twice the momentum of photon B.

Q # 18. Why don't we observe Compton effect with visible light?

Ans. We don't observe a Compton effect with visible light because photons of visible light have smaller energy and momentum then the photons of X-rays.

Q # 19. Can pair production takes place in vaccum? Explain.

Ans. No, pair production can't take place in vacuum. Because, in vacuum, there is no heavy nucleus present. Pair production always takes place in the presence of a heavy nucleus.

Q # 20. Is it possible to create a single electron from energy? Explain.

Ans. No it is not possible to create a single electron from energy. The creation of single electron from energy is violation of law of conservation of charge. Whenever pair production takes place, the electrons and positrons are created at the same time.

Q # 21. If electrons behaved only light particles, what pattern would you expect on the sucreen after the electron passing through double slit?

Ans. If electron behave only like particles then, after passing through the double slit, only those parts of the screen are affected which are in front of the slits.

Q # 22. If an electron and proton have the same de Broglie wavelength, which particle have greater speed?

Ans. The de Broglie wavelength associated with moving particle is given by expression:

$$\lambda = \frac{h}{mv} \Longrightarrow v = \frac{h}{m\lambda}$$

As the wavelength is same for both electron and proton beam, therefore:

$$v \propto \frac{1}{m}$$

As mass of electron is smaller then proton, so electron has greater speed.

Q # 23. We don't notice the de Broglie wavelength for a pitched cricket. Explain. Why?

Ans. The de Broglie wavelength associated with moving particle is given by expression:

$$\lambda = \frac{h}{mv}$$

Due to large mass and small speed, the wavelength associated with moving cricket ball is very small. As the diffraction produced by the ball is also very small. So it is impossible to measure de Broglie wavelength for a pitched cricket ball.

Q # 24. If the following particles all have the same energy, which has the shortest wavelengths? Electrons, α −particle, neutron, proton.

Ans. The de Broglie wavelength associated with moving particle is given by expression:

$$\lambda = \frac{h}{mv}$$

$$\lambda = \frac{h}{m\sqrt{\frac{2E}{m}}} = \frac{h}{\sqrt{2mE}}$$

For same energy of beam of particles, wehave:

$$\lambda \propto \frac{1}{\sqrt{m}}$$

Thus the massive particle has shorter wavelength. As mass of alpha particle is greater, so it has the shorter wavelength.

Q # 25. When does light behave as a wave? When does it behave as a particle?

Ans. Light behaves as wave in the phenomenon of:

- Interference
- Diffraction
- Polarization

Light behaves as particle in

- Photo electric effect
- Compton effect
- Pair production

Q # 26. What advantage an electron microscope has over an optical microscope?

Ans. The resolving power of electron microscope is thousand times greater then an Optical microscope.

The internal structure of an object can also be obtained by electron microscope which is not possible with optical microscope.

Q # 27. If measurement shows a precise position for an electron, can those measurements show precise momentum also? Explain.

Ans. According to Heisenberg's uncertainty principle, it is impossible that measure both position and momentum precisely at the same time. Mathematically:

$$\Delta x \, \Delta p = h$$

Thus if one measurement is precise, then the other is uncertain.

EXERCISE SHORT QUESTIONS

Q # 1. Bohr's theory of hydrogen atom is based upon several assumptions. Do any of these assumptions contradict classical physics?

Ans. Bohr's first postulate disagrees with the classical physics. According to this postulate:

An electron in an orbit revolving around the nucleus doesn't radiate energy by radiation. But according to the classical physics, an accelerated electron radiates energy due to its circular motion around nucleus.

Q # 2. What is meant by line spectrum? Explain, how line spectrum can be used for identification of elements?

Ans. A spectrum which consists of isolated sharp parallel lines, in which each line corresponds to a definite frequency and wavelength, is called line spectra.

Each element gives its own characteristic lines of definite wavelengths. Thus an element can be easily identified by observing its spectrum.

Q # 3. Can the electron in the ground state hydrogen absorb a photon of energy 13.6 eV and greater than 13.6 eV.

Ans. Yes it can absorb a photon of energy 13.6 eV and greater than 13.6 eV.

Since the ionization energy of the electron in the ground state of hydrogen atom is 13.6 eV. So by absorbing a photon having energy greater than 13.6 eV, ionization of H-atom will take place and the surplus energy of photon is taken away by electron as kinetic energy.

Q # 4. How can the hydrogen emission spectrum contain so many lines although it contains one electron only?

Ans. When H-atom de-excites, the electron will come from higher energy level to ground level by several jumps. As the result, photons of different wavelengths are emitted. That's why the spectrum of hydrogen contains so many lines.

Q # 5. Is energy conserved when an atom emit a photon of light?

Ans. The energy emitted during de-excitation is exactly equal to the energy absorbed by the atom during excitations. So the energy is conserved in this process, i.e., total energy remains the same.

Q # 6. Explain why a glowing gas gives only certain wavelength of light and why that is capable of absorbing the same wavelength? Give a reason why it is transparent to other wavelengths?

Ans. Atoms have fixed energy levels. When electron jumps from higher to lower energy level during de-excitation, photons of particular wavelengths are emitted.

On the other hand, when white light is passed through gas, it absorbs only those photons which have the energy equal to the difference of energy levels in atoms of the gas. All other photons pass through the gas un-absorbed. In other words, gas is transparent for those photons.

Q # 7. Why do you mean when we say that the atom is excited?

Ans. If the certain amount of energy is supplied to the electrons of an atom by an external source, it will be raised up to one of the higher allowed states by absorption of energy. Then the atom is said to be in excited state.

Q # 8. Can X-rays be reflected, refracted, diffracted and polarized just like any other waves? Explain.

Ans. Yes, X-rays can be reflected, refracted, diffracted and polarized as they are also electromagnetic waves of higher frequency and smaller wavelength. Therefore, the X-rays posses the entire properties specific to light waves.

Q # 9. What are the advantages of laser over ordinary light?

Ans. The laser light over ordinary light has following advantages:

- Laser light is monochromatic, while ordinary light has number of wavelengths.
- Laser light is coherent, while ordinary light has no phase coherence.
- Laser light moves in the same direction, while ordinary light spreads in all direction.
- Laser light is much more intense than ordinary light.

Q # 10. Explain why laser action could not occur without pollution inversion between atomic levels.

Ans. In population inversion, more than 50% vacancies in the meta-stable states become filled. Then all the electrons in the meta-stable state simultaneously jump to the ground level, thereby producing a pulse of coherent photons. Without population inversion, laser action could not occur.

EXERCISE SHORT QUESTIONS

Q # 1: What are isotopes? What do they have in common and what are their differences?

Ans. Isotopes are those nuclei, which have same atomic number but have different mass number. The isotopes have the same number of protons and have different number of neutrons.

Q # 2: Why are heavy nuclei unstable?

Ans. The heavy nuclei have very small value of their binding energy per nucleon. So they are unstable, and less energy is required to split it.

Q # 3: If a nucleus has a half life of 1 year, does this mean that it will be completely decayed after 2 years? Explain.

Ans. No. As decay rate decreases with the decrease of number of radioactive atoms, so total life is much greater than twice of half life. Total decay is possible after infinite years.

Q # 4: What fraction of a radioactive sample decays after two half lives have elapsed?

Ans. The total un-decayed atoms of an radioactive element N is described by the formula:

$$N = N_0 \left(\frac{1}{2}\right)^n$$

where N_0 is the total number of atoms of radioactive element and n is total number of half lives. So,

- Number of un-decayed atoms after two half lives $= N_0 \left(\frac{1}{2}\right)^2 = \frac{N_0}{4} = 25\ \%$
- Number of decayed atoms after two half lives $= 75\ \%$

Q # 5: The radioactive element $^{226}_{88}Ra$ has a half-life of 1.6×10^3 years. Since the earth is about 5 billion years old, how can you explain why we still can find this element in nature?

Ans. The half life of $^{226}_{88}Ra$ is 1.6×10^3 years but its total life is equal to infinity. This is common property of all radioactive elements. That's why $^{226}_{88}Ra$ still found on earth while earth's life is 5 billion years.

Q # 6: Describe a brief account of interaction of various types of radiations with matter.

Ans. Electromagnetic radiation interact with matter in three different ways mainly depending upon their energies. These three processes are:

- Photoelectric effect
- Compton effect
- Pair production

Q # 7: Explain how α and β −particles may ionize an atom without directly hitting the electrons? What is the difference in the action of two particles for producing ionization?

Ans. An α −particle is nucleus of helium, it requires electrons. So an energetic α −particle, while passing through matter, ionizes thousands of atoms by attracting their electrons.

But the energetic β −particles ionize the atoms by ejecting their electrons by the force of repulsion.

Q # 8: A particle which produces more ionization is less penetrating. Why?

Ans. A particle with greater ionizing power will loose its whole of energy in a short distance inside a medium. So, its range in that medium is very small.

Q # 9: What information is revealed by the length and shape of the tracks of an incident particle in Wilson cloud chamber?

Ans. In Wilson cloud chamber, the length and shape of the tracks gives the following information.

- The tracks of α −particles are straight, continuous and thicker because these particles have greater mass as well as greater ionizing power.
- The tracks of β −particles are thinner, short and discontinuous tracks because these particles has less mass and less value of ionizing power as compared to α −particles.
- γ −rays have no definite tracks bacuse of high penetrating power and less ionizing power.

Q # 10: Why must a Geiger Muller tube for detecting α −particle have a very thin end window? Why does a Geiger Muller tube for detecting γ − rays not need a window at all?

- The GM tube has a very thin end window for detecting α −particles because this window provides easy way for these low penetrating particles, to enter into the tube.
- For detecting γ −rays, there is no need of such a window because γ −rays are highly penetrating.

Q # 11: Describe the principle of operation of a solid state detector of ionizing radiation in terms of generation and detection of charge carriers.

Ans. Its principle based upon the production of electron-hole pair by getting energy from incident radiation. These generated carriers cause current pulse, which is used for detection purposes.

Q # 12: What do we mean by term critical mass?

Ans. It is the quantity of mass of nuclear fuel, which is enough to absorb most of neutrons for self sustained fission chain reaction.

Q # 13: Discuss the advantages and disadvantages of nuclear power compared to the use of fossil fuel generated power.

Advantages

Nuclear power fossil	Fuel generated fossil
It is cheaper for electricity	It is not cheaper
It is permanent for a given period of time	It is not permanent and not for long period of time
It does not produce smoke	It produces smoke
It is of large amount	It is not of large amount

Disadvantages

Nuclear power has radiation effects which makes it dangerous.

Q # 14: What factors make a fusion reaction difficult to achieve?

Ans. The fusion reaction requires temperature up to million degree centigrade and high energy. These requirements are very difficult to achieve.

Q # 15: Discuss the advantage and disadvantages of fusion power from the point of safety, pollution and resources.

Ans.

Advantage: As the fusion reaction is free from radioactive fossil products, so it is not dangerous. It also gives more energy per nucleon as compared with nuclear fission reaction.

Disadvantage: The fusion reaction requires temperature up to million degree centigrade and high energy. These requirements are very difficult to achieve.

Q # 16: What do you understand by "background radiations"? State the two sources of this radiation.

Ans. The radiation present due to cosmic rays and due to presence of radioactive materials under crest of earth, are called background radiations.

Q # 17: If you swallowed a α −source and β −source, which would be more dangerous to you? Explain why?

Ans. If someone swallowed α −source, then it will damage more blood cells due to its high ionizing power as compare to β −source.

Q # 18: Which radiation does would deposit more energy to your body (a) 10 mGy to your hands or (b) 1 mGy does to your entire body.

Ans. We know that

$$(Absorbed\ Energy) = (Absorbed\ Dose) \times (Mass)$$

As the mass of body is much greater than hand so in second case, more energy will be absorbed.

Q # 19: What is radioactive tracer? Describe on application in medicine, agriculture and industry.

- The use of phosphorous or nitrogen as a tracer has helped to adopt a better mode of fertilizer supply to plants.
- Radioactive iodine can be used to check that a person's thyroid gland is working properly or not. A similar method can be used to study the circulation of blood using sodium-24.

Q # 20: How can radioactivity help in treatment of cancer?

Ans. High energy radiation can penetrate deep into the body and can be used to intentional selective destruction of tissues, such as cancer tumor.