UNIT -1 : ELECTROSTATICS
TWO MARK QUESTION AND ANSWERS

1. State law of conservation of electric charge.
   * The total electric charge in the universe is constant and charge can neither be created nor be destroyed.
   * In any physical process, the net change in charge will always be zero.

2. What is meant by quantization of charges?
   * The charge q on any object is equal to an integral multiple of this fundamental unit of charge e.
   * $q = ne$
   * Here n is any integer $(0, \pm 1, \pm 2, \dots)$
   * This is called quantization of electric charge.

3. State Coulomb's law.
   Coulomb's law states that the electrostatic force is directly proportional to the product of the magnitude of the two point charges and inversely proportional to the square of the distance between the two point charges.

4. Write down Coulomb's law in vector form and mention what each term represents.
   ▪ $\vec{F}_{21} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\hat{r}_{12}$
   ▪ $\vec{F}_{21}$ - force on the charge q_2 exerted by the charge q_1.
   ▪ $q_1\ and\ q_2$ - two point charges.
   ▪ r – distance between the two point charges
   ▪ $\hat{r}_{12}$ - unit vector from $q_1\ to\ q_2$.
   ▪ ε_0 – permittivity of free space.
   ▪ $\varepsilon_0 = 8.85 \times 10^{-12}\ C^2 N^{-1} m^{-2}$

5. Define relative permittivity.
   • Relative permittivity is defined as the ratio of permittivity of the medium to the permittivity of free space.
   • $\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$
   • For vacuum or air, $\varepsilon_r = 1$ and
   • For all other media $\varepsilon_r > 1$.

6. State superposition principle of electric charge.
   The total charge acting on a given charge is equal to the vector sum of forces exerted on it by all the other charges.

7. Define Electric field.
   • Electric field at a point P at a distance r from the point charge q is the force experienced by a unit charge.
   • $\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$
   • It is a vector quantity.
   • Its SI unit is NC^{-1}

8. Write Coulomb's law in terms of electric field.
   • If the electric field at a point P is $\vec{E}$, then the force experienced by the test charge q_0 placed at the point P is $\vec{F} = q_0\vec{E}$
   • This is Coulomb's law in terms of electric field.

9. What is meant by Electric field lines?
   Electric field lines are the imaginary curved path along which a unit charge tends to move in an electric field.

10. The electric field lines never intersect. Justify.
    • No two electric field lines intersect each other.
    • If two lines cross at a point, then there will be two different electric field vectors at the same point.
    • As a consequence, if some charge is placed in the intersection point, then it has to move in two different directions at the same time, which is physically impossible.
    • Hence, electric field lines do not intersect.

11. Define Electric dipole.
    • Two equal and opposite charges separated by a small distance constitute an electric dipole.
    • Examples: CO, H_2O, NH_3, HCl

12. What is general definition of electric dipole moment?
    • The magnitude of the electric dipole moment is equal to the product of one of the charges and the distance between them.
    • p = q2a
    • It is a vector quantity.
    • Its SI unit is C m

13. Define electric potential difference.
    The electric potential difference is defined as the work done by an external force to bring unit positive charge form one point to another point.

14. Define electrostatic potential.
    The electric potential at a point P is equal to the work done by an external force to bring a unit positive charge with constant velocity from infinity to the point P in the region of the external electric field $\vec{E}$.

An equipotential surface is a surface on which all the points are at the same potential.

16. Give the relation between electric field and electric potential.
   - The electric field is the negative gradient of the electric potential.
   - $E = -\frac{dV}{dx}$
   - $\vec{E} = -\left(\frac{\partial V}{\partial x}\hat{\imath} + \frac{\partial V}{\partial y}\hat{\jmath} + \frac{\partial V}{\partial z}\hat{k}\right)$

17. Define electrostatic potential energy.
   The electrostatic potential energy is defined as the work done to bring a test charge from one point to another point in an electrostatic field.

18. Define electric flux.
   - The number of electric field lines crossing a given area kept normal to the electric field lines is called electric flux.
   - It is a scalar quantity.
   - Its unit is N m^2 C^{-1}

19. What is meant by electrostatic energy density?
   - The energy stored per unit volume of space is defined as energy density.
   - Energy stored is $U_E = \frac{1}{2}\varepsilon_0 (Ad)E^2$
   - Energy density is $u_E = \frac{1}{2}\varepsilon_0 E^2$

20. What is dielectric or an insulator?
   - A dielectric is a non-conducting material has no free electrons.

   - The electrons in a dielectric are bound within the atoms.
   - Examples: Ebonite, Glass, and Mica

21. What is Polarisation?
   - Polarisation $\vec{P}$ is defined as the total dipole moment per unit volume of the dielectric.
   - $\vec{P} = \chi_e \vec{E}_{ext}$

22. What is dielectric breakdown?
   - When the external electric field applied to a dielectric is very large, it tears the atoms apart so that the bound charges become free charges.
   - Then the dielectric starts to conduct electricity.
   - This is called dielectric breakdown.

23. What is dielectric strength?
   The maximum electric field the dielectric can withstand before it breakdowns is called dielectric strength.

24. Define capacitance. Give its unit.
   - The capacitance C of a capacitor is defined as the ratio of the magnitude of charge on either of the conductor plates to the potential difference existing between the conductors.
   - $C = \frac{Q}{V}$
   - Its SI unit is coulomb per volt or *farad* (F)

25. What is action at points or corona discharge?
   The leakage of electric charges from the sharp points of the charged conductor is called as action at points or corona discharge.

1. Discuss the basic properties of electric charges.
   Electric charge:
   * The electric charge is an intrinsic and fundamental property of particles.
   * The SI unit of charge is coulomb.
   Conservation of charges:
   * The total electric charge in the universe is constant and charge can neither be created nor be destroyed.
   * In any physical process, the net change in the charge will always be zero.
   Quantization of charges:
   * The charge q on any object is equal to an integral multiple of this fundamental unit of charge e.
   * $q = ne$
   * Here n is any integer $(0, \pm 1, \pm 2, ...)$
   * This is called quantization of electric charge.

2. What are the differences between Coulomb force and gravitational force?

Gravitational force	Coulomb force
It is always attractive between two masses.	It can be attractive or repulsive, depending upon the nature of charges
G = 6.626 x 10^{-11} N m^{2}kg^{-2}	k = 9 x 10^9 N m^{2}C^{-2}
It is independent of the medium	It depends on nature of the medium in which the two charges are kept at rest.
It is same whether two point masses are at rest or in motion	If the charges are in motion, yet another force (Lorentz force) comes into play in addition to coulomb force.

3. Write a short note on superposition principle of electric charge.

   Superposition principle of electric charge:

   The total force acting on a give charge is equal to the vector sum of forces exerted on it by all the other charges.

   * Consider a system of n charges, namely $q_1, q_2, q_3, \dots \dots q_n$.

   * $\vec{F}_{12} = k\frac{q_1 q_2}{r^2}\hat{r}_{21}$

   * $\vec{F}_{13} = k\frac{q_1 q_3}{r^2}\hat{r}_{31}$

   * By continuing this, the total force acting on the charge due to all other charges is given by

   * $\vec{F}_1^{tot} = \vec{F}_{12} + \vec{F}_{13} + \cdots + \vec{F}_{1n}$

   * $\vec{F}_1^{tot} = \left[\frac{q_1 q_2}{r^2}\hat{r}_{21} + \frac{q_1 q_3}{r^2}\hat{r}_{31} + \cdots \frac{q_1 q_n}{r^2}\hat{r}_{n1}\right]$

4. What are the properties of electric field lines?
   * They start form a positive charge and end at negative charge or at infinity.
   * For a positive point charge, the electric field lines pint radially outward
   * For a negative point charge, the electric field lines point radially inward.
   * The electric field vector at a point in space is tangential to the electric field line at that point.
   * The electric field lines are denser in a region where the electric field has large magnitude and less dense in a region where the electric field is of smaller magnitude.

   * No twos electric field lines intersect each other.
   * The number of electric field lines that emanate from the positive charge or end at a negative charge is directly proportional to the magnitude of the charges.

5. What are the properties of an equipotential surface?
   ➤ The work done to move a charge q between any two points A and B, $W = q(V_B - V_A)$
   ➤ If the points A and B lie on the same equipotential surface, work done is zero because $V_A = V_B$
   ➤ The electric field is normal to an equipotential surface.

6. Discuss the various properties of conductors in electrostatic equilibrium.
   * The electric field is zero everywhere inside the conductor. This is true regardless of whether the conductor is solid or hollow.
   * There is no net charge inside the conductors. The charges must reside only on the surface of the conductors.
   * The electric field outside the conductor is perpendicular to the surface of the conductor and has a magnitude of $\frac{\sigma}{\varepsilon_0}$
   * The electrostatic potential has the same value on the surface and inside of the conductor.

7. Write a short note on electrostatic shielding.
   * Consider a cavity inside the conductor
   * Whatever the charges at the surfaces and whatever the electrical disturbances outside, the electric field inside the cavity is zero.

   * A sensitive electrical instrument which is to be protected from external electrical disturbance is kept inside this cavity.
   * This is called electrostatic shielding.
   * Faraday cage is an instrument used to demonstrate this effect.

8. Differentiate between non-polar and polar molecules.

Non – polar molecules	Polar molecules
In polar molecules, the centers of positive and negative charges coincide.	In polar molecules, the centers of the positive and negative charges are separated even in the absence of external electric field.
They have no permanent dipole moment.	They have a permanent dipole moment.
Ex: H_2, O_2, CO_2	Ex: H_2O, N_2O, HCl

9. Obtain an expression for the capacitance of a parallel plate capacitor.
   * Consider a capacitor with two parallel plates each of cross-sectional area A and separated by a distance d.
   * The electric field between two infinite parallel plates is uniform and is given by $E = \frac{\sigma}{\varepsilon_0}$
   * Where σ is the surface charge density, $\sigma = \frac{Q}{A}$
   * If $d^2 \ll A$, then the above result is used even for finite – sized parallel plate capacitor.
   * The electric field between the plates is $E = \frac{Q}{A\varepsilon_0}$
   * The electric potential between the plates is $V = Ed = \frac{Qd}{A\varepsilon_0}$

- The capacitance , $C = \dfrac{Q}{V} = \dfrac{\varepsilon_0 A}{d}$
- $C \propto A$
- $C \propto \dfrac{1}{d}$
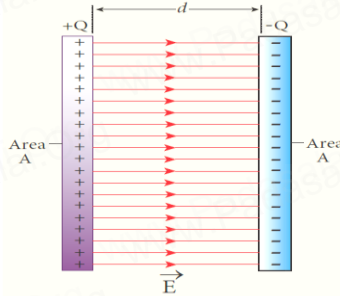
10. Obtain the expressions for the energy stored in the capacitor and energy density.
   - Capacitor not only stores the charge but also it stores energy.
   - dW = V dQ
   - V = Q / C
   - $W = \displaystyle\int_0^Q \dfrac{Q}{C}\,dQ = \dfrac{Q^2}{2C}$
   - This work done is stored as electrostatic potential energy (U_E) in the capacitor.
   - $U_E = \dfrac{Q^2}{2C} = \dfrac{1}{2}CV^2$
   - As $C = \dfrac{\varepsilon_0 A}{d}$ and V = Ed
   - $U_E = \dfrac{1}{2}\varepsilon_0 (Ad)E^2$
   - $Ad = volume$ of the space between the capacitor plates.
   - The energy stored per unit volume of space is defined as energy density, $u_E = \dfrac{U_E}{Volume}$
   - The energy density, $u_E = \dfrac{1}{2}\varepsilon_0 E^2$
   - The energy density depends only on the electric field and not on the size of the plates of the capacitor.

11. What are the applications of capacitor?
   - Capacitors are used as flash capacitors in digital camera to release the energy as flash.
   - Capacitors are used in heart defibrillator device to give a sudden surge of a large amount electrical energy to the patient's chest to retrieve the normal heart function.
   - Capacitors are used in the ignition system of automobile engines to eliminate sparking.
   - Capacitors are used to reduce power fluctuations in power supplies and to increase the efficiency of power transmission.

12. Is it safer to be sit inside a bus than standing under a tree during lightning accompanied by thundering?
   - During lightning accompanied by a thunderstorm, it is always safer to sit inside a bus than in open ground or under a tree.
   - The metal body of the bus provides electrostatic shielding.
   - Since, the electric field inside is zero.
   - During lightning, the charges flow through the body of the conductor to the ground with no effect on the person inside that bus.

13. Write a short note on lightning arrester or lightning conductor.
   - Lightning arrester is a device used to protect tall buildings from lightning strikes.
   - It works on the principle of action at points or corona discharge.
   - This device consists of a long thick copper rod passing from top of the building to the ground.
   - The upper end of the rod has a sharp spike or a sharp needle.
   - The lower ned of the rod is connected to the copper plate which is buried deep into the ground.
   - When a negatively charged cloud is passing above the building, it induces a positive charge on the spike.
   - Since the induced charge density on thin sharp spike is large, it results in a corona discharge.
   - This positive charge ionizes the surrounding air which in turn neutralizes the negative charge in the cloud.
   - The negative charge pushed to the spikes passes through the copper rod and is sagely diverted to the Earth.
   - The lightning arrester does not stop the lightning: rather it diverts the lightning to the ground safely.

FIVE MARKS

1. Explain in detail Coulomb's law and its various aspects.
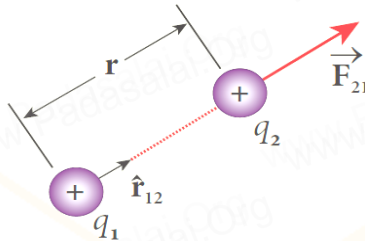
Coulomb's law:

Coulomb's law states that the electrostatic force is directly proportional to the product of the magnitude of the two point charges and is inversely proportional to the square of the distance between the two point charges.

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

Important aspects of Coulomb's law:

➢ The force on the charge q_2 exerted by the charge q_1 always lies along the line joining the two charges.

➢ In SI units, $k = \frac{1}{4\pi\varepsilon_0}$ and its value is 9×10^9 N m^{2}C^{-2}.

➢ Here ε_0 is the permittivity of fee space or vacuum and the value of $\varepsilon_0 = 8.85 \times 10^{-12} \, C^2 N^{-1} m^{-2}$

➢ The magnitude of the electrostatic force between two charges each of one coulomb and separated by a distance of 1 m is 9×10^9 N

➢ This is a huge quantity, almost equivalent to the weight of one million ton.

➢ We never come across 1 coulomb of charge in practice.

➢ Most of the electrical phenomena in day – to – day life involve electrical charges of the order of μC or nC.

➢ In vacuum , $\vec{F}_{21} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\hat{r}_{12}$.

➢ In a medium of permittivity ε , $\vec{F}_{21} = \frac{1}{4\pi\varepsilon}\frac{q_1 q_2}{r^2}\hat{r}_{12}$

➢ Since $\varepsilon > \varepsilon_0$, the force between two point charges in a medium other than vacuum is always less than that in vacuum.

➢ Relative permittivity, $\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$

➢ For vacuum or air, $\varepsilon_r = 1$

➢ For all other media, $\varepsilon_r > 1$

➢ Coulomb's law has same structure as Newton's law of gravitation.

➢ Both are inversely proportional to the square of the distance between the particles.

➢ The electrostatic force is directly proportional to the product of the magnitude of two point charges and gravitational force is directly proportional to the product of two masses.

➢ The electrostatic force obeys Newton's third law. $\vec{F}_{12} = -\vec{F}_{21}$

➢ The expression for Coulomb force is true only for point charges.

➢ But the point charge is an ideal concept.

➢ However we can apply Coulomb's law for two charged objects whose sizes are very much smaller than the distance between them.

➢ In fact, Coulomb discovered his law by considering the charged spheres in the torsion balance as point charges.

➢ The distance between the two charged spheres is much greater than the radii of the spheres.

2. Define electric field and discuss its various aspects.

Electric field:

• The electric field at the point P at a distance r form the point charge q is the force experienced by a unit charge and is given by $\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$

• It is a vector quantity

• Its SI unit is NC^{-1}

Important aspects of Electric field:

∗ If the charge q is positive then the electric filed points away from the source charge

∗ If q is negative, the electric filed points towards the source charge q.

∗ If the electric field at a point P is $\vec{E}$, then the force experienced by the test charge q_0 placed at the point P is $\vec{F} = q_0 \vec{E}$

∗ This is the Coulomb's law in terms of electric filed.

∗ The electric field is independent of the test charge q_0 and it depends only on the source charge q.

∗ As distance increases, the electric filed decreases in magnitude.

∗ Test charge is made sufficiently small so such that it will not modify the electric field of the source charge.

∗ For continuous and finite charge distributions, integration techniques must be used.

* There are two kinds of electric field: uniform electric field and non – uniform electric field.
* Uniform electric filed will have the same direction and constant magnitude at all points in space.
* Non – uniform electric field will have different directions or different magnitudes or both at different points in space.
* This non – uniformity arises, both in direction and magnitude, with the direction being radially outward or inward and the magnitude changes as distance increases.

3. How do we determine the electric field due to a continuous charge distribution? Explain.
* Consider the following charged object of irregular shape as shown in figure.
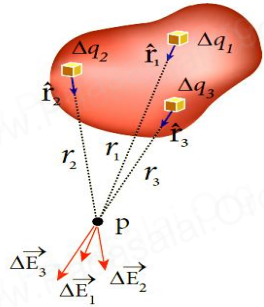
* The entire charged object is divided into a large number of charge elements $\Delta q_1, \Delta q_2, \Delta q_3 \ldots \Delta q_n$, and each charge element Δq is taken as point charge.
* The electric field at a point P is given by
  $$\vec{E} \approx \frac{1}{4\pi\varepsilon_0} \sum_{i=1}^{n} \frac{\Delta q_i}{r_{iP}^2} \hat{r}_{iP} \qquad \text{------------- (1)}$$
* However the above equation is only an approximation.

* To incorporate the continuous distribution of charge, we take the limit $\Delta q \to 0$.
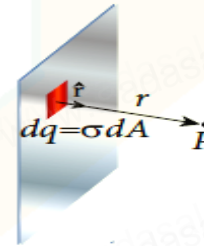* Equation (1) now becomes, $\vec{E} = \frac{1}{4\pi\varepsilon_0} \int \frac{dq}{r^2} \hat{r}$

Linear charge distribution:
* Linear charge density is defined as the charge per unit length.
* $\lambda = \frac{Q}{L}$
* Its unit is C m^{-1}
* $dq = \lambda dl$
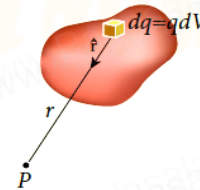* $\vec{E} = \frac{\lambda}{4\pi\varepsilon_0} \int \frac{dl}{r^2} \hat{r}$
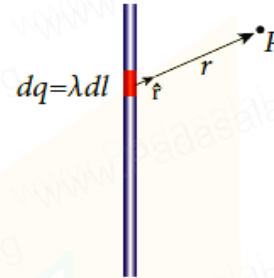
Surface charge distribution:
* Surface charge density is defined as the charge per unit area.
* $\sigma = \frac{Q}{A}$
* Its unit is C m^{-2}
* $dq = \sigma dA$
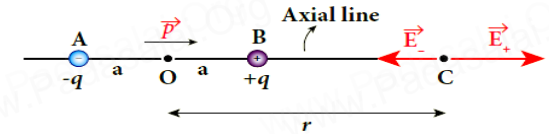* y $\vec{E} = \frac{\sigma}{4\pi\varepsilon_0} \int \frac{dA}{r^2} \hat{r}$

Volume charge distribution:
* Volume charge density is defined as the charge per unit volume.
* $\rho = \frac{Q}{V}$
* Its unit is C m^{-3}
* $dq = \rho dV$
* $\vec{E} = \frac{\rho}{4\pi\varepsilon_0} \int \frac{dV}{r^2} \hat{r}$

4. Calculate the electric field due to an electric dipole at points on its axial line.
➢ AB is an electric dipole.
➢ A point C is located at a distance r from the midpoint O of the dipole along the axial line.

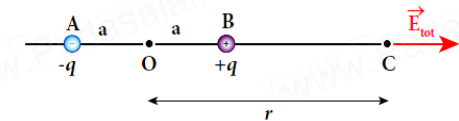➢ $\vec{E}_+ = k \frac{q}{(r-a)^2} \hat{p}$ ($\hat{p}$ acts along BC)

➢ $\vec{E}_- = -k \frac{q}{(r+a)^2} \hat{p}$

➢ $\vec{E}_{tot} = \vec{E}_+ + \vec{E}_-$

➢ $\vec{E}_{tot} = kq \left[\frac{1}{(r-a)^2} - \frac{1}{(r+a)^2} \right] \hat{p}$

➢ $\vec{E}_{tot} = kq \left[\frac{4ra}{(r^2-a^2)^2} \right] \hat{p}$

➢ The total electric field is along $\vec{E}_+$, since +q is closer to C than –q.

➢ If $r \gg a$, then $(r^2 - a^2)^2 = r^4$
➢ $\vec{E}_{tot} = k \left(\frac{4aq}{r^3} \right) \hat{p}$ $(r \gg a)$
➢
➢ $2aq \, \hat{p} = \vec{p}$ and $k = \frac{1}{4\pi\varepsilon_0}$

➢ $\vec{E}_{tot} = \frac{1}{4\pi\varepsilon_0} \frac{2\vec{p}}{r^3}$ $(r \gg a)$

5. Calculate the electric field due to an electric dipole at points on its equatorial line.

- AB is an electric dipole.
- A point C is located at a distance r from the midpoint O of the dipole on the equatorial plane.
- $\vec{E}_+ = k \dfrac{q}{(r^2+a^2)}$ (along BC)

- $\vec{E}_- = k \dfrac{q}{(r^2+a^2)}$ (along CA)

- $\vec{E}_{tot} = -|\vec{E}_+|\cos\theta\ \hat{p} - |\vec{E}_-|\cos\theta\ \hat{p}$

- $\vec{E}_{tot} = -2|\vec{E}_+|\cos\theta\ \hat{p}$ $(\because |\vec{E}_+| = |\vec{E}_-|)$

- $\vec{E}_{tot} = -k \dfrac{2q\cos\theta}{(r^2+a^2)}\ \hat{p}$

- $\vec{E}_{tot} = -k \dfrac{2qa}{(r^2+a^2)^{\frac{3}{2}}}\ \hat{p} \left(\because \cos\theta = \dfrac{a}{\sqrt{r^2+a^2}}\right)$

- $\vec{E}_{tot} = -k \dfrac{\vec{p}}{(r^2+a^2)^{\frac{3}{2}}}$ $(\because \vec{p} = 2qa\hat{p})$

- At very large distances, r >> a

- $\vec{E}_{tot} = -\dfrac{1}{4\pi\varepsilon_0}\dfrac{\vec{p}}{r^3}$ $(r \gg a)(k = \dfrac{1}{4\pi\varepsilon_0})$
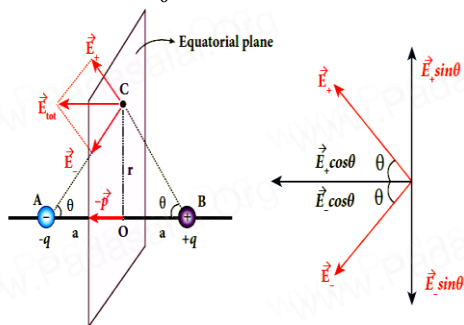

6. Derive an expression for the torque experienced by a dipole due to a uniform electric field.

* Consider an electric dipole of dipole moment $\vec{p}$ placed in a uniform electric field $\vec{E}$.
* Two forces acting at different points will constitute a couple and the dipole experience a torque.
* This torque tends to rotate the dipole.
* $\vec{\tau} = \overrightarrow{OA} \times (-q\vec{E}) + \overrightarrow{OB} \times (q\vec{E})$
* $\tau = (OA)(qE)\sin\theta + (OA)(qE)\sin\theta$
* $\tau = 2qaE\sin\theta$
* $\tau = pE\sin\theta$
* $\vec{\tau} = \vec{p} \times \vec{E}$
* Torque is maximum when $\theta = 90°$
* Torque is zero when $\theta = 0°$
* If the electric field is not uniform, then there will be net force acting on the dipole in addition to the torque.
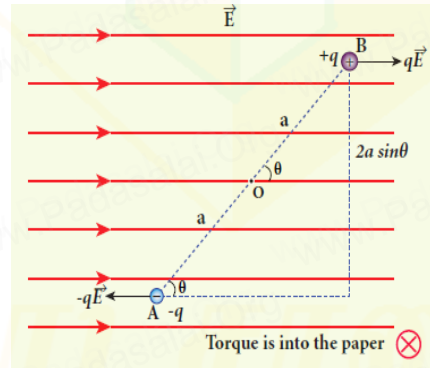
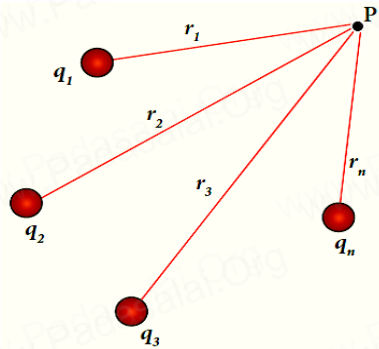7. Derive an expression for electrostatic potential due to a point charge.

* Consider a positive charge q kept fixed at the origin.
* Let P be a point at distance r from the charge q.
* The electric potential at P is $V = -\int_\infty^r \vec{E}.d\vec{r}$
* $\vec{E} = k\dfrac{q}{r^2}\hat{r}$
* $V = -k\int_\infty^r \dfrac{q}{r^2}\ \hat{r}.d\vec{r}$
* $V = -k\int_\infty^r \dfrac{q}{r^2}\ dr$ $(\because \hat{r}.d\vec{r} = dr)$
* After integration, $V = k\dfrac{q}{r}$
* $V = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{r}$ $\left(\because k = \dfrac{1}{4\pi\varepsilon_0}\right)$
* For positive charge, $V > 0$
* For negative charge, $V < 0$
* For negative charge, $V = -\dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{r}$
* The potential due to positive charge decreases as the distance increases.
* The potential due to negative charge increases as the distance is increased.
* At infinity, electrostatic potential is zero.
* A positive charge moves from a point of higher electrostatic potential to lower electrostatic potential.
* A negative charge moves from a point of lower electrostatic potential to higher electrostatic potential.
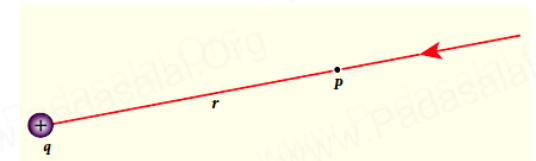
* Potential due to collection of point charges is
* $V_{tot} = V_1 + V_2 + V_3 + \cdots + V_4$

* $V_{tot} = k \left[\frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{r_3} \cdots \cdots + \frac{q_n}{r_n} \right]$

* $V_{tot} = \frac{1}{4\pi\varepsilon_0} \sum\limits_{i=1}^{n} \frac{q_i}{r_i}$

8. Derive an expression for electrostatic potential due to an electric dipole.
   * Consider two equal and opposite charges separated by a small distance $2a$.
   * The point P is located at a distance r from the midpoint of the dipole.
   * $V_1 = k\frac{q}{r_1}$
   * $V_2 = -k\frac{q}{r_2}$
   * $V = kq \left[\frac{1}{r_1} - \frac{1}{r_2} \right]$

calculation for $\frac{1}{r_1}$	calculation for $\frac{1}{r_2}$
By the cosine law for triangle BOP	By the cosine law for triangle AOP
$r_1^2 = r^2 + a^2 - 2ra\,\cos\theta$	$r_2^2 = r^2 + a^2 + 2ra\,\cos\theta$
$r_1^2 = r^2 \left(1 + \frac{a^2}{r^2} - \frac{2a}{r} cos\,\theta \right)$	$r_2^2 = r^2 \left(1 + \frac{a^2}{r^2} + \frac{2a}{r} cos\,\theta \right)$
Neglecting $\frac{a^2}{r^2}$ since r >> a	Neglecting $\frac{a^2}{r^2}$ since r >> a
$r_1^2 = r^2 \left(1 - \frac{2a}{r} cos\,\theta \right)$	$r_2^2 = r^2 \left(1 + \frac{2a}{r} cos\,\theta \right)$
$r_1 = r \left(1 - \frac{2a}{r} cos\,\theta \right)^{\frac{1}{2}}$	$r_2 = r \left(1 + \frac{2a}{r} cos\,\theta \right)^{\frac{1}{2}}$
$\frac{1}{r_1} = \frac{1}{r} \left(1 - \frac{2a}{r} cos\,\theta \right)^{-\frac{1}{2}}$	$\frac{1}{r_2} = \frac{1}{r} \left(1 + \frac{2a}{r} cos\,\theta \right)^{-\frac{1}{2}}$
Using Binomial theorem	Using Binomial theorem
$\frac{1}{r_1} = \frac{1}{r} \left(1 + \frac{a}{r} cos\,\theta \right)$	$\frac{1}{r_2} = \frac{1}{r} \left(1 - \frac{a}{r} cos\,\theta \right)$

* $V = kq \left[\frac{1}{r} \left(1 + \frac{a}{r} cos\,\theta \right) - \frac{1}{r} \left(1 - \frac{a}{r} cos\,\theta \right) \right]$

* $V = k\,\frac{2aq\,cos\,\theta}{r^2}$

* $V = k\,\frac{p\,cos\,\theta}{r^2}$ $(\because p = q2a)$

* $V = \frac{1}{4\pi\varepsilon_0} \frac{p\,cos\,\theta}{r^2}$ $\left(\because k = \frac{1}{4\pi\varepsilon_0} \right)$

* $V = \frac{1}{4\pi\varepsilon_0} \frac{\vec{p}\cdot\hat{r}}{r^2}$ (r >> a) $(\because p\,cos\,\theta = \vec{p}\cdot\hat{r})$
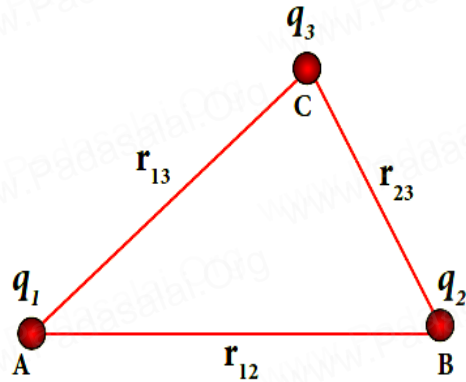
Special cases:

* If $\theta = 0°$, then $V = \frac{1}{4\pi\varepsilon_0} \frac{p}{r^2}$

* If $\theta = 180°$, then $V = -\frac{1}{4\pi\varepsilon_0} \frac{p}{r^2}$
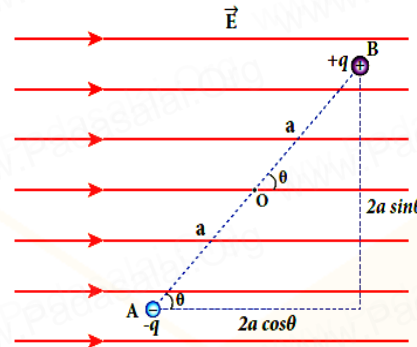
* If $\theta = 90°$, then $V = 0$
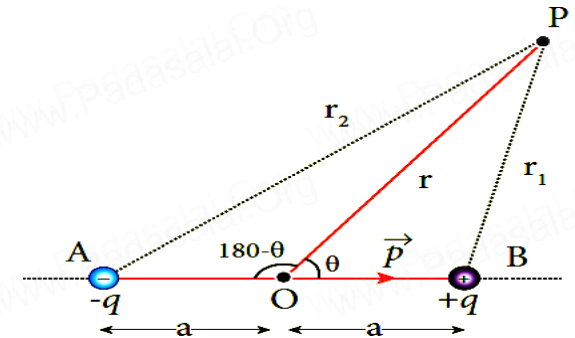
9. Obtain an expression for potential energy due to a collection of three point charges which are separated by finite distances.

* $V_{1B} = k\frac{q_1}{r_{12}}$
* $W = q_2\,V_{1B}$
* $U = k\frac{q_1 q_2}{r_{12}}$
* $W = q_3(V_{1C} + V_{2C})$
* $U = k \left(\frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}} \right)$

- Total energy of the system is

- $U = k \left(\dfrac{q_1 q_2}{r_{12}} + \dfrac{q_1 q_3}{r_{13}} + \dfrac{q_2 q_3}{r_{23}} \right)$

10. Derive an expression for electrostatic potential energy of the dipole in a uniform electric field.

$$W = \int_{\theta'}^{\theta} \tau_{ext} \, d\theta$$

$$\vec{\tau}_E = \vec{p} \times \vec{E}$$

$$\tau_{ext} = \tau_E = |\vec{p} \times \vec{E}| = pE \sin\theta$$

$$W = \int_{\theta'}^{\theta} pE \sin\theta \, d\theta$$

$$W = pE(\cos\theta' - \cos\theta) d\theta$$

$$U(\theta) - U(\theta') = \Delta U = pE\cos\theta' - pE\cos\theta$$

If $\theta' = 90°$, then $U(\theta') = 0$

The energy stored in the dipole is

$$U = -pE\cos\theta = -\vec{p}.\vec{E}$$

$If\ \theta = 180°$, then $U(\theta) = pE$, maximum

11. Obtain Gauss's law form Coulomb's law.

➢ A positive point charge Q is surrounded by an imaginary sphere of radius r.

➢ Total electric flux through the closed surface of the sphere is $\phi_E = \oint \vec{E}.d\vec{A} = \oint E \, dA \cos\theta$

➢ The electric field of the point charge is directed radially outward at all points on the surface of the sphere.

➢ Therefore, the direction of the area element $d\vec{A}$ is along the electric field $\vec{E}$ and $\theta = 0°$

When the charge is at the center of the sphere, the electric field is everywhere normal to the surface and constant in magnitude.
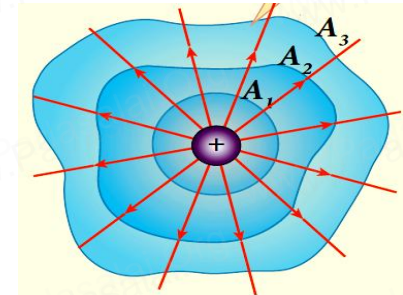
Spherical gaussian surface
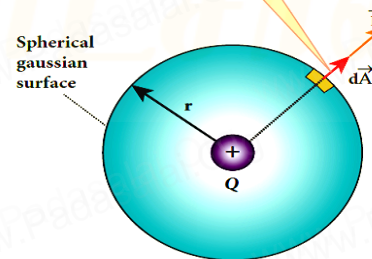
➢ $\phi_E = \oint E \, dA \quad (\because \cos 0° = 1)$

➢ $\phi_E = E \oint dA$

➢ $\oint dA = 4\pi r^2$ and $E = k\dfrac{Q}{r^2}$

➢ $\phi_E = \dfrac{Q}{\varepsilon_0}$ ------------ (1)

➢ The above equation is called Gauss's law.

➢ The equation (1) is equally true for any arbitrary shaped surface which encloses the charge Q.

➢ It is seen that the total electric flux is the same for closed surfaces A_1, A_2 and A_3.

➢ Gauss's law states that if a charge Q is enclosed by an arbitrary closed surface, then the total electric flux ϕ_E through the closed surface is

$$\phi_E = \dfrac{Q_{encl}}{\varepsilon_0}$$

➢ Q_{encl} denotes the charges inside the closed surface.

infinitely long charged wire.

* Consider an infinitely long straight wire having uniform linear charge density λ.

* Let P be a point located at a perpendicular distance r from the wire.

* The electric field at the point P can be found using Gauss's law.

* Let us choose a cylindrical Gaussian surface of radius r and length L.

* The total electric flux in this closed surface is

$$\phi_E = \oint \vec{E} \cdot d\vec{A}$$

* $$\phi_E = \underset{\substack{\text{Curved} \\ \text{surface}}}{\int \vec{E} \cdot d\vec{A}} + \underset{\substack{\text{Top} \\ \text{surface}}}{\int \vec{E} \cdot d\vec{A}} + \underset{\substack{\text{Bottom} \\ \text{surface}}}{\int \vec{E} \cdot d\vec{A}}$$

* For the curved surface, $\vec{E} \cdot d\vec{A} = E \cdot dA$
$$(\because \theta = 0°, \cos 0° = 1)$$

* For the top and bottom surfaces, $\vec{E} \cdot d\vec{A} = 0$
$$(\because \theta = 90°, \cos 90° = 0)$$

* Therefore, the total electric flux through the curved surface is

* $$\phi_E = \underset{\substack{\text{Curved} \\ \text{surface}}}{\int \vec{E} \cdot d\vec{A}} = \frac{Q_{encl}}{\varepsilon_0}$$

* $$Q_{encl} = \lambda L$$

* $$E \underset{\substack{\text{Curved} \\ \text{surface}}}{\int dA} = \frac{\lambda L}{\varepsilon_0}$$

* $$\underset{\substack{\text{Curved} \\ \text{surface}}}{\int dA} = 2\pi r L$$

* $$E \cdot 2\pi r L = \frac{\lambda L}{\varepsilon_0}$$

* $$E = \frac{1}{2\pi\varepsilon_0} \frac{\lambda}{r}$$

* $$\vec{E} = \frac{1}{2\pi\varepsilon_0} \frac{\lambda}{r} \hat{r}$$
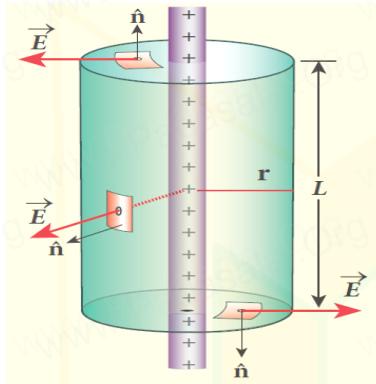
13. Obtain the expression for electric field due to a charged infinite plane sheet.

* Consider an infinite plane sheet of charges with uniform surface charge density σ.

* Let P be a point at a distance of r from the sheet.

* Since the plane is infinitely large, the electric field should be same at all points equidistant from the plane and radially directed at all points.

* A cylindrical shaped Gaussian surface of length 2r and area A of the flat surfaces is chosen such that the infinite plane sheet passes perpendicular through the middle part of the Gaussian surface.

$$\phi_E = \oint \vec{E} \cdot d\vec{A}$$

$$\underset{\substack{\text{Curved} \\ \text{surface}}}{\int \vec{E} \cdot d\vec{A}} + \underset{P}{\int \vec{E} \cdot d\vec{A}} + \underset{P'}{\int \vec{E} \cdot d\vec{A}} = \frac{Q_{encl}}{\varepsilon_0}$$

* At curved surfaces, $\vec{E} \cdot d\vec{A} = 0$
$$(\because \theta = 90°, \cos 90° = 0)$$

* At P and P', $\vec{E} \cdot d\vec{A} = E \cdot dA$
$$(\because \theta = 0°, \cos 0° = 1)$$

* $$\underset{P}{\int E \cdot dA} + \underset{P'}{\int E \cdot dA} = \frac{Q_{encl}}{\varepsilon_0}$$

* $$Q_{encl} = \sigma A$$

* $$2E \underset{P}{\int dA} = \frac{\sigma A}{\varepsilon_0}$$

* $$\underset{P}{\int dA} = A$$

* $$2EA = \frac{\sigma A}{\varepsilon_0}$$

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

* $$\vec{E} = \frac{\sigma}{2\varepsilon_0} \hat{n}$$
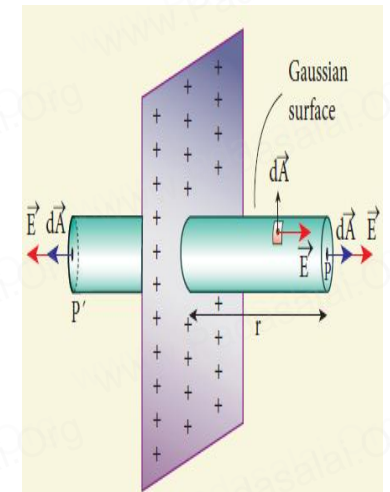
14. Obtain the expression for electric field due to a uniformly charged spherical shell.

At a point outside the spherical shell (r >R):

* Let us choose a point P outside the shell at a distance r from the center.

* The charge is uniformly distributed on the surface of the sphere.

* Hence the electric field must point radially outward if $Q > 0$ and point radially inward if $Q < 0$.

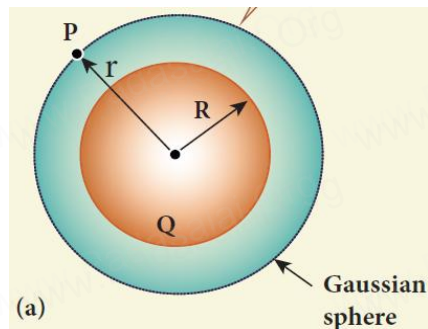* $\oint\limits_{\substack{Gaussian \\ surface}} \vec{E}.d\vec{A} = \dfrac{Q}{\varepsilon_0}$

* $E \oint\limits_{\substack{Gaussian \\ surface}} .dA = \dfrac{Q}{\varepsilon_0}$

* $\oint\limits_{\substack{Gaussian \\ surface}} dA = 4\pi r^2$

* $E.4\pi r^2 = \dfrac{Q}{\varepsilon_0}$

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

* $\vec{E} = \dfrac{1}{4\pi\varepsilon_0}\dfrac{Q}{r^2}\hat{r}$

(a)

At a point on the surface of the spherical shell (r = R):

$\vec{E} = \dfrac{1}{4\pi\varepsilon_0}\dfrac{Q}{r^2}\hat{r}$ (r = R)

At a point outside the spherical shell (r <R):

* Consider a point P inside the shell at a distance r form the center.
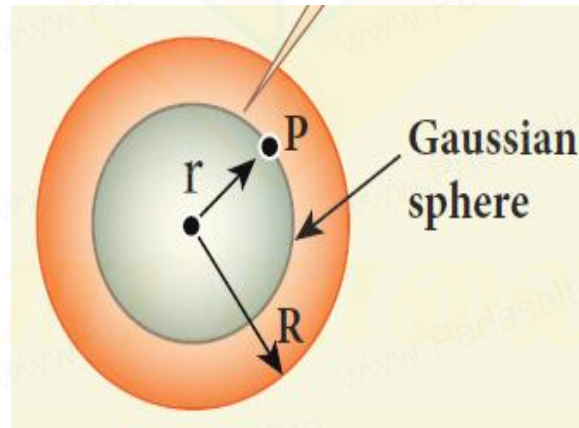
* A Gaussian sphere of radius r is constructed.

* $\oint\limits_{\substack{Gaussian \\ surface}} \vec{E}.d\vec{A} = \dfrac{Q}{\varepsilon_0}$

* $E.4\pi r^2 = \dfrac{Q}{\varepsilon_0}$

* Since Gaussian surface encloses no charge, $Q = 0$.

* $E = 0$.

* The electric field due to the uniformly charged spherical shell is zero at all points inside the shell.

Gaussian sphere

15. Explain in detail the effect of a dielectric placed in a parallel plate capacitor When the capacitor is disconnected from the battery:

* Consider a capacitor with two parallel plates each of cross –sectional area A and are separated by a distance d.

* The capacitor is charged by a battery of voltage V_o and the charge stored si Q_o.

* The capacitance of the capacitor without the dielectric is $C_o = V_o / Q_o$

* The battery is then disconnected from the capacitor and the dielectric is inserted between the plates.

* The introduction of dielectric between the plates will decrease the electric field.

* $E = \dfrac{E_0}{\varepsilon_r}$

* E_0 is the electric field inside the capacitors when there is no dielectric.

* ε_r is the relative permeability of the dielectric.

* Since $\varepsilon_r > 1,$ $E < E_0$

* As a result, the electrostatic potential difference between the plates is also reduced.

* But at the same time, the charge will remain constant once the battery is disconnected.

* $V = Ed = \dfrac{E_0}{\varepsilon_r}d = \dfrac{V_0}{\varepsilon_r}$

* $C = \dfrac{Q_0}{V}$

* $C = \varepsilon_r \dfrac{Q_0}{V_0} = \varepsilon_r C_0$

* $C = \varepsilon_r C_0$

* Since $\varepsilon_r > 1$, $C > C_0$

* Thus insertion of the dielectric increases the capacitance.

* $C = \dfrac{\varepsilon_r \varepsilon_0 A}{d} = \dfrac{\varepsilon A}{d}$

* The energy stored in the capacitor before the insertion of dielectric is $U_0 = \dfrac{1}{2} \dfrac{Q_0^2}{C_0}$

* The energy stored in the capacitor after the insertion of dielectric is $U = \dfrac{U_o}{\varepsilon_r}$

* Since $\varepsilon_r > 1$, $U < U_0$

* There is a decrease in energy because, when the dielectric is inserted, the capacitor spends some energy in pulling the dielectric inside.
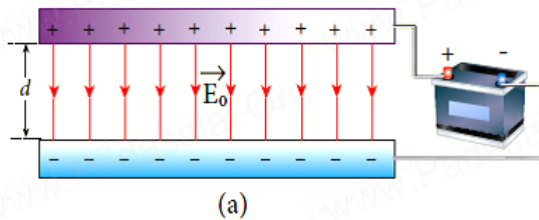

(a)
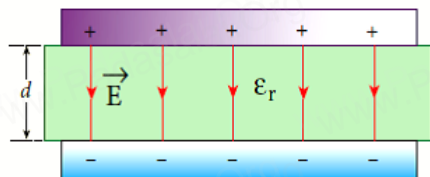
(b)

a parallel plate capacitor when the battery remains connected to the capacitor.

* The potential difference V_0 across the plates remains constant.

* But it is found experimentally that when dielectric is inserted, the charge stored in the capacitor is increased by a factor ε_r.

* $Q = \varepsilon_r Q_0$

* $C = \varepsilon_r C_0$

* $C_0 = \dfrac{\varepsilon_0 A}{d}$

* $C = \dfrac{\varepsilon A}{d}$

* The energy stored in the capacitor before the insertion of dielectric is $U_0 = \dfrac{1}{2} C_0 V_0^2$

* The energy stored in the capacitor after the insertion of dielectric is $U = \varepsilon_r U_o$

(அ)
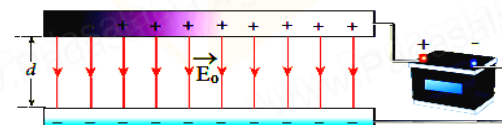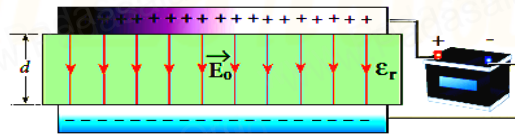
when capacitors are connected in series and in parallel.

Capacitors in series	Capacitors in parallel
Three capacitors of capacitance C_1, C_2 and C_3 are connected in series.	Three capacitors of capacitance C_1, C_2 and C_3 are connected in parallel.
Charge Q across each capacitor is same	Potential difference across each capacitor is same.
$V = V_1 + V_2 + V_3$	$Q = Q_1 + Q_2 + Q_3$
$Q = CV$	$Q = CV$
$V = \dfrac{Q}{C_1} + \dfrac{Q}{C_2} + \dfrac{Q}{C_3}$	$Q = C_1 V + C_2 V + C_3 V$
$V = \dfrac{Q}{C_S}$	$Q = C_P V$
$\dfrac{Q}{C_S} = \dfrac{Q}{C_1} + \dfrac{Q}{C_2} + \dfrac{Q}{C_3}$	$C_P V = C_1 V + C_2 V + C_3 V$
$\dfrac{1}{C_S} = \dfrac{1}{C_1} + \dfrac{1}{C_2} + \dfrac{1}{C_3}$	$C_P = C_1 + C_2 + C_3$

18. Explain in detail the construction and working of a Van de Graff generator.

Principle: Action of points and Electrostatic induction.

Construction:

- A hollow metallic sphere A is mounted on insulating pillars.
- A pulley B is mounted at the centre of the sphere.
- Another pulley C is mounted near the bottom.
- A silk belt moves over the pulleys.
- The pulley C is driven continuously by an electric motor.
- The comb shaped conductors D and E are mounted near the pulleys.
- A positive potential of 10^4 **V** is given to D by a power supply.
- E is connected to the inner side of the hollow sphere.

WORKING:

ACTION OF POINTS:

- Because of high electric field near D, the air gets ionized due to action of points.
- The negative charges in air move towards the needles and positive charges are repelled on towards the belt.
- These positive charges stick to the belt, move up and reach near E.

ELECTROSTATIC INDUCTION:

- As a result of electrostatic induction, the comb E acquires negative charge and the sphere acquires positive charge.
- The acquired positive charge is distributed on the outer surface of the sphere.

- The high electric field at E ionizes the air.
- The negative charges are repelled to the belt, neutralizes the positive charge on the belt before the belt passes over the pulley.
- Hence the descending belt will be left uncharged.

Leakage of electric charge:

- Thus the machine continuously transfers the positive charge to the sphere.
- As a result, the potential of the sphere keeps increasing till it attains a limiting value.
- After this stage leakage of charge to the surrounding starts due to the ionization of the air.

Prevention of leaking electric charge:

- **The leakage of charge** from the sphere can be **reduced by enclosing it in a gas filled steel chamber** at a very high temperature.

Uses:

- It is used to produce large electrostatic potential difference of the order of 10^7 **V.**
- This high voltage is used to **accelerate positive ions (protons, deuterons) for the purpose of nuclear disintegration.**
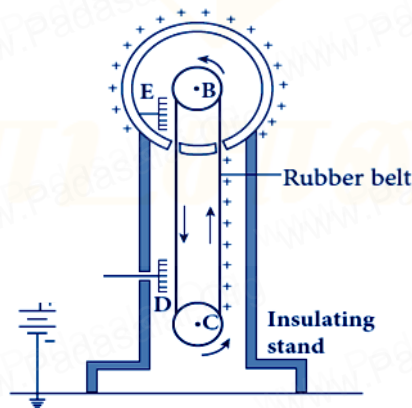
UNIT – 2. CURRENT ELECTRICITY
TWO MARK QUESTIONS:

1. Define drift velocity.

   Drift velocity is defined as the velocity with which free electrons get drifted towards the positive terminal, when an electric field is applied. Its unit is $m\ s^{-1}$

2. Define mobility.

   Mobility is defined as the drift velocity acquired per unit electric field. Its unit is $m^2\ V^{-1}\ s^{-1}$

3. Define current density.
   - The current density is defined as the current per unit area of cross section of the conductor.
   - It is a vector quantity.
   - Its unit is $A\ m^{-2}$

4. Write the microscopic form Ohm's law:
   - $\vec{J} = \sigma\vec{E}$
   - $\vec{J}$ is the current density
   - σ conductivity of the conductor
   - $\vec{E}$ is the electric field in the conductor

5. State macroscopic form of Ohm's law.

   At constant temperature, the steady current flowing through a conductor is directly proportional to the potential difference between the two ends of the conductor. $I \propto V$

6. Define resistance of a conductor.

Resistance of a conductor is defined as the ratio of potential difference across the conductor to the current flowing through it. Its unit is ohm.

7. Define electrical resistivity.

The electrical resistivity of a material is defined as the resistance offered to current flow by a conductor of unit length having unit area of cross section. Its unit is $\Omega\, m$.

8. What is superconductivity?

The ability of certain metals, their compounds and alloys to **conduct electricity with zero resistance at very low temperature** is called superconductivity.

9. Define temperature coefficient of resistance.

The temperature coefficient of resistance is defined as the ratio of increase in resistivity per degree rise in temperature to its resistivity at T_0. Its unit is per $°C$.

10. What is internal resistance of a cell?

During the process of flow current inside the cell, a resistance offered to current flow by the electrolyte of the cell is known as the internal resistance of the cell.

11. **State Kirchoff's first rule or current rule or junction rule.**

It states that the algebraic sum of the currents at any junction of a circuit is zero.

12. **Kirchoff's second rule or voltage rule or loop rule:**

The algebraic sum of the products of resistance and current in each part of any closed circuit is equal to the algebraic sum of the emf's in that closed circuit.

13. Distinguish between electric energy and electric power.

Electric energy	Electric power
It is the capacity to do work.	It is the rate of doing electric work.
Its unit is J	Its unit is watt.
1 kWh = 36 x 10^5 J	P = VI

14. Why current is a scalar?
- The electric current does not obey the laws of vector addition.
- Also, $I = \vec{J}.\vec{A} = JA\cos\theta$
- Hence, current is a scalar.

15. What are ohmic and non ohmic conductors?
- The devices which obey the Ohm's law are called ohmic conductors.
- Example: Copper wire, Metals
- The devices which do not obey the Ohm's law are called non – ohmic conductors.
- Example: Diodes, Filament lamp, Semiconductor.

16. Derive expression for power P = VI in electrical circuit.
- $P = \dfrac{dU}{dt} = \dfrac{d}{dt}(V.dQ)$
- $P = V\dfrac{dQ}{dt}$
- $P = VI \qquad (\because I = \dfrac{dQ}{dt})$
-

17. Write down the various forms of expression for power in electrical circuit.
- P = VI
- P = I^2R
- P = V^2/R

18. State the principle of potentiometer.
- The emf of the cell is directly proportional to the balancing length.
- $\xi \propto l$

19. State Joule's law of heating.

Joule's law heating states that the heat developed in an electrical circuit due to the flow of electric current varies directly as
- the square of the current
- the resistance of the circuit
- the time of flow

20. What is thermoelectric effect?

Conversion of temperature differences into electrical voltage and vice versa is known as thermoelectric effect.

21. What is Seebeck effect?

Seebeck discovered that in a closed circuit consisting of two dissimilar metals, when the junctions are maintained at different temperatures an emf is developed.

22. What is Peltier effect?

When an electric current is passed through a circuit of a thermocouple, heat is evolved at one junction and absorbed at other junction. This is Peltier effect.

23. What is Thomson effect?

If two points in a conductor are at different temperatures, the density of electrons at these points will differ and as result the potential difference is created between these points. Thomson effect is also reversible.

THREE MARK QUESTIONS:

1. Describe the microscopic model of current and obtain the microscopic form of Ohm's law.
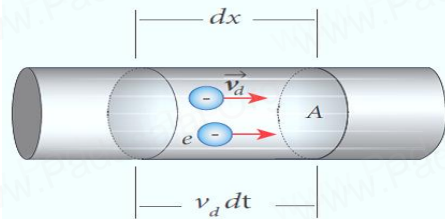
- A is the area of cross section of the conductor.
- An electric field E is applied from right to left

- v_d is the drift velocity of the free electrons.
- $dx = v_d \, dt$
- n is the number of free electrons per unit volume.
- The electrons available in the volume of length dx is $= nA dx = nAv_d \, dt$
- $dQ = neAv_d \, dt$
- $I = \dfrac{dQ}{dt}$
- $I = neAv_d$

Current density:

- The current density is defined as the current per unit area of cross section of the conductor.
- It is a vector quantity.
- Its unit is $\boxed{A\ m^{-2}}$

- $\dfrac{I}{A} = nev_d$

- $J = nev_d$

- $\vec{J} = ne\vec{v}_d$

- $\vec{v}_d = -\dfrac{e\tau}{m}\vec{E}$

- $\vec{J} = -\dfrac{ne^2\tau}{m}\vec{E}$
- $\vec{J} = -\sigma\vec{E}$
- Conventionaly we take the direction of current density as the direction of electric field.
- The above equation can be written as $\vec{J} = \sigma\vec{E}$

2. Obtain the macroscopic form of Ohm's law from its microscopic form and discuss its limitations.

➢ Ohm's law can be derived from $J = \sigma E$
➢ Consider a segment for wire of length l and area of cross section A.
➢ When a potential difference V is applied across the wire, a net electric field is created in the wire which constitutes the current.
➢ The electric field is uniform in the entire length of the wire.
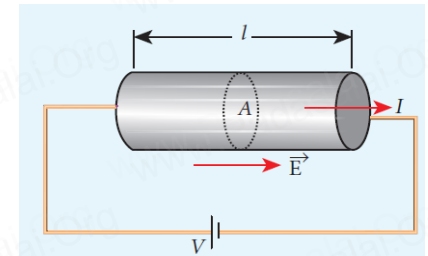
➢ V = El

➢ $J = \sigma E$

➢ $J = \sigma \dfrac{V}{l}$
➢ $J = \dfrac{I}{A}$

➢ $\dfrac{I}{A} = \sigma \dfrac{V}{l}$

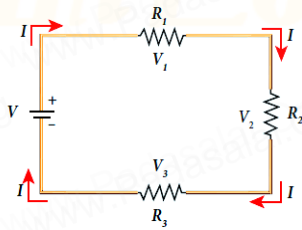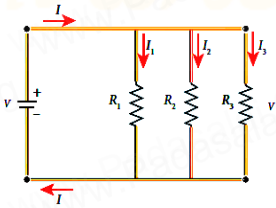➢ $V = I\left(\dfrac{l}{\sigma A}\right)$

➢ $\dfrac{l}{\sigma A} = R$, R is the resistance.

➢ The resistance is directly proportional to the length of the conductor and

➢ Inversely proportional to area of cross section.

- The macroscopic from of Ohm's law, V= IR

- From the above equation, $R = V / I$

- The unit of resistance is ohm.

- The resistance is the ratio of the potential difference across the given conductor to the current passing through the conductor.

- The graph between current versus voltage is straight line.

- Its slope is equal to the inverse of resistance R of the conductor.

3. Explain the effective resistance of a series network and parallel network.

RESISTORS IN SERIES	RESISTORS IN PARALLEL
Three resistors of resistances R_1, R_2 and R_3 are connected in series connection.	Three resistors of resistances R_1, R_2 and R_3 are connected in parallel connection.
The current I through each resistor is same	The potential difference V across each resistor is same.
$V = V_1 + V_2 + V_3$	$I = I_1 + I_2 + I_3$
$V_1 = IR_1$ $V_2 = IR_2$ $V_3 = IR_3,$	$I_1 = \dfrac{V}{R_1}$ $I_2 = \dfrac{V}{R_2}$ $I_3 = \dfrac{V}{R_3},$
$V = IR_S$	$I = \dfrac{V}{R_P}$
$IR_S = I(R_1 + R_2 + R_3)$	$\dfrac{V}{R_P} = V\left(\dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3}\right)$
$R_S = R_1 + R_2 + R_3$	$\dfrac{1}{R_P} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3}$

4. Explain the determination of internal resistance of a cell using voltmeter.

(b)
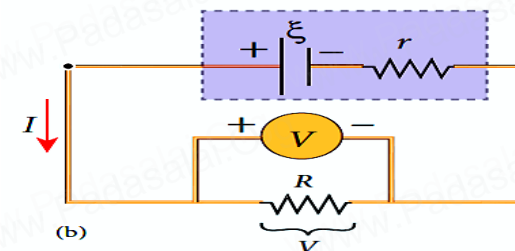
* The circuit connections are made as shown in figure.
* The emf of ξ cell is measured by connecting a high resistance voltmeter across it without connecting the external resistance R.
* Since the voltmeter draws very little current for deflection, the circuit may be considered as open..
* Hence the voltmeter reading gives the emf of the cell.
* Then external resistance R is included in the circuit and current I is established in the circuit.
* The potential difference across R is equal to potential difference across cell.
* The potential drop across R, $\boxed{V = IR}$
* Due to internal resistance r of the cell, the voltmeter reads a value V, less than the emf of cell.
* $V = \xi - Ir$
* $Ir = \xi - V$
* $r = \left(\dfrac{\xi - V}{V}\right) R$
* Since ξ, V and R are known, r of the cell can be determined.

5. State and explain Kirchoff's first law.
   Kirchoff's first law:

   The law states that the algebraic sum of the currents meeting at any junction of a circuit is zero.

   Explanation:
   - It is a statement of conservation of electric charge.
   - All charges that enter a given junction in a circuit must leave that junction.
   - Current entering the junction is taken as positive.
   - Current leaving the junction is taken as negative.
   - $I_1 + I_2 = I_3 + I_4 + I_5$
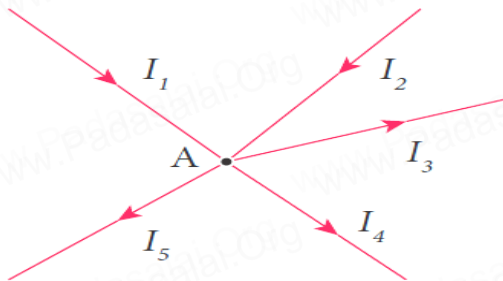
6. State and explain Kirchoff's second law.
   Kirchoff's second law:
   - The law states that in a closed circuit the algebraic sum of the products of current and resistance of each part of the circuit is equal to the to the total emf include in the circuit.
   - This law is a consequence of conservation of energy.

Explanation:
- The product of current and resistance is taken as positive when the direction of the current is followed.
- Suppose if the direction of current is opposite to the direction of the loop, then product of current and voltage across the resistor is negative.
- Kirchhoff's voltage rule has to be applied only when all currents in the circuit reach a steady state condition.

Going from a to b

$V = +IR$

Going from b to a

$V = -IR$
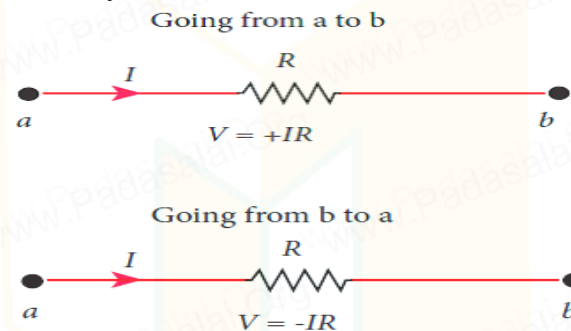
7. Obtain an expression for the balancing condition of Wheatstone's bridge.
   Principle:
   An important application of Kirchoff's rule is the Wheatstone's bridge.

   Uses:
   It is used to compare resistances and also helps in determining the unknown resistance in electrical network.

   Construction:
   * Wheatstone's network consists of resistances P, Q, R and S connected to form a closed path.

* A galvanometer G is connected between B and D.
* The battery is connected between A and C.
* G is the galvanometer resistance.
* I_G is the current through the galvanometer.
* $I_1 - I_G - I_3 = 0$
* $I_2 + I_G - I_4 = 0$
* $I_1 P + I_G G - I_2 R = 0$
* $I_1 P + I_3 Q - I_4 S - I_2 R = 0$
* $I_G = 0$
* $I_1 = I_3$
* $I_2 = I_4$
* $I_1 P = I_2 R$
* $I_1(P + Q) = I_2(R + S)$
* $\dfrac{I_1(P+Q)}{I_1 P} = \dfrac{I_2(R+S)}{I_2 R}$
* $\dfrac{P}{Q} = \dfrac{R}{S}$
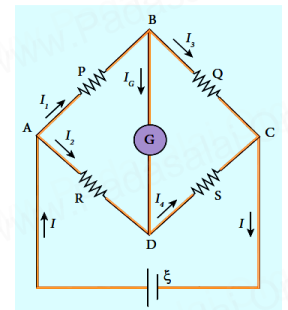
8. Describe an experiment to find unknown resistance and temperature coefficient of resistance using Metre Bridge.
   Principle:
   Metre bridge is one form of Wheatstone's bridge. It works on the principle of Kirchoff's laws.

   Construction:
   * It consists of thick strips of copper, of negligible resistance, fixed to a wooden board.

* G_1 and G_2 are the two gaps between these strips.
* AB is a uniform manganin wire of length 1 metre.
* The temperature coefficient of the wire is low.
* The wire is stretched along a metre scale and its ends are soldered to two copper strips.
* P is an unknown resistance connected in the gap G_1.
* Q is a standard resistance connected in the gap G_2.
* A metal jockey J is connected to B through a galvanometer (G), and high resistance (HR) and it can make contact at any point on the wire AB.
* Across the two ends of the wire, a Leclanche cell and a key are connected.

Working:

* Adjust the position of the jockey on metre bridge wire so that the galvanometer shows zero deflection.
* Let the point be J.
* AJ and JB of the wire now replace the resistances R and S of Wheatstone's bridge.

* $\dfrac{P}{Q} = \dfrac{R}{S} = \dfrac{R' \, AJ}{R' \, JB}$
* $\dfrac{P}{Q} = \dfrac{AJ}{JB} = \dfrac{l_1}{l_2}$
* $P = Q\dfrac{l_1}{l_2}$

Conclusion:

* The bridge wire is soldered at the ends of the copper strips.

* Due to imperfect contact, some resistance might be introduced at the contact.
* These are called end resistances.
* This error can be eliminated, if another ser of readings are taken with P and Q interchanged and the average value of P is found.
* Resistance, $R = \rho\dfrac{l}{A}$
* **Resistivity:** $\rho = P\dfrac{\pi r^2}{L}$,

Metre Scale
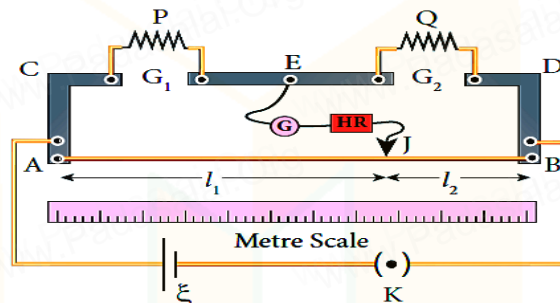
9. Explain the principle of potentiometer.
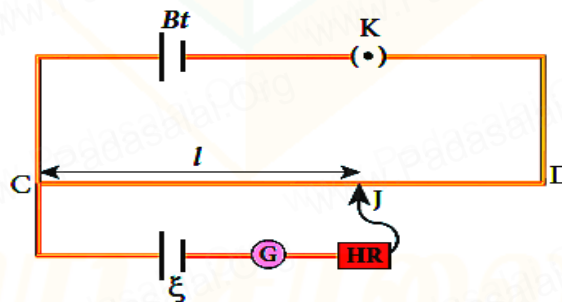
* The potentiometer is an instrument to measure the potential differences.
* It consists of a ten metre long uniform wire of manganin stretched in ten segments.

* A battery Bt is connected between the ends C and D of a potentiometer wire through a key K.
* A steady current I flows through the wire.
* This forms the primary circuit.
* A primary cell ξ is connected in series with the positive terminal C of the potentiometer, a galvanometer, a high resistance and jockey.
* This forms the secondary circuit.
* If the potential difference between C and J is equal to the emf of the cell, no current flows through the galvanometer. It shows zero deflection.
* CJ is called the balancing length.
* $\boxed{CJ = Irl}$
* r is the resistance per unit length of the potentiometer wire and I is the current in the primary circuit.
* $\xi = Irl$
* $\xi \propto l$
* ***Emf of the cell is directly proportional to the balancing length.***
* This is the principle of potentiometer.

10. Explain the comparison of emfs of two given cells using potentiometer.

Principle: *Emf of the cell is directly proportional to its balancing length.*

Construction:

* CD is the potentiometer wire connected in series with a battery (Bt), key (K), rheostat (Rh).
* This forms the primary circuit.

- The end C of potentiometer is connected to the terminal M of a DPDT switch.
- The terminal N is connected to the jockey (J) through a galvanometer (G) and high resistance (HR).
- The cell of emf E_1 is connected between M_1 and N_1 of the DPDT switch.
- CJ The cell of emf E_2 is connected between M_2 and N_2 of the DPDT switch.
- This forms the secondary circuit.

Working:

- The DPDT switch is pressed towards E_1 so that it is included in the circuit.
- The balancing length l_1 is determined.
- The DPDT switch is pressed towards E_2.
- The balancing length l_2 is determined.
- Let I be the current flowing through the primary circuit and r be the resistance per unit length of the potentiometer wire.

- $\xi_1 = Irl_1$

- $\xi_2 = Irl_2$

- $\dfrac{\xi_1}{\xi_2} = \dfrac{l_1}{l_2}$
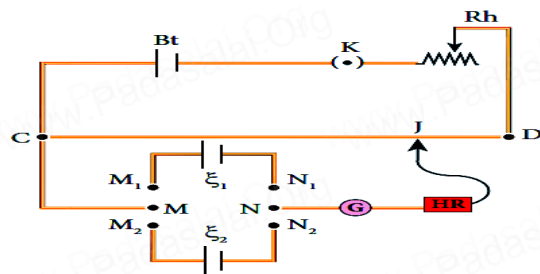
11. Explain series and parallel combination of cells.

Cells in series connection	Cells in parallel connection
Total emf $= n\xi$	Total emf $= \xi$
Total resistance $= nr + R$	Total resistance $= R + \dfrac{r}{n}$
$I = \dfrac{n\xi}{nr + R}$	$I = \dfrac{n\xi}{r + nR}$
If $r \ll R$,	If $r \gg R$,
$I = \dfrac{n\xi}{R} \approx nI_1$	$I = \dfrac{n\xi}{r} = nI_1$
If $r \gg R$,	If $r \ll R$,
$I = \dfrac{\xi}{r}$	$I = \dfrac{\xi}{R}$

12. How will you determine the internal resistance of a cell using potentiometer?

* The circuit connections are made as shown in the figure.
* A resistance box R and key K_2 are connected across the cell ξ.
* With key K_1 open, the balancing point J is obtained and balancing length CJ $= l_1$ is measured.
* Since the cell is in open circuit,
* $\xi \propto l_1$ ----------------- (1)
* A suitable resistance in the resistance box is included and the key K_2 is closed.
* r is the internal resistance of the cell.
* $I = \dfrac{\xi}{R+r}$
* $V = IR = \dfrac{\xi R}{R+r}$
* $V \propto l_2$ ---------------(2)

* $\dfrac{\xi R}{R+r} \propto l_2$

* $\dfrac{(1)}{(2)} \Rightarrow \dfrac{\xi}{V} \propto \dfrac{l_1}{l_2}$

* $\dfrac{R+r}{R} = \dfrac{l_1}{l_2}$

* $r = R\left(\dfrac{l_1 - l_2}{l_2}\right)$
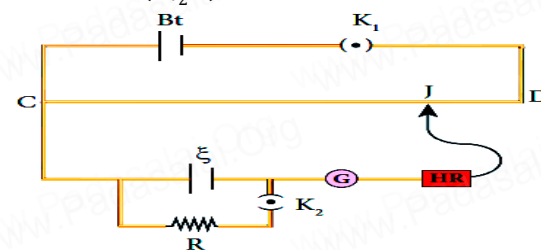
13. What are the applications of Seebeck effect?
  * Seebeck effect is used in thermoelectric generators.
  * Thers thermoelectric generators are used in power plants to convert waste heat into electricity.
  * This effect is utilized in automobiles as automotive thermoelectric generators.
  * Seebeck effect is used in thermocouples and thermopiles to measure the temperature difference between the two objects.

3. MAGNETISM AND MAGNETIC EFFECTS OF ELECTRIC CURRENT

Two mark questions:

1. What is magnetic declination?
   The angle between magnetic meridian at a point and geographical meridian is called the magnetic declination (D).

2. What is dip or magnetic inclination?
   The angle subtended by the Earth's total magnetic field with the horizontal direction in the magnetic meridian is called dip or magnetic inclination (I).

3. Define magnetic dipole moment.
   * The magnetic dipole moment is defined as the product of its pole strength and magnetic length.
   * It is a vector quantity.
   * $p_m = q_m \, 2l$
   * Its unit is A m^2

4. Define magnetic field.
   * The magnetic field $\vec{B}$ at appoint is defined as a force experienced by the bar magnet of unit pole strength.
   * $\vec{B} = \dfrac{\vec{F}}{q_m}$
   * Its unit is N A^{-1} m^{-1}

5. Define magnetic flux.
   * The number of magnetic field lines crossing a given area is defined as magnetic flux Φ_B
   * It is a scalar quantity.
   * Its SI unit is Wb.

6. Define magnetic flux density.
   * The magnetic flux density is defined as the number of magnetic field lines crossing unit area kept normal to the direction of line of force.
   * Its unit is Wb m^{-2} or tesla.

7. State Coulomb's inverse square law in magnetism.
   * The force of attraction or repulsion between two magnetic poles is
   * directly proportional to the product of their pole strengths and
   * inversely proportional to the square of the distance between them.
   * $\vec{F} \propto \dfrac{q_{m_A} q_{m_B}}{r^2} \hat{r}$

8. State tangent's law
   When a magnetic needle or magnet is freely suspended in two mutually perpendicular uniform magnetic fields, it will come to rest in the direction of the resultant of the two fields.

9. What is magnetizing field?
   * The magnetic field which is used to magnetize a sample is called the magnetizing field.
   * It is a vector quantity.
   * Its unit is A m^{-1}

10. What is magnetic permeability?
    The magnetic permeability is the measure of ability of the material to allow the passage of magnetic field lines through it.

11. Define relative permeability.
    The relative permeability is defined as the ratio between absolute permeability of the medium to the permeability of free space.

12. What is intensity of magnetization?
    * The net magnetic moment per unit volume of the material is known as intensity of magnetization.
    * It is a vector quantity.
    * Its unit is A m^{-1}

13. Define magnetic susceptibility.
    * It is defined as the ratio of the intensity of magnetization $\vec{M}$ induced in the material due to the magnetizing field $\vec{H}$.
    * $\chi_m = \dfrac{M}{H}$

14. State Curie's law
    * As temperature is increased, thermal vibration will upset the alignment of magnetic dipole moments.

- Therefore, the magnetic susceptibility decreases with increase in temperature.
- $\chi_m = \frac{C}{T}$ --- This is Curie's law.

15. State Curie - Weiss law
- As temperature increases, the ferromagnetism decreases due to the increased thermal agitation of the atomic dipoles.
- At a particular temperature, ferromagnetic material becomes paramagnetic.
- This temperature is known as Curie temperature T_c.
- $\chi_m = \frac{C}{T - T_C}$ ---- This Curie – Weiss law.

16. Define remanence or retentivity.

It is defined as the ability of the materials to retain the magnetism in them even magnetizing field vanishes.

17. What is coercivity?

The magnitude of the reverse magnetizing field for which the residual magnetism of the material vanishes is called its coercivity.

18. What is hysteresis?

The phenomenon of lagging of magnetic induction behind the magnetizing field is called hysteresis.

19. State right hand thumb rule.

If we hold the current carrying conductor in our right hand such that the thumb points in the direction of current flow, then the fingers encircling the wire points in the direction of the magnetic field lines produced.

20. State Maxwell's right hand cork screw rule.

The law states that if we rotate a right – handed screw using a screw driver, then the direction of current is same as the direction in which screw advances and the direction of rotation of the screw gives the direction of the magnetic field.

21. State Biot – Savart law

Biot – Savart law states that the magnetic induction dB at point due to the element of length dl is
- directly proportional to the current (I)
- directly proportional to the length of the element (dl)
- directly proportional to the sine of the angle between $d\vec{l}$ and $\hat{r}$
- inversely proportional to the square of the distance between the point P and the element $d\vec{l}$
- $$dB \propto \frac{Idl \sin \theta}{r^2}$$

22. State Ampere's circuital law.
- The line integral of magnetic field over a closed loop is μ_0 times net current enclosed by the loop.
- $\oint_C \vec{B}.\overrightarrow{dl} = \mu_o I_{enclosed}$

23. Define one tesla
- The strength of the magnetic field is one tesla if unit charge moving in it with unit velocity experiences unit force.
- $1\ T = 1\ N\ A^{-1}\ m^{-1}$

24. What are the limitations of cyclotron?
- The speed of the ion is limited.
- Electron cannot be accelerated
- Uncharged particles cannot be accelerated.

25. State Fleming's left hand rule.

Stretch forefinger, the middle finger and the thumb of the left hand such that they are in mutually perpendicular directions, If
- forefinger points the direction of magnetic field,
- the middle finger points in the direction of the electric current, then
- thumb will point in the direction of the force experienced by the conductor.

26. Define one ampere.

One ampere is defined as that current when it is passed through each of the two infinitely long parallel straight conductors kept at a distance of one meter apart in vacuum causes each conductor to experience a force of 2×10^{-7} N m^{-1} of the conductor.

27. Define figure of merit of a galvanometer.

It is defined as the current which produces a deflection of one scale division in the galvanometer.

28. Define current sensitivity of galvanometer.

It is defined as the deflection produced per unit current flowing through it.

29. How can we increase the current sensitivity of a galvanometer?
   - By increasing the number of turns N
   - By increasing the magnetic induction B
   - By increasing the area of the coil A
   - By decreasing the couple per unit twist of the suspension sire K.

30. Define voltage sensitivity of a galvanometer.
   It is defined as the deflection produced per unti voltage applied across it.

3 MARKS

1. What are the properties of magnet?
   * A freely suspended bar magnet will always point along the north – south direction.
   * A magnet attracts another magnet or magnetic substances towards itself.
   * The attractive force is maximum near the end of the bar magnet.
   * When a bar magnet is dipped into iron filling, they cling to the ends of the magnet.
   * When a magnet is broken into pieces, each piece behaves like a magnet with poles at its ends.
   * Two poles of a magnet have pole strength equal to one another.
   * The length of the bar magnet is called geometrical length
   * The length between two poles in a bar magnet is called magnetic length.
   * Magnetic length is always slightly smaller than geometrical length.
   * The ratio of magnetic length and geometrical length is 5/6.

2. What are the properties of magnetic field lines?
   1. Magnetic field lines are continuous closed curves.
   2. The direction of magnetic field lines is from North pole to South pole outside the magnet and South pole to North pole inside the magnet.
   3. The direction of magnetic field at any point on the curve is known by drawing tangent to the magnetic line of force at the point.
   4. Magnetic field lines never intersect each other.
   5. The magnetic field is strong where magnetic field lines crowd and weak where magnetic field lines thin out.
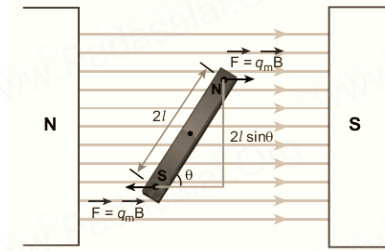
3. Differentiate Uniform and Non-uniform magnetic fields.

Uniform Magnetic field	Non – Uniform magnetic field
Magnetic field is said to be uniform if it has same magnitude and direction at all the points in a given region.	Magnetic field is said to be non – uniform if the magnitude or direction or both varies at all points

4. Obtain an expression for torque acting on a bar magnet when it is placed in a uniform magnetic field.
   - $\vec{\tau} = \overrightarrow{ON} \times \vec{F}_N + \overrightarrow{OS} \times \vec{F}_S$
   - $\vec{\tau} = \overrightarrow{ON} \times (q_m\vec{B}) + \overrightarrow{OS} \times (-q_m\vec{B})$
   - $\tau = (ON)(q_mB)\sin\theta + (OS)(q_mB)\sin\theta$
   - $\tau = 2l \times q_mB\sin\theta$
   - $\tau = p_mB\sin\theta \qquad (\because p_m = 2l \times q_m)$

- $\vec{\tau} = \vec{p} \times \vec{B}$

5. Obtain an expression for potential energy of a bar magnet when it is placed in a uniform magnetic field.

$$W = \int_{\theta'}^{\theta} \tau_{ext}\, d\theta$$

$\vec{\tau}_B = \vec{p}_m \times \vec{B}$

$\tau_{ext} = \tau_B = |\vec{p}_m \times \vec{B}| = p_mB\sin\theta$

$$W = \int_{\theta'}^{\theta} p_mB\,sin\,\theta\, d\theta$$

$W = p_mB\left(cos\,\theta' - cos\,\theta\right)$
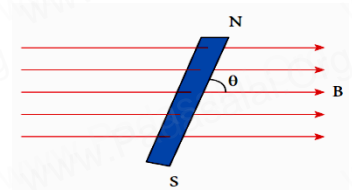
$U = p_mB(\cos\theta' - \cos\theta)$

$If\ \theta' = 90°,\ U = -p_mB\cos\theta$

$U = -\vec{p}_m.\vec{B}$

$If\ \theta = 0°,\ U = -p_mB$

$If\ \theta = 180°,\ U(\theta) = p_mB$

6. Compare the properties of Dia, Para and Ferro magnetic materials.

Magnetic properties	Dia magnetic materials	Para magnetic materials	Ferro magnetic materials
Magnetic susceptibility	negative	positive and small	positive and large
Relative permeability	slightly less than unity	greater than unity	large
When placed in a magnetic field	magnetic field lines are repelled by these materials	magnetic field lines are attracted into these materials	magnetic field lines are strongly attracted into these materials
Temperature	susceptibility is independent of temperature	susceptibility is inversely proportional to temperature.	susceptibility is inversely proportional to temperature.

7. Differentiate between soft and hard ferromagnetic materials.

Properties	Soft ferromagnetic materials	Hard ferromagnetic materials
When external field is removed	Magnetisation disappears	Magnetisation persists
Area of the loop	Small	Large
Retentivity	Low	High
Coercivity	Low	High
Susceptibility	High	Low
Permeability	High	Low
Hysteresis loss	Less	More
Uses	Solenoid core, transformer core, electromagnets	Permanent magnets
Examples	Soft iron, Mumetal, Stalloy	Steel, Alnico, Lodestone

8. What are the applications of hysteresis loop?

Permanent magnets:
- The materials with high retentivity, high coercivity and high permeability are suitable for making permanent magnets.
- Example: Steel and Alnico

Electromagnets:
- The materials with high initial permeability, low retentivity, low coercivity and thin hysteresis loop with smaller area are preferred to make electromagnets.
- Examples: Soft iron and Mumetal (Nickel Iron alloy)

Core of the transformer:
- The materials with high initial permeability, large magnetic induction and thin hysteresis loop with smaller area are needed to design transformer cores.
- Examples: soft iron

9. Differentiate between Coulomb's law and Biot – Savart law.

Coulomb's law	Biot – Savart law
Produced by a scalar source	Produced by a vectos source
Produced by an electric charge q	Produced by a current element $Id\vec{l}$
It is directed along the position vector joining the source and the point at which the field is calculated	It is directed perpendicular to the position vector $\vec{r}$ and the current element $Id\vec{l}$
Does not depend on angle	Depends on the angle between the position vector $\vec{r}$ and the current element $Id\vec{l}$

10. What are the special features of magnetic Lorentz force?

- $\vec{F}_m = q(\vec{v} \times \vec{B})$
- $\vec{F}_m$ is directly proportional to the magnetic field $\vec{B}$
- $\vec{F}_m$ is directly proportional to the velocity $\vec{v}$
- $\vec{F}_m$ is directly proportional to sine of the angle between the velocity and magnetic field
- $\vec{F}_m$ is directly proportional to the magnitude of the charge q
- The direction of $\vec{F}_m$ is always perpendicular to $\vec{v}$ and $\vec{B}$
- The direction of force on negative charge is opposite to the direction of force on positive charge.
- If velocity $\vec{v}$ of the charge q is along $\vec{B}$, then $\vec{F}_m$ is zero.

5 MARKS

1. Obtain the magnetic induction at a point on the axial line of a bar magnet.
   - ➤ NS is a bar magnet.
   - ➤ C is the point at a distance r from the midpoint of the bar magnet on its axial line.
   - ➤ $\vec{F}_N = k \frac{q_m}{(r-l)^2} \hat{\imath}$
   - ➤ $\vec{F}_S = -k \frac{q_m}{(r+l)^2} \hat{\imath}$
   - ➤ $\vec{F}_{tot} = \vec{F}_N + \vec{F}_S$

- ➤ $\vec{F}_{tot} = k q_m \left[\frac{1}{(r-l)^2} - \frac{1}{(r+l)^2} \right] \hat{\imath}$
- ➤ $\vec{F}_{tot} = k q_m \left[\frac{4rl}{(r^2-l^2)^2} \right] \hat{\imath}$
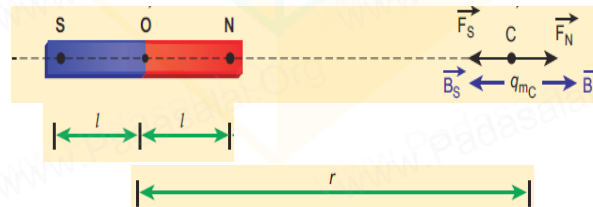- ➤ If $r \gg l$, $(r^2 - l^2)^2 = r^4$
- ➤ $\vec{F}_{tot} = k \left(\frac{4l q_m}{r^3} \right) \hat{\imath}$ $(r \gg a)$
- ➤ $q_m 2l = p_m$, $k = \frac{\mu_0}{4\pi}$
- ➤ $\vec{F}_{tot} = k \left(\frac{2p_m}{r^3} \right) \hat{\imath}$
- ➤ At point C, $\vec{F}_{tot} = \vec{B}_{tot}$
- ➤ $\vec{B}_{tot} = \frac{\mu_0}{4\pi} \frac{2\vec{p}_m}{r^3}$ $(\vec{p}_m = p_m \hat{\imath})$

2. Obtain the magnetic induction at a point on the equatorial line of a bar magnet.
   - NS is a bar magnet.
   - C is the point at a distance r from the midpoint of the bar magnet on its axial line.
   - $\vec{F}_N = k \frac{q_m}{(r^2+a^2)}$

- $\vec{F}_S = -k \frac{q_m}{(r^2+a^2)}$
- $\vec{F}_{tot} = -\left(\vec{F}_N \cos\theta + \vec{F}_s \cos\theta \right) \hat{\imath}$
- $\vec{F}_{tot} = -2\vec{F}_N \cos\theta \, \hat{p}$ $(\because F_N = F_S)$
- $\vec{F}_{tot} = -k \frac{2q_m \cos\theta}{(r^2+l^2)} \hat{\imath}$
- $\vec{F}_{tot} = -k \frac{2q_m l}{(r^2+l^2)^{\frac{3}{2}}} \hat{\imath} \left(\because \cos\theta = \frac{l}{\sqrt{r^2+l^2}} \right)$
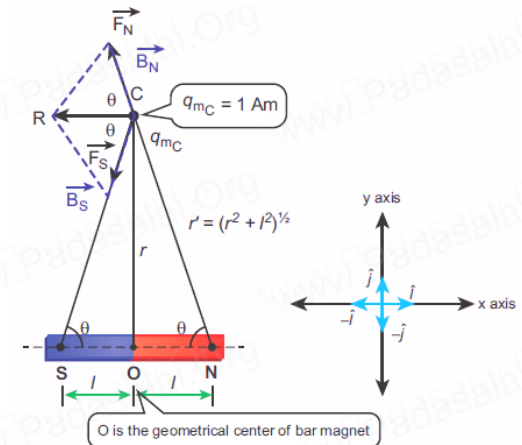- $\vec{F}_{tot} = -k \frac{\vec{p}_m}{(r^2+a^2)^{\frac{3}{2}}}$ $(\because \vec{p}_m = 2q_m l\hat{\imath})$
- If $r \gg l$
- $\vec{F}_{tot} = -k \frac{\vec{p}_m}{r^3}$
- At point C, $\vec{F}_{tot} = \vec{B}_{tot}$
- $\vec{B}_{tot} = -\frac{\mu_0}{4\pi} \frac{\vec{p}_m}{r^3}$ $(\because k = \frac{\mu_0}{4\pi})$

O is the geometrical center of bar magnet

3. Deduce the relation for the magnetic induction at a point due to an infinitely long straight conductor carrying current.
   * Consider a long straight wire NM with current I flowing from N to M.
   * Let P be the point at a distance a from the point O.
   * Consider an element of length $d\vec{l}$ of the wire at a distance l form point O and $\vec{r}$ be the vector joining the element $d\vec{l}$ with the point P.
   * Let θ be the angle between $d\vec{l}$ and $\vec{r}$
   * Then, the magnetic field at P due to this element is
   * $dB = k \frac{Id\vec{l}}{r^2} \sin\theta$

   * $\tan(\pi - \theta) = \frac{a}{l}$

   * $l = -a \cot\theta$

   * $r = a \, cosec \, \theta$

   * $dl = a \, cosec^2 \, \theta \, d\theta$

   * $\frac{dl}{r^2} = \frac{d\theta}{a}$

   * $dB = kI \left(\frac{\sin\theta \, d\theta}{a} \right)$

   * $dB = \frac{\mu_0 I}{4\pi a} \sin\theta \, d\theta \quad \left(\because k = \frac{\mu_0}{4\pi} \right)$

   * $d\vec{B} = \frac{\mu_0 I}{4\pi a} \sin\theta \, d\theta \, \hat{n}$
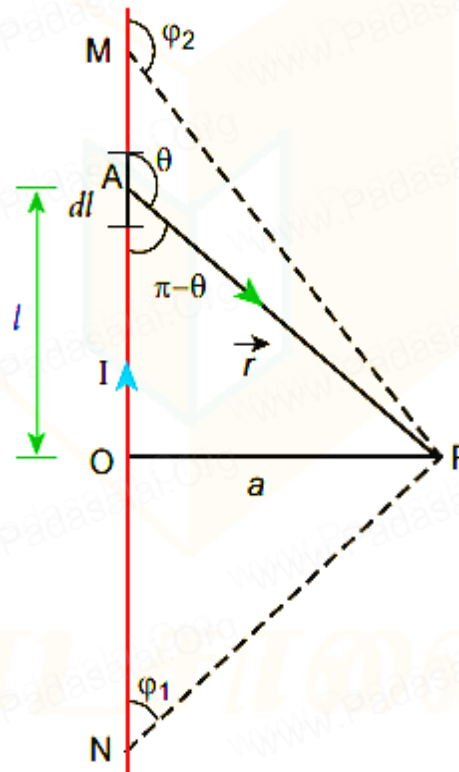
   * $\vec{B} = \frac{\mu_0 I}{4\pi a} \int_{\varphi_1}^{\varphi_2} \sin\theta \, d\theta \, \hat{n}$

   * for infinitely long straight wire
   * $\varphi_1 = 0, \quad \varphi_2 = \pi$

   * $\vec{B} = \frac{\mu_0 I}{4\pi a} (\cos\varphi_1 - \cos\varphi_2)\hat{n}$

   * $\vec{B} = \frac{\mu_0 I}{2\pi a}\hat{n}$

4. Deduce the relation for the magnetic induction at a point along the axis of a circular coil carrying current.
   * Consider a current carrying circular loop of radius R.
   * Let I be the current flowing through the wire in the direction as shown in the figure.
   * The magnetic field at a point P on the axis of the circular coil at a distance z from its center of the coil O.
   * Let $\vec{r}$ be the vector joining the current element at C to the point P.
   * $PC = PD = r = \sqrt{R^2 + z^2}$

   * $\angle CPO = \angle DPO = \theta$

   * $d\vec{B} = \frac{\mu_0}{4\pi a} \frac{Id\vec{l} \times \hat{r}}{r^2}$
   * The magnitude of magnetic field due to current element $Id\vec{l}$ at C and D are equal because of equal distance from the coil.
   * The magnetic field due to each current element is resolved into two components.
   * $dB \sin\theta$ along y – direction
   * $dB \cos\theta$ along z – direction.
   * Horizontal components of each current element cancel out while the vertical components alone contribute to total magnetic field at the point P.
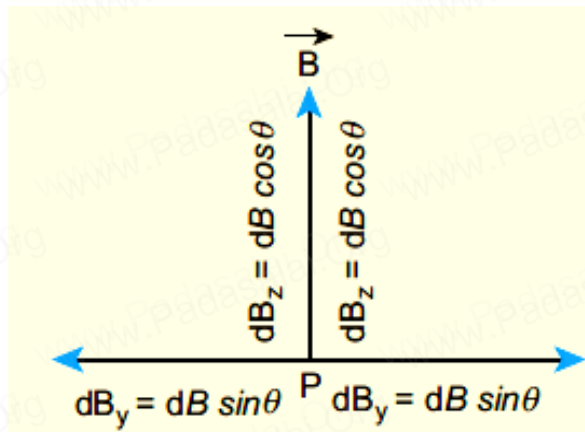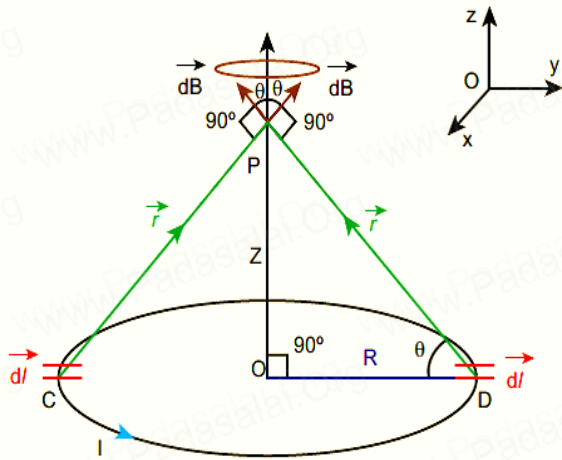
   * $\vec{B} = \int dB = \frac{\mu_0 I}{4\pi a} \int dB \cos\theta \, \hat{k}$

   * $\vec{B} = \frac{\mu_0 I}{4\pi a} \int \frac{dl}{r^2} \cos\theta \, \hat{k}$

* $\cos\theta = \dfrac{R}{(\sqrt{R^2+z^2})}$

* $r^2 = R^2 + z^2$

* $\vec{B} = \dfrac{\mu_0 I}{2a} \dfrac{R^2}{(R^2+z^2)^{\frac{3}{2}}} \hat{k}$

5. Find the magnetic induction due to a long straight conductor using Ampere's circuital law.
   * Consider a straight conductor of infinite length carrying current I and the direction of magnetic field lines shown in figure.
   * Since the wire is geometrically cylindrical in shape and symmetrical about its axis,
   * We construct an Amperian loop in the form of a circular shape at a distance r from the centre of the conductor.
   * From Ampere's law, $\oint_C \vec{B}\,.\,d\vec{l} = \mu_0 I$
   * The angle between magnetic field and vector and line element is zero.

   * $\oint_C B\,dl = \mu_0 I$

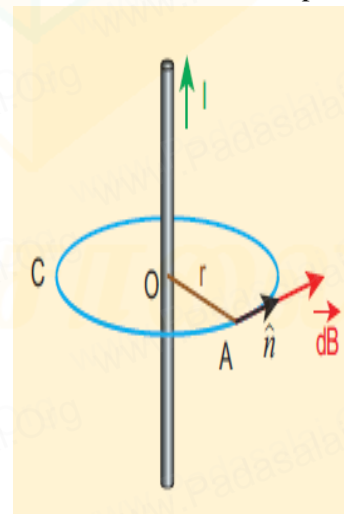   * Due to symmetry, the magnitude of the magnetic field is uniform over the Amperian loop.

   * $B \oint_C dl = \mu_0 I$

   * $\oint_C dl = 2\pi r$

   * $B.\,2\pi r = \mu_0 I$

   * $B = \dfrac{\mu_0 I}{2\pi r}$

   * $\vec{B} = \dfrac{\mu_0 I}{2\pi r}\hat{n}$

6. Find the magnetic induction due to a long current carrying solenoid using Ampere's circuital law.
   * Consider a solenoid of length L and having number of turns N.
   * The diameter of the solenoid is assumed to be much smaller when compared to its length and the coil is wound very closely.
   * In order to calculate the magnetic field at any point inside the solenoid, we use the Ampere's circuital law.
   * $\oint_C \vec{B}\,.\,d\vec{l} = \mu_0 I$
   * $\oint_C \vec{B}.\,d\vec{l} = \int_a^b \vec{B}.\,d\vec{l} + \int_b^c \vec{B}.\,d\vec{l} + \int_c^d \vec{B}.\,d\vec{l} + \int_d^a \vec{B}.\,d\vec{l}$
   * The elemental lengths along bc and da are perpendicular to the magnetic field.
   * $\int_b^c \vec{B}.\,d\vec{l} = \int_d^a \vec{B}.\,d\vec{l} = 0$
   * Outside the solenoid, $\int \vec{B}.\,d\vec{l} = 0$
   * For the path along ab, the integral is
   * $\int_a^b \vec{B}.\,d\vec{l} = B \int_a^b dl$
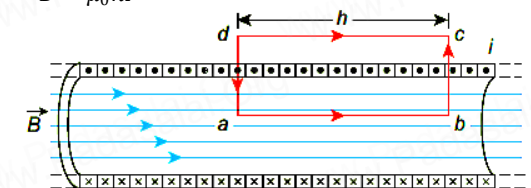   * $\int_a^b dl = L$
   * $\int_a^b \vec{B}.\,d\vec{l} = BL$
   * Let NI be the current passing through the solenoid of N
   * $\int_a^b \vec{B}.\,d\vec{l} = \mu_0 NI$
   * $B = \dfrac{\mu_0 NI}{L}$
   * $\dfrac{N}{L} = n$
   * $B = \mu_0 nI$

7. Find the magnetic induction at a point inside and outside of a current carrying toroid using Ampere's circuital law.

* A solenoid is bent in such a way its ends are joined together to form a closed ring shape is called a toroid.
* The magnetic field has constant magnitude inside the toroid whereas in the interior region and exterior region the magnetic field is zero.

Open space interior to the toroid:

* $L_1 = 2\pi r_1$
* $\oint_{loop1} \vec{B}_P . \vec{dl} = \mu_0 I_{enclosed}$
* $I_{enclosed} = 0$
* $\oint_{loop1} \vec{B}_P . \vec{dl} = 0$
* $\vec{B}_P = 0$

Open space exterior to the toroid:

➢ $L_3 = 2\pi r_3$
➢ $\oint_{loop3} \vec{B}_Q . \vec{dl} = \mu_0 I_{enclosed}$
➢ $I_{enclosed} = 0$

➢ $\oint_{loop3} \vec{B}_Q . \vec{dl} = 0$
➢ $\vec{B}_Q = 0$

Inside the toroid:

➢ $L_2 = 2\pi r_2$

➢ $\oint_{loop2} \vec{B}_S . \vec{dl} = \mu_0 I_{enclosed}$

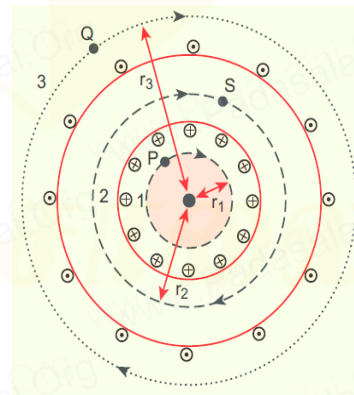➢ $I_{enclosed} = NI$

➢ $\oint_{loop2} \vec{B}_S . \vec{dl} = \mu_0 NI$

➢ $\oint_{loop2} \vec{B}_S . \vec{dl} = B_S 2\pi r_2$

➢ $B_S 2\pi r_2 = \mu_0 NI$

➢ $B_S = \dfrac{\mu_0 NI}{2\pi r_2}$

➢ $n = \dfrac{N}{2\pi r_2}$

➢ $B_S = \mu_0 nI$

8. Explain the construction and working of a cyclotron.

* Cyclotron is used to accelerate the charged particles to gain large kinetic energy.
* It is also called as high energy accelerator.

Principle:

When a charged particle moves normal to the magnetic field, it experiences magnetic Lorentz force.

Construction:

* The schematic diagram of cyclotron is shown in figure.
* The particles are allowed to move in between two semi-circular metal containers called Dees.
* Dees are enclosed in an evacuated chamber and it is kept in a region with uniform magnetic field controlled by an electromagnet.
* The direction of magnetic field is normal to the plane of the Dees.
* The two Dees are kept separated with a gap and the source S is placed at the center in the gap between the Dees.
* Dees are connected to high frequency alternating potential difference.

Working:

* Let us assume that the ion ejected from source S is positively charged.

* As soon as ion is ejected, it is accelerated towards a Dee which has negative potential at that time.
* Since the magnetic field is normal to the plane of the Dees, the ion undergoes circular path.
* After one semi – circular path in Dee -1, the ion reaches the gap between Dees.
* At this time, the polarities of the Dees are reversed so that the ion is now accelerated towards Dee – 2 with a greater velocity.
* For this circular motion, the centripetal force of the charged particle q is provided by Lorentz force.
* $\frac{mv^2}{r} = qvB$

* $r = \frac{mv}{qB}$

* $r \propto v$
* From the above equation, the increase in velocity increases the radius of circular path.
* This process continues and hence the particle undergoes spiral path of increasing radius.
* Once it reaches near the edge, it is taken out either the help of deflector plate and allowed to hit the target T.
* Very important condition in cyclotron operation is the resonance condition.
* It happens when the frequency at which the positive ion circulates in the magnetic field

must be equal to the constant frequency of the electrical oscillator.

* $\int_{osc} = \frac{Bq}{2\pi m}$

* $T = \frac{2\pi m}{Bq}$

* $KE = \frac{1}{2} mv^2 = \frac{B^2 q^2 r^2}{2m}$

Limitations of Cyclotron:

* the speed of the ion is limited
* electron cannot be accelerated
* uncharged particles cannot be accelerated

9. Obtain an expression for the force on a current carrying conductor placed in a magnetic field.
   * When a current carrying conductor is placed in a magnetic field, the force experienced by the wire is equal to the sum of Lorentz forces on the individual charge carriers in the wire.
   * Consider a small segment of wire of length dl, with cross-sectional area A and current I.
   * The free electrons drift opposite to the direction of current.
   * $I = neAv_d$
   * $\vec{F} = -e(\vec{v}_d \ X \ \vec{B})$
   * $n = \frac{N}{V}$
   * $N = nV = nAdl$

* $d\vec{F} = -enAdl(\vec{v}_d \ X \ \vec{B})$

* $I\vec{dl} = -enA\vec{v}_d dl$
* $d\vec{F} = (I\vec{dl} \ X \ \vec{B})$
* $\vec{F} = (I\vec{l} \ X \ \vec{B})$
* $F = BIl \sin\theta$

Special cases:
* If $\theta = 0°$, $F = 0$
* If $\theta = 90°$, $F = BIl$

Fleming's left hand rule:

Stretch forefinger, the middle finger and the thumb of the left hand such that they are in mutually perpendicular directions, If
* forefinger points the direction of magnetic field,
* the middle finger points in the direction of the electric current, then
* thumb will point in the direction of the force experienced by the conductor.

10. Explain the principle, construction and working of a moving coil galvanometer.

* Moving coil galvanometer is a device which is used to indicate the flow of current in an electrical circuit.

Principle:

When a current carrying loop is placed in a uniform magnetic field it experiences a torque.

Construction:

* A moving coil galvanometer consists of a rectangular coil PQRS of insulated thin copper wire.
* The coil contains a large number of turns wound over a light metallic frame.
* A cylindrical soft – iron core is placed symmetrically inside the coil.
* The rectangular coil is suspended freely between two pole pieces of a horse – shoe magnet.
* The upper end of the rectangular coil is attached to one end of fine strip of phosphor bronze and the lower end of the coil is connected to a hair spring which is also made up of phosphor bronze.
* In a fine suspension strip W, a small plane mirror is attached to order to measure the deflection of the coil with the help of lamp and scale arrangement.
* The other end of the mirror is connected to a torsion head T.

* In order to pass electric current through the galvanometer, the suspension strip W and the spring S are connected to terminals.

Working:

* Consider a single turn of the rectangular coil PQRS whose length be l and breadth b
* PQ = RS = l and QR = SP = b
* Let I be the electric current flowing through the rectangular coil PQRS.
* The horse- shoe magnet has semi-spherical magnetic poles which produces a radial magnetic field.
* Due to this radial field, the sides QR and SP are always parallel to the B – field and experience no force.
* The sides PQ and RS are always perpendicular to the B – field and experience force and due to this torque is produced.
* $\tau = bF = bBIl = (lb)BI = ABI$
* $A = lb$
* For N turns, $\tau = NABI$
* Due to this deflecting torque, the coil gets twisted and restoring torque is developed.
* $\tau = K\theta$
* K is torsional constant of the spring.
* At equilibrium, $NABI = K\theta$
* $I = \dfrac{K}{NAB}\theta$
* $I = G\theta$
* $G = \dfrac{K}{NAB}$ is the figure of merit of the galvanometer.
* Current sensitivity: $I_S = \dfrac{\theta}{I} = \dfrac{1}{G}$

* Voltage sensitivity: $V_S = \dfrac{}{V} = \dfrac{}{IR_g} = \dfrac{}{GR_g} = \dfrac{}{R_g}$
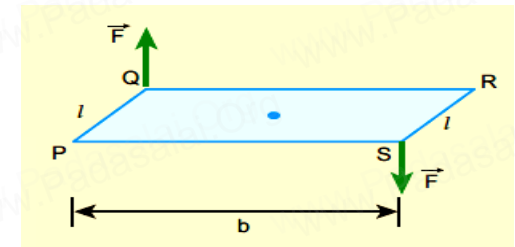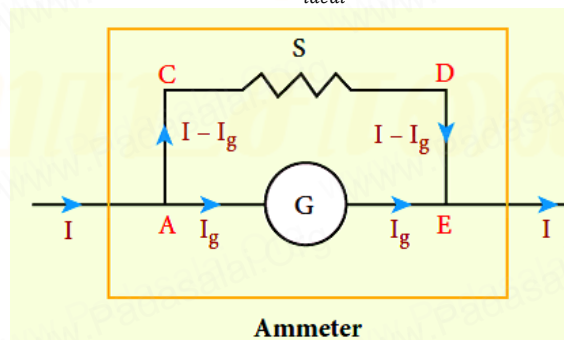

11. How will you convert a galvanometer into an ammeter?

* Ammeter is an instrument used to measure current flowing in the electrical circuit.
* The ammeter must offer low resistance such that it will not change the current passing through it.
* SO ammeter is connected in series to measure the circuit current.
* A galvanometer is converted into an ammeter by connecting a low resistance in parallel with the galvanometer.
* This low resistance is called shunt resistance S.
* The scale is now calibrated in ampere and the range of ammeter depends on the values of the shunt resistance.
* Let I be the current passing through the circuit.
* When current I reaches the junction A, it divides into two components.

- Let I_g be the current passing through the galvanometer of resistance R_g through a path AGE
- The remaining current ($I - I_g$) passes along the path ACDE through shunt resistance S.
- The value of shunt resistance is so adjusted that current I_g produces full scale deflection in the galvanometer.
- The potential difference across galvanometer is same as the potential difference across shunt resistance.
- $V_g = V_S$
- $I_g R_g = (I - I_g) S$
- $S = \frac{I_g}{(I-I_g)} R_g$
- $I_g = \left(\frac{S}{S+R_g}\right) I$
- $I_g \propto I$
- Since, the deflection in the galvanometer is proportional to the current passing through it.
- $\theta = \frac{I_g}{G}$
- $\theta \propto I_g$
- $\theta \propto I$
- So, the deflection in the galvanometer measures the current I passing through the circuit.
- Shunt resistance is connected in parallel to galvanometer.

- Therefore, resistance of ammeter can be determined by computing the effective resistance, which is
- $R_{eff} = \frac{R_g S}{R_g + S} = R_a$
- The Shunt resistance is a very low resistance and the ratio $\frac{S}{R_g}$ is also small.
- This means R_g is also small.
- So, when we connect ammeter in series, the ammeter will not change the resistance appreciably and also the current in the circuit.
- For an ideal ammeter, the resistance must be equal to zero.
- Hence, the reading in ammeter is always lesser than the actual current in the circuit.
- Let I_{ideal} be current measured from ideal ammeter and I_{actual} be the actual current measured in the circuit by the ammeter.
- Then, the percentage error in measuring a current through an ammeter is
- $\frac{\Delta I}{I}$ x 100 % $= \frac{I_{ideal} - I_{actual}}{I_{ideal}}$ x 100 %

Ammeter

12. How will you convert a galvanometer into a voltmeter?
    - A voltmeter is an instrument used to measure potential difference across any two points in the electrical circuits.
    - It should not draw any current from the circuit otherwise the value of potential difference to be measured will change.
    - Voltmeter must have high resistance and when it is connected in parallel, it will not draw appreciable current so that it will indicate the true potential difference.
    - A galvanometer is converted into a voltmeter by connecting high resistance R_h in series with galvanometer.
    - The scale is now calibrated in volt and the range of voltmeter depends on the values of the resistance connected in series.
    - The value of resistance is so adjusted that only current I_g produces full scale deflection in the galvanometer.
    - Let R_g be the resistance of galvanometer and I_g be the current with which the galvanometer produces full scale deflection.
    - Since galvanometer is connected in series with high resistance, the current in the electrical circuit is same as the current passing through the galvanometer.
    - $I = I_g$
    - The voltmeter resistance is $R_v = R_g + R_h$

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

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

- $I_g \propto V$

- The deflection in the galvanometer is proportional to current I_g.

- But current I_g is proportional to the potential difference.

- Hence, the deflection in the galvanometer is proportional to potential difference.

- Since the resistance of voltmeter is very large, a voltmeter connected in an electrical circuit will draw least current in the circuit.

- An ideal voltmeter is one in which has infinite resistance.

Voltmeter
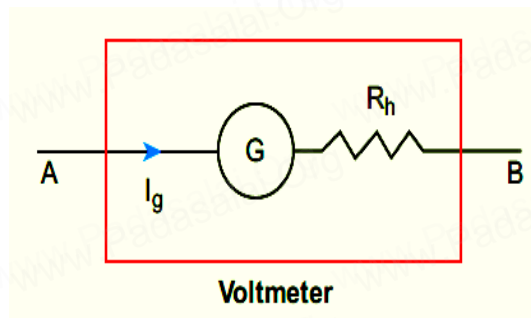
13. State Tangent's law and explain it in detail.

Tangent's law:

   When a magnetic needle or magnet is freely suspended in two mutually perpendicular uniform magnetic fields, it will come to rest in the direction of the resultant of the two fields.

- The working of tangent galvanometer is based on tangent's law.

- Let B be the magnetic field produced by passing current through the coil of the tangent galvanometer.

- B_H be the horizontal component of Earth's magnetic field.

- Under the action of two magnetic fields, the needle comes to rest making angle θ with B_H.

- $B = B_H \tan\theta$

- When no current is passed through the coil, the small magnetic needle lies along horizontal component of Earth's magnetic field.

- When the circuit is switched ON, the electric current will pass through the circular coil and produce magnetic field.

* When an electric current is passed through a circular coil of radius R having N truns, the magnitude of magnetic field at the center is $B = \mu_0 \frac{NI}{2R}$

* $B_H = \frac{\mu_0 N}{2R} \frac{I}{\tan\theta}$
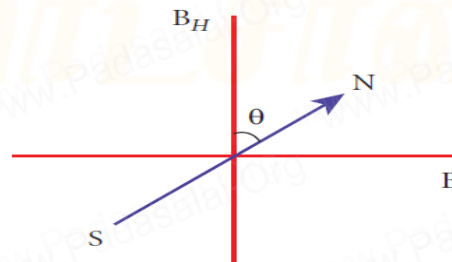
14. Obtain the expressions for time period, frequency and angular frequency of a charged particle moving in a uniform magnetic field.

* Consider a charged particle of charge q having mass m enters into a region of uniform magnetic field $\vec{B}$ with velocity $\vec{v}$ such that velocity is perpendicular to the magnetic field.

* As soon as the particle enters into the field, Lorentz force acts on it in a direction perpendicular to both magnetic field $\vec{B}$ and velocity $\vec{v}$.

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

* Magnitude of Lorentz force is $F = qvB$

* This Lorentz force acts as centripetal force for the particle to execute circular motion.

* $qvB = \frac{mv^2}{r}$

* $r = \frac{mv}{qB} = \frac{p}{qB}$

* $p = mv$

* Time period, $T = \frac{2\pi r}{v}$

* $T = \frac{2\pi m}{Bq}$

* Frequency, $f = \frac{1}{T} = \frac{Bq}{2\pi m}$

* Angular frequency, $\omega = 2\pi f = \frac{Bq}{m}$
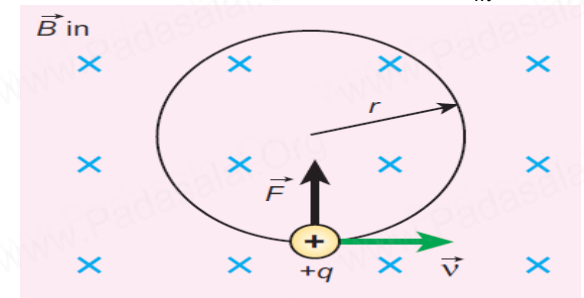
15. Obtain an expression for the force between two long parallel current carrying conductors.

* Two long straight parallel current carrying conductors separated by a distance r are kept in air.
* Let I_1 and I_2 be the electric currents passing through the conductors A and B in same direction.
* The net magnetic field at a distance r due to current I_1 in conductor A is
* $\vec{B}_1 = -\frac{\mu_0 I_1}{2\pi r}\,\hat{\imath}$
* From thumb rule, the direction of magnetic field is along negative $\hat{\imath}$ direction.
* Lorentz force on the element dl of conductor B is
* $d\vec{F} = \left(I_2 d\vec{l} \times \vec{B}_1\right)$
* $d\vec{F} = I_2 dl\ \hat{k} \times B_1(-\hat{\imath})$
* $d\vec{F} = -I_2 dl\ B_1\left(\hat{k} \times \hat{\imath}\right)$
* $d\vec{F} = -\frac{\mu_0 I_1 I_2 dl}{2\pi r}\,\hat{\jmath}$
* The force per unit length of the conductor B due to the conductor A is
* $\frac{\vec{F}}{l} = -\frac{\mu_0 I_1 I_2}{2\pi r}\,\hat{\jmath}$
* The net magnetic field at a distance r due to current I_2 in conductor B is
* $\vec{B}_2 = \frac{\mu_0 I_1}{2\pi r}\,\hat{\imath}$
* From thumb rule, the direction of magnetic field is along positive $\hat{\imath}$ direction.
* Lorentz force on the element dl of conductor A is
* $d\vec{F} = \left(I_1 d\vec{l} \times \vec{B}_2\right)$

* $dF = I_1 dl\ k \times B_2 \hat{\imath}$
* $d\vec{F} = I_1 dl\ B_2\left(\hat{k} \times \hat{\imath}\right)$
* $d\vec{F} = \frac{\mu_0 I_1 I_2 dl}{2\pi r}\,\hat{\jmath}$
* The force per unit length of the conductor B due to the conductor A is
* $\frac{\vec{F}}{l} = \frac{\mu_0 I_1 I_2}{2\pi r}\,\hat{\jmath}$
* The force experienced by two parallel current carrying conductors is attractive if the direction of the electric current passing through them is same.
* The force experienced by two parallel current carrying conductors is repulsive if the direction of the electric current passing through them is opposite.
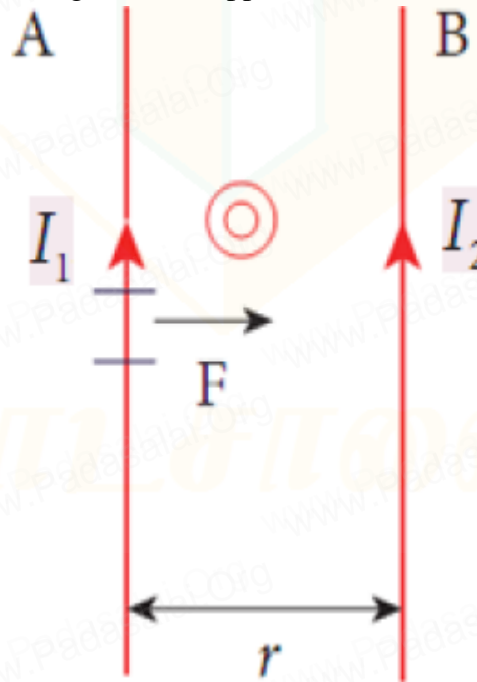
16. Obtain expression for the torque produced on a current carrying rectangular coil when its unit vector n̂ is perpendicular to the magnetic field.

   * Consider a single rectangular loop PQRS kept in a uniform magnetic field $\vec{B}$.
   * The unit vector n̂ is perpendicular to the field and plane of the loop is lying on XY plane.
   * Let the loop be divided into four sections PQ, QR, RS and SP.

Parts	$\vec{l}$	$\vec{B}$	$\vec{F} = I\vec{l} \times \vec{B}$	$\vec{\tau} = \vec{r} \times \vec{F}$
PQ	$-a\hat{j}$	$B\hat{i}$	$IaB\hat{k}$	$\frac{1}{2}abIB\hat{j}$
QR	$b\hat{i}$	$B\hat{i}$	$\vec{0}$	$0\hat{j}$
RS	$a\hat{j}$	$B\hat{i}$	$-IaB\hat{k}$	$\frac{1}{2}abIB\hat{j}$
SP	$-b\hat{i}$	$B\hat{i}$	$\vec{0}$	$0\hat{j}$
	Net force		$\vec{F} = \vec{0}$	Net torque $\vec{\tau} = abIB\hat{j} = A\,BI\hat{j}$
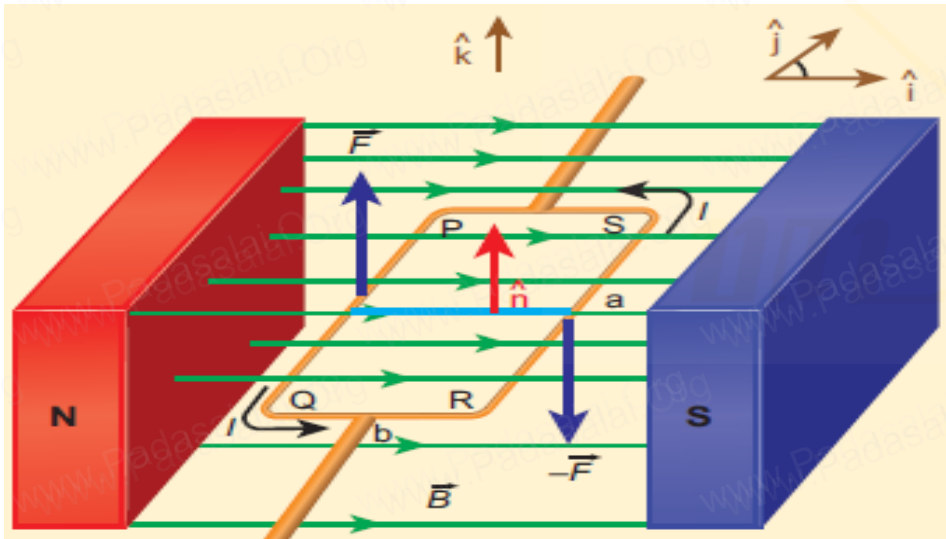
17. Obtain expression for the torque produced on a current carrying rectangular coil when its unit vector n̂ is at an angle θ with the magnetic field

   * The unit vector n̂ makes an angle with the magnetic field $\vec{B}$
   * Let the loop be divided into four sections PQ, QR, RS and SP.

Parts	$\vec{l}$	$\vec{B}$	$\vec{F} = I\vec{l} \times \vec{B}$
PQ	$-a\hat{j}$	$B\hat{i}$	$IaB\hat{k}$
QR	$b\cos\left(\frac{\pi}{2}-\theta\right)\hat{i} - b\sin\left(\frac{\pi}{2}-\theta\right)\hat{k}$	$B\hat{i}$	$-IlbB\cos\theta\,\hat{j}$
RS	$a\hat{j}$	$B\hat{i}$	$-IaB\hat{k}$
SP	$-b\cos\left(\frac{\pi}{2}-\theta\right)\hat{i} + b\sin\left(\frac{\pi}{2}-\theta\right)\hat{k}$	$B\hat{i}$	$IlbB\cos\theta\,\hat{j}$
		Net force	$\vec{F} = \vec{0}$

* Net torque $\vec{\tau} = \left(\overrightarrow{OA} \times \vec{F}_{PQ}\right) + \left(\overrightarrow{OB} \times \vec{F}_{RS}\right)$

* $\overrightarrow{OA} = \frac{b}{2}\left(-\sin\theta\,\hat{i} + \cos\theta\,\hat{k}\right)$

* $\overrightarrow{OC} = \frac{b}{2}\left(\sin\theta\,\hat{i} - \cos\theta\,\hat{k}\right)$

* $\overrightarrow{OA} \times \vec{F}_{PQ} = \frac{1}{2}abIB\sin\theta\,\hat{j}$

* $\overrightarrow{OC} \times \vec{F}_{RS} = \frac{1}{2}abIB\sin\theta\,\hat{j}$

* $\vec{\tau} = abIB\sin\theta\,\hat{j}$

* $\vec{\tau} = AIB\sin\theta\,\hat{j}$

* $\vec{p}_m = I\vec{A} = Iab\,\hat{n}$

* $\vec{\tau} = \vec{p}_m \times \vec{B}$

(c)