1. Electrostatics

1. Discuss the basic properties of electric charges.

Properties of electric charge :

1. Electric charge 2. Conservation of charge 3. Quantisation of charge

1. Electric Charge :

- Objects in the universe are made up of atoms.
- Atoms are made up of protons , neutrons and electrons.
- These particles have mass , an inherent property of particles.
- Electric charge is another intrinsic and fundamental property of particles.
- S I Unit of electric charge is Coulomb.

2. Conservation of Charge :

- Total electric charge in the universe is constant.
- Charge can neither be created nor be destroyed.
- Net change in charge will always be zero.
- Objects are electrically neutral before rubbing process happen.
- After rubbing simply transfers charges from one object to the others.

Example :

1. When a glass rod rubbed with silk cloth then negative charge transferred from glass to silk.
2. As a result , glass rod is positively charged and silk cloth is negatively charged.

3. Quantisation of charge :

The charge q on any object is equal to an integral multiple of fundamental unit of charge e.

$$q = n e$$

n is any integer ($0, \pm 1, \pm 2$) ; Charge of electron : -1.6×10^{-19} C

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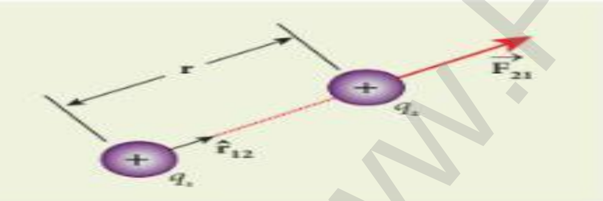
2. Explain in detail Coulomb's law and its various aspects .

Coulomb's law states that , 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 charges.



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

1. The force on the charge q_2 exerted by the charge q_1 always lies along the line joining the two charges. $\hat{r}_{12}$ is a unit vector pointing from charge q_1 to q_2. The force on the charge q_1 exerted q_2 is along $-\hat{r}_{12}$.

2. **Value of proportionality constant K :**

$$K = \frac{1}{4 \pi \varepsilon_0} = 9 \times 10^9 \ N m^2 C^{-2}$$

$$\varepsilon_0 = \frac{1}{4 \pi K} = 8.854 \times 10^{-12} \ C^2 N^{-1} m^{-2}$$

3. The magnitude of the electrostatic force between two charges each of one coulomb and separated by a distance 1 m is calculated as follows :

$$|F| = \frac{9 \times 10^9 \times 1 \times 1}{1^2} = 9 \times 10^9 \ N$$

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4. Coulomb's law in vacuum : $\vec{F}_{21} = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r^2} \hat{r}_{12}$

Coulomb's law in medium : $\vec{F}_{21} = \frac{1}{4\pi\varepsilon} \frac{q_1 q_2}{r^2} \hat{r}_{12}$

- Permittivity of free space or vacuum ⟶ ε_0
- Permittivity of a medium ⟶ ε ($\varepsilon > \varepsilon_0$)
- Relative permittivity of free space ⟶ ε_r ($\varepsilon_r = \varepsilon / \varepsilon_0$)
- For vacuum or air , $\varepsilon_r = 1$ and for other media $\varepsilon_r > 1$.

5. Similarity between Coulomb's law and Newton's gravitational law.

- Coulomb's law have same structure as Newton's law of gravitation.
- Both are inversely proportional to distance between the particles.
- Electrostatic force : Directly proportional to product of two point charges.
- Gravitational force : Directly proportional to product of two masses.

6. Difference between Coulomb's force and Gravitational force :

S.No	Coulomb Force	Gravitational Force
1.	It may be attractive or repulsive.	It is always attractive in nature
2.	It depends upon medium.	It does not depend upon the medium.
3.	It is always greater in magnitude. K = 9×10^9 N m^2 C^{-2}	It is lesser than Coulomb force G = 6.67×10^{-11} N m^2 kg^{-2}
4.	The force between the charges will not be same during motion or rest.	It is always same whether the two masses are rest or motion.

7. Force on the charge q_1 exerted by the charge q_2 : $\vec{F}_{12} = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r^2} \hat{r}_{21}$

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

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3. Define electric field and discuss its various aspects .

Electric Field :

Electric field at a point P, at a distance r from the point charge q is the force experienced by a unit point charge.

Formula : $\vec{E} = \frac{\vec{F}}{q_0} = \frac{1}{4\pi\varepsilon_0} \frac{q}{r^2} \hat{r}$ S I unit : N C^{-1}

Important aspects of Electric field :

1. * If q is positive , electric field points away from the source charge q.
   * If q is negative , electric field points towards the source charge q.

2. Force experienced by the test charge q_0 is $\vec{F} = q_0 \vec{E}$
3. Electric field is independent of test charge q_0 and depends only on source charge q.
4. Electric field is a vector quantity which has unique direction and magnitude .
5. As distance increases electric field decreases in magnitude.
6. Test charge q_0 is small , not modify the electric field of source charge.

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7. Electric field equation is only valid for point charges.
8. There are two kinds of the electric field. Uniform (constant) electric field and non - uniform electric field.
9. Uniform electric field : Have same direction and constant magnitude at all points.
10. Non – uniform electric field : Different directions and different magnitudes or both at different points.

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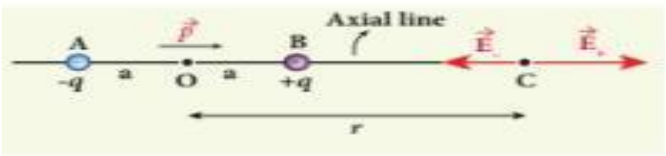
4. Calculate the electric field due to a dipole on its axial line and equatorial plane.

i) Electric field due to a electric dipole on its axial line:

Diagram :



Formula :

$$\vec{E}_{axial} = \frac{1}{4\pi\varepsilon_0}\frac{2\vec{p}}{r^3}$$

Explanation :

Consider an electric dipole placed on the x - axis . A point C is located at a distance of r from the midpoint O of the dipole on the axial line. Electric dipole moment vector $\vec{p}$ is from -q to +q and is directed along BC.

Derivation :

1. Electric field due to + q : $\vec{E}_+ = \frac{1}{4\pi\varepsilon_0}\frac{q}{(r-a)^2}\hat{p}$

2. Electric field due to - q : $\vec{E}_- = \frac{-1}{4\pi\varepsilon_0}\frac{q}{(r+a)^2}\hat{p}$

Since +q is located closer to the point C than -q , $\vec{E}_+$ is stronger than $\vec{E}_-$. Length of the $\vec{E}_+$ vector is larger than $\vec{E}_-$.

3. Total Electric field by superposition principle : $\vec{E} = \vec{E}_+ + \vec{E}_-$

4. $$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{(r-a)^2}\hat{p} - \frac{1}{4\pi\varepsilon_0}\frac{q}{(r+a)^2}\hat{p}$$

5. $$\vec{E} = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{(r-a)^2} - \frac{1}{(r+a)^2}\hat{p}\right]$$

6. $$\vec{E} = \frac{q}{4\pi\varepsilon_0}\left[\frac{(r+a)^2 - (r-a)^2}{(r-a)^2(r+a)^2}\hat{p}\right]$$

7. $$\vec{E} = \frac{q}{4\pi\varepsilon_0}\left[\frac{4ar}{(r^2-a^2)^2}\hat{p}\right]$$

If the point C is far away from the dipole (r >> a) then $(r^2 - a^2)^2 = r^4$

8. $$\vec{E} = \frac{q}{4\pi\varepsilon_0}\left[\frac{4ar}{r^4}\hat{p}\right]$$

9. $$\vec{E} = \frac{1}{4\pi\varepsilon_0}\left[\frac{2.\ 2qa}{r^3}\hat{p}\right]$$

10. Since $2aq\hat{p} = \vec{p}$

$$\vec{E}_{axial} = \frac{1}{4\pi\varepsilon_0}\frac{2\vec{p}}{r^3}$$

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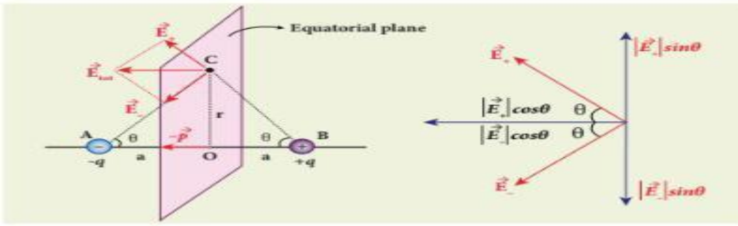
ii) Electric field due to a electric dipole on its Equatorial plane:

Diagram :



Formula :

$$\vec{E}_{equatorial} = \frac{-1}{4\pi\varepsilon_0}\frac{\vec{p}}{r^3}$$

Explanation :

- Let a point C at a distance r from the midpoint O of the dipole on equatorial plane.
- The point C is equi distant from + q and – q , the magnitude of the electric fields is same.
- The direction of $\vec{E}_+$ along BC and direction of $\vec{E}_-$ along CA.
- $\vec{E}_+$ and $\vec{E}_-$ can be resolved into two components.
- One component parallel to the dipole axis and other perpendicular to it.
- Perpendicular components $|\vec{E}_+|$ sin θ and $|\vec{E}_-|$ cos θ are equal in magnitude and oppositely directed , they cancel each other.
- Magnitude of total electric field is the sum of the parallel component of $\vec{E}_+$ and $\vec{E}_-$ and its direction along p.

Total electric field :

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

2. $|\vec{E}_+| = |\vec{E}_-| = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2+a^2}$

3. $\vec{E}_{tot} = -2\,|E_+|\cos\theta\,\hat{p}$

4. $\vec{E}_{tot} = -2\frac{1}{4\pi\varepsilon_0}\frac{q}{r^2+a^2}\cos\theta\,\hat{p}$

5. $\vec{E}_{tot} = -\frac{2q}{4\pi\varepsilon_0(r^2+a^2)}\cos\theta\,\hat{p}$

6. From triangle OAC , $\cos\theta = a/(r^2+a^2)^{1/2}$

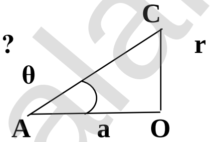
7. $\vec{E}_{tot} = -\frac{2q}{4\pi\varepsilon_0(r^2+a^2)}\frac{a}{(r^2+a^2)^{1/2}}\hat{p}$

8. $\vec{E}_{tot} = -\frac{2qa}{4\pi\varepsilon_0(r^2+a^2)^{3/2}}\hat{p}$

9. At very large distance (r >> a) then $(r^2+a^2)^{3/2} = r^3$ and $\vec{p} = 2qa\,\hat{p}$

10. $$\vec{E}_{equatorial} = \frac{-1}{4\pi\varepsilon_0}\frac{\vec{p}}{r^3}$$

Hyp ?



$Hyp = (r^2 + a^2)^{1/2}$

$$\cos\theta = \frac{adj}{hyp} = \frac{a}{(r^2+a^2)^{1/2}}$$

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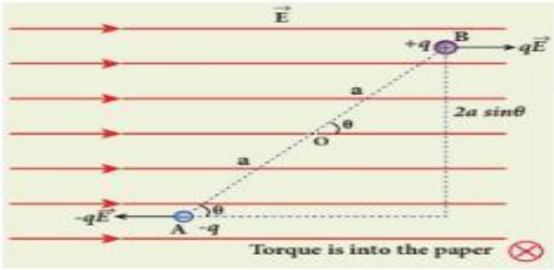
5. Derive an expression for the torque experienced by a dipole due to a uniform electric field.

Diagram :



Formula :

$$\vec{\tau} = \vec{p} \times \vec{E} = p\,E \sin\theta$$

Torque on dipole due to uniform electric field :

1. Consider an electric dipole moment $\vec{p}$ placed in a uniform electric field $\vec{E}$.
2. Uniform electric field $\vec{E}$ whose field lines are equally spaced and point in the same direction.
3. Charge + q will experience a force $q\vec{E}$ in the direction of the field.
4. Charge - q will experience a force $-q\vec{E}$ in the direction opposite to the field.
5. The external field $\vec{E}$ is uniform , the total force acting on the dipole is zero.
6. These two forces acting at different points will constitute a couple.
7. The dipole experience a torque and the torque tends to rotate the dipole.

Derivation :

1. Total torque on the dipole : $\vec{\tau} = \vec{OA} \times (-q\vec{E}) + \vec{OB} \times q\vec{E}$
2. Using right – hand corkscrew rule , total torque is perpendicular to the plane of the paper and is directed into it.
3. Magnitude of total torque : $\tau = |\vec{OA}|\,|(-q\vec{E})| \sin\theta + |\vec{OB}|\,|q\vec{E}| \sin\theta$
4. $\tau = qE \,.\, 2a\sin\theta$
5. Where θ is the angle made by $\vec{p}$ with $\vec{E}$. Since p = 2 q a .
6. The torque is written in terms of the vector produce as $\vec{\tau} = \vec{p} \times \vec{E}$
7. Torque experienced by a dipole at uniform electric field $\vec{\tau} = \vec{p} \times \vec{E} = p\,E\sin\theta$
8. Magnitude of torque is $\tau = p\,E\sin\theta$ and is maximum when $\theta = 90^0$.
9. This tends to rotate the dipole and align it with the electric field E.
10. If $\vec{p}$ is aligned with $\vec{E}$, the total torque on the dipole becomes zero.

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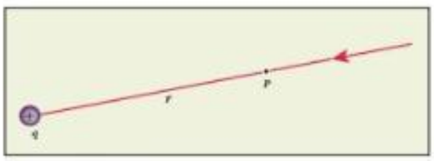
6. Derive an expression for electrostatic potential due to a point charge.

Diagram :



Formula :

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

Explanation :

- Consider a positive charge q kept fixed at a origin .
- Let P be a point at distance r from charge q.

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Derivation :

1. Electric potential at the point P.

$$V = \int_{\infty}^{r} (-\vec{E}).\vec{dr} = -\int_{\infty}^{r} \vec{E}.\,\vec{dr}$$

2. Electric field due to positive point charge q is

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

3. $V = \frac{-1}{4\pi\varepsilon_0}\int_{\infty}^{r}\frac{q}{r^2}\hat{r}\,\vec{dr}$

4. $V = \frac{-1}{4\pi\varepsilon_0}\int_{\infty}^{r}\frac{q}{r^2}\hat{r}\,dr\,\hat{r}$ $\quad (\vec{dr} = dr\,\hat{r})$

5. $V = \frac{-1}{4\pi\varepsilon_0}\int_{\infty}^{r}\frac{q}{r^2}dr\,\hat{r}.\hat{r}$ $\quad (\hat{r}.\hat{r} = 1)$

6. $V = \frac{-1}{4\pi\varepsilon_0}\int_{\infty}^{r}\frac{q}{r^2}dr$

7. $V = \frac{-1}{4\pi\varepsilon_0}q\left[\frac{-1}{r}\right]_{\infty}^{r}$

8. $V = \frac{-q}{4\pi\varepsilon_0}\left[\frac{-1}{r}\right]$

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

S.NO	Charge	Potential Formula	Potential Value	Distance
1.	Positive	$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$	Decreases	Increases
2.	Negative	$V = \frac{-1}{4\pi\varepsilon_0}\frac{q}{r}$	Increases	Increases

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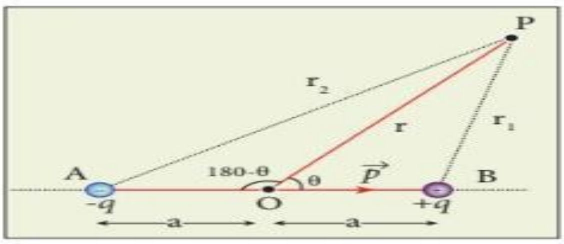
7. Derive an expression for electrostatic potential due to an electric dipole.

Diagram :



Formula :

$$V = \frac{1}{4\pi\varepsilon_0}\frac{\vec{p}.\hat{r}}{r^2}$$

Explanation

- Consider two equal and opposite charges separated by a small distance 2 a.

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- The point P is located at a distance r from the midpoint of the dipole.
- Let θ be the angle between the line OP and dipole axis AB.
- Let r_1 be the distance of point P from +q.
- Let r_2 be the distance of point P from -q.

Derivation :

1. Potential at P due to charge + q $= \frac{1}{4\pi\varepsilon_0}\frac{q}{r_1}$

2. Potential at P due to charge - q $= \frac{-1}{4\pi\varepsilon_0}\frac{q}{r_2}$

3. Total potential at point P

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r_1} - \frac{1}{4\pi\varepsilon_0}\frac{q}{r_2}$$

$$V = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{r_1} - \frac{1}{r_2}\right] \longrightarrow (1)$$

4. By the cosine law for triangle BOP

$$r_1^2 = r^2 + a^2 - 2ar\cos\theta$$

$$r_1^2 = r^2\left[1 + \frac{a^2}{r^2} - \frac{2ar\cos\theta}{r^2}\right]$$

$$r_1^2 = r^2\left[1 + \frac{a^2}{r^2} - \frac{2a\cos\theta}{r}\right]$$

5. Since the point P far from the dipole (r >>a). As a result term $\frac{a^2}{r^2}$ is very small and be neglected.

$$r_1^2 = r^2\left[1 - \frac{2a\cos\theta}{r}\right]$$

$$r_1 = r\left[1 - \frac{2a\cos\theta}{r}\right]^{1/2}$$

$$\frac{1}{r_1} = \frac{1}{r}\left[1 - \frac{2a}{r}\cos\theta\right]^{-1/2}$$

6. Since $\frac{a}{r} << 1$, we can use binomial theorem and retain the term up to first order

$$\frac{1}{r_1} = \frac{1}{r}\left[1 + \frac{2a}{2r}\cos\theta\right]$$

$$\frac{1}{r_1} = \frac{1}{r}\left[1 + \frac{a}{r}\cos\theta\right] \longrightarrow (2)$$

7. By the cosine law for triangle AOP

$$r_2^2 = r^2 + a^2 - 2ar\cos(180 - \theta) \qquad [\cos(180 - \theta) = -\cos\theta]$$

$$r_2^2 = r^2\left[1 + \frac{a^2}{r^2} + \frac{2a\cos\theta}{r}\right]$$

8. Since the point P far from the dipole (r >> a). As a result term a^2 / r^2 is very small and be neglected.

$$r_2^2 = r^2\left[1 + \frac{2a\cos\theta}{r}\right]$$

$$r_2 = r\left[1 + \frac{2a\cos\theta}{r}\right]^{1/2}$$

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$$\frac{1}{r_2} = \frac{1}{r}\left[1 + \frac{2a}{r}\cos\theta\right]^{-1/2}$$

9. Since $\frac{a}{r} << 1$, we can use binomial theorem and retain the term up to first order

$$\frac{1}{r_2} = \frac{1}{r}\left[1 - \frac{2a}{2r}\cos\theta\right]$$

$$\frac{1}{r_2} = \frac{1}{r}\left[1 - \frac{a}{r}\cos\theta\right] \longrightarrow (3)$$

10. Sub (2) and (3) in eqn (1)

$$V = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{r}\left[1 + \frac{a}{r}\cos\theta - \left[1 - \frac{a}{r}\cos\theta\right]\right]\right]$$

$$V = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{r}\left[\not{1} + \frac{a}{r}\cos\theta - \not{1} + \frac{a}{r}\cos\theta\right]\right]$$

$$V = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{r}\left[\frac{a}{r}\cos\theta + \frac{a}{r}\cos\theta\right]\right]$$

$$V = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{r}\ \frac{2a}{r}\cos\theta\right]$$

$$V = \frac{1}{4\pi\varepsilon_0}\ \frac{2qa}{r^2}\cos\theta$$

$$V = \frac{1}{4\pi\varepsilon_0}\ \frac{p\cos\theta}{r^2} \quad (p = 2qa)$$

$$V = \frac{1}{4\pi\varepsilon_0}\ \frac{\vec{p}\cdot\hat{r}}{r^2} \quad (p\cos\theta = \vec{p}\cdot\hat{r})$$

Special Cases :

S. NO	Point P lies on the axial line of dipole	Value of θ	Electric Potential
1.	On the side of + q	$\theta = 0$	$V = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^2}$
2.	On the side of - q	$\theta = 180^0$	$V = \frac{-1}{4\pi\varepsilon_0}\frac{p}{r^2}$
3.	Point P lies on equatorial line of dipole	$\theta = 90^0$	V = 0

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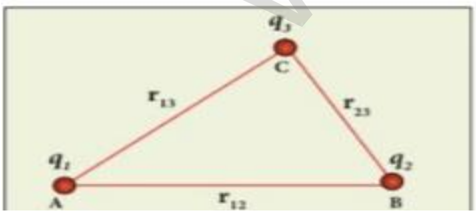
8. Obtain expression for potential energy due to collection of three point charges which are separated by finite distance.

Diagram :



Formula :

$$U = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1 q_2}{r_{12}} + \frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}}\right]$$

Explanation :

1. Bringing a charge q_1 from infinity to the point A requires no work , because there are no other charges already present in the vicinity of charge q_1.

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2. To bring the second charge q_2 to the point B , work must be done against the electric field created by the charge q_1 . So the work done on the charge q_2 is $W = q_2 V_{1B}$. Here V_{1B} is the electrostatic potential due to charge q_1 at point B.

$$U_I = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r_{12}}$$

3. Similarly to bring the charge q_3 to the point C , work must be done against the total electric field due to both charges q_1 and q_2 . So the work done to bring the charge q_3 is $W = q_3 (V_{1C} + V_{2C})$. Here V_{1C} is the electrostatic potential due to charge q_1 at point C and V_{2C} is the electrostatic potential due to charge q_2 at point C.

$$U_{II} = \frac{1}{4\pi\varepsilon_0} \left[\frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}} \right]$$

4. Total electrostatic potential energy for the system of charges q_1, q_2 and q_3 is

$$U_{III} = \frac{1}{4\pi\varepsilon_0} \left[\frac{q_1 q_2}{r_{12}} + \frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}} \right]$$

5. Electrostatic potential is independent of the configuration of charges since force is conservative one.

S.NO	Charges	Work done	Potential Energy
1.	Bring the charge q_1 from infinity to the point A	Requires no work	No other charges present in the vicinity of charge q_1
2.	Bring the charge q_2 to the point B	$W = q_2 V_{1B}$	$U_I = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r_{12}}$
3.	Bring the charge q_3 to the point C	$W = q_3 (V_{1C} + V_{2C})$	$U_{II} = \frac{1}{4\pi\varepsilon_0} \left[\frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}} \right]$

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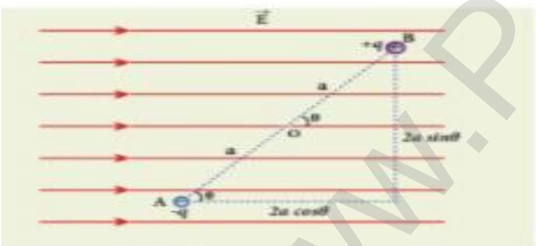
9. Derive an expression for electrostatic potential energy of the dipole in a uniform electric field.

Diagram :



Formula :

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

Explanation :

1. Consider a dipole placed in the uniform electric field $\vec{E}$.
2. A dipole experiences a torque when kept in an uniform electric field $\vec{E}$.
3. This torque rotates the dipole to align it with the direction of the electric field.
4. To rotate the dipole from its initial angle θ to another angle θ' against the torque exerted by the electric field.
5. An equal and opposite external torque must be applied on the dipole.

Derivation :

1. Work done by the external torque to rotate the dipole from angle θ to θ' at constant velocity

$$W = \int_{\theta'}^{\theta} \tau \, d\theta \quad (\tau = \tau_{ext}) \longrightarrow (1)$$

2. Since , $\vec{\tau}_{ext}$ is equal and opposite to $\vec{\tau}_E = \vec{p} \times \vec{E}$

3. $$|\vec{\tau}_{ext}| = |\vec{\tau}_E| = |\vec{p} \times \vec{E}| = p E \sin \theta \longrightarrow (2)$$

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4. Sub eqn (2) in eqn (1)

$$W = \int_{\theta'}^{\theta} p\,E \sin\theta \; d\theta$$

5. After integrating we get ,

$$W = p\,E \int_{\theta'}^{\theta} \sin\theta \; d\theta$$

$$W = p\,E\,(-\cos\theta)_{\theta'}^{\theta}$$

$$W = p\,E\,(-\cos\theta - (-\cos\theta'))$$

$$W = p\,E\,(-\cos\theta + \cos\theta')$$

$$W = -\,p\,E\cos\theta + p\,E\cos\theta'$$

6. This work done is equal to the potential energy difference between the angular positions θ and θ' .

$$U(\theta) - U(\theta') = \Delta U = -\,p\,E\cos\theta + p\,E\cos\theta'$$

7. If the initial angle is $\theta' = 90^0$ and is taken as reference point , then $U(\theta') = p\,E\cos 90^0 = 0$

8. Potential energy stored in the system of dipole kept in uniform electric field is given by $U(\theta) = -\,p\,E\cos\theta = -\,\vec{p}\cdot\vec{E}$

9. The potential energy is maximum when the dipole is aligned anti – parallel ($\theta = \pi$) to the external electric field.

10 . The potential energy is minimum when the dipole is aligned parallel ($\theta = 0$) to the external electric field.

---

10. Obtain Gauss law from Coulomb's law.

Diagram :

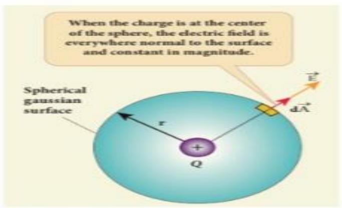

Figure 1.34 Total electric flux of point charge

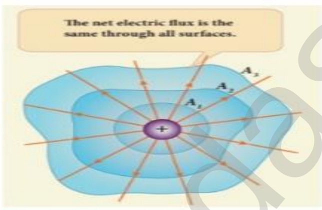

Figure 1.35 Gauss law for arbitrarily shaped surface

Formula :

$$\Phi_E = \oint \vec{E}\cdot d\vec{A} = \frac{Q_{encl}}{\varepsilon_0}$$

Explanation

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

2. Total electric flux through the closed surface of the sphere $\Phi_E = \oint \vec{E}\cdot d\vec{A} = \oint E\; dA\cos\theta$

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

4. The direction of the area element d A is along the electric field $\vec{E}$ and $\theta = 0^o$ then $\Phi_E = \oint E\; dA\cos 0^0 = \oint E\; dA$

5. E is uniform on the surface of the sphere $\Phi_E = E\oint dA$

6. $E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$ $\oint dA = 4\pi r^2$

7. $\Phi_E = E\oint dA = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2} \times 4\pi r^2 = \frac{Q}{\varepsilon_0}$

8. Gauss law for arbitrarily shaped surface A_1, A_2 ,A_3t total electric flux is same for closed surface.

9. 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

$$\Phi_E = \oint E\,.\,dA = \frac{Q_{encl}}{\varepsilon_0}$$

Where Q_{encl} denotes the charges within the closed surface.

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11. Obtain the expression for electric field due to an infinitely long charged wire.

Diagram :

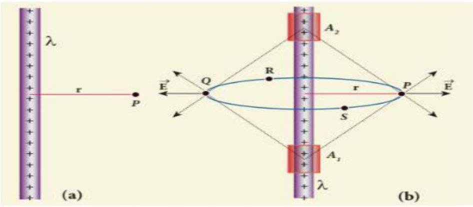

Figure 1.36 Electric field due to infinite long charged wire

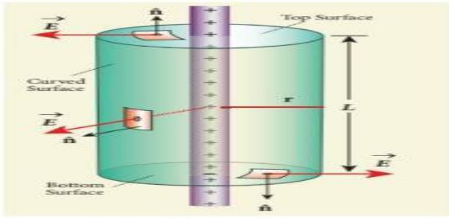

Figure 1.37 Cylindrical Gaussian surface

Formula :

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

Explanation :

1. Consider an infinitely long straight wire having uniform linear charge density λ .
2. Let P be a point located at a perpendicular distance r from the wire.
3. The electric field at the point P can be found using Gauss law.
4. Two small charge elements A_1 ,A_2 on the wire which are at equal distances from point P.
5. Resultant electric field due to two charge elements points radially away from charged wire.
6. The magnitude of electric field is same at all points on the circle of radius r.
7. The charged wire possesses a cylindrical symmetry , cylindrical Gaussian surface of radius r and length L.

Derivation :

1. Total electric flux through the closed surface $\Phi_E = \oint \vec{E}.\vec{dA}$

2. $\Phi_E = \int_{\text{Curved surface}} \vec{E}.\vec{dA} + \int_{\text{Top surface}} \vec{E}.\vec{dA} + \int_{\text{Bottom surface}} \vec{E}.\vec{dA}$

3. For the curved surface , E is parallel to $\vec{A}$ then , $\vec{E}.d\vec{A} = E\,dA$

4. For the top and bottom surface , E is perpendicular to A then , E . d A = 0.

5. Applying Gauss law to the cylindrical surface , $\Phi_E = \int_{\text{Curved surface}} \vec{E}.\vec{dA} = \frac{Q_{encl}}{\varepsilon_0}$

6. $\Phi_E = E \int_{\text{Curved surface}} dA = \frac{Q_{encl}}{\varepsilon_0}$

7. The magnitude of the electric field for the entire curved surface is constant , E is taken out of the integration.

8. Linear charge density (charge per unit length) : $\lambda = \frac{Q_{encl}}{L}$

9. Q_{encl} is given by $Q_{encl} = \lambda L$.

10. Total area of the curved surface : $\int_{\text{Curved surface}} dA = 2\pi r L$

11. $\Phi_E = E \int_{\text{Curved surface}} dA = \frac{Q_{encl}}{\varepsilon_0}$

$$E \,.\, 2\pi r L = \frac{\lambda L}{\varepsilon_0}$$

12. Electric field due to infinite long charged wire , $E = \frac{1}{2\pi\varepsilon_0}\frac{\lambda}{r}$

In vector form , $\vec{E} = \frac{1}{2\pi\varepsilon_0}\frac{\lambda}{r}\hat{r}$

13. The electric field due to infinite charged wire depends on $1/r$ rather than $1/r^2$ which is for a point charge.

14. If $\lambda > 0$ then $\vec{E}$ points perpendicularly outward ($\hat{r}$) from the wire.

15. If $\lambda < 0$ then $\vec{E}$ points perpendicularly inward ($-\hat{r}$) from the wire.

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12. Obtain the expression for electric field due to a charged infinite plane sheet.

Diagram :

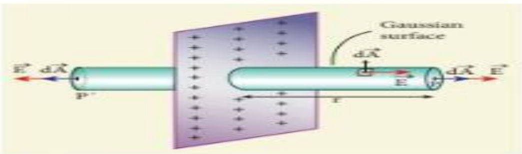

Figure 1.38 Electric field due to charged infinite planar sheet

Formula :

$$\vec{E} = \frac{\sigma}{2\,\varepsilon_0}\,\hat{n}$$

Explanation :

1. Consider an infinite plane sheet of charges with uniform surface charge density σ .
2. Let P be a point at a distance r from the sheet.
3. The plane sheet is infinitely large , the electric field should be same at all points equidistant from the plane and radially directed outward at all points.
4. A cylindrical Gaussian surface of length 2r and two flats surface each of area A is chosen.
5. The infinite plane sheet passes perpendicularly through the middle part of the Gaussian surface.

Derivation :

1. Total electric flux linked with the cylindrical surface $\Phi_E = \oint \vec{E}\cdot d\vec{A}$

2. $\Phi_E = \int_{\text{Curved surface}} \vec{E}\cdot d\vec{A} + \int_{P} \vec{E}\cdot d\vec{A} + \int_{P'} \vec{E}\cdot d\vec{A}$

3. For curved surface : Electric field is perpendicular to the area element at all points. $\int_{\text{Curved surface}} E\,.\,d A = 0$

4. At P and P : Electric field is parallel to the area element at all points. $\Phi_E = \int_{P} E\ dA + \int_{P'} E\ dA$

5. The magnitude of the electric field at these two equal flat surfaces is uniform.

$$\Phi_E = E \int_{P} dA + E \int_{P'} dA$$

$$\Phi_E = E\,A + E\,A = 2EA$$

6. Surface charge density = charge present per unit area ($\sigma = Q / A$)

7. Total charge enclosed by the area $Q_{encl} = \sigma A$

8. By using Gauss law , $\Phi_E = \frac{Q_{encl}}{\varepsilon_0}$

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

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

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

9. In vector form , $\vec{E} = \frac{\sigma}{2\,\varepsilon_0}\,\hat{n}$

10. If $\sigma > 0$ then $\vec{E}$ points perpendicularly outward to the plane ($\hat{n}$) .

11. If $\sigma < 0$ then $\vec{E}$ points perpendicularly inward to the plane ($-\hat{n}$) .

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13. Obtain the expression for electric field due to a uniformly charged spherical shell.

1. Consider a uniformly charged spherical shell of radius R and total charge Q .
2. The electric field at points outside and inside the sphere can be found using Gauss law.

Diagram :

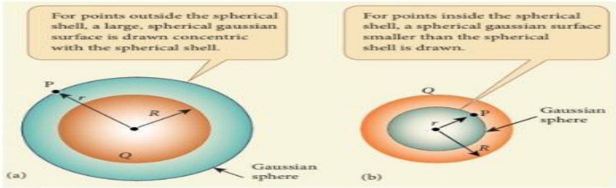

Figure 1.40 The electric field due to a charged spherical shell

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

For point outside the spherical shell , a large spherical Gaussian surface is drawn concentric with the spherical shell.

Explanation :

1. Let us choose a point P outside the shell at a distance r from the centre.
2. The charge is uniformly distributed on the surface of the sphere. (spherically symmetry)
3. The electric field must point radially outward if Q > 0.
4. The electric field must point radially inward if Q < 0.
5. Spherical Gaussian surface of radius r is chosen.

Derivation :

1. Applying Gauss law : $\oint_{\text{Gaussian Surface}} \vec{E} \cdot d\vec{A} = \frac{Q}{\varepsilon_0}$

2. The electric field $\vec{E}$ and $d\vec{A}$ point in the same direction at all the points on the Gaussian surface.

3. The magnitude of E is also the same at all points due to the spherical symmetry of charge distribution.

4. $E \oint_{\text{Gaussian Surface}} dA = \frac{Q}{\varepsilon_0}$

5. Total area of the Gaussian surface $\oint dA = 4\pi r^2$

6. $E \cdot 4\pi r^2 = \frac{Q}{\varepsilon_0}$

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

8. In vector form , $\vec{E} = \frac{1}{4\pi\varepsilon_0} \frac{Q}{r^2} \hat{r}$

9. The electric field must point radially outward if Q > 0 and radially inward if Q < 0.

10. The electric field at a point outside the shell will be same if the entire charge Q is concentrated at the centre of the spherical shell.

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

The electric field at points on the spherical shell (r = R) is given by $\vec{E} = \frac{1}{4\pi\varepsilon_0} \frac{Q}{R^2} \hat{r}$

Case iii : At a point inside the spherical shell (r < R)

For point outside the spherical shell , a spherical Gaussian surface smaller than the spherical shell is drawn .

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Explanation :

1. Consider a point P inside the shell at a distance r from the centre.
2. A Gaussian sphere of radius r is constructed .
3. Applying Gauss law : $\oint \vec{E}.d\vec{A} = \frac{Q}{\varepsilon_0}$
4. Total area of the Gaussian surface $\int dA = 4\pi r^2$
5. $E . 4\pi r^2 = \frac{Q}{\varepsilon_0}$
6. Gaussian surface encloses no charge , Q = 0 then E = 0 (r < R)
7. The electric field due to the uniformly charged spherical shell is zero at all points inside the shell.

Electric field versus distance for spherical shell of radius R

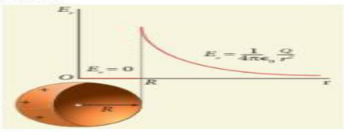

Figure 1.41 Electric field versus distance for a spherical shell of radius R

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14. Discuss the various properties of conductors in electrostatic equilibrium.

1. " The electric field is zero everywhere inside the conductor. This is true regardless of whether the conductor is solid or hollow ".

Figure 1.42 Electric field of conductors

- If electric field is not zero inside the metal , there will be force on mobile charge.
- There will be net motion of mobile charge which contradicts with conductor in electrostatic equilibrium.
- Thus electric field is zero everywhere inside the conductor.
- Before applying external field , the free electrons in conductor are uniformly distributed.
- After applying external field , left plate be negatively charged and right plate be positively charged.
- Due to realignment of free electron internal electric field created inside the conductor.
- Internal electric field nullifies the external electric field.
- Conductor reach electrostatic equilibrium in the order of 10^{-16} s.

2. " There is no net charge inside the conductor. The charges must reside only on the surface of the Conductor".

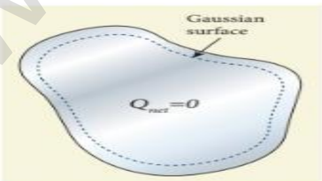

Figure 1.43 No net charge inside the conductor

Consider an arbitrarily shaped conductor.

- Gaussian surface drawn inside the conductor which is very close to conductor.
- Electric field is zero everywhere inside the conductor , net electric flux is also zero over this Gaussian surface.
- From Gauss's law , this implies that there is no net charge inside the conductor.
- Even if some charge is introduced inside the conductor , it immediately reaches the surface of the conductor.

3. " The electric field outside the conductor is perpendicular to the surface the conductor and has a magnitude of σ / ε_0 where σ is the surface charge density at that point ".

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- If electric field component has parallel to surface of conductor , then the free electron on the surface of the conductor experience acceleration . Then conductor is not in equilibrium.
- At electrostatic equilibrium , the electric field will be perpendicular to conductor surface.

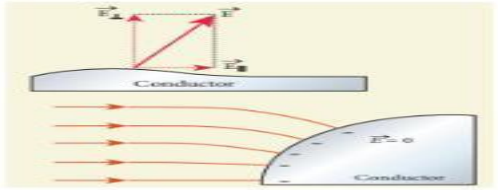

Figure 1.44 (a) Electric field is along the surface (b)Electric field is perpendicular to the surface of the conductor

c) <u>Electric field on the surface of the conductor</u>

Figure 1.45 The electric field on the surface of the conductor

- Consider a small cylindrical Gaussian surface and one half of this cylinder is embedded inside the conductor.
- Electric field is normal to the surface of the conductor.

i . <u>Curved part :</u> Electric flux is zero.
ii . <u>Bottom part :</u> Electric flux is zero.
iii . <u>Top part :</u> Electric flux is not zero.

- By applying Gauss law , $E\,A = \frac{\sigma A}{\varepsilon_0}$
- In vector form , $\vec{E} = \frac{\sigma}{\varepsilon_0}\hat{n}$

4. " The electrostatic potential has same value on the surface and inside of the conductor ".

- Conductor has no parallel electric component on the surface.
- Charges can be moved on surface without doing any work.
- It is possible only of electrostatic potential is constant.
- No potential difference between any points on the surface.
- Electric field is zero inside the conductor , potential is same.
- At electrostatic equilibrium , the conductor always be equipotential.

---

15. Explain the process of electrostatic induction.

<u>Electrostatic induction :</u>

- Charging without actual contact is called "*electrostatic* induction "
- Various steps to be followed in process of electrostatic induction.

<u>Diagram :</u>

rod. But the total charge is zero.

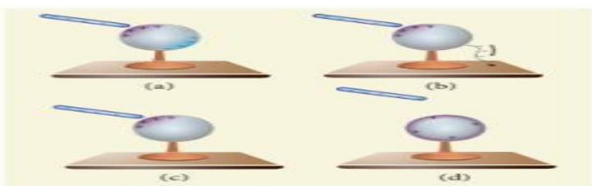

Figure 1.47 Various steps in electrostatic induction

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Step 1 :

- Consider an uncharged (neutral) conducting sphere at rest on an insulating stand.
- Negatively charged rod bring near the conductor without touching it.
- Negative charged rod repels electron , positive charges induced near the region of rod.

Step 2 :

- Conducting sphere is connected to ground through a conducting wire. This is called grounding.
- Grounding removes electron from the conducting sphere.
- Positive charge not flow to ground because attracted by negative charge of the rod.

Step 3 :

When the grounding wire is removed from the conductor , the positive charges remain near the charged rod.

Step 4 :

- Now charged rod is taken away from the conductor.
- Positive charge gets distributed uniformly on the surface of the conductor.
- By this , neutral conducting sphere becomes positively charged.

---

16. Explain dielectrics in detail and how an electric field is induced inside a dielectric.

Dielectric or Insulators :

- A dielectric is a non-conducting material and has no free electrons.
- The electrons in a dielectric are bound within the atoms.
- It is made up of either polar molecule or non polar molecule.

Examples : Ebonite , glass and mica.

1. When an external electric field is applied on a *conductor*

The charges aligned in such a way that an internal electric field is created which tends to cancel external electric field.

2. When an external electric field is applied on a *dielectric*

It has no free electrons so the external electric field only realigns the charges so that an internal electric field is produced.

- The magnitude of the internal electric field is smaller than that of external electric field.
- The net electric field inside the dielectric is not zero but is parallel to an external electric field with magnitude less than that of the external electric field.

3. For Example :

Let us consider a rectangular dielectric slab placed between two oppositely charged plates.

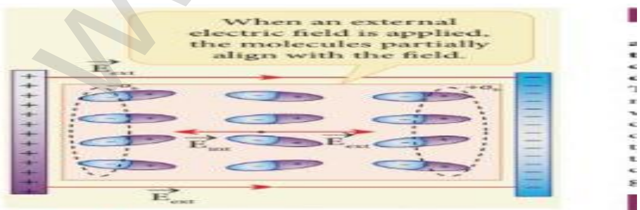

Figure 1.50 Induced electric field lines inside the dielectric

1. The uniform electric field between the plates acts as an external field E_{ext} which polarizes the dielectric placed between plates.
2. The positive charges are induced on one side surface and negative charges are induced on other side of surface.
3. Dielectric in external field is equivalent to two oppositely charged sheets with surface charge densities $+\sigma_b$, $-\sigma_b$.
4. These charges are called *bound charges* .
5. They are not free to move like free electrons in conductors.

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Example :

The charged balloon after rubbing sticks onto wall. The reason is that the negatively charged balloon is brought near the wall , it polarizes opposite charges on the surface of the wall , which attracts the balloon.

---

17. Obtain the expression for capacitance for a parallel plate capacitor.

Diagram :

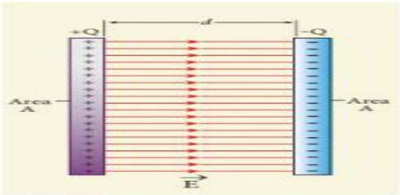

Figure 1.54 Capacitance of a parallel plate capacitor

Formula :

$$C = \frac{\varepsilon_0 A}{d}$$

Explanation :

Consider a capacitor with two parallel plates.

- Cross – sectional area → A
- Distance between the plates → d
- Electric Field → E
- Surface charge density → σ

1. Electric Field

The electric field between two infinitely parallel plates is uniform and is given by, $E = \sigma / \varepsilon_0$ → (1)

If the separation distance d is very much smaller than the size of the plate ($d^2 << A$) , then the above result can be used even for finite – sized parallel plate capacitor.

2. Surface Charge Density

Charge per unit area is known as surface charge density. $\sigma = Q / A$ → (2)

3. Substitute eqn (2) in eqn (1)

$$E = \frac{Q}{A \varepsilon_0}$$

4. Electric Potential Difference

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

5. Capacitance of a Capacitor

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

$$C = \frac{\varepsilon_0 A}{d}$$

- Capacitance is directly proportional to the area of cross section (A)
- Capacitance is inversely proportional to the distance between the plates . (d)

---

18. Obtain the expression for energy stored in the parallel plate capacitor.

Explanation :

1. Capacitor not only stores charge but also it stores energy.
2. When battery connected to capacitor , electrons of charge -Q transfer from one plate to other plate.
3. To transfer the charge , work is done by the battery.
4. Work done is stored as electrostatic potential energy in the capacitor.

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Derivation :

1. Work Done : $dW = V\,dQ$
2. Capacitance : $C = Q / V$
3. Potential : $V = Q / C$
4. Total Work done : $W = \int_0^Q \frac{Q}{C}\,dQ = \frac{1}{C}\int_0^Q Q\,dQ = \frac{Q^2}{2C}$
5. Electrostatic Potential Energy :

$$U_E = \frac{Q^2}{2C} \qquad (Q = CV)$$

$$U_E = \frac{(CV)^2}{2C} = \frac{1}{2} C V^2$$

The stored energy is directly proportional to the capacitance, square of the voltage between the plates of the capacitor.

6. We know that , $C = \frac{\varepsilon_0 A}{d}$ and $V = E\,d$

$$U_E = \frac{1}{2} C V^2 = \frac{1}{2} \frac{\varepsilon_0 A}{d} E^2 d^2$$

$$U_E = \frac{1}{2} \varepsilon_0 (A d) E^2$$

$$U_E = \frac{1}{2} \varepsilon_0 V E^2 \qquad (\text{Volume} = V = A d)$$

$$u_E = \frac{U_E}{\text{Volume}} = \frac{1}{2} \varepsilon_0 E^2$$

7. The energy stored per unit volume of space is defined as energy density .

---

19. Explain in detail the effect of dielectric placed in a parallel plate capacitor .

The dielectric can be inserted into the plates in two different ways.
i) When the capacitor is disconnected from the battery. ii) When the capacitor is connected to the battery.

i) When the capacitor is disconnected from the battery :

- Consider a capacitor with two parallel plates.
- Cross – sectional area ⟶ A
- Distance between plates ⟶ d
- Voltage of battery ⟶ V_0
- Stored charge value ⟶ Q_0 (Remains constant)

Capacitance of Capacitor without dielectric : $C_0 = Q_0 / V_0$

Battery is disconnected from the capacitor and inserted dielectric

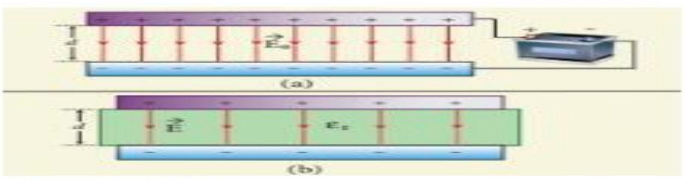

Figure 1.56 (a) Capacitor is charged with a battery (b) Dielectric is inserted after the battery is disconnected

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1. Electric Field :

Without Dielectric : $E_0 = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$

With Dielectric : $E = \frac{1}{4\pi\varepsilon_0\varepsilon_r}\frac{q_1 q_2}{r^2}$ $(\varepsilon_r > 1)$

$$E = \frac{E_0}{\varepsilon_r}$$ $(E < E_0)$

2. Electrostatic Potential :

Without Dielectric : $V = E_0 d$

With Dielectric : $V = E d$

$$V = \frac{E_0 d}{\varepsilon_r}$$

$$V = \frac{V_0}{\varepsilon_r}$$ $(V < V_0)$

3. Capacitance :

Without Dielectric : $C_0 = \frac{Q_0}{V_0}$

With Dielectric : $C = \frac{Q_0}{V}$

$$C = \frac{Q_0 \varepsilon_r}{V_0}$$

$$C = C_0 \varepsilon_r$$ $(C > C_0)$

4. Energy :

Without Dielectric : $U_0 = \frac{1}{2}\frac{Q_0^2}{C_0}$

With Dielectric : $U = \frac{1}{2}\frac{Q_0^2}{C}$

$$U = \frac{1}{2}\frac{Q_0^2}{\varepsilon_r C_0}$$

$$U = \frac{U_0}{\varepsilon_r}$$ $(U < U_0)$

ii) When the capacitor is connected to the battery :

- Voltage V_0 remains constant.
- Charge increased by ε_r ⟶ $Q = Q_0 \varepsilon_r$

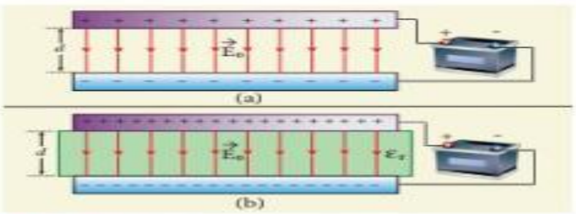

Figure 1.57 (a) Capacitor is charged through a battery (b) Dielectric is inserted when the battery is connected.

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1.**Capacitance :**

Without Dielectric : $C_0 = \frac{Q_0}{V_0}$

With Dielectric : $C = \frac{Q}{V_0}$

$C = \frac{Q_0\, \varepsilon_r}{V_0}$

$$C = C_0\ \varepsilon_r$$

2.**Energy :**

Without Dielectric : $U_0 = \frac{1}{2}\ C_0 V_0^2$

With Dielectric : $U = \frac{1}{2}\ C\ V^2$

$U = \frac{1}{2}\ C_0 V_0^2\ \varepsilon_r$

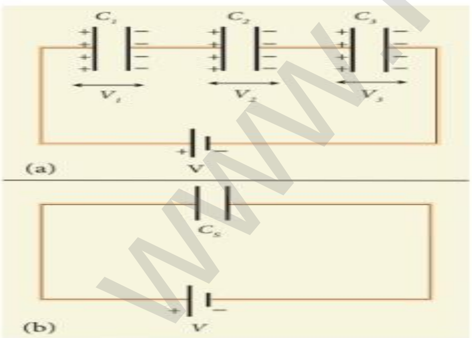
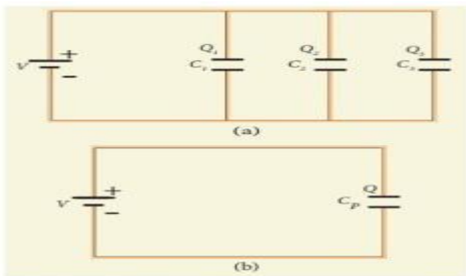
$$U = \varepsilon_r\ U_0$$

Effects of dielectric in capacitors :

S.NO	Dielectric inserted	Charge Q	Voltage V	Electric Field E	Capacitance C	Energy U
1.	When Ba is disconnected	Constant	Decreases	Decreases	Increases	Decreases
2.	When Ba is connected	Increases	Constant	Constant	Increases	Increases

---

20. Derive the expression for resultant capacitance, when capacitors are connected in series and in parallel.

S.NO	Capacitance in series	Capacitance in parallel
1.	 Figure 1.58 (a) Capacitors connected in series (b) Equivalent capacitors C_s	 Figure 1.59 (a) capacitors in parallel (b) equivalent capacitance with the same total charge
2.	Three capacitance C_1 , C_2 and C_3 in series.	Three capacitance C_1 , C_2 and C_3 in parallel.
3.	Each capacitors stores same amount of charge. (Q)	Charge on each capacitor not same. (Q_1 Q_2 Q_3)
4.	Voltage across each capacitor is differ. (V_1 V_2 V_3)	Voltage across each capacitor is same . (V)

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5.	Sum of voltages across the capacitor $V = V_1 + V_2 + V_3$ $\frac{Q}{C} = \frac{Q_1}{C_1} + \frac{Q_2}{C_2} + \frac{Q_3}{C_3}$ $\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$	Sum of charges across the capacitor $Q = Q_1 + Q_2 + Q_3$ $C\,V = C_1 V + C_2 V + C_3 V$ $C_P = C_1 + C_2 + C_3$
6.	Inverse of equivalent capacitance C_S is equal to sum of inverse of each capacitance.	Equivalent capacitance C_p is equal to sum of individual capacitance.
7.	C_S is always less than the smallest individual capacitance	C_P is always greater than largest individual capacitance.

---

21. Explain in detail how charges are distributed in a conductor and the principle behind the lightning conductor.

Diagram :

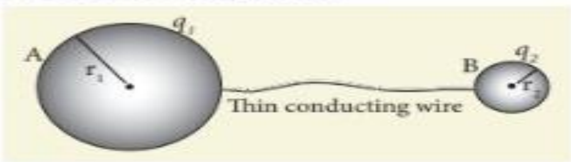

Figure 1.60 Two conductors are connected through conducting wire

Formula :

$\sigma\ r = \text{constant}$

Explanation

1. Consider the conducting sphere A and B of radii r_1 and r_2.
2. They are connected by a thin conducting wire.
3. Distance between the spheres is much greater than radii of either sphere.
4. If a charge Q is introduced in any of the sphere , this charge Q is redistributed into both the spheres such that the electrostatic potential is same .
5. They are now uniformly charged and attain electrostatic equilibrium.
6. Let q_1 be the charge residing on the surface of sphere A .
7. Let q_2 be the charge residing on the surface of sphere B.
8. such that $Q = q_1 + q_2$. The charges are distributed only on the surface.
9. There is no net charge inside the conductor.

Derivation :

1. Electrostatic potential at the surface of the sphere A is given by $V_A = \frac{1}{4\pi\varepsilon_0}\frac{q_1}{r_1}$

2. Electrostatic potential at the surface of the sphere B is given by $V_B = \frac{1}{4\pi\varepsilon_0}\frac{q_2}{r_2}$

3. The surface of the conductor is an *equipotential.* The spheres are connected by the conducting wire , the surfaces of both the spheres together form an equipotential surface. $V_A = V_B$

4. $$\frac{1}{4\pi\varepsilon_0}\frac{q_1}{r_1} = \frac{1}{4\pi\varepsilon_0}\frac{q_2}{r_2}$$

$$\frac{q_1}{r_1} = \frac{q_2}{r_2}$$

5. Let the charge density on the surface of sphere A be σ_1 then $q_1 = 4\pi r_1^2\ \sigma_1$

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6. Let the charge density on the surface of sphere A be σ_2 then $q_2 = 4\pi r_2^2 \sigma_2$

7. $$\frac{4\pi r_1^2 \sigma_1}{r_1} = \frac{4\pi r_2^2 \sigma_2}{r_2}$$

8. $$r_1 \sigma_1 = r_2 \sigma_2$$

9. Surface charge density is inversely proportional to the radius of the sphere. σr = constant

10. For a smaller radius , the charge density will be larger and vice versa.

Lightning of conductor Working :

1. Consists of a long thick copper rod passing from top of the building to the ground.
2. The upper end of the rod has sharp spike and sharp needle.
3. The lower end of the rod is connected to copper plate.
4. Negatively charges cloud passing above the cloud , induces positive charge on the spike.
5. The induced charge density on thin sharp spike is large , it results in a *corona discharge.*
6. This positive charge ionizes the surrounding air which in turn neutralizes the negative charge in the cloud.
7. The negative charge pushed to the spike through the copper rod and is safely diverted to the earth.
8. The lightning arrester does not stop the lightning rather it diverts the lightning to the ground safely.

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

Principle :

Based on the principle of 1. Electrostatic Induction 2. Action at points (Corona discharge)

Potential Difference :

It produces large amount of electrostatic potential difference 10^7 V.

Applications:

The high voltage produced in this Van de Graaff generator is used to accelerate positive ions (protons and deuterons) for nuclear disintegrations and other applications.

Diagram :

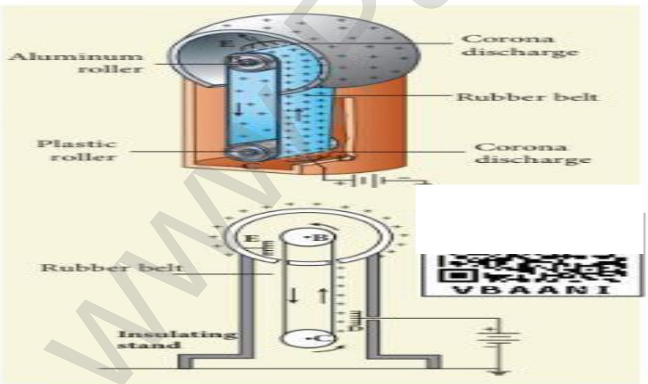

Figure 1.63 Van de Graaff generator

Construction :

1. A large hollow spherical conductor is fixed on the insulating stand.
2. A pulley B is mounted at the centre of the hollow sphere and pulley C is fixed at the bottom .
3. A belt made up of insulating materials like silk or rubber runs over both pulleys.
4. The pulley C is driven continuously by the electric motor.
5. Two comb shaped metallic conductors E and D are fixed near the pulleys.
6. The comb D is maintained at a positive potential of 10^4 V by a power supply.
7. The upper comb E is connected to the inner side of the hollow metal sphere.

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Working :

1. Due to high electric field at comb D air between belt and comb D gets ionized by *action of points.*
2. Positive charge pushed towards belt and negative charges are attracted towards the comb D.
3. The positive charges stick to the belt and move up.
4. When the positive charges on the on the belt reach the point near the comb E , it acquires negative charge and sphere acquires positive charge due to *electrostatic induction.*
5. As a result , the positive charges are pushed away from the comb E and they reach the outer surface of the sphere.
6. The sphere is a conductor, the positive charge are distributed uniformly on the outer surface of the hollow sphere.
7. At the same time, the negative charge nullify the positive charges in the belt due to corona discharge before it passes over the pulley
8. When the belt descends, it has almost no net charge.
9. At the bottom, it again gains a large positive charge.
10. The belt goes up and delivers the positive charges to the outer surface of the sphere.
11. This process continues until the outer surface produces the potential difference of the order of 10^7 which is the limiting value.
12. We cannot store charges beyond this limit since the extra charge starts leaking to the surrounding due to ionization of air.
13. The leakage of charges can be reduced by enclosing the machine in a gas filled steel chamber at very high pressure.

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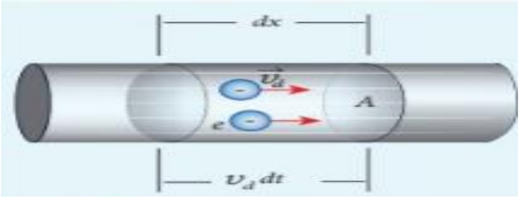
Current Electricity

1.Describe the microscopic model of current and obtain general form of Ohm's law.

Diagram :



Formula :

$$\vec{J} = \sigma \vec{E}$$

Theory :

- Let us consider a conductor .
- Area of cross section → A
- Electrons per unit volume → n
- Drift velocity of electron → v_d
- Electron move through distance → dx
- Small interval of time → dt

Derivation :

1. Drift velocity : $v_d = \frac{dx}{dt}$
2. Distance : $dx = v_d \; dt$
3. volume element : $= A\,dx \times n = A\,(v_d \; dt)\,n$
4. Total charge : $dQ = n\,e\,A\,v_d \; dt$
5. Current : $I = \frac{dQ}{dt} = e\,A\,v_d\,n$
6. Current Density : $J = \frac{I}{A} = n\,e\,v_d$
7. Drift velocity : $\vec{v_d} = -\frac{e\,\tau\,\vec{E}}{m}$
8. $\vec{J} = n\,e\left(-\frac{e\,\tau}{m}\right)\vec{E} = -\frac{n\,e^2\,\tau\,\vec{E}}{m}$
9. Conductivity : $\sigma = \frac{n\,e^2\,\tau}{m}$
10. Microscopic form of Ohm's law : $\vec{J} = \sigma \vec{E}$

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

Theory :

- Let us consider a segment of wire.
- Length of a wire → l
- Cross sectional area → A
- Potential difference → V
- Electric field → E

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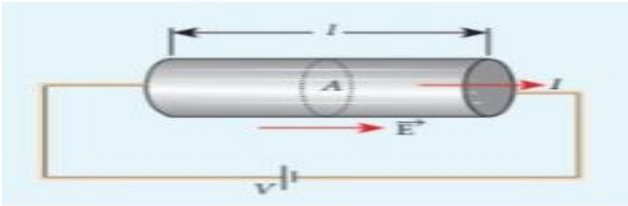
Diagram :



Formula :

$$V = I R$$

Explanation :

1. When a potential difference V is applied across the wire , a net electric field is created in the wire.
2. It will constitutes the current in the wire.
3. The electric field is uniform in the entire length of the wire.
4. The potential difference $V = E\,l$

Derivation :

1. Microscopic Ohm's law : $J = \sigma E$

2. Potential Difference : $V = E\,l$

3. Electric Field : $E = \frac{V}{l}$

4. Current Density : $J = \frac{I}{A}$

5. $J = \sigma E$

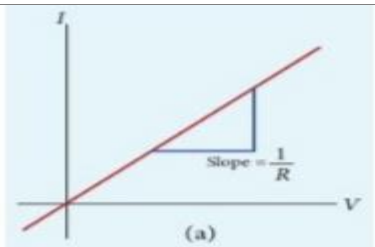
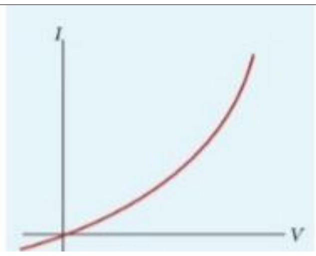
$$\frac{I}{A} = \sigma \frac{V}{l}$$

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

6. Resistance : $R = \frac{l}{\sigma A}$

7. Macroscopic form of Ohm's law : $V = I R$

Limitation :

S . NO	Ohmic Device	Non Ohmic Device
1.	Obeys Ohms law.	Not obey Ohms law.
2.	Graph is straight line.	Graph is non linear.
3.		

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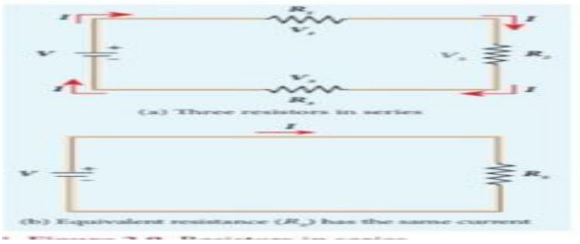
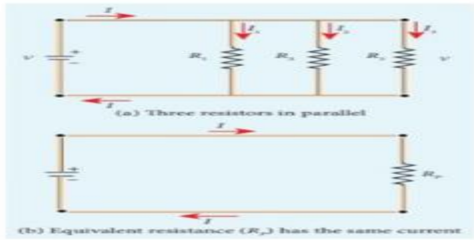
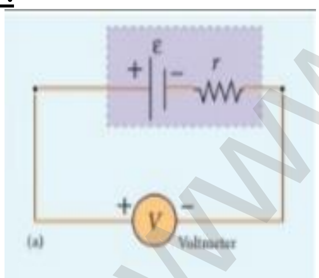
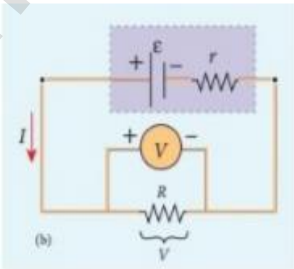
3. Explain the equivalent resistance of a series and parallel resistor network.

S.No	Resistance in series	Resistance in parallel
1.		
2.	R_1 , R_2 , R_3 are connected end to end.	R_1 , R_2 , R_3 are connected across voltage.
3.	Current be same. (I)	Current is differ. (I_1 , I_2 , I_3)
4.	Potential difference vary. (V_1 , V_2 , V_3)	Potential difference is same. (V)
5.	$V = V_1 + V_2 + V_3$ $IR = IR_1 + IR_2 + IR_3$ $R_S = R_1 + R_2 + R_3$	$I = I_1 + I_2 + I_3$ $\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$ $\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$
6.	The value of equivalent resistance in series connection will be **greater** than each individual resistance.	The value of equivalent resistance in parallel connection will be **lesser** than each individual resistance.

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

Diagram :





Formula :

$$r = \left(\frac{\varepsilon - V}{V} \right) R$$

Theory :

- Emf of cell ε is measured by connecting high resistance voltmeter across it.

S.NO	Without external resistance	With external resistance
1.	It is open circuit.	It is closed circuit.
2.	Voltmeter draws very little current.	Current I is established in the circuit.
3.	Voltmeter gives the emf of the cell.	The potential difference across R is equal to the potential difference across the cell (V)

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Derivation :

- Due to internal resistance r of the cell , V Which is less than the emf of cell ε.
- Certain amount of voltage Ir has dropped across the internal resistance.

$$V = \varepsilon - Ir$$

$$Ir = \varepsilon - V$$

1. Due to external resistance : $I R = V \longrightarrow (1)$

2.Due to internal resistance : $I r = \varepsilon - V \longrightarrow (2)$

3. Eqn (2) % eqn (1)

$$\frac{I r}{I R} = \frac{\varepsilon - V}{V}$$

4. $$\frac{r}{R} = \frac{\varepsilon - V}{V}$$

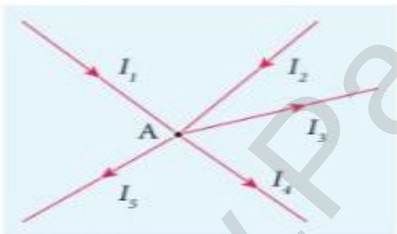
5. Internal Resistance : $$r = \left(\frac{\varepsilon - V}{V}\right) R$$

---

5. State and explain Kirchhoff's rules.

1. **Kirchhoff's First Rule:**

- Current rule or junction rule.
- Law of conservation of electric charge.
- It states that the algebraic sum of currents of any junction of a circuit is zero.
- Charge enter a junction must leave the junction.
- Current entering the junction as positive, current leaving the junction as negative.

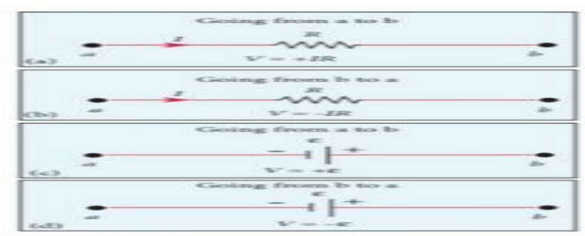


Kirchhoff's current rule

$$I_1 + I_2 - I_3 - I_4 - I_5 = 0$$
$$I_1 + I_2 = I_3 + I_4 + I_5$$

2. **Kirchhoff's Second Rule:**

- Voltage rule or loop rule.
- Law of conservation of energy.
- Product of current and resistance is taken as positive $V = + I R$.
- Product of current and resistance is taken as negative $V = - I R$.
- In a closed circuit the algebraic sum of the products of the current and resistance of each part of the circuit is equal to total emf included in the circuit.



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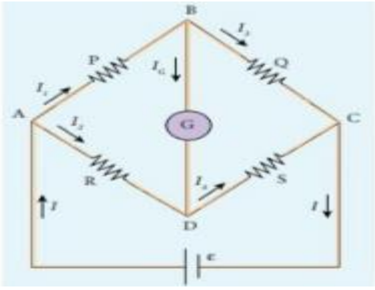
6. Obtain the condition for bridge balance in Wheatstone's bridge.

Diagram :



Parts :

PQRS	–	Resistance
G	–	Galvanometer
ε	–	Battery
I	–	current

Formula :

$$\frac{P}{Q} = \frac{R}{S}$$

Circuit connection :

1. The bridge consists of four resistance P , Q , R and S.
2. A galvanometer is connected between B and D.
3. The battery is connected between A and C.
4. The current through the galvanometer is I_G .

Kirchhoff's Current Rule

1. At junction B : $I_1 - I_G - I_3 = 0$

2. At junction D : $I_2 + I_G - I_4 = 0$

Kirchhoff's Voltage Rule

3. ABDA Loop : $I_1 P + I_G G - I_2 R = 0$

4. BCDB Loop : $I_3 Q - I_4 S - I_G G = 0$

Balancing Condition $I_G = 0$

$I_1 = I_3$, $I_2 = I_4$ | $I_1 P = I_2 R$, $I_3 Q = I_4 S$ | $\frac{I_1 P}{I_3 Q} = \frac{I_2 R}{I_4 S}$

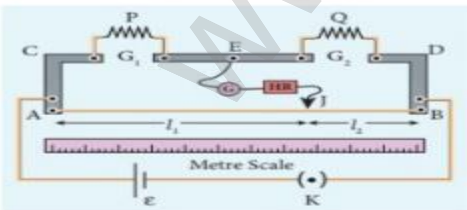
Condition for bridge balance:

$$\frac{P}{Q} = \frac{R}{S}$$

---

7. Explain the determination of unknown resistance using meter bridge.

Diagram:



Formula :

$$P = Q \frac{l_1}{l_2}$$

Construction :

1. Meter bridge is another form of Wheatstone bridge.
2. AB is one meter length manganin wire.
3. A meter scale on wooden board.
4. Two copper strips C, D another strip is E.
5. Two gaps are G_1 and G_2.
6. Unknown resistance P and known resistance Q.

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7. Jockey connected with G and HR.
8. Lechlance cell, key connected to end of bridge wire.

Working:

- The position of the jockey on the wire is adjusted.
- Adjust jockey on the wire, galvanometer shows zero deflection.
- Let the position of jockey at the wire is J.

Bridge balance:

The resistances corresponding to AJ to JB of the bridge wire form the resistance R and S of the Wheatstone's bridge.

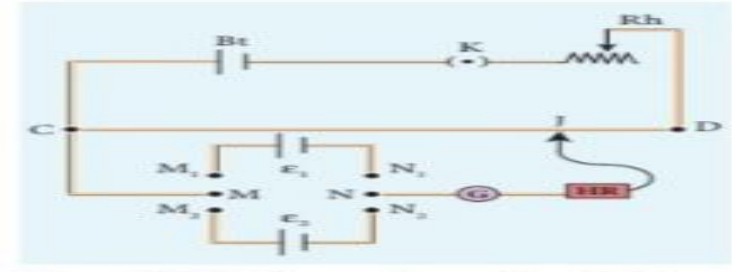
$$\frac{P}{Q} = \frac{R}{S} = \frac{r \cdot AJ}{r \cdot JB} = \frac{l_1}{l_2}$$

$$P = Q \frac{l_1}{l_2}$$

---

8. How the emf of two cells are compared using potentiometer?

Diagram:



Formula :

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{l_1}{l_2}$$

Theory:

1) To compare the emf of the cells , the circuit connections are made.
2) Potentiometer wire is CD is connected to a battery Bt and key K in series.
3) This is the primary circuit.
4) The end C of the wire is connected to the terminal M of DPDT. (double pole double throw switch)
5) The other terminal N is connected to jockey though galvanometer G and high resistance HR.
6) The cells whose emf are ε_1 and ε_2 to be connected to the terminals M_1, N_1 and M_2, N_2 of DPDT switch.
7) The positive terminals of Bt , ε_1 and ε_2 should connected to the same end C.

Working:

1) DPDT switch pressed towards M_1 and N_1.
2) Cell ε_1 included in secondary circuit.
3) Balancing length is l_1 adjust jockey for zero deflection.
4) Cell ε_2 included in secondary circuit.
5) Balancing length is l_2 adjust jockey for zero deflection.

Derivation:

- Let r be the resistance per unit length of the potentiometer.
- I be the current flowing through the wire.

$$\varepsilon_1 = I\ r\ l_1 \text{ -------- } (1)$$

$$\varepsilon_2 = I\ r\ l_2 \text{ -------- } (2)$$

Equation (1) divide by (2)

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{I\ r\ l_1}{I\ r\ l_2}$$

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{l_1}{l_2}$$

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3. Magnetism & magnetic effects of electric current

1. Discuss Earth's magnetic field in detail.

1. Willam Gilbert

In 1600 proposed that Earth itself behaves like a gigantic powerful magnet.

2. Gover

- Earth's magnetic field due to hot rays coming out from the sun.
- These rays heat up the air near the equatorial region.
- Once air becomes hotter , it rises above and move towards northern and southern hemisphere and get electrified.
- This may be responsible to magnetize the ferromagnetic material near Earth surface.

3. Geographic Poles

- North pole of magnetic compass needle is attracted towards magnetic south pole of earth which near the geographic north pole.
- South pole of magnetic compass needle is attracted towards magnetic north pole of Earth which near the geographic south pole.

4. Terrestrial Magnetism

Branch of physics which deals with Earth's magnetic field is called " Geomagnetism or Terrestrial magnetism ".

5. Elements of Earth magnetic field

a . Magnetic Declination (D)

Angle between magnetic meridian at a point and geographical meridian.

b. Magnetic dip or inclination (I)

Angle subtended by Earth's total magnetic field with horizontal direction in the magnetic meridian.

c. Horizontal component of Earth magnetic field (B_H)

- Horizontal Component $B_H = B_E \cos I$
- Vertical Component $B_V = B_E \sin I$

$$\tan I = \frac{B_V}{B_H}$$

i) At magnetic equator

The Earth's magnetic field parallel to the surface of the Earth at an angle of dip $I = 0^0$

- $B_H = B_E$ (Horizontal component maximum at equator)
- $B_V = O$ (Vertical component zero at equator)

i) At magnetic poles

Earth's magnetic field perpendicular to the surface of the Earth at an angle of dip $I=90^0$

- $B_H = 0$ (Horizontal component zero at poles)
- $B_V = B_E$ (Vertical component maximum at poles)

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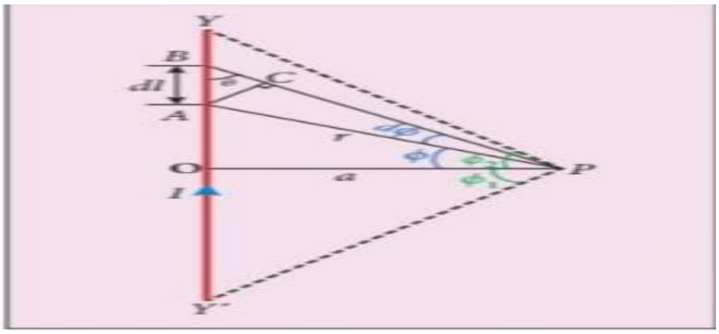
2. Deduce the relation for the magnetic field at a point due to infinitely long straight conductor carrying current.

Theory :

- Let YY' be an infinitely long straight conductor.
- I be current through the conductor.
- dB be magnetic field at a point P which is at distance 'a'.
- Let us consider small line element dl be the segment AB.

Diagram :



Formula :

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

Biot Savart's Law :

$$\vec{dB} = \frac{\mu_0}{4\pi}\frac{I\,dl\,\sin\theta}{r^2}\hat{n} \longrightarrow (1)$$

To apply trigonometry

Δ ABC	Δ APC	Δ OPA
$\sin\theta = \frac{AC}{AP}$	$\sin d\phi = \frac{AC}{AB}$	$\cos\phi = \frac{OP}{AP}$
$\sin\theta = \frac{AC}{dl}$	$d\phi = \frac{AC}{r}$	$\cos\phi = \frac{a}{r}$
$AC = dl\sin\theta$	$AC = r\,d\phi$	$\frac{1}{r} = \frac{\cos\phi}{a}$

$$dl\sin\theta = r\,d\phi \longrightarrow (2)$$

$$\frac{1}{r} = \frac{\cos\phi}{a} \longrightarrow (3)$$

Sub eqn (2) & (3) in (1)

1. $\vec{dB} = \frac{\mu_0}{4\pi}\frac{I\,dl\,\sin\theta}{r^2}\hat{n}$

2. $\vec{dB} = \frac{\mu_0 I}{4\pi}\frac{r\,d\phi}{r^2}\hat{n}$

3. $\vec{dB} = \frac{\mu_0 I}{4\pi}\frac{1}{r}\,d\phi\,\hat{n}$

4. $\vec{dB} = \frac{\mu_0 I}{4\pi}\frac{\cos\phi}{a}\,d\phi\,\hat{n}$

5. $\int dB = \frac{\mu_0 I}{4\pi a}\int_{-\phi_1}^{\phi_2}\cos\phi\,d\phi\,\hat{n}$

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6. $\vec{B} = \frac{\mu_0 I}{4\pi a} [\sin\phi]_{-\phi_1}^{\phi_2} \hat{n}$

7. $\vec{B} = \frac{\mu_0 I}{4\pi a} [\sin\phi_2 - (\sin(-\phi_1))] \hat{n}$

8. $\vec{B} = \frac{\mu_0 I}{4\pi a} [\sin\phi_2 + \sin\phi_1] \hat{n}$

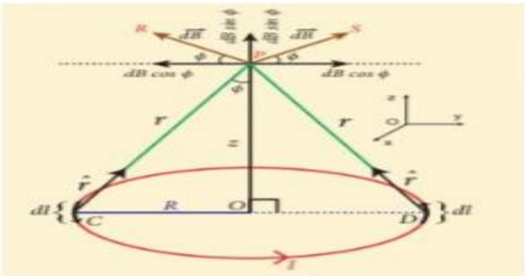
9. For infinitely long conductor , $\phi_1 = \phi_2 = 90^0$ then $\sin 90^0 + \sin 90^0 = 1 + 1 = 2$

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

---

3. Obtain the relation for the magnetic field at a point along the axis of a circular coil carrying current.

Diagram :



Formula :

$$\vec{B} = \frac{\mu_0 N I}{2R} \hat{k}$$

Theory :

Consider a current carrying circular coil.

- Radius of the loop ⟶ R
- Current through the loop ⟶ I
- Magnetic field at a point ⟶ P
- Distance from O to P ⟶ Z
- Line element of the coil ⟶ dl

Biot – Savart' s Law :

$$dB = \frac{\mu_0}{4\pi} \frac{I\, dl\, \sin\theta}{r^2} \longrightarrow (1)$$

If angle between $I\vec{dl}$ and $\vec{r}$ is 90^0 then $\sin 90^0 = 1$

$$dB = \frac{\mu_0}{4\pi} \frac{I\, dl}{r^2} \longrightarrow (2)$$

Component of dB :

- dB cos ϕ along y - direction.
- dB sin ϕ along z - direction.

Net Magnetic field :

- Horizontal component cancel out each other.
- Vertical component contribute net magnetic field.

$$\int \vec{dB} = \int dB \sin\phi\, \hat{k} \longrightarrow (3)$$

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Sub eqn (2) in eqn (3)

$$\int dB = \frac{\mu_0 I}{4\pi} \frac{1}{r^2} \sin\phi \, \hat{k} \int dl \longrightarrow (4)$$

From triangle Δ O C P

$$Hyp^2 = Opp^2 + Adj^2$$

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

$$r = (R^2 + z^2)^{1/2}$$

$$\sin\phi = \frac{Opp}{Hyp}$$

$$\sin\phi = \frac{R}{(R^2 + z^2)^{1/2}}$$

$$\int dl = 2\pi R$$

$$\vec{B} = \frac{\mu_0 I}{4\pi} \frac{1}{R^2 + z^2} \frac{R}{(R^2 + z^2)^{1/2}} \hat{k} \, 2\pi R$$

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

If the circular coil contains N turns then ,

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

The magnetic field at the centre of the coil is zero , z = 0 then $(R^2 + z^2)^{3/2} = R^3$

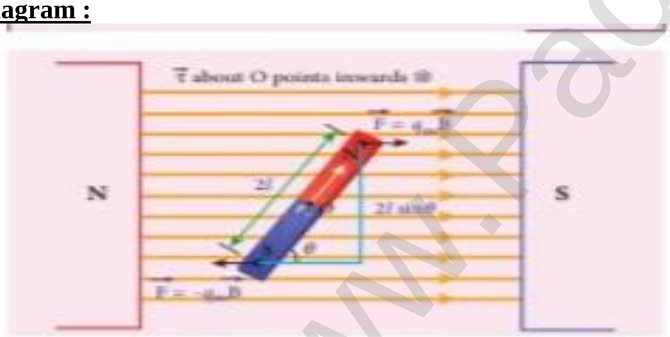
$$\vec{B} = \frac{\mu_0 N I}{2} \frac{R^2}{R^3} \hat{k}$$

$$\boxed{\vec{B} = \frac{\mu_0 N I}{2R} \hat{k}}$$

---

4. Compute the torque experienced by a magnetic needle in a uniform magnetic field.

Diagram :



Formula :

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

Theory :

1. Consider a magnet of length 2*l*
2. Pole strength q_m kept in a uniform magnetic field.
3. Each pole experiences a force of magnitude $q_m \vec{B}$ and act in opposite direction.
4. Net force acting on the magnet is zero so there is no translatory motion.
5. Two equal and opposite forces constitute a couple tend to align magnet in B direction.

Derivation :

1. Force experienced by north pole $\vec{F}_N = q_m \vec{B}$

2. Force experienced by south pole $\vec{F}_S = - q_m \vec{B}$

3. Net force acting on dipole $\vec{F} = \vec{F}_N + \vec{F}_S = 0$

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Moment of Force / Torque :

1. $\vec{\tau} = \vec{ON} \times \vec{F_N} + \vec{ON} \times \vec{F_S}$
2. $\vec{\tau} = \vec{ON} \times q_m \vec{B} + \vec{ON} \times (-q_m \vec{B})$
3. By using right hand cork screw rule

$$|\vec{ON}| = |\vec{OS}| = l$$

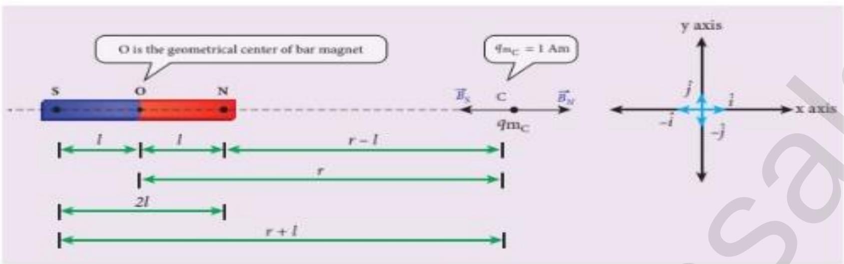
$$|q_m \vec{B}| = |-q_m \vec{B}| = l$$

4. $\tau = l \times q_m B \sin\theta + l \times q_m B \sin\theta$
5. $\tau = 2 l \times q_m B \sin\theta$
6. $\tau = p_m B \sin\theta \quad (p_m = q_m \times 2l)$ $\boxed{\vec{\tau} = \vec{p_m} \times \vec{B}}$

---

5. Calculate the magnetic field at a point on the axial line of a bar magnet.

Diagram :



Formula :

$$\vec{B}_{axial} = \frac{\mu_0}{4\pi} \frac{2}{r^3} \vec{p_m}$$

Theory :

1. Consider a bar magnet NS.
2. Let N be north pole and S be the south pole.
3. Each of pole strength q_m and are separated by a distance of 2 l.
4. Magnetic field at a point C at a distance r.
5. Geometrical centre ' O ' of the bar magnet.

Magnetic Field at C

1. Due to north pole : $\vec{B_N} = \frac{\mu_0}{4\pi} \frac{q_m}{(r-l)^2} \hat{i}$
2. Due to south pole : $\vec{B_S} = -\frac{\mu_0}{4\pi} \frac{q_m}{(r+l)^2} \hat{i}$
3. Net magnetic field : $\vec{B} = \vec{B_N} + \vec{B_S}$
4. $\vec{B} = \frac{\mu_0}{4\pi} \frac{q_m}{(r-l)^2} \hat{i} - \frac{\mu_0}{4\pi} \frac{q_m}{(r+l)^2} \hat{i}$
5. $\vec{B} = \frac{\mu_0 q_m}{4\pi} \left[\frac{1}{(r-l)^2} - \frac{1}{(r+l)^2} \hat{i} \right]$
6. $\vec{B} = \frac{\mu_0 q_m}{4\pi} \left[\frac{4rl}{(r^2 - l^2)^2} \hat{i} \right]$
7. $\vec{B} = \frac{\mu_0}{4\pi} \left[\frac{2r.\, 2 q_m l}{(r^2 - l^2)^2} \hat{i} \right]$

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8. $\vec{B} = \frac{\mu_0}{4\pi}\left[\frac{2\,r\,p_m}{(r^2 - l^2)^2}\,\hat{i}\right]$ $\quad (p_m = 2\,q_m\,l)$

9. If $r >>> l$ then $(r^2 - l^2)^2 = r^4$

$$\vec{B} = \frac{\mu_0}{4\pi}\left[\frac{2\,r\,p_m}{r^4}\,\hat{i}\right]$$

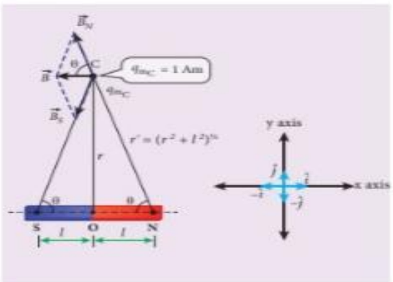
10. $\vec{B} = \frac{\mu_0}{4\pi}\left[\frac{2\,p_m}{r^3}\,\hat{i}\right]$ $\quad (\vec{p}_m = p_m\,\hat{i})$

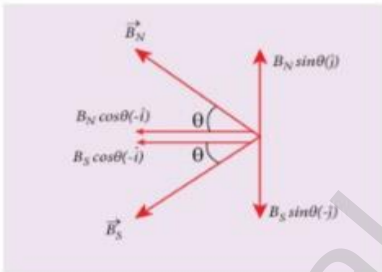
$$\boxed{\vec{B}_{axial} = \frac{\mu_0}{4\pi}\,\frac{2\,\vec{p}_m}{r^3}}$$

---

6. Obtain the magnetic field at a point on the equatorial line of a bar magnet.

Diagram :





Formula :

$$\boxed{\vec{B}_{equatorial} = -\frac{\mu_0}{4\pi}\,\frac{\vec{p}_m}{r^3}}$$

Theory :

1. Consider a bar magnet NS .
2. Let N be the north pole and S be the south pole.
3. Pole strength q_m be separated by a distance 2l.
4. Magnetic field at point C at a distance r.
5. Geometrical centre of the bar magnet is O.

Magnetic Field at C :

1. Due to north pole : $\vec{B}_N = -B_N\cos\theta\,\hat{i} + B_N\sin\theta\,\hat{j}$

2. Due to south pole : $\vec{B}_S = -B_S\cos\theta\,\hat{i} - B_S\sin\theta\,\hat{j}$

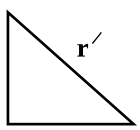
3. Net magnetic field : $\vec{B} = \vec{B}_N + \vec{B}_S$

4. Since $B_N = B_S$: $B = -(B_N + B_S)\cos\theta\,\hat{i}$

5. Here , $B_N = B_S = -\frac{\mu_0}{4\pi}\,\frac{q_m}{r'^2}$

6. $B = -\frac{2\mu_0}{4\pi}\,\frac{q_m}{r'^2}\cos\theta\,\hat{i}$

7. In triangle ONC



$Hyp^2 = Opp^2 + Adj^2$

$r'^2 = r^2 + l^2$

$r' = (r^2 + l^2)^{1/2}$

$\cos\theta = \frac{adj}{hyp}$

$\cos\theta = \frac{l}{(r^2 + l^2}$

8. $\vec{B} = -\frac{2\mu_0}{4\pi}\,\frac{q_m}{r'^2}\cos\theta$

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Substitute r'^2 and $\cos\theta$

$$\vec{B} = -\frac{2\mu_0}{4\pi}\frac{q_m}{(r^2 + l^2)}\frac{l}{(r^2 + l^2)^{1/2}}\hat{i}$$

9. $$B = -\frac{\mu_0}{4\pi}\frac{2 q_m l}{(r^2 + l^2)^{3/2}}\hat{i}$$

10. If $r >>> l$ then $(r^2 + l^2)^{3/2} = r^3$ and magnetic dipole moment $p_m = 2 q_m l$

11. $$\vec{B} = -\frac{\mu_0}{4\pi}\frac{p_m}{r^3}\hat{i}$$

12. $$\vec{B} = -\frac{\mu_0}{4\pi}\frac{p_m}{r^3} \qquad (\vec{p}_m = p_m\hat{i})$$

$$\vec{B}_{equatorial} = -\frac{\mu_0}{4\pi}\frac{\vec{p}_m}{r^3}$$

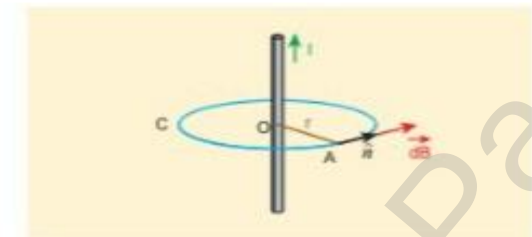
---

7. Find the magnetic field due to a long straight conductor using Ampere's circuit law.

Theory :

1. Consider a straight conductor of infinite length carrying current I.
2. The wire is geometrically cylindrical in shape and symmetrical about its axis.
3. We construct Amperian loop in the form of circular shape.
4. Current enclosed by Amperian loop is I.
5. Distance from centre of conductor is r.
6. Line element along Amperian loop is dl.

Diagram :



Formula :

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

By Ampere's Law :

1. $$\oint_c \vec{B}\cdot\vec{dl} = \mu_0 I$$

2. The angle between magnetic field vector and line element is zero.

3. $$\oint_c B\,dl = \mu_0 I$$

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

5. $$B\oint_c dl = \mu_0 I$$

6. For a circular loop , the circumference is $2\pi r$.

7. $B \cdot 2\pi r = \mu_0 I$

8. $$B = \frac{\mu_0 I}{2\pi r}$$

9. In vector form , the magnetic field is

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

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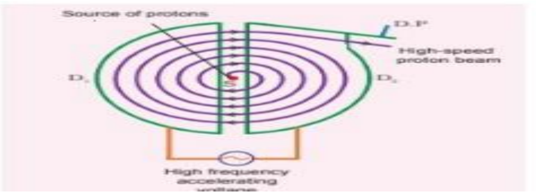
8. Discuss the working of cyclotron in detail.

Cyclotron :

1. It is device used to accelerate the charged particle to gain large kinetic energy.
2. It is also called as high energy accelerator.
3. It was invented by Lawrence and Livingston in 1934.

Diagram :



Formula :

$$f_{osc} = \frac{B\,q}{2\,\pi\,m}$$

Principle :

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

Construction :

1. The particles are allowed to move in between two semi circular metal container called DEES .
2. Dees are enclosed in an evacuated chamber.
3. And kept in a region with uniform magnetic field controlled by an electromagnet.
4. Two Dees are kept separated with a gap and source S.
5. The source S is which ejects the particle to be accelerated.
6. Dees are connected to high frequency alternating potential difference.

Working :

1. The ion ejected from source S is positively charged.
2. The ion is ejected it is accelerated towards a Dee which is at negative potential.
3. Magnetic field is normal to the plane of the Dees , the ion moves in the circular path.
4. After one semi – circular path inside Dee – 1 , the ion reaches gap between the Dees.
5. The polarities of the Dees are reversed so that the ion is now accelerated towards Dee – 2 with the greater velocity.

Derivation :

1. For circular motion : Centripetal Force $= \frac{m\,v^2}{r}$

2. For uniform magnetic field : Lorentz Force = B q v

$$B\,q\,v = \frac{m\,v^2}{r}$$

$$r = \frac{m\,v}{q\,B}$$

$$r \propto v$$

3. Velocity increases , radius increases .
4. Particle moves in spiral path of increasing radius.
5. Particle taken out with the help of deflector plate and allowed to hit the target.

Resonance condition in Cyclotron :

When the frequency f at which the positive ion circulates in the magnetic field must be equal to constant frequency of the electrical oscillator f_{osc} . This is called " Resonance condition "

$$\omega = 2\,\pi\,f$$

$$f = \frac{\omega}{2\,\pi}$$

$$f = \frac{v/r}{2\,\pi} \qquad (v = r\,\omega)$$

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$$f_{osc} = \frac{B\,q}{2\,\pi\,m}$$

Time period of oscillation :

$$T = \frac{1}{f} = \frac{2\,\pi\,m}{B\,q}$$

Kinetic Energy of charged particle :

$$K.E = \frac{1}{2}\,m\,v^2$$

$$v = \frac{B\,q\,r}{m}$$

$$K.E = \frac{1}{2}\,m\,\frac{B^2\,q^2\,r^2}{m^2}$$

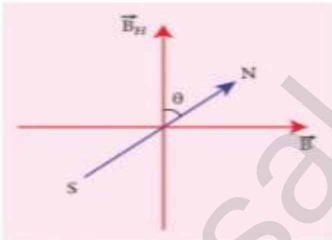
$$K.E = \frac{B^2\,q^2\,r^2}{2m}$$

---

9. What is tangent law ? Discuss in detail.

Tangent Law :

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



$$B = B_H \tan\theta$$

Tangent Galvanometer :

- **T G is a device used to detect very small current.**
- **It is a moving magnet type galvanometer.**
- **Its working based on tangent law.**

Construction :

1. T G consists of copper coil of turns wound on a non-magnetic circular frame.
2. The frame is made up of brass or wood which is mounted vertically.
3. A horizontal base table with three levelling screws.
4. In lab experiments contains coils on 2 turns , 5 turns and 50 turns.
5. At the centre of turn table , a compass box is placed.
6. Compass box consists of two needle as magnetic needle and aluminium pointer.
7. Centres of both magnetic needle and circular coil exactly coincide.
8.Thin aluminium pointer attached perpendicular to magnetic needle over graduated circular scale.
9. Circular scale divided into four quadrant and graduated in degrees 0^0 to 90^0.
10. To avoid parallax error in measurement , mirror is placed below aluminium pointer.

Precautions :

1. Avoid magnetic material away from instrument.
2. Using sprit level , Adjust levelling screw.
3. Rotate compass box reads 0^0 - 0^0.
4. Coil remains in magnetic meridian.

Theory :

- **When no current is passed through coil , magnetic needle lies along horizontal component of earth's magnetic field.**
- **When the circuit is closed , the electric current pass through the circular coil and produce magnetic field at the centre of the coil.**

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Two Fields :

1. The magnetic field (B) due to the electric current in the coil acting normal to the plane of the coil.
2. The horizontal component of Earth magnetic field (B_H)

Derivation :

1. From tangent law : $B = B_H \tan\theta$

2. Magnitude of magnetic field at the centre : $B = \frac{\mu_0 N I}{2R}$

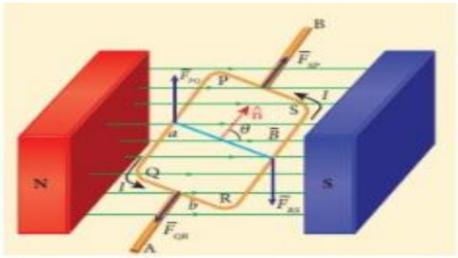
3. $B_H \tan\theta = \frac{\mu_0 N I}{2R}$

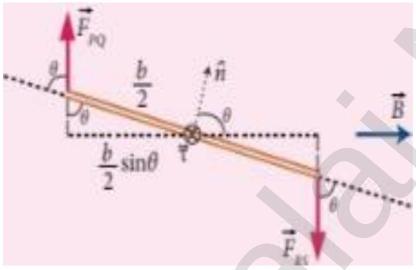
$$B_H = \frac{\mu_0 N}{2R} \frac{I}{\tan\theta}$$

---

10. Derive the expression for the torque on a current carrying coil in a magnetic field.

Diagram :





Formula

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

$$\tau = N I B \sin\theta$$

Theory :

- Consider a rectangular loop P Q R S.
- Current through the coil is I.
- Uniform magnetic field is B.
- Length of the rectangular loop is 'a '.
- Breadth of the rectangular loop is 'b' .

Magnitude of magnetic force :

1. On the arm $F_{PQ} = I a B \sin(\pi/2) = I a B$

2. On the arm $F_{QR} = I b B \sin(\pi/2 - \theta) = I b \cos\theta$

3. On the arm $F_{RS} = I a B \sin(\pi/2) = I a B$

4. On the arm $F_{SP} = I b B \sin(\pi/2 + \theta) = I b \cos\theta$

5. The forces F_{QR} and F_{SP} are equal , opposite and collinear , they cancel each other.

6. The forces F_{PQ} and F_{RS} , which are equal in magnitude and opposite in direction not acting along the straight line.

7. F_{PQ} and F_{RS} constitute the couple which exerts a torque on the loop.

Magnitude of Torque :

1. On the arm PQ about AB is $\tau_{PQ} = \left(\frac{b}{2} \sin\theta\right) I a B$

2. On the arm RS about AB is $\tau_{RS} = \left(\frac{b}{2} \sin\theta\right) I a B$

Total Torque acting on the loop

1. $\tau = \left(\frac{b}{2} \sin\theta\right) I a B + \left(\frac{b}{2} \sin\theta\right) I a B$

2. $\tau = 2 \frac{b}{2} \sin\theta \; I a B$

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3. $\tau = I\,(a\ b)\,B \sin\theta$

4. $\tau = I\,A\,B \sin\theta$

5. $\vec{\tau} = (I\,\vec{A}) \times \vec{B}$

6. $\vec{\tau} = \vec{p}_m \times \vec{B}$ where $\vec{p}_m = I\,\vec{A}$

If there are N turns in the rectangular loop , then the toque is

$$\tau = N\,I\,A\,B \sin\theta$$

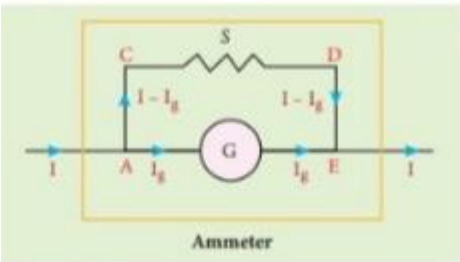
Cases :

Plane of the loop parallel to magnetic field	$\theta = 90^0$	$\tau_{max} = I\,A\,B$	Torque is maximum
Plane of the loop perpendicular to magnetic field	$\theta = 0^0 / 180^0$	$\tau = 0$	Torque is zero

---

11. Discuss the conversion of galvanometer into an ammeter and also voltmeter.

Diagram :



Galvanometer to ammeter:

1. Used to measure the current flows in circuit.
2. Connect low resistance parallel with galvanometer is as ammeter.
3. Low parallel resistance is "*shunt resistance* "
4. Current through the circuit is I .
5. Current through galvanometer is I_g .
6. Resistance of galvanometer is R_g.
7. Current along the path ACDE is $I - I_g$.
8. Value of shunt resistance is S .

Derivation :

1. $V_{galvanometer} = V_{shunt}$

2. $I_g R_g = (I - I_g)\, S$

3. $I_g R_g = I\,S - I_g\,S$

4. $I_g\,S + I_g R_g = I\,S$

5. $(S + R_g)\, I_g = I\,S$

6. $I_g = \dfrac{S}{S + I_g}\, I$

Deflection on galvanometer :

$$\theta \ \alpha \ I$$

$$\theta = \frac{I_g}{G}$$

- Deflection produced in the galvanometer is a measure of current through the circuit.
- Deflection in the galvanometer is proportional to the current passing through it.

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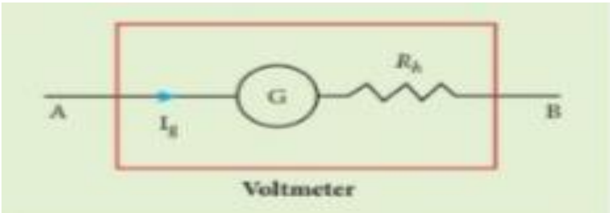
Resistance of Ammeter :

- Shunt resistance is connected in *parallel* to galvanometer.
- $\frac{1}{R_{eff}} = \frac{1}{R_g} + \frac{1}{S} = \frac{R_g S}{R_g + S}$

$$R_a = R_{eff} = \frac{R_g S}{R_g + S}$$

- Shunt resistance is a very low resistance , R_a is small.
- Resistance offered by the ammeter is small.
- An ammeter is a low resistance instrument , always connected in *series* .
- Ammeter will not change the current in the circuit.

Galvanometer to a voltmeter :



1. Used to measure potential difference.
2. Connect high resistance series with galvanometer act as voltmeter.
3. Current through the circuit is I .
4. Current through galvanometer is I_g .
5. High resistance is denoted as R_h.
6. Voltmeter resistance is denoted as $R_v = R_g + R_h$

Derivation :

Current through the circuit is same as current pass through galvanometer.

$$I = I_g$$

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

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

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

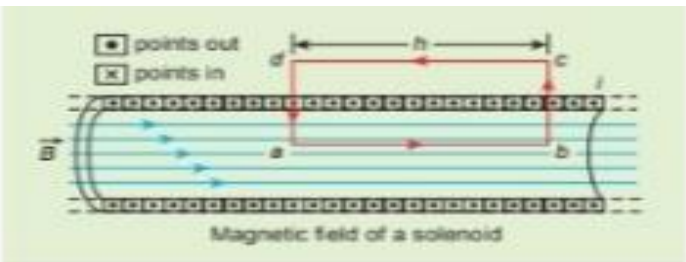
- Deflection in galvanometer is proportional to current I_g.
- Current I_g is proportional to potential difference.
- Resistance of voltmeter is *large.*
- Voltmeter is high resistance instrument connected in *parallel* with circuit.

$$I_g \propto V$$

---

12. Calculate the magnetic field inside and outside of the long solenoid using Ampere's circuital law.

Diagram :



Formula :

$$B = \mu_0 n I$$

Consider a solenoid of length L having N turns.

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- Consider rectangular loop a b c d.
- Diameter of solenoid is assumed to be much smaller when compared to its length.

Ampere's Circuital Law :

1. $\oint_c \vec{B}\cdot\vec{dl} = \mu_0 \; I_{enclosed}$
2. $\oint_c B\cdot dl = \mu_0 \times$ (Total current enclosed by Amperian loop)

L. H . S

3. $\oint_c B\cdot dl = \int_a^b B\cdot dl + \int_b^c B\cdot dl + \int_c^d B\cdot dl + \int_d^a B\cdot dl$

4. The element length along b c and d a are perpendicular to magnetic field which is along the axis of solenoid .

5. $\int_b^c B\cdot dl = \int_b^c B\, dl \cos 90^0 = 0$

6. $\int_d^a B\cdot dl = \int_d^a B\, dl \cos 90^0 = 0$

7. Since magnetic field outside the solenoid is zero.

8. $\int_c^d B\cdot dl = 0$

9. For the path along a b , the integral is $\int_a^b B\cdot dl = B \int_a^b dl \cos 0^0 = B\int_a^b dl$

10. Length of the loop a b is h but the length of the loop is arbitrary. We can take very large loop such that it is equal to the length of the solenoid is L.

11. $B\int_a^b dl = B\;L$

12. Let I be the current passing through the solenoid of N turns.

13. $B\;L = \mu_0\; N\; I$

14. $B = \mu_0 \dfrac{N\;I}{L}$

15. Number of turns per unit length $N / L = n$

$$B = \mu_0\, n\, I$$

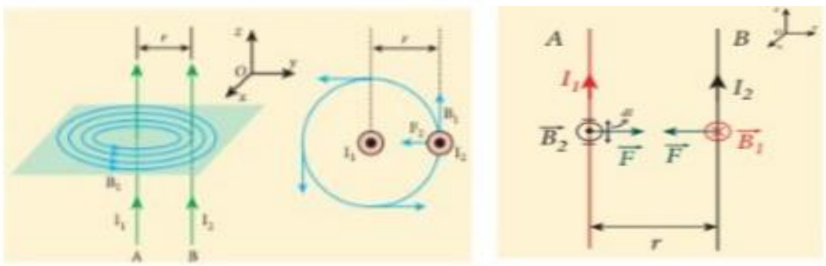
---

13. **Derive the expression for the force between two parallel , current carrying conductors.**

Consider two conductor long straight parallel current carrying conductor.

- Two parallel long conductors ⟶ A , B
- Current through the conductor ⟶ I_1 , I_2
- Distance between the conductor ⟶ r
- Magnetic Field along conductor ⟶ B_1 , B_2
- Force between two conductor ⟶ F

Diagram :



Formula :

$$\frac{F}{l} = \frac{\mu_0\, I_1\, I_2}{2\,\pi\, r}\,\hat{j}$$

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S. NO	On Conductor A	On Conductor B
1.	$\vec{B_1} = \frac{\mu_0 I_1}{2\pi r}(-\hat{i})$ $\vec{B_1} = -\frac{\mu_0 I_1}{2\pi r}\hat{i}$	$\vec{B_2} = \frac{\mu_0 I_2}{2\pi r}(\hat{i})$ $\vec{B_2} = \frac{\mu_0 I_2}{2\pi r}\hat{i}$
2.	$\vec{dF} = I_1 \vec{dl} \times \vec{B_2}$ $\vec{dF} = I_1 dl \frac{\mu_0 I_2}{2\pi r}(\hat{k} \times \hat{i})$ $\vec{dF} = \frac{\mu_0 I_1 I_2}{2\pi r} dl\, \hat{j}$	$\vec{dF} = I_2 \vec{dl} \times \vec{B_1}$ $\vec{dF} = -I_2 dl \frac{\mu_0 I_2}{2\pi r}(\hat{k} \times \hat{i})$ $\vec{dF} = -\frac{\mu_0 I_1 I_2}{2\pi r} dl\, \hat{j}$
3.	$\int \vec{dF} = \frac{\mu_0 I_1 I_2}{2\pi r}\hat{j} \int dl$ $\vec{F} = \frac{\mu_0 I_1 I_2}{2\pi r}\hat{j}\, l$ $\frac{\vec{F}}{l} = \frac{\mu_0 I_1 I_2}{2\pi r}\hat{j}$	$\int \vec{dF} = \frac{\mu_0 I_1 I_2}{2\pi r}\hat{j} \int dl$ $\vec{F} = \frac{\mu_0 I_1 I_2}{2\pi r}\hat{j}\, l$ $\frac{\vec{F}}{l} = \frac{\mu_0 I_1 I_2}{2\pi r}\hat{j}$

- **The force between two parallel current carrying conductors is *attractive* if they carry current in *same* current.**
- **The force between two parallel current carrying conductors is *repulsive* if they carry current in *opposite* current.**

---

14. Give an account of magnetic Lorentz force.

1. **When an electric charge q is kept at rest in a magnetic field , no force acts on it. At the same time , if the charge moves in the magnetic field it experience a force.**
2. **This force is different from Coulomb force and known as magnetic force.** $\vec{F} = q(\vec{v} \times \vec{B})$
3. **If the charge is moving in both electric and magnetic fields , the total force experienced by the charge is given by ,** $\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$ **. It is known as " Lorentz Force " .**

<u>Force on a moving charge in a magnetic field :</u>

When an electric charge q is moving with velocity $\vec{v}$ in the magnetic field $\vec{B}$, it experiences a force

$$\vec{F_m} = q(\vec{v} \times \vec{B}) = q\, v\, B \sin\theta$$

1. **$\vec{F_m}$ is directly proportional to the magnetic field $\vec{B}$.**
2. **$\vec{F_m}$ is directly proportional to the velocity $\vec{v}$ of the moving charge.**
3. **$\vec{F_m}$ is directly proportional to the sine of the angle between the velocity and magnetic field.**
4. **$\vec{F_m}$ is directly proportional to the magnitude of the charge q.**
5. **The direction of $\vec{F_m}$ is always perpendicular to $\vec{v}$ and $\vec{B}$ as $\vec{F_m}$ is the cross product of $\vec{v}$ and $\vec{B}$.**
6. **The direction of $\vec{F_m}$ on negative charge is opposite to the direction of $\vec{F_m}$ on positive charge .**
7. **If velocity $\vec{v}$ of the charge q is long magnetic field $\vec{B}$ then , $\vec{F_m}$ is zero.**

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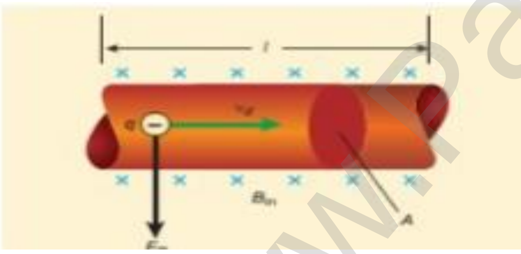
15. Compare the properties of soft and hard ferromagnetic materials.

S.No	Properties	Soft Ferromagnetic	Hard Ferromagnetic
1.	When external field is removed	Magnetisation disappears	Magnetisation Persists
2.	Area of the loop	Small	Large
3.	Retentivity	Low	High
4.	Coercivity	Low	High
5.	Susceptibility ,magnetic permeability	High	Low
6.	Hysteresis Loop	Less	More
7.	Uses	Solenoid core, Transformer Core	Permanent Magnets.
8.	Examples	Soft iron , Mumetal , Stalloy.	Carbon steel , Alnico , Lodestone

---

16. Derive the expression for the force on a current carrying conductor in a magnetic field.

Diagram :



Formula :

$F_{total} = I\, l \times B = B I l \sin\theta$

Theory :

- When a current carrying conductor is placed in a magnetic field , the force experienced by the conductor is equal to the sum of Lorentz forces on the individual charge carriers in the conductor.
- Consider a small segment of conductor of length dl , with cross – sectional area A and current I . The free electrons drift opposite to the direction of current.

Derivation :

1. Relation between current and drift velocity : $I = n e A v_d$

2. If the conductor is kept in a magnetic field , then average force experienced by the charge in the conductor, $\vec{F} = -e(\vec{v_d} \times \vec{B})$

3. If n is the number of free electrons in the unit volume , $n = N / V$

4. Lorentz force on the elementary section of length dl is the product of the number of electrons and the force acting on each electron.

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$\vec{F} = - N e \ (\vec{v_d} \times \vec{B})$

$\vec{F} = - n V e \ (\vec{v_d} \times \vec{B})$

$\vec{F} = - n A l e \ (\vec{v_d} \times \vec{B})$

$\vec{F} = - \ e n A dl \ (\vec{v_d} \times \vec{B})$

5. The current element in the conductor is $I \ d\vec{l} = n e A \vec{v_d} \ d\vec{l}$

6. The force on the small elemental section of the current carrying conductor is $d\vec{F} = I \ d\vec{l} \times \vec{B}$

7. The force on a straight current carrying conductor of length placed in a uniform magnetic field is,

$$F_{total} = I \ l \times B = B I l \sin \theta$$

Cases :

Conductor is placed along the direction of the magnetic field	$\theta = 0^0$	Force experienced by the conductor is zero.
Conductor is placed perpendicular direction of the magnetic field	$\theta = 90^0$	Force experienced by the conductor is maximum. $F_{total} = B I l$

---

17. Explain the principle and working of a moving coil galvanometer.

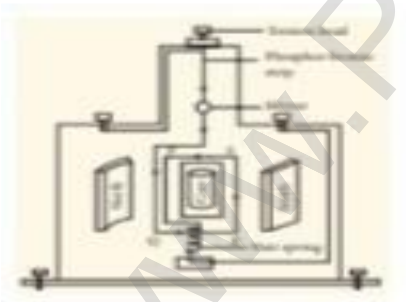
Moving Coil Galvanometer :

Used to detect 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.

Diagarm :



Construction :

1. Moving coil galvanometer consists of rectangular coil P Q R S of insulated thin copper wire.
2. A cylindrical soft – iron core is placed symmetrically inside the coil.
3. Rectangular coil is suspended freely between two pole pieces of horse – shoe magnet.
4. Upper end of the coil is attached to phosphor bronze and lower end of the coil connected to hair spring.
5. Small plane mirror is attached to measure the deflection of coil with help of lamp and scale arrangement.
6. Other end of the mirror is connected to torsion head.

Working :

Consider the rectangular coil P Q R S .

- Length of the coil P Q = R S = l

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- **Breadth of the coil QR = SP = b**
- **Current through coil is I .**

Magnetic Field :

- **Horse shoe magnet has hemi spherical magnetic poles , produce radial magnetic field. Sides QR and Sp are always parallel to magnetic field and experience no force .**
- **Sides PQ and RS are always perpendicular to magnetic field and experience equal forces in opposite direction . Due to this , torque is produced.**

Deflecting Torque :

1 . $\tau = b\,F = b\,B\,I\,l = (l\,b)\,B\,I = A\,B\,I$

2. For coil with N turns $\tau = N\,A\,B\,I$

3. Due to deflecting torque , coil gets twisted and restoring torque is developed. $\tau = K\,\theta$

4. At equilibrium , The deflecting couple is equal to restoring couple.

$$\tau = N\,A\,B\,I = K\,\theta$$

$$I = \frac{K\,\theta}{N\,A\,B}$$

$$I = G\,\theta$$

5. Galvanometer constant or current reduction factor of the galvanometer.

$$G = \frac{K}{N\,A\,B}$$

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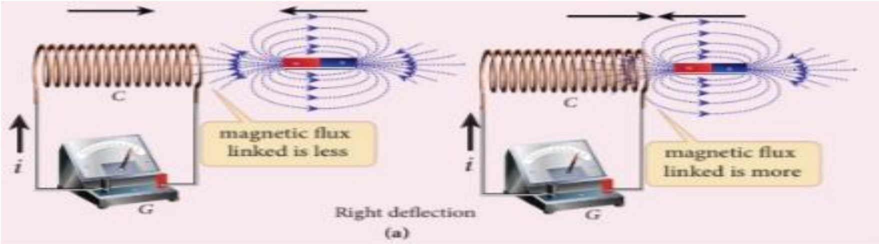
4 . Electromagnetic induction & Alternating Current

1. Establish the fact that relative motion between the coil and the magnet induces an emf in the coil of a closed circuit.

Diagram :



Theory :

1. Whenever the magnetic flux linked with a closed coil changes an emf is induced and an electric flows in the circuit.

2. This current is called an induced current and the emf giving rise to such current is called an induced emf. This phenomenon is known as " *electromagnetic induction* ".

3. A bar magnet is placed closed to a coil , some of the magnetic lines force of the bar magnet pass through the coil , the magnetic flux is linked with the coil . When the bar magnet and the coil approach each other , the magnetic flux linked with the coil increases.

4. The increases in magnetic flux induces an emf and transient electric current flows in the circuit in one direction . At the same time , when they recede away from one another , the magnetic flux linked with the coil decreases.

5. The decrease in magnetic flux again induces an emf in opposite direction . So there is deflection in the galvanometer when there is a relative motion between the coil and the magnet.

---

2. Give an illustration of determining direction of induced current by using Lenz's law.

Lenz's Law :

" The direction of the induced current is such that it always opposes the cause responsible for its production ".

$$\varepsilon = -\frac{d\,(N\,\phi_B)}{dt}$$

Diagram :

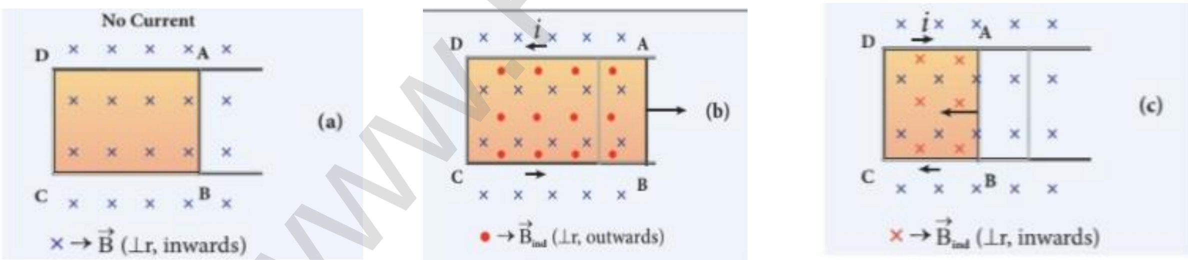


Illustration :

1. Consider a uniform magnetic field , with its field lines perpendicular to the plane of the paper and pointing inwards and represented by cross (x) .

2. A rectangular metallic frame A B C D is placed in this magnetic field , with its plane perpendicular to the field . Arm A B is movable it can slide towards right or left.

3. If the arm A B slides to our right side , the number of field lines passing through the frame A B C D increases and a current is induced.

4. By Lenz's law , the induced current opposes this flux increase and it tries to reduce it by producing another magnetic field pointing outwards i.e opposite to the existing magnetic field.

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5. The magnetic lines of this induced field are represented by dots . From the direction of the magnetic field thus produced , the direction of induced current is found to be anti - clockwise by using right hand thumb rule.

6. The leftward motion of arm A B decreases the magnetic flux. The induced current produces magnetic field in the inward direction i.e in the direction of existing magnetic field.

7. The flux decrease is opposed by the flow of induced current . From this , it is found that induced current flows in clockwise direction.

---

3. Show that Lenz's law is in accordance with the law of conservation of energy.

1. It is on the basis of the law of conservation of energy.

2. According to Lenz's law , when the magnet is moved either towards or away from the coil , the induced current opposes its motion.

3. As a result , there will be a resisting force on the moving magnet . Work has to be done by some external agency to move the magnet against this resisting force.

4. Mechanical energy of the moving magnet is converted into electrical energy gets converted into joule heat in the coil energy is converted from one form to another.

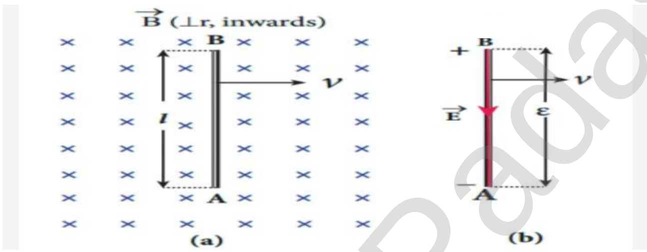
5. When we push the magnet little bit towards the coil , the induced current helps the movement of the magnet towards the coil. Then the magnet starts moving towards he coil without any expense of energy. This becomes a perpetual motion machine.

6. Hence Lenz's law is an excellent example of conservation of energy.

---

4. Obtain an expression for motional emf from Lorentz force.

Diagram :



Formula :

$$\varepsilon = B\ l\ v$$

Theory :

1. Consider a straight conducting rod A B of length l in a uniform magnetic field $\vec{B}$.
2. Let the rod move with a constant velocity $\vec{v}$ towards right side.
3. When the rod moves , the free electrons present in it also moves with same velocity $\vec{v}$ in $\vec{B}$.
4. Lorentz force acts on free electrons in the direction from B to A and accumulates the free electrons at the end A.
5. Accumulation of free electrons produces potential difference across the rod produces electric field $\vec{E}$ directed along BA .
6. Due to the electric field $\vec{E}$, the Coulomb force starts acting on the free electrons along AB .
7. Magnitude of electric field $\vec{E}$ keeps on increasing as long as accumulation of electrons at the end A continues.
8. The force $\vec{F}_E$ also increases until equilibrium is reached.
9. At equilibrium , the magnetic Lorentz force $\vec{F}_B$ and the Coulomb force $\vec{F}_E$ balance each other.
10. No further accumulation of free electrons at the end A takes place.

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Derivation :

1. Lorentz force : $\vec{F}_B = -e(\vec{v} \times \vec{B})$
2. Coulomb force : $\vec{F}_E = -e\vec{E}$
3. $|\vec{F}_B| = |\vec{F}_E|$
4. $-|e(\vec{v} \times \vec{B})| = -|e\vec{E}|$
5. $v B \sin 90^0 = E$
6. $v B = E$
7. Potential difference : $V = E l$

$V = v B l$

$\varepsilon = B l v$

This emf is produced due to the movement of the rod , called as " *Motional emf* ".

---

5. Give the uses of Foucault current.

1. Induction Stove :

1. Used to cook food quickly and safely with less energy consumption.
2. Below cooking zone , there is a tightly wound coil of insulated wire.
3. Stove is switched on , an alternating current flowing in the coil produce magnetic field induces eddy current.
4. The eddy current in the pan produce so much heat due to joule heating which is used to cook the food.

2. Eddy current brake:

1. Used in high speed train and roller coaster.
2. Strong electromagnets are fixed just above the rails.
3. To stop train , electromagnets are switched on.
4. Magnetic field of these magnets induces eddy current.
5. Eddy currents in the rails which oppose or resist the movement of current called as eddy current linear brake.

3. Eddy current testing :

1. Non – destructive testing methods to find defects like surface cracks , air bubbles present in a specimen.
2. A coil of insulated wire is given an alternating electric current produces an alternating magnetic field.
3. When the coil brought near the test surface eddy current is induced.
4. The presence of defects causes the change in phase and amplitude of eddy current.
5. The defects present in the specimen are identified.

4. Electromagnetic damping :

1. The armature of galvanometer coil is wound on soft iron cylinder.
2. The relative motion between soft iron cylinder and radial magnetic field induces eddy current.
3. Damping force due to the flow of eddy current brings armature to rest immediately and shows steady deflection.
4. This is called electro magnetic damping.

---

6. Define self – inductance of a coil in terms of i) magnetic flux ii) induced emf

1. If i = 1A then $L = N\phi_B$ Self induction of a coil is defined as flux linkage of coil when 1 A current flows through it.

2. When the current I changes with time , an emf is induced in it. From Faraday's law electromagnetic induction , the self induced emf is given by ,

$$\varepsilon = -\frac{d(N\phi_B)}{dt}$$

$$\varepsilon = -\frac{d(Li)}{dt}$$

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$$\varepsilon = -L\frac{di}{dt}$$

$$L = -\frac{\varepsilon}{di/dt}$$

3. The negative sign in the above equation means that the self – induced emf always opposes the change in current with respect time. If $di/dt = A\,s^{-1}$ then $L = -\varepsilon$.

4. Inductance of a coil is also defined as the opposing emf induced in the coil when the rate of change of current through the coil is $1\,A\,s^{-1}$.

---

7. How will you define the unit of inductance ?

i) Unit of Inductance :

1. Inductance is a scalar.
2. Unit is Wb^{-1} or $V\,s\,A^{-1}$
3. Henry $1\,H = 1\,Wb\,A^{-1} = V\,s\,A^{-1}$
4. Dimensional formula $M L^2 T^{-2} A^{-2}$

ii) $L = \frac{N\phi_B}{i}$

If $i = 1\,A$ and $N\phi_B = 1$ W b turns then $L = 1\,H$. Therefore the inductance of the coil is said to be one henry if current of 1 A produces unit flux linkage in the coil.

iii) $L = \frac{-\varepsilon}{di/dt} = -\frac{\varepsilon\,dt}{di}$

If $di/dt = 1\,A\,s^{-1}$ and $\varepsilon = -1\,V$ then $L = 1\,H$. Therefore the inductance of the coil is one henry if a current changing at the rate of $1\,A\,s^{-1}$ induces an opposing emf of 1 V in it.

$$1\,H = 1\,Wb\,A^{-1} = 1\,V\,s\,A^{-1}$$

---

8. What do you understand by self induction of a coil ? Give its physical significance .

Self Induction :

1. If magnetic flux is changed by changing the current , an emf is induced in the same coil . This phenomenon is known as " Self induction "

2. Self induction of a coil is defined as the flux linkage with the coil when 1 A current flows through it.

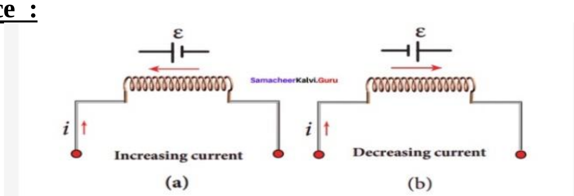
$$\varepsilon = -\frac{d(N\phi_B)}{dt}$$

$$\varepsilon = -\frac{d(Li)}{dt}$$

$$\varepsilon = -L\frac{di}{dt}$$

$$L = -\frac{\varepsilon}{di/dt}$$

Physical Significance :



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1. **When a circuit is switched on**

   The increasing current induces an emf which opposes the growth of current in a circuit.

2. **When a circuit is switched off**

   The decreasing current induces an emf in the reverse direction . This emf now opposes the decay of current.

3. Inductance of the coil opposes any change in current & tries to maintain the original state.

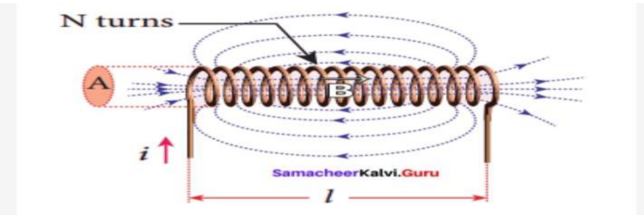
---

9. Assuming that the length of the solenoid is large when compared to its diameter , find the equation for its solenoid.

Theory :

1. Consider a long solenoid of length l and cross – sectional area A .
2. Let n be the turns per unit length of the solenoid.
3. When an electric current i passed through solenoid.
4. Magnetic field produced inside is almost uniform.
5. It is directed along the axis of the solenoid.

Diagram :



Formula :

$$L = \mu n^2 A l$$

Derivation :

1. Magnetic field inside the solenoid : $B = \mu_0 n i$ -------- (1)
2. Magnetic flux through the solenoid : $\phi_B = \int \vec{B} . d\vec{A}$

$$\phi_B = B A \cos \theta$$

$$\phi_B = B A \quad \text{since } \theta = 0^0$$

$$\phi_B = B A \text{ ------------------- (2)}$$

3. Substitute eqn (2) in (1)

$$\phi_B = (\mu_0 n i) A$$

4. Total flux linkage of the solenoid with N turns ($N = n l$)

$$N \phi_B = (n l)(\mu_0 n i) A$$

$$N \phi_B = (\mu_0 n^2 A l) i \text{ ------------ (3)}$$

5. We know that $N \phi_B = L i$ ----------------------- (4)

6. Substitute eqn (4) in (3)

$$L i = (\mu_0 n^2 A l) i$$

$$L = \mu_0 n^2 A l$$

7. If the solenoid is filled with dielectric medium of relative permeability μ_r ,

$$L = \mu_0 \mu_r n^2 A l$$

8. $$L = \mu n^2 A l \quad (\mu = \mu_0 \mu_r)$$

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Theory :

1. Whenever current is established in the circuit ,inductance opposes the growth of the current.
2. In order to establish a current in the circuit , work is done against this opposition by some external agency. This work done is stored as magnetic potential energy.

Derivation :

1. Work done : $dW = -\varepsilon\, dq = -\varepsilon\, i\, dt$ ---------- (1)

2. Induced emf : $\varepsilon = -L \frac{di}{dt}$ ------------ (2)

3. Substitute eqn (2) in (1)

$$dW = -\left(-L \frac{di}{dt}\right) i\, dt$$

$$dW = L\, i\, dt$$

$$\int dW = L \int i\, di$$

$$W = L \frac{i^2}{2}$$

4. Work done is stored as magnetic potential energy $U_B = L \frac{i^2}{2}$ ----------(3)

5. Energy stored in an inductor : $U_B = L \frac{i^2}{2}$

6. Energy Density : Energy stored per unit volume is known as " energy density "

$$u_B = \frac{U_B}{V} = \frac{U_B}{A\,l} \quad \text{--------------------------} \quad (4)$$

7. Substitute eqn (3) in (4)

$$u_B = \frac{L\, i^2}{2 A l}$$

8. Self inductance of a long solenoid $L = \mu_0 n^2 A\, l$ --------------------- (5)

9. Substitute eqn (5) in eqn (4)

$$u_B = \frac{(\mu_0 n^2 A\, l)\, i^2}{2 A\, l} = \frac{\mu_0 n^2 i^2}{2}$$

10 . Multiply and divide by μ_0

$$u_B = \frac{\mu_0 n^2 i^2}{2} \times \frac{\mu_0}{\mu_0}$$

$$u_B = \frac{\mu_0^2 n^2 i^2}{2\mu_0} \quad \text{--------------------} \quad (6)$$

11. Magnetic field : $B = \mu_0 n i$ ---------------- (7)

12. Substitute eqn (7) in (6)

Energy Density : $u_B = \frac{B^2}{2\mu_0}$

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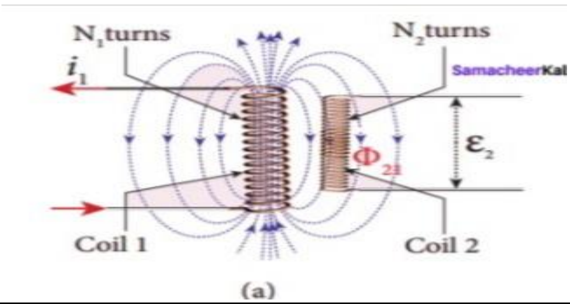
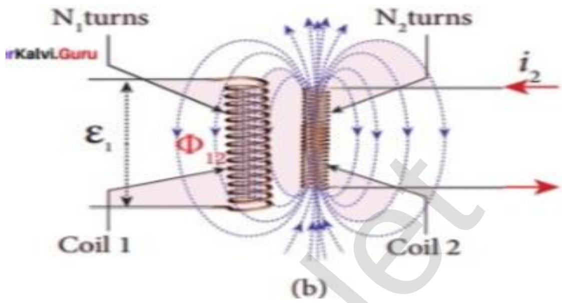
11. Show that the mutual inductance between a pair of coils is same ($M_{12} = M_{21}$)

Mutual induction :

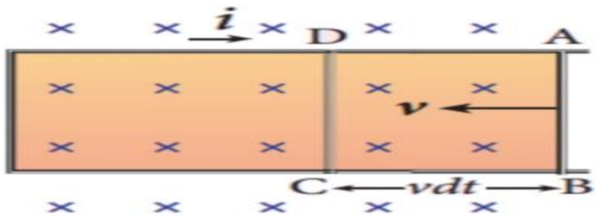
When an electric current passing through a coil changes with time , an emf is induced in the neighbouring coil. This phenomenon is known as mutual induction and the emf induced is called mutually induced emf.

S. NO	Coil 1	Coil 2
		
1.	Electric current sent through coil 1 is i_1	Electric current sent through coil 2 is i_2
2.	Magnetic flux linked with each turn of the coil 2 of N_2 turns due to the current in coil 1 is ϕ_{21}.	Magnetic flux linked with each turn of the coil 1 of N_1 turns due to the current in coil 1 is ϕ_{12}.
3.	Total flux linked with coil 2 of N_2 ϕ_{21} is proportional to the current i_1 in the coil 1.	Total flux linked with coil 1 of N_1 ϕ_{12} is proportional to the current i_2 in the coil 2.
4.	$N_2 \phi_{21} \propto i_1$ $N_2 \phi_{21} = M_{21} i_1$ $M_{21} = \frac{N_2 \phi_{21}}{i_1}$	$N_1 \phi_{12} \propto i_2$ $N_1 \phi_{12} = M_{12} i_2$ $M_{12} = \frac{N_1 \phi_{12}}{i_2}$
5.	$\varepsilon_2 = - \frac{d(N_2 \phi_{21})}{dt}$ $\varepsilon_2 = - \frac{M_{21}\, di_1}{dt}$ $M_{21} = \frac{-\varepsilon_2}{di_1 / dt}$	$\varepsilon_1 = - \frac{d(N_1 \phi_{12})}{dt}$ $\varepsilon_1 = - \frac{M_{12}\, di_2}{dt}$ $M_{12} = \frac{-\varepsilon_1}{di_2 / dt}$

---

12. How will you induce an emf by changing the area enclosed by the coil ?

Diagram :



Formula :

$\varepsilon = B\, l\, v$

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Theory :

- Consider a conducting rod of length l moving with velocity v towards left on a rectangular fixed metallic framework.
- The whole arrangement is placed in a uniform magnetic field B whose magnetic lines are perpendicularly directed into the plane of the paper.
- As the rod moves from A B to D C in a time dt , the area enclosed by the loop .
- Hence the magnetic flux through the loop decreases.

Derivation :

1. Change in magnetic flux in time dt ,

$$d\phi_B = B \times \text{Change in area } (dA)$$

$$d\phi_B = B \times \text{Area } ABCD \text{ ------- } (1)$$

2. Area of A B C D = l (v dt) -------------- (2)

3. Substitute eqn (2) in (1)

$$d\phi_B = B\, l\, v\, dt$$

$$\frac{d\phi_B}{dt} = B\, l\, v$$

4. As a result of change in flux , an emf is generate in the loop.

5. The magnitude of the induced emf is ,

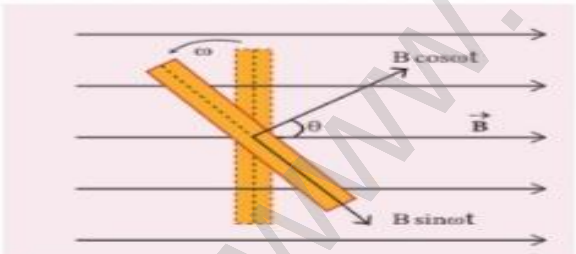
$$\varepsilon = \frac{d\phi_B}{dt}$$

$$\boxed{\varepsilon = B\, l\, v}$$ " motional emf "

---

13. Show mathematically that the rotation of a coil in a magnetic field over one rotation induces an alternating emf of one cycle. (or) Obtain the expression for the induced emf by changing relative orientation of the coil with the magnetic field.

Diagram :



Formula :

$$\boxed{\varepsilon = \varepsilon_m \sin \omega t}$$

Theory :

1. Consider a rectangular coil N turns kept in a uniform magnetic field $\vec{B}$.
2. The coil rotates in anti – clockwise direction with an angular velocity ω about an axis , perpendicular to the field and to the plane of the paper.
3. At time t = 0 , the plane of the coil is perpendicular to the field.
4. The flux linked with the coli has its maximum value : $\Phi_m = N B A$
5. In a time t sec , the coil is rotated through an angle θ (= ω t) in anti – clockwise direction.
6. In this position , the flux linked N B A cos ω t is due to the component of $\vec{B}$ normal to the plane of the coil.
7. The component B sin ω t parallel to the plane has no role in electromagnetic induction.

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Variation of induced emf as a function of ω t :

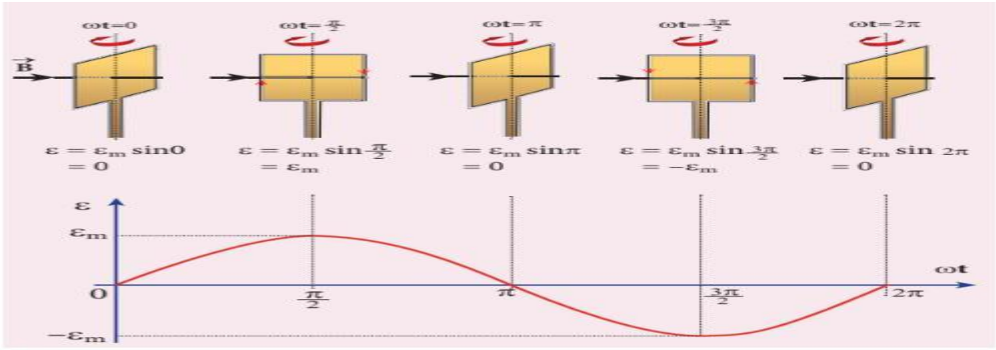


Figure 4.25 Variation of induced emf as a function of ωt

Derivation :

1. $N\phi_B = N\ B\ A\ \cos\ \theta$
2. $N\phi_B = N\ B\ A\ \cos\ \omega t$
3. By Faraday's law ,

$$\varepsilon = -\frac{d(N\phi_B)}{dt}$$

$$\varepsilon = \frac{-d}{dt}(N\ B\ A\ \cos\ \omega t)$$

$$\varepsilon = -N\ B\ A\ (-\sin\ \omega t)\ \omega$$

$$\varepsilon = N\ B\ A\ \omega\ \sin\ \omega t$$

4. When the coil is rotated through 90^0 from initial position , $\sin\ \omega t = 1$
5. The maximum value of induced emf $\varepsilon_m = N\ B\ A\ \omega$
6. Sinusoidal emf or alternating emf $\varepsilon = \varepsilon_m\ \sin\ \omega t$
7. The induced emf varies as sine function of the time angle ω t.

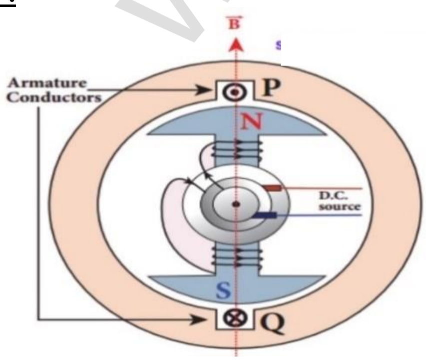
---

14. Elaborate the standard construction details of AC generator.

Construction of AC generator :

- Alternator consists of two major parts : 1. Stator 2 . Rotar
- Stator is stationary while rotor rotates inside the stator.
- Armature winding is mounted on stator and the field magnet on rotor.

Diagram :



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i) Stator :

1. The stationary part which has armature windings mounted in it .
2. It has two components namely stator core and armature winding.
3. stator core or armature core is made up iron or steel alloy.
4. It is a hollow cylinder and is laminated to minimize eddy current loss.
5. The slots are cut on inner surface of the core to accommodate armature windings.
6. Armature winding is the coil , wound on slots provided in the armature core.

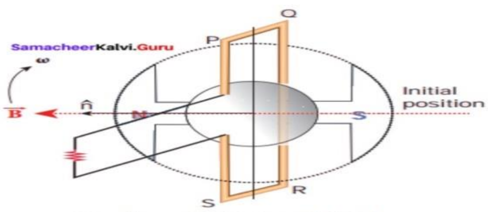
ii) Rotor :

1. Rotor contains magnetic field windings .
2. The magnetic poles are magnetized by D C source .
3. The ends of field windings are connected to a pair of slip rings.
4. It is attached to a common shaft about which rotor rotates.
5. Slip rings rotate along with rotor.
6. To maintain connection between the D C source and field windings .
7. Two brushes are used which continuously slide over the slip rings.

---

15. Explain the working of a single - phase A C generator with necessary diagram.

Diagram :



The loop PQRS and field magnet in its initial position

Construction :

1. The armature conductors are connected in series to form a single circuit which generates single phase emf . So it is called single phase alternator.
2. A single - turn rectangular loop P Q R S mounted on the stator.
3. The field winding is fixed inside the stator and it can be rotated about an axis.
4. The loop P Q R S is stationary and is also perpendicular to the plane of the paper.
5. When field windings are excited , magnetic field is produced around it.
6. Let the field magnet be rotated in clockwise direction .

Working :

Angle	Position of loop PQRS	Induced emf		Point on Graph	Direction of Current
		Magnitude	Direction		
0^0	Magnetic field ⊥r PQRS	Zero		Origin O	
90^0	Magnetic field ∥ P QRS	Max	PQ downwards RS upwards	Point A	Along PQRS
180^0	Magnetic field ⊥r PQRS	Zero		Point B	
270^0	Magnetic field ∥ P QRS	Max	PQ upwards RS downwards	Point C	Along SRQP
360^0	Magnetic field ⊥r PQRS	Zero		Point D	

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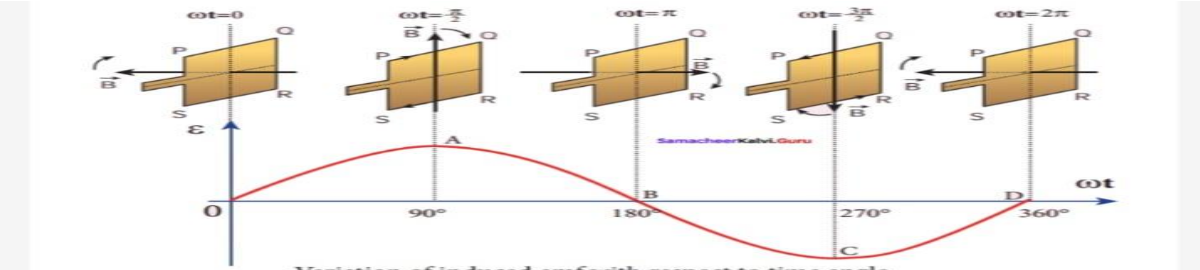
The direction of induced emfs across PQ & RS is maximum at an angle of 90^0 and 270^0. They are connected in series , emfs are added up and the direction of emf is given by Fleming's right hand rule. From the graph , emf induced in PQRS is alternating in nature.

Variation of induced emf w.r.t time angle :

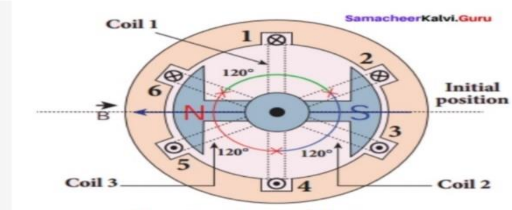


Variation of induced emf with respect to time angle

---

16. How are the three different emfs generated in a three - phase AC generator ? Show the graphical representation of these three emfs.

Three - phase AC generator :

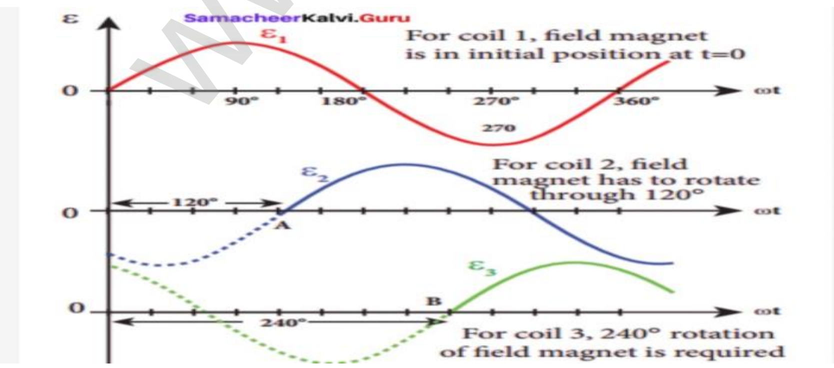


Construction of three-phase AC generator

Theory :

1. Three - phase A C generator the armature , the armature core has 6 slots .
2. Each slot is 60^0 away from one another.
3. Six armature conductors are mounted in these slots.
4. The conductors 1 and 4 are joined in series to coil 2 while the conductors 5 and 2 from coil 3.
5. These coils are rectangular in shape and are 120^0 apart from one another.
6. The initial position of the field magnet is horizontal and field direction is perpendicular to the plane of coil 1.
7. When field magnet is rotated from that position in clockwise direction , alternating emf ε_1 in coil 1 begins cycle from origin O.
8. The corresponding cycle for alternating emf ε_2 in coil 2 starts at point A after field magnet has rotated through 120^0 .
9. The phase difference between ε_1 and ε_2 is 120^0 .
10. The emf ε_3 in coil 3 would begin its cycle at point B after 240^0 rotation of field magnet from initial position.
11. These emfs produced in the three phase AC generator have 120^0 phase difference between one another.

Variation of emfs ε_1 ε_2 ε_3 with time angle :



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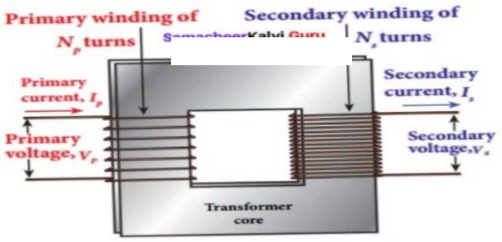
17. Explain the construction and working of transformer.

Diagram :



Construction of transformer

Principle :

- **Mutual induction between two coils .**

"When an electric current passing through a coil changes with time , an emf is induced in the neighbouring coil".

Construction :

1. **There are two coils of high mutual inductance wound over the transformer core**
2. **Core is generally laminated and is made up of magnetic material like silicon steel.**
3. **Coils are electrically insulated but magnetically linked via transformer core.**
4. **The coil across which alternating voltage is applied called *primary coil P*.**
5. **The coil from which output power is drawn is called *secondary coil* Q.**
6. **The core and coil are kept in a container which is filled with suitable medium for better insulation, cooling purpose.**

Working :

1.If the primary coil is connected to a source of alternating voltage , an alternating magnetic flux is set up in the laminated core.
2.If the there is no magnetic flux leakage , magnetic flux linked with the primary coil is also linked with secondary coil.
3. The rate at which magnetic flux changes through each turn is same for both primary and secondary coils.

S . NO	Primary Coil	Secondary Coil
1.	Induced emf or Back emf $\varepsilon_p = -N_p \frac{d\phi_B}{dt}$	Induced emf or Back emf $\varepsilon_s = -N_s \frac{d\phi_B}{dt}$
2.	Voltage across primary coil $v_p = -N_p \frac{d\phi_B}{dt}$	Voltage across primary coil $v_s = -N_s \frac{d\phi_B}{dt}$
3.	Voltage Transformation ratio : $\frac{V_S}{V_P} = \frac{N_S}{N_P} = K$	
4.	INPUT POWER = OUTPUT POWER $V_P i_P = V_S i_S$	
5.	$\frac{V_S}{V_P} = \frac{N_S}{N_P} = \frac{i_P}{i_S} = K$	

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Cases :

$N_S > N_P$	$V_S > V_P$	$I_S < N_P$	K > 1	Voltage increases	Current decreases	Step up transformer
$N_S < N_P$	$V_S < V_P$	$I_S > I_P$	K < 1	Voltage decreases	Current increases	Step down transformer

Efficiency of transformer : (η) $\eta = \frac{\text{output power}}{\text{input power.}} \times 100\ \%$

---

18. Mention the various energy losses in a transformer.

i) Core loss or Iron loss :

1. This loss takes place in transformer core.
2. *Hysteresis loss and eddy current loss* are known as " core loss " or " Iron loss "

Hysteresis Loss :

1.Transformer core is magnetized & demagnetized repeatedly by the alternating voltage applied across primary coil .
2. Hysteresis takes place due to which some energy is lost in the form of heat.
3. It is minimized by using high silicon content in making transformer core.

Eddy current Loss :

1. Alternating magnetic flux in the core induces eddy currents in it.
2. There is energy loss due to the flow of eddy current loss.
3. It is minimized by using very thin lamination of transformer core .

i i) Copper loss :

1. Transformer windings have electrical resistance.
2. When an electric current flows through them , some amount of energy is dissipated due to joule heating.
3. This energy loss is called " *copper loss* ".
4. It is minimized by using wires of larger diameter.

iii) Flux leakage :

1. When the magnetic lines of primary coil are not completely linked with secondary coil .
2. It is minimized by windings coils one over the other.

---

19. Give the advantages of AC in long distance power transmission with an illustration.

1. Electric power is produced in a large scale at electric power stations with the help of AC generators.
2. Most of the power stations are located at remote places. Hence the electric power generated is transmission over long distances through transmission lines to reach towns or cities where it is actually consumed . This process is called " *power transmission* ".
3. During power transmission , electric power is lost due to Joule heating ($I^2 R$) in transmission lines which are hundreds kilometre long.
4. This power loss reduced by reducing current I or by reducing R.
5. The resistance R can be reduced with *thick wires of copper or aluminium.*
6. The cost of production is expense so it is not economically viable.
7. Most important property of alternating voltage can be stepped up and stepped down by using transformer could be exploited in reducing current and power losses.
8. The voltage is increased and the current is decreased by using *step up transformer.*
9. The voltage is decreased and the current is increased by using *step down transformer.*
10. Thus power transmission is done efficiently and economically.

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Diagram :

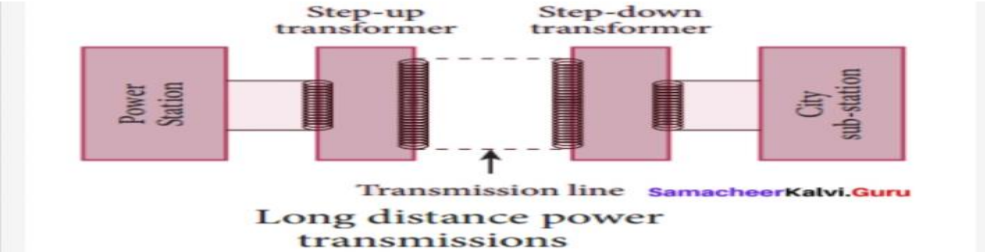


Illustration :

An electric power of 2 M W is transmitted to a place through transmission lines of total Resistance R = 40 Ω at lower voltage 10 K V and 100 K V.

Given :

$P = 2\ MW = 2 \times 10^6\ W$

$R = 40\ \Omega$

$V = 10\ KV = 10 \times 10^3\ V$

$V = 100\ KV = 100 \times 10^3\ V$

Power loss in case i :

Current : $I = \frac{P}{V}$

$I = \frac{2 \times 10^6}{10 \times 10^3} = 200\ A$

Power Loss = Heat produced

$I^2 R = (200)^2 \times 40 = 1.6 \times 10^6\ W$

$\%\ \text{Power Loss} = \frac{1.6 \times 10^6}{2 \times 10^6} \times 100\ \% = 80\ \%$

Power loss in case ii :

Current : $I = \frac{P}{V}$

$I = \frac{2 \times 10^6}{100 \times 10^3} = 20\ A$

Power Loss = Heat produced

$I^2 R = (20)^2 \times 40 = 0.016 \times 10^6\ W$

$\%\ \text{Power Loss} = \frac{0.016 \times 10^6}{2 \times 10^6} \times 100\ \% = 0.8\ \%$

Thus , when an electric power is transmitted at higher voltage , the power loss is reduced to large extent.

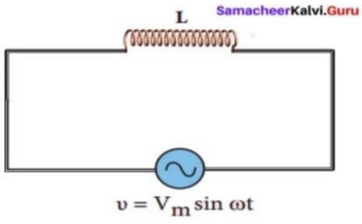
---

20 . Find out the phase relationship between the applied voltage and current in a pure inductive circuit.

Theory :

1. Consider a circuit containing a pure inductor of inductance L connected across an alternating voltage source.
2. The instantaneous value of alternating voltage is given by $v = V_m \sin \omega t$
3. The alternating current flowing through the inductor induces a self - induced emf or back emf in the circuit.

Diagram :



AC circuit with inductance

Formula :

$$i = I_m \sin(\omega t - \pi/2)$$
$$X_L = \omega L$$

4. The back emf is given by , $\varepsilon = -L \frac{di}{dt}$

5. By applying Kirchhoff's loop to the purely inductive circuit ,

$$v + \varepsilon = 0$$

$$v = -\varepsilon$$

$$V_m \sin \omega t = -\left(-L \frac{di}{dt}\right)$$

$$di = \frac{V_m}{L} \sin \omega t \, dt$$

6. Integrating both sides , we get

$$i = \frac{V_m}{L} \int \sin \omega t \, dt$$

$$i = \frac{V_m}{L\omega} (-\cos \omega t) + \text{constant}$$

$$i = \frac{V_m}{L\omega} (\sin(\omega t - \pi/2)) t$$

$$\boxed{i = I_m (\sin(\omega t - \pi/2)) t}$$

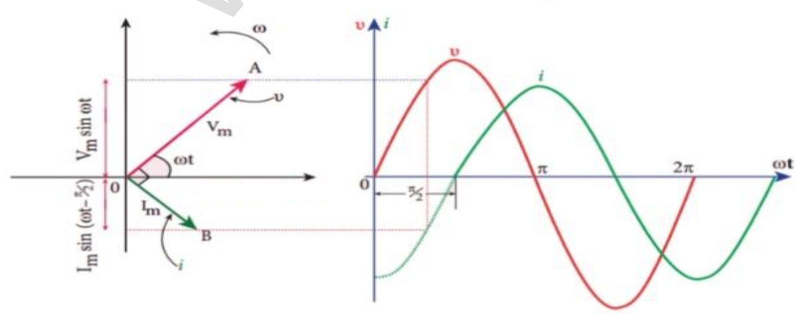
7. Peak value of alternating current in the circuit is $I_m = V_m / L\omega$

8. The current lags behind the applied voltage by $\pi / 2$ in an inductive circuit.

Inductive reactance : $X_L = \omega L$

The quantity ωL is the resistance offered by the inductor is called as *inductive reactance*

Phasor and Wave diagram :



Phasor diagram and wave diagram for AC circuit with L

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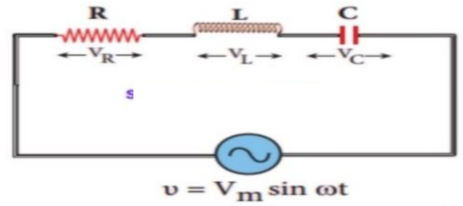
21. Derive an expression for phase angle between the applied voltage and current in a series R L C circuit.

Diagram :



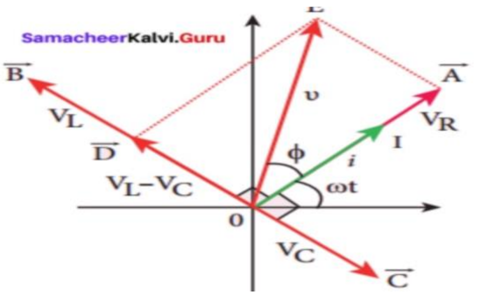
AC circuit containing *R*, *L* and *C*

Theory :

1. Consider a circuit containing a resistor of resistance R , an inductor L and capacitor C connected across an alternating voltage source.
2. Let i be the current in the circuit at that instant.
3. The voltage is developed across R , L and C.
4. Voltage across R (V_R) is in phase with i.
5. Voltage across L (V_L) leads i by $\pi / 2$.
6. Voltage across R (V_R) lags behind i by $\pi / 2$.

Phasor Diagram :

The phasor diagram is drawn with the current as the reference phasor.



1. Current is represented by the phasor $\vec{OI}$.
2. V_R by $\vec{OA}$; V_L by $\vec{OB}$; V_C by $\vec{OC}$;
3. Length of these phasors : $OI = I_m$; $OA = I_m R$; $OB = I_m X_L$; $OC = I_m X_C$;
4. Let us assume that $V_L > V_C$.
5. Net voltage drop across L – C combination is $V_L - V_C = \vec{OD}$.
6. By parallelogram law , OE gives resultant voltage $OE = V_m$

Derivation :

1. $V_m^2 = V_R^2 + (V_L - V_C)^2$
2. $V_m = \sqrt{(I_m R)^2 + (I_m X_L - I_m X_C)^2}$
3. $V_m = I_m \sqrt{(R)^2 + (X_L - X_C)^2}$
4. $I_m = \dfrac{V_m}{\sqrt{(R)^2 + (X_L - X_C)^2}}$
5. $I_m = V_m / Z$ Where $Z = \sqrt{(R)^2 + (X_L - X_C)^2}$
6. Z is called *impedance* of the circuit , refers to the effective opposition to the current by the series R L C circuit.

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Voltage triangle & Impedance triangle :

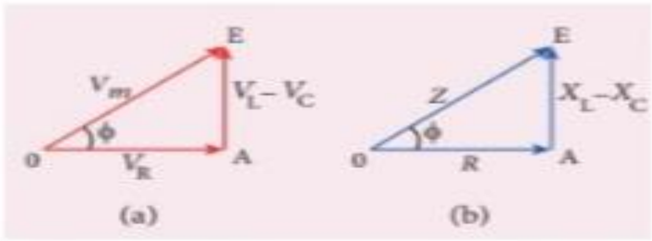

Figure 4.48 Voltage and impedance triangle when $X_L > X_C$

Phase Angle :

$$\tan \phi = \frac{V_L - V_C}{V_R} = \frac{X_L - X_C}{R}$$

Special Cases :

S. NO	$X_L > X_C$	$X_L < X_C$	$X_L = X_C$
1.	$X_L - X_C$ is positive.	$X_L - X_C$ is negative.	$X_L - X_C$ is zero.
2.	Phase angle ϕ positive.	Phase angle ϕ is negative.	Phase angle ϕ is negative.
3.	Voltage leads current by ϕ	Current leads voltage by ϕ	Currentvoltage same phase.
4.	The circuit is inductive.	The circuit is capacitive.	The circuit is resistive.
5.	$v = V_m \sin \omega t$; $i = I_m \sin(\omega t - \phi)$	$v = V_m \sin \omega t$; $i = I_m \sin(\omega t + \phi)$	$v = V_m \sin \omega t$; $i = I_m \sin \omega t$

---

22. Define inductive and capacitive reactance . Give their units.

Inductive Reactance :

1. The peak value of current I_m is given by $I_m = V_m / \omega L$.
2. The quantity ωL plays the same role as the resistance in resistive circuit.
3. This is the resistance offered by the inductor called inductive reactance.
4. It is measured in ohm.

$$X_L = \omega L$$

Capacitive Reactance :

1. The peak value of current I_m is given by $I_m = V_m / 1 / C\omega$.
2. The quantity $1 / \omega C$ plays the same role as the resistance in resistive circuit.
3. This is the resistance offered by the inductor called capacitive reactance.
4. It is measured in ohm.
5. The capacitive reactance varies inversely as the frequency .
6. For a steady current , f = 0 .

$$X_C = \frac{1}{\omega C}$$

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi C} = \frac{1}{0} = \infty$$

7. Thus a capacitive circuit offers infinite resistance to the steady current.
8. So that current cannot flow through the capacitor.

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23. Obtain an expression for average power of AC over a cycle. Discuss its special cases.

Power of a circuit :

1. The rate of consumption of electric energy in that circuit.
2. It is given by the product of the voltage and current.
3. Alternating voltage and alternating current in the series inductive R L C circuit

$$v = V_m \sin \omega t \;;\; \text{and} \;\; i = I_m \sin(\omega t + \phi)$$

Instantaneous Power :

1. $P = v\,i$
2. $P = V_m I_m \sin \omega t \sin(\omega t + \phi)$
3. $P = V_m I_m \sin \omega t (\sin \omega t \cos \phi + \cos \omega t \sin \phi)$
4. $P = V_m I_m (\cos \phi \sin^2 \omega t + \sin \omega t \cos \omega t \sin \phi)$
5. Average of $\sin^2 \omega t$ over a cycle is ½.
6. $\sin \omega t \cos \omega t$ value is zero.

Average Power :

1. $P_{av} = V_m I_m \cos \phi \times 1/2$
2. $P_{av} = \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} \cos \phi$
3. $P_{av} = V_{RMS} I_{RMS} \cos \phi$
4. $V_{RMS} I_{RMS}$ is called *apparent power*.
5. $\cos \phi$ is called *power factor.*
6. Average power is called true power .

Special cases :

S. NO	Circuit	Phase Angle	Cos ϕ value	Average Power
1.	Purely Resistive	Zero	$\cos 0 = 1$	$P_{av} = V_{RMS} I_{RMS}$
2.	Purely Inductive	$\pm \pi / 2$	$\cos(\pm \pi/2)$	$P_{av} = 0$
3.	Series RLC circuit	$\phi = \tan^{-1}\left[\frac{X_L - X_C}{R}\right]$	If $\phi = 0$, $\cos \phi = 1$	$P_{av} = V_{RMS} I_{RMS}$

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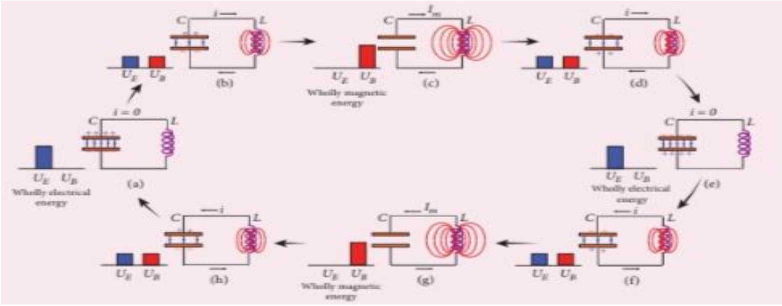
24. Explain the generation of LC oscillations in a circuit containing an inductor of inductance L and a capacitor of capacitance C.

<u>Generation of LC oscillation :</u>



1. **<u>Capacitor is fully charged with maximum charge Q_m :</u>**

   1. Energy stored in capacitor is $U_E = Q^2 / 2C$.
   2. No current in the inductor.
   3. Energy stored in inductor is $U_B = 0$.
   4. Total energy is wholly electrical.

2. **<u>Capacitor begins to discharge through inductor :</u>**

   1. Current i in clockwise direction.
   2. Current produces magnetic field around inductor.
   3. Energy stored in inductor is $U_B = L i^2 / 2$.
   4. Charge in the capacitor decreases .
   5. Energy stored in capacitor is $U_E = q^2 / 2C$.
   6. Total energy is the sum of electrical and magnetic energies.

3. **<u>Charges in the capacitor are exhausted :</u>**

   1. Energy stored in capacitor is $U_E = 0$.
   2. Energy is fully transferred to magnetic field of inductor.
   3. Energy stored in inductor is $U_B = L I_m^2 / 2$.
   4. I_m is the maximum current flowing in the circuit .
   5. Total energy is wholly magnetic energy.

4. **<u>Capacitor begins to charge in opposite direction :</u>**

   1. Even though the charge in the capacitor is zero.
   2. Current is made to flow with decreasing magnitude.
   3. A part of energy is transferred from inductor back to the capacitor .
   4. Charge in the capacitor decreases .
   5. Total energy is the sum of electrical and magnetic energies.

5. **<u>Capacitor begins to fully charged in the opposite direction :</u>**

   1. Even when the Current in circuit reduces to zero.
   2. The energy stored in the capacitor becomes maximum.
   3. Energy stored in inductor is $U_B = 0$.
   4. Total energy is wholly electrical .

6. **<u>Capacitor starts to discharge through inductor :</u>**

   1. The state of circuit is similar to the initial state .
   2. Capacitor discharge through inductor with anti-clockwise current.
   3. Total energy is the sum of electrical and magnetic energies.

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L C oscillations :

1. The processes are repeated in opposite direction .
2. Finally the circuit returns to the initial state.
3. The circuit goes through these stages , an alternating current flows in the circuit.
4. As this process is repeated again and again , the electrical oscillations of definite frequency are generated. These are known as *LC oscillation.*
5. Oscillations will continue indefinitely such oscillations are called *undamped oscillation.*

---

25 . Prove that the total energy is conserved during LC oscillations.

- During LC oscillations in LC circuits , the energy of the system oscillates between the electric field of the capacitor and magnetic field of the inductor.
- Total energy remains constant .
- LC oscillations takes place in accordance with law of conservation of energy.

$$U = U_E + U_B = \frac{q^2}{2C} + \frac{1}{2} L i^2$$

Case i :

When charge q = Q_m and current i = 0

- Total energy is wholly electrical.

$$U = \frac{Q_m^2}{2C} + 0 = \frac{Q_m^2}{2C}$$

Case ii :

When charge q = 0 and current i = I_m

- Total energy is wholly magnetic.

$$U = 0 + \frac{1}{2} L I_m^2 = \frac{1}{2} L I_m^2$$

Case iii :

When charge = q and current = i

- Total energy remains constant .

$$U = \frac{q^2}{2C} + \frac{1}{2} L i^2$$

- $q = Q_m \cos \omega t$; $i = -\frac{dq}{dt} = Q_m \omega \sin \omega t$
- $U = \frac{Q_m^2 \cos^2 \omega t}{2C} + \frac{L \omega^2 Q_m^2 \sin^2 \omega t}{2}$
- $U = \frac{Q_m^2 \cos^2 \omega t}{2C} + \frac{L Q_m^2 \sin^2 \omega t}{2LC}$
- Here , $\omega^2 = \frac{1}{LC}$
- $U = \frac{Q_m^2}{2C} (\cos^2 \omega t + \sin^2 \omega t) = \frac{Q_m^2}{2C}$

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26. Compare the electromagnetic oscillation of LC circuit with the mechanical oscillations of block spring system qualitatively to find the expression for angular frequency of LC oscillator.

<u>Qualitative treatment :</u>

1.The electromagnetic oscillations of LC system compared with mechanical oscillations of a spring - mass system.
2. There are two forms of energy involved in LC oscillations. One is electrical energy of the charged capacitor. The other magnetic energy of the inductor carrying current.
3. The mechanical energy of the spring mass system exists in two forms. The potential energy of the compressed or extended spring and kinetic energy of the mass.

- **Angular frequency of oscillations of a spring – mass is given by** $\omega = k / m$
- **Angular frequency of LC oscillations is given by** $\omega = 1 / LC$

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Lesson – 5

1. Write down Maxwell equation in integral form.

First equation : Gauss's Law of electricity

$$\oint_S \vec{E}\cdot d\vec{A} = \frac{Q_{enclosed}}{\epsilon_0}$$

* It relates the net electric flux to net electric charge enclosed in a surface.

1. $\vec{E}$ is the electric field.
2. Q enclosed is net charge enclosed by the surface S.
3. It is true for both discrete and continuous distribution of charges.
4. Electric field lines start from positive charge and terminate at negative charge.
5. Electric field lines do not form continuous closed path.
6. An isolated positive charge or negative charge can exist.

Second equation : Gauss's law for magnetism

$$\oint_S \vec{B}\cdot d\vec{A} = 0$$

* The surface integral of magnetic field over a closed surface is zero

1. $\vec{B}$ is the magnetic field.
2. Magnetic lines of force form continuous closed path.
3. No isolated magnetic monopole exists.

Third equation : Faraday's law for magnetism :

$$\oint_l \vec{E}\cdot d\vec{l} = -\frac{d\Phi_B}{dt}$$

* This relates electric field with the changing magnetic flux.

The line integral of electric field around any closed path is equal to the rate of change of magnetic flux through the closed path bounded by the surface.

Fourth equation: Ampere's circuital law:

$$\oint_l \vec{B}\cdot d\vec{l} = \mu_0 i_c + \mu_0 \varepsilon_0 \frac{d}{dt}\oint_S \vec{E}\cdot d\vec{A}$$

1. This is also known as Ampere – Maxwell law.
2. This law relates the magnetic field around any closed path to the conduction current and displacement current through the path.

---

2. Write short notes on a) Microwave b) X - ray c) Radio waves d) Visible spectrum

a) Microwaves :

- It is produced by special vacuum tubes such as klystron , magnetron and Gunn diode.
- The frequency range is from 10^9 Hz to 10^{11} Hz.
- They undergoes reflection and can be polarised.
- It is used in radar systems for aircraft navigation.
- It is used in speed of vehicle , microwave oven for cooking and very long distance wireless communication through satellites.

b) X- ray :

- It is produced when there is sudden stopping of high speed electrons at high atomic number target and also by electronic transitions among the innermost orbits of atoms.
- The frequency range is from 10^{17} Hz to 10^{19} Hz.
- X- rays have more penetrating power than ultra violet radiation.
- They are used in extensively in studying structures of inner atomic electron shells and crystal structures.
- It is used in detecting fractures , diseased organs , formation of bones and stones
- It is used in observing the progress of healing bones.
- It is used to detect faults , cracks , flaws and holes.

c) Radio waves :

- They are produced by accelerated motion of charges in conducting wires.
- The frequency range is from a few Hz to 10^9 Hz.
- They show reflection and refraction.

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- They are used in radio and television systems.
- They are used in cellular phones to transmit voice communication in the ultra high frequency band.

d) Visible Spectrum :

- It is produced by incandescent bodies and also it is radiated by excited atoms in gases.
- The frequency range is from a 4×10^{14} Hz to 8×10^{14} Hz.
- It obeys law of reflection and refraction.
- It undergoes interference , diffraction and can be polarised.
- It exhibits photo – electric effect also.
- It can be used to study the structure of molecules , arrangement of electron in external shells of atoms.
- It causes sensation of vision.

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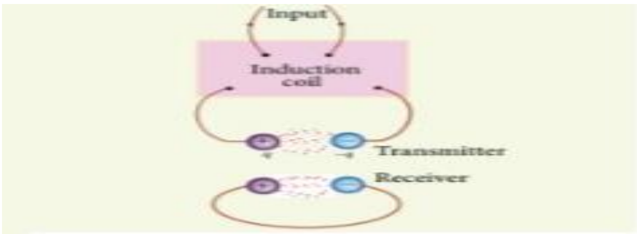
3. Discuss the Hertz experiment.

Hertz Experiment : Production of EM waves



Theory :

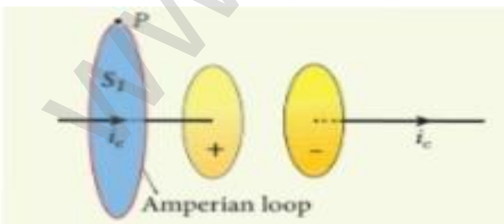
1. It consists of two metal electrodes.
2. They are made of small spherical metals.
3. These are connected to larger sphere.
4. The end of the sphere connected to induction coil.
5. Coil with large number of turns to produce very high emf.
6. Since the coil is maintained at high potential.
7. Air between electrodes gets ionized and spark is produced.
8. Discharge of electricity affects another electrode which is kept at far distance.
9. The energy is transmitted from electrode to the receiver in the form of waves, known as electromagnetic waves.
10. If the receiver is rotated by 90^{o}, then no spark is observed by the receiver.
11. This confirms that electromagnetic waves are transverse waves as predicted by Maxwell.
12. Hertz detected radio waves and also computed the speed of radio waves which is equal to speed pf light.

---

4. Explain the Maxwell's modification of Ampere's circuital law.

- Let us consider charging a parallel plate capacitor which contains medium between the plates.
- Ampere's circuital law can be used to find magnetic field produced around the current carrying wire.

i) On the surface S_1



1. Time dependent current i_c called as conduction current.
2. To calculate the magnetic field at a point P near the wire and outside the capacitor.
3. Let us draw a circular Amperian loop which encloses the circular surface S_1.

Using Ampere's circuital law,

$$\oint_{\text{enclosing } S_1} \vec{B} \cdot \vec{dl} = \mu_0 \, i_c$$

$\mu_0 \longrightarrow$ Permeability of free space.

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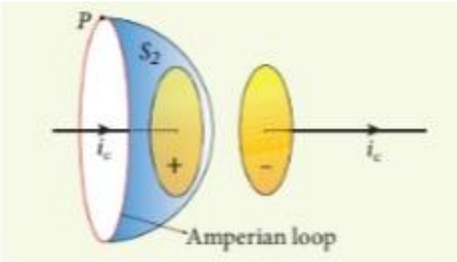
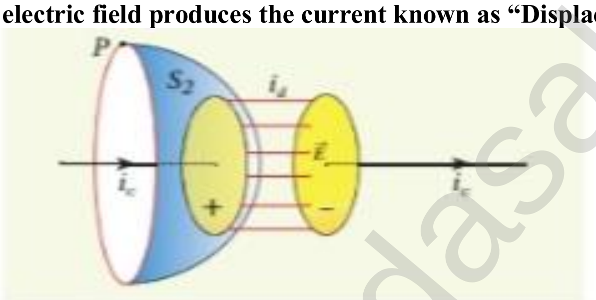
ii) On surface S_2



1. The same loop is enclosed by balloon shaped surface S_2.
2. The boundaries of two surfaces S_1 and S_2 same.
3. But the shape of the surface is different.
4. By applying Ampere's circuital law, $\oint_{\text{enclosing } S_2} \vec{B} \cdot \vec{dl} = 0$
5. Because the surface S_2 now where touches the wire carrying conduction current.
6. There is no current flows between the plates of capacitor.
7. So, the magnetic field at point p is zero .

iii) Maxwell Theory

1. While the capacitor charged up, varying electric field is produced.
2. The current associated with the changing electric field between capacitor plates.
3. Time varying electric field produces the current known as "Displacement current".



i v) From Gauss's law:

$$\Phi_E = \oint_S E \cdot dA = E A$$

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

$$\frac{d\Phi_E}{dt} = \frac{1}{\varepsilon_0} \frac{dq}{dt}$$

$$\frac{dq}{dt} = \varepsilon_0 \frac{d\Phi_E}{dt}$$

Displacement Current :

$$i_d = \varepsilon_0 \frac{d\Phi_E}{dt}$$

V)Maxwell modified Ampere's law :

$$\oint B \cdot dl = \mu_0 \, i = \mu_0 \,(i_c + i_d)$$

$$\oint_l B \cdot dl = \mu_0 \, i_c + \mu_0 \, \epsilon_0 \frac{d\Phi_E}{dt}$$

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5. Explain the importance of Maxwell's correction.

1. Earth receives radiations from sun and other stars. These radiations travel through empty space. So, there is no electric change and no electric current.

2. Ampere's Law :

Time - varying electric field or the displacement current produce magnetic field . Though the conduction current is zero in an empty space , displacement current does exist.

3. Maxwell's Law :

$$\oint_l \vec{B} \cdot \vec{dl} = \mu_0 \ \varepsilon_0 \ \frac{d\Phi_E}{dt}$$

Maxwell correction term $\longrightarrow$ $\mu_0 \ \varepsilon_0 \ \frac{d\Phi_E}{dt}$

In stars , due to thermal excitation of atoms , time varying electric field is produced which in turn produce time – varying magnetic field.

4. Faraday's Law :

Time – varying magnetic field again produces time – varying electric field.

5. Em Waves :

The coupled time – varying electric and magnetic fields travel through empty space with the speed of light and is called as " electromagnetic waves ". Maxwell correction term explains one of the important aspects of the universe , namely the existence of em waves.

---

6. Write down the properties of electromagnetic waves.

1. EM waves are produced by any accelerated charge.
2. EM waves do not require any medium for propagation. EM waves is non – mechanical wave.
3. EM waves do not deflected by electric or magnetic field.
4. EM waves can exhibit interference , diffraction and polarization.
5. EM waves also carry energy , linear momentum and angular momentum.
6. EM waves are transverse in nature. The oscillating electric field vector , oscillating magnetic field vector and propagation vector are mutually perpendicular to each other.
7. EM waves travel with speed which is equal to speed of light in vacuum.

$$C = \frac{1}{\sqrt{\epsilon_0 \mu_0}} = 3 \times 10^8 \ m\,s^{-1}$$

$\epsilon_0 \longrightarrow$ **Permittivity of free space or vacuum**

$\mu_0 \longrightarrow$ **Permeability of free space or vacuum**

8.In a medium with permittivity € ,permeability μ ,the speed of EM wave V is less than that in free space or vacuum .

$$n = \frac{C}{V} = \frac{1/\sqrt{\epsilon_0 \mu_0}}{1/\sqrt{\epsilon \mu}} = \sqrt{\epsilon_r \mu_r} \qquad (V < C)$$

$\epsilon_r \longrightarrow$ **Relative permittivity of free space or vacuum**
$\mu_r \longrightarrow$ **Relative permeability of free space or vacuum**

9. If the electromagnetic wave incident on a material surface completely absorbed , then the energy delivered is U and momentum imparted on the surface is p = U / c

10. If the incident electromagnetic wave of energy U is totally reflected from the surface, then the momentum delivered to the surface is $\Delta p = \frac{U}{c} - \left(-\frac{U}{c}\right) = 2\frac{U}{c}$

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7. Discuss the source of electromagnetic waves.

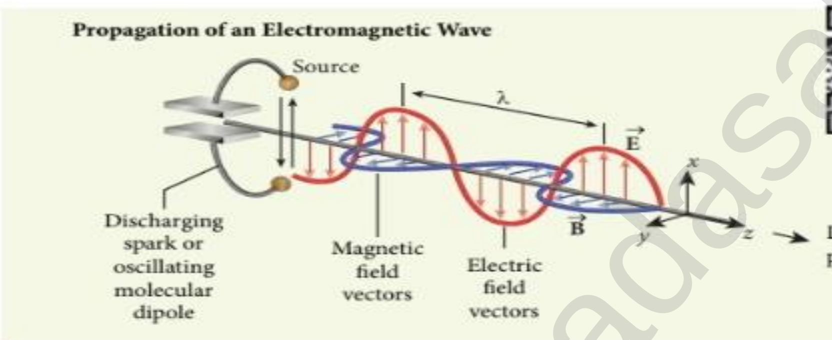
1. When the charges move with uniform velocity , it produces steady current which gives rise to magnetic field around the conductor in which charge flows.
2. If the charged particle accelerates , it produces magnetic field in addition to electric field.
3. Both electric and magnetic fields are time varying fields.
4. The electromagnetic waves are transverse waves , the direction of propagation of electromagnetic waves is perpendicular to the planes containing electric and magnetic field vectors.
5. Any oscillatory motion is also an accelerated motion.
6. When the charge oscillates about their mean position produces electromagnetic waves.
7. The electromagnetic field in free space propagates along z – direction and if the electric field vector points along x – axis , then the magnetic field vector will be mutually perpendicular to both electric field and the direction of wave propagation.

$$E_x = E_o \sin(kz - \omega t)$$

$$B_y = B_o \sin(kz - \omega t)$$

8. E_o and B_o are amplitudes of oscillating electric and magnetic field. K is a wave number and ω is the angular frequency of the wave.
9. The both electric field and magnetic field oscillate with a frequency which is equal to the frequency of the source.
10. In free space or in vacuum , the ratio between E_o and B_o is equal to the speed of electromagnetic wave and is equal to speed of light c.

$$C = \frac{E_o}{B_o}$$



$$V = \frac{E_o}{B_o} < C$$

11. In any medium , the ratio E_o and B_o is equal to the speed of electromagnetic wave in that medium.
12. The energy of electromagnetic waves comes from the energy of the oscillating charge.

8.Explain the types of emission spectrum.

Emission Spectrum :

- When the spectrum of self luminous source is taken , we get emission spectrum.
- Each source has its own characteristics emission spectrum.

i) Continuous emission spectrum :

- If the light from incandescent lamp is allowed to pass through prism , it splits up into seven colours.
- It consists of wavelength containing all visible colours ranging from violet to red.
- Example : Spectrum obtain from carbon arc and incandescent solids.

ii) Line emission spectrum :

- Light from hot gas is allowed to pass through prism , line spectrum is observed .
- Line spectra are also known as discontinuous spectra.
- It consists of sharp lines of definite wavelength or frequency.
- Such spectra arise due to excited atoms of elements.
- These lines are characteristics of the element and different elements.
- Example : Spectra of atomic hydrogen , helium.

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Figure 5.13 continuous emission spectra

iii) **Band emission spectrum :**

- Band spectrum consists of several number of very closely spaced spectral lines.
- It overlap together forming specific bands which are separated by dark spaces.
- Spectrum has sharp edge at one end and fades at other end.
- Such spectra arise when the molecules are excited.
- It is the characteristics of the molecule.
- The structure of the molecules be studied.
- Example : Spectra of ammonia gas in discharge tube.

---

9. Explain the types of absorption spectrum.

Emission Spectrum :

When light is allowed to pass through a medium or an absorbing substance then the spectrum obtained is known as absorption spectrum.

i) **Continuous absorption spectrum :**

When we pass white light through a blue glass plate , it absorbs all colours except blue and gives continuous absorption spectrum.

ii) Line absorption spectrum :

- When light from the incandescent lamp is passed through cold gas.
- The spectrum obtained through the dispersion due to prism is line absorption spectrum.
- If the light from the carbon arc is made to pass through sodium vapour , a continuous spectrum of carbon arc with two dark lines in the yellow region are obtained.

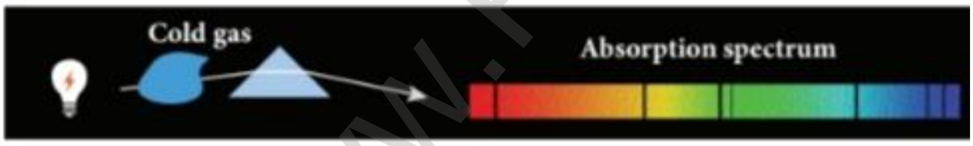

Figure 5.15 line absorption spectra

iii) **Band absorption spectrum :**

1.When white light is passed through the iodine vapour , dark bands on continuous bright background is obtained.

2. This type of band is also obtained when white light is passed through diluted solution of blood or chlorophyll or through certain solutions of organic or inorganic compounds.

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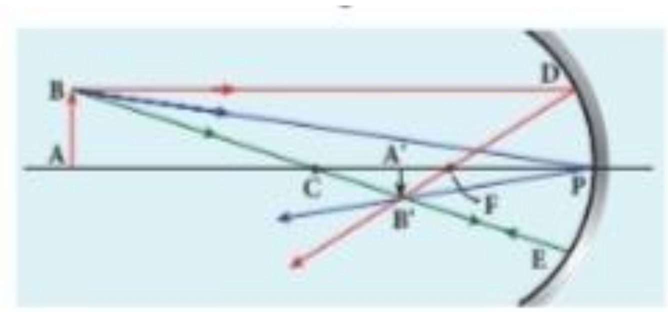
LESSON 6

1.Derive the mirror equation and the equation for lateral magnification.

Mirror Equation :

It relates object distance u , image distance v and focal length f.

Diagram :



Formula :

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

Theory :

1. A B is object and A′B′ is an image.
2. BD is first paraxial ray.
3. BP is second paraxial ray.
4. BC is third paraxial ray.

Derivation :

1. Δ B P A and Δ B′ P A′

$$\frac{A'B'}{AB} = \frac{PA'}{PA}$$

2. Δ D P F and Δ B′A′F

$$\frac{A'B'}{PD} = \frac{A'F}{PF}$$

3. $$\frac{A'B'}{AB} = \frac{PA'}{PF}$$

4. $$\frac{PA'}{PA} = \frac{A'F}{PF}$$

5. $$\frac{PA'}{PA} = \frac{PA' - PF}{PF}$$

6. PA = - u ; P A′ = - v ; P F = f ;

7. $$\frac{-v}{-u} = \frac{-v-(-f)}{-f}$$

8. $$\frac{v}{u} = \frac{-v+f}{-f}$$

9. $$\frac{v}{u} = \frac{-v}{-f} + \frac{f}{-f}$$

10. $$\frac{v}{u} = \frac{v}{f} - 1$$

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11. Dividing both sides with v

$$\frac{1}{u} = \frac{1}{f} - \frac{1}{v}$$

12.
$$\boxed{\frac{1}{f} = \frac{1}{u} + \frac{1}{v}}$$

Lateral Magnification Equation

1. Magnification $= \frac{\text{Height of the image}}{\text{Height of the object}}$

2. $m = \frac{h'}{h} = -\frac{v}{u}$

3. $m = \frac{f - v}{f} = \frac{f}{f - u}$

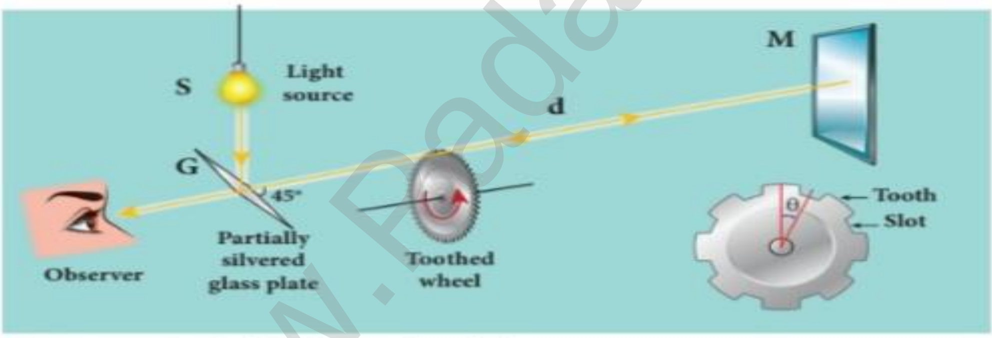
---

2. Describe the Fizeau's method to determine the speed of light.

Theory :

1. The light from the source is S .
2. Partially silvered glass plate is G.
3. The light is fall on the glass plate.
4. The angle produced is 45^0 .
5. Toothed wheel with N teeth and N cuts.
6. Mirror is kept a distance about 8 km.

Diagram :



Working :

1. Angular speed of rotation increased from 0 to ω .
2. Light pass through one cut completely blocked by tooth.
3. Light disappearing while looking through glass plate.

Speed of light :

$$V = \frac{2\, d\, N\, \omega}{\pi} = 2.99792 \times 10^8\ m\, s^{-1}$$

Derivation:

1. $V = \frac{2\, d}{t}$

2. $\omega = \frac{\theta}{t}$

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3. $\Theta = \frac{\text{Total angle of circle in radian}}{\text{No of teeth + No of cuts}}$

4. $\Theta = \frac{2\pi}{2N} = \frac{\pi}{N}$

5. $\omega = \frac{\pi}{Nt}$

6. $t = \frac{\pi}{N\omega}$

7. $V = \frac{2dN\omega}{\pi} = 2.99792 \times 10^{8}\ m\,s^{-1}$

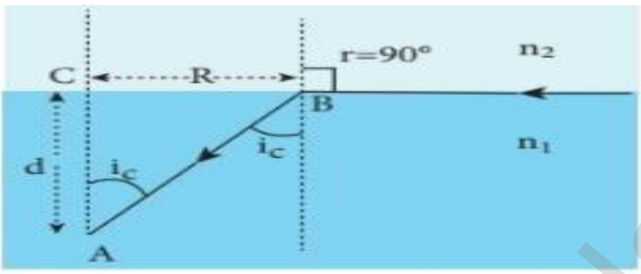
---

4. Obtain the equation for radius of illumination or Snell's window.

Snell's window

When light entering the water form outside is seen from inside the water , the view is restricted to a particular angle equal to critical angle. The restricted circular area is called " Snell's window ".

Diagram :



Formula :

$$R = \frac{d}{\sqrt{n^2 - 1}}$$

Theory :

1. The angle of view for water is restricted to twice the critical angle.
2. Critical angle for water is 48. 6^{0} .
3. The angle of view is 97.2 ^{0} .
4. Light seen from point at A.
5. Refractive index of medium is n .
6. Radius of circular area is R.
7. It depends on depth d.

Radius of illumination :

Snell ' s law in product form

1. $n_1 \sin i = n_2 \sin r$
2. $n_1 \sin i_c = n_2 \sin 90^0$
3. $n_1 \sin i_c = n_2$
4. $\sin i_c = \frac{n_2}{n_1}$

From Triangle ABC

5. $\sin i_c = \frac{R}{\sqrt{d^2 + R^2}}$

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6. $$\frac{n_2}{n_1} = \frac{R}{\sqrt{d^2 + R^2}}$$

7. Squaring on both sides.

$$\frac{R^2}{d^2 + R^2} = \frac{n_2^2}{n_1^2}$$

8. Take reciprocal

$$\frac{d^2 + R^2}{R^2} = \frac{n_1^2}{n_2^2}$$

9. Further simplification

$$\frac{d^2}{R^2} + \frac{R^2}{R^2} = \frac{n_1^2}{n_2^2}$$

10. $$\frac{d^2}{R^2} + 1 = \frac{n_1^2}{n_2^2}$$

11. $$\frac{d^2}{R^2} = \frac{n_1^2}{n_2^2} - 1$$

12. $$\frac{d^2}{R^2} = \frac{n_1^2 - n_2^2}{n_2^2}$$

13. Again taking reciprocal

$$\frac{R^2}{d^2} = \frac{n_2^2}{n_1^2 - n_2^2}$$

14. Take square root on both sides

$$\frac{R}{d} = \sqrt{\frac{n_2^2}{n_1^2 - n_2^2}}$$

15. <u>Radius of illumination</u>

$$R = d\sqrt{\frac{n_2^2}{n_1^2 - n_2^2}}$$

16. If rarer medium is air, then $n_2 = 1$ and $n_1 = n$

$$R = d\sqrt{\frac{1}{n^2 - 1}}$$

---

4. Derive the equation for acceptance angle and numerical aperture of optical fibre.

<u>Acceptance Angle :</u>

To ensure the critical angle incidence in the core cladding inside the optical fibre , the light should be incident at a certain angle called " acceptance angle " .

<u>Formula :</u>

$$i_a = \sin^{-1}\sqrt{(n_1^2 - n_2^2)}$$

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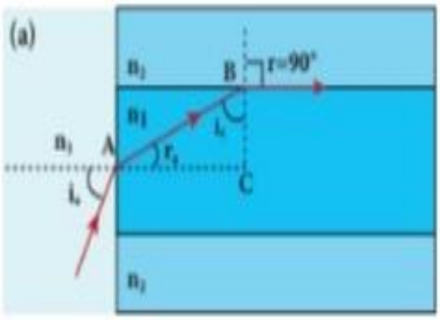
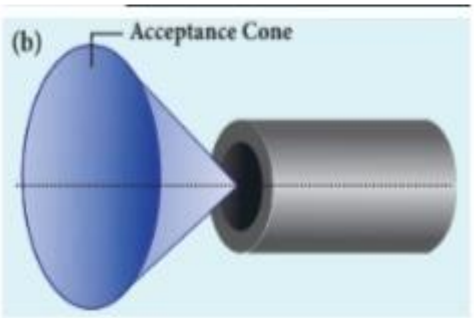
i . Acceptance Angle



ii . Acceptance Cone



Theory :

1. Refractive index of core → n_1
2. Refractive index of cladding → n_2
3. Refractive index of outer → n_3
4. Acceptance Angle → i_a
5. Critical Angle → i_c

Derivation :

1. Snell's law in product form , at point A

$$n_3 \sin i_a = n_1 \sin r_a \longrightarrow (1)$$

2. Snell's law in product form , at point B

$$n_1 \sin i_c = n_2 \sin 90^0 \longrightarrow (2)$$

3. $$n_1 \sin i_c = n_2$$

4. $$\sin i_c = \frac{n_2}{n_1} \longrightarrow (3)$$

5. From triangle Δ A B C

$$i_c = 90^0 - r_a \longrightarrow (4)$$

6. sub eqn (4) in eqn (2)

$$\sin (90^0 - r_a) = \frac{n_2}{n_1}$$

7. $$\cos r_a = \frac{n_2}{n_1} \longrightarrow (5)$$

8. $$\sin r_a = \sqrt{1 - \cos^2 r_a}$$

9. $$\sin r_a = \sqrt{1 - \left(\frac{n_2}{n_1}\right)^2} = \sqrt{\frac{n_1^2 - n_2^2}{n_1^2}} \longrightarrow (6)$$

10. sub eqn (6) in eqn (1)

$$n_3 \sin i_a = n_1 \sqrt{\frac{n_1^2 - n_2^2}{n_1^2}} = \sqrt{n_1^2 - n_2^2}$$

11. $$\sin i_a = \sqrt{\frac{n_1^2 - n_2^2}{n_3}} = \sqrt{\frac{n_1^2 - n_2^2}{n_3^2}}$$

12. $$i_a = \sin^{-1}\left[\sqrt{\frac{n_1^2 - n_2^2}{n_3^2}}\right]$$

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13. If outer medium is air $n_3 = 1$ then

$$i_a = \sin^{-1}\left(\sqrt{n_1^2 - n_2^2}\right)$$

14. **Acceptance Cone :**

Light can have angle of incidence from 0 to i_a with the normal at the end of the optical fibre forming conical shape called " Acceptance cone "

15. **Numerical Aperture :**

The term $n_3 \sin i_a$ is called as " Numerical Aperture " NA

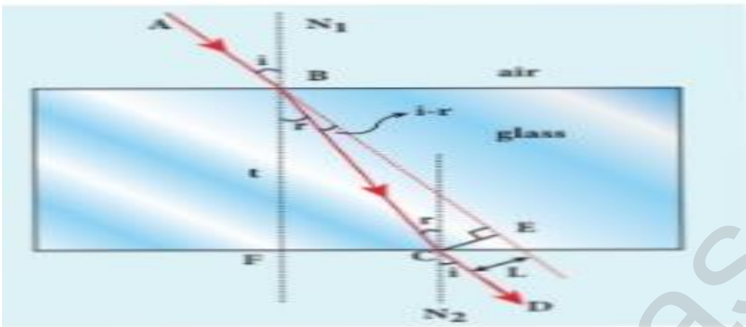
$$NA = n_3 \sin i_a = \sqrt{n_1^2 - n_2^2}$$

If $n_3 = 1$ then $NA = \sin i_a = \sqrt{n_1^2 - n_2^2}$

---

5. Obtain the equation for lateral displacement of light passing through a glass slab.

Diagram :



Formula :

$$L = t\left(\frac{\sin(i - r)}{\cos r}\right)$$

Theory :

Let us consider a light passing through glass slab.

- Thickness of glass slab → t
- Refractive Index → n
- Path of light → A B C D
- Angle of incidence → i
- Angle of refraction → r
- Lateral Displacement → L
- Normal → N_1 , N_2

In Δ B C E

$$\sin(i - r) = \frac{L}{BC}$$

$$BC = \frac{L}{\sin(i - r)}$$

In Δ B C E

$$\cos r = \frac{t}{BC}$$

$$BC = \frac{t}{\cos r}$$

$$\frac{L}{\sin(i - r)} = \frac{t}{\cos r}$$

Lateral Displacement :

$$L = t\left(\frac{\sin(i - r)}{\cos r}\right)$$

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Lateral Displacement Depends on

- Thickness of the slab (t)
- Angle of incidence (i)
- Refractive index (n)
- Angle of refraction (r)

Larger lateral displacement

- Thicker the slab
- Greater angle of incidence
- Higher refractive index

---

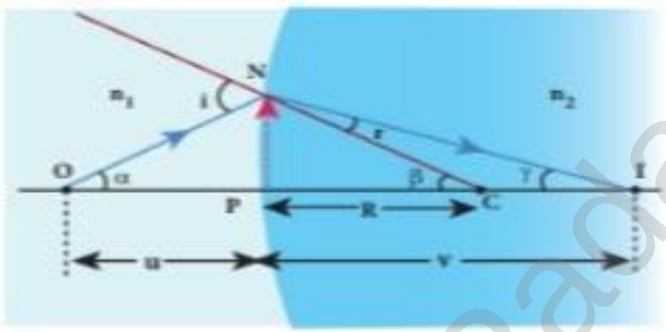
6. Derive the equation for refraction at single single spherical surface.

Theory :

Let us consider a single spherical surface.

- Refractive Indices ⟶ n_1 , n_2
- Centre of curvature ⟶ C
- Principal Axis ⟶ OC
- Pole point ⟶ P
- Point object ⟶ O
- Point image ⟶ I

Diagram :



Formula :

$$\frac{n}{v} - \frac{1}{u} = \frac{(n - 1)}{R}$$

Snell's law in product form

$n_1 \sin i = n_2 \sin r$

If the angles are small then sin i = i and sin r = r

$n_1 \, i = n_2 \, r$ ⟶ (1)

Let the angles be,

$\angle NOP = \alpha$; $\angle NCP = \beta$; $\angle NIP = \gamma$

Δ NOP	Δ NCP	Δ NIP
$\tan\alpha = \frac{PN}{PO}$	$\tan\beta = \frac{PN}{PC}$	$\tan\gamma = \frac{PN}{PI}$
$\alpha = \frac{PN}{PO}$	$\beta = \frac{PN}{PC}$	$\gamma = \frac{PN}{PI}$

Δ ONC , $i = \alpha + \beta$

Δ INC , $\beta = r + \gamma$, $r = \beta - \gamma$

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Sub i and r values in snell eqn

$$n_1 (\alpha + \beta) = n_2 (\beta - \gamma)$$

$$n_1 \alpha + n_1 \beta = n_2 \beta - n_2 \gamma$$

$$n_1 \alpha + n_2 \gamma = n_2 \beta - n_1 \beta$$

$$n_1 \alpha + n_2 \gamma = (n_2 - n_1) \beta$$

sub α , β and γ values,

$$n_1 \left(\frac{PN}{PO} \right) + n_2 \left(\frac{PN}{PI} \right) = (n_2 - n_1) \left(\frac{PN}{PC} \right)$$

Further simplifying by cancelling PN

$$\frac{n_1}{PO} + \frac{n_2}{PI} = \frac{(n_2 - n_1)}{PC}$$

By sign conventions :

PO = - u ; PI = V ; PC = R

$$\frac{n_1}{-u} + \frac{n_2}{v} = \frac{(n_2 - n_1)}{R}$$

$$\frac{n_1}{-u} + \frac{n_2}{v} = \frac{(n_2 - n_1)}{R}$$

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{(n_2 - n_1)}{R}$$

If $n_1 = 1$ then $n_2 = n$ then,

$$\boxed{\frac{n}{v} - \frac{1}{u} = \frac{(n - 1)}{R}}$$

---

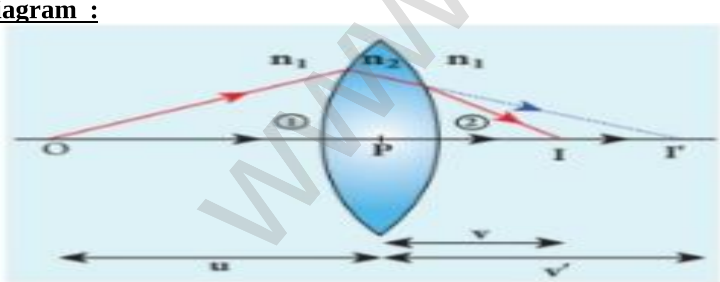
7. Obtain lens maker's formula and mention its significance.

Theory :

Let us consider a thin lens made up of a medium of refractive index n_2 placed in a medium of refractive index n_1.

- Radii curvature of two spherical surfaces ⟶ R_1 , R_2

Diagram :



Formula :

$$\boxed{\frac{1}{f} = (n - 1) \left(\frac{1}{R_1} - \frac{1}{R_2} \right)}$$

Derivation :

1. General eqn for refraction at a single spherical surface

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{(n_2 - n_1)}{R}$$

2. For refracting surface (1) , Light goes from n_1 to n_2

$$\frac{n_2}{v'} - \frac{n_1}{u} = \frac{(n_2 - n_1)}{R_1} \longrightarrow (1)$$

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3. For refracting surface (2), Light goes from n_2 to n_1

$$\frac{n_1}{v} - \frac{n_2}{v'} = \frac{(n_1 - n_2)}{R_2} \longrightarrow (2)$$

$$\frac{n_1}{v} - \frac{n_2}{v'} = \frac{-(n_2 - n_1)}{R_2} \longrightarrow (3)$$

4. Adding eqn (1) and (2)

$$\frac{n_2}{v'} - \frac{n_1}{u} + \frac{n_1}{v} - \frac{n_2}{v'} = \frac{(n_2 - n_1)}{R_1} - \frac{(n_2 - n_1)}{R_2}$$

5. $$\frac{n_1}{v} - \frac{n_1}{u} = (n_2 - n_1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

6. $$n_1\left(\frac{1}{v} - \frac{1}{u}\right) = (n_2 - n_1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

7. $$\frac{1}{v} - \frac{1}{u} = \frac{(n_2 - n_1)}{n_1}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

8. $$\frac{1}{v} - \frac{1}{u} = \left(\frac{n_2}{n_1} - \frac{n_1}{n_1}\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

9. $$\frac{1}{v} - \frac{1}{u} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

10. For $u = \infty$, $v = f$

$$\frac{1}{f} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

11. If $n_1 = 1$ and $n_2 = n$ then

$$\frac{1}{f} = (n - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

12. Lens maker's formula :

$$\boxed{\frac{1}{f} = (n - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)}$$

13. Significance :

It tells the lens manufactures what curvature is needed for a material of particular refractive index to make a lens of desired focal length.This formula holds good also for any type of lens.

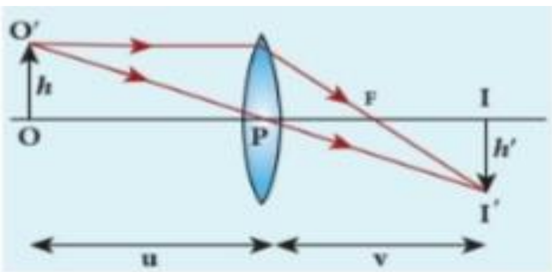
14. Lens equation :

$$\boxed{\frac{1}{f} = \frac{1}{v} - \frac{1}{u}}$$

---

8. Derive the equation for thin lens and for magnification.

Diagram :



Formula :

$$\boxed{m = \frac{f}{f+u} = \frac{f - v}{f}}$$

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Theory :

- Object → $O\ O'$
- Image → $I\ I'$
- Height → $h\ ,\ h'$

Lateral Magnification or Transverse magnification :

It is defined as the ratio of the height of the image to height of the object.

Similar triangles $\Delta\ POO'$ and $\Delta\ PII'$

$$m = \frac{II'}{OO'} = \frac{PI}{PO}$$

- On applying sign convention

$$m = -\frac{h}{h'} = \frac{v}{-u}$$

- Magnification :

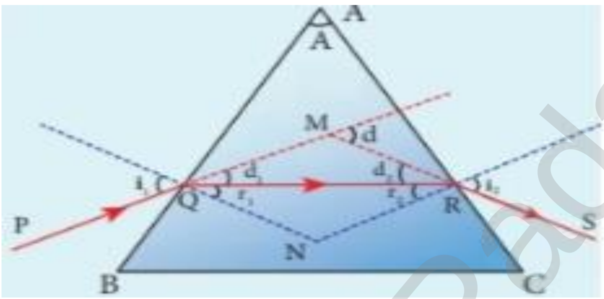
$$m = \frac{h}{h'} = \frac{v}{u}$$

- Magnification is negative for real image and positive for virtual image.
- Magnification always positive for concave lens and less than one.

---

9. Derive the equation for angle of deviation produced by a prism and thus obtain the equation for refractive index of material of the prism.

Angle of deviation :



Formula :

$$n = \frac{\sin\left(\frac{A+D}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

Theory :

- Consider a prism A B C.
- Polished face → A B , A C
- Rough face → B C
- Incident Ray → P Q
- Emergent Ray → R S
- Angle of incidence → $i_1\ ,\ i_2$
- Angle of refraction → $r_1\ ,\ r_2$

Angle of deviation :

The minimum value of angle of deviation is called "angle of deviation."

At surface A B : $\angle RQM = d_1 = i_1 - r_1$

At surface A C : $\angle QRM = d_2 = i_2 - r_2$

Total angle of deviation : $d = d_1 + d_2$

$$d = i_1 - r_1 + i_2 - r_2$$

$$d = i_1 + i_2 - (r_1 + r_2) \quad \text{-------- (1)}$$

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Quadrilateral AQNR : $\angle A + \angle QNR = 180^0$

Triangle QNR : $r_1 + r_2 + \angle QNR = 180^0$

$$A = r_1 + r_2 \quad \text{----------} (2)$$

sub eqn (2) in (1) : $d = i_1 + i_2 - A$ --------- (3)

At minimum deviation : $d = D$; $i_1 = i_2 = i$; $r_1 = r_2 = r$

$r_1 + r_2 = A$	$D = i_1 + i_2 - A$
$r + r = A$	$D = i + i - A$
$2r = A$	$D = 2i - A$
$r = \frac{A}{2}$	$i = \frac{A + D}{2}$

Snell's law : $n = \frac{\sin i}{\sin r}$

Refractive Index :

$$n = \frac{\sin\left(\frac{A + D}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

---

10. What is the dispersion ? Obtain the equation for dispersive power of a medium.

Dispersion :

- Splitting of white colour into its constituent colours .
- Band of colours of light is called its spectrum.

Diagram :

Formula :

$$\omega = \frac{n_V - n_R}{n - 1}$$

Refractive Index :

$$n = \frac{\sin\left(\frac{A + D}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

- Angle of small angle prism → A
- Angle of minimum deviation → δ

$$n = \frac{\sin \frac{A + \delta}{2}}{\sin \frac{A}{2}}$$

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- $\sin \frac{A+\delta}{2} = \frac{A+\delta}{2}$
- $\sin \frac{A}{2} = \frac{A}{2}$
- $n = \frac{\frac{A+\delta}{2}}{\frac{A}{2}} = \frac{A+\delta}{A} = \frac{A}{A} + \frac{\delta}{A}$
- $n = 1 + \frac{\delta}{A}$
- $\frac{\delta}{A} = n - 1$
- $\delta = A(n-1)$

Colours	Violet	Red
Angle of minimum deviation	δ_v	δ_R
Refractive Index	n_V	n_R

- For violet colour $\delta_v = (n_V - 1)A$
- For red colour $\delta_R = (n_R - 1)A$
- $\delta_v - \delta_R = (n_V - 1)A - (n_R - 1)A$
- $\delta_v - \delta_R = n_V A - A - n_R A + A$
- $\delta_v - \delta_R = n_V A - n_R A$
- $\delta_v - \delta_R = (n_V - n_R)A$

Angular dispersion :

The angular separation between the two extreme colours violet and red in spectrum is called " angular dispersion "

$$\delta_v - \delta_R = (n_V - n_R)A$$

Dispersive Power :

The angular dispersion for the extreme colours to the deviation for any middle colour is known as " dispersive power "

$$\omega = \frac{\text{Angular Dispersion}}{\text{Middle Deviation}}$$

$$\omega = \frac{\delta_v - \delta_R}{\delta}$$

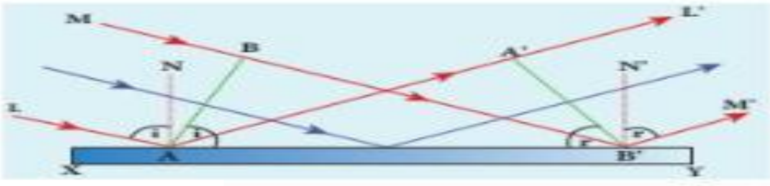
$$\omega = \frac{(n_V - n_R)A}{(n-1)A}$$

$$\omega = \frac{n_V - n_R}{n-1}$$

LESSON - 7

1. Prove law of reflection using " Huygen's principle .

Diagram :



Laws of reflection

Formula :

i = r

Theory :

* Let us consider parallel beam of light is incident on a reflecting plane surface.

1. Plane mirror → X Y
2. Incident wave front → A B
3. Reflected wavefront → A′ B′
4. Incident rays → L , M
5. Reflected rays → L′ , M′
6. Two Normals → N , N′

* By the time of point A of the incident wavefront touches reflecting surface , the point B travel distance B B′.
* By the time of point B of the incident wavefront touches reflecting surface , the point A travel distance A A′.

As the reflection happens in the same medium :

1) Speed of light is same before and after the reflection.
2) Time taken for light to travel from B to B′ and A to A′ are the same.
3) Distance B B′ is equal to the distance A A′ .
4) The incident rays , the reflected rays and the normal are lie in the same plane.
5) Angle of incidence , < i = < N A L = 90⁰ - < N B A = < B A B′
6) Angle of reflection, < i = < N′B′M′ = 90⁰ - < N′ B′ A′ = < A′ B′ A

For the right angle triangles , Δ A B B′ and Δ B′ A′ A

- Two right angles are < B and < A are equal′. (< B = < A′ = 90^0)
- Two sides A A′ and B B′are equal. (A A′ = B B′)
- The side A B′ is common.
- The two angles < B A B′ and < A′B′ A must be equal.
- Thus , the triangles are congruent.
- < BAB′ and < A′BA must also be equal.

Hence , the laws of reflection are proved.

---

2. Prove law of refraction using " Huygen's principle .

Diagram :

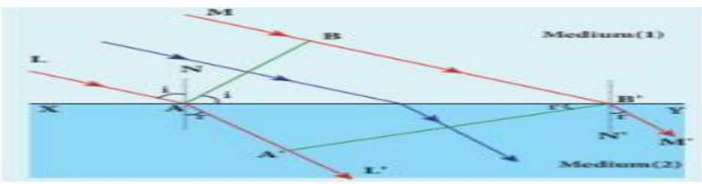


Figure 7.5 Law of refraction

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Theory :

* Let us consider parallel beam of light is incident on a refracting plane surface.

1. Plane mirror → X Y
2. Incident wave front → A B in rarer medium (1)
3. Reflected wavefront → A′ B′ in denser medium (2)
4. Incident rays → L , M
5. Reflected rays → L′ , M′
6. Two Normals → N , N′

* By the time of point A of the incident wavefront touches reflecting surface , the point B travel distance B B′.
* By the time of point B of the incident wavefront touches reflecting surface , the point A travel distance A A′.

As the reflection happens from rarer medium (1) to denser medium (2):

1. Speed of light is v_1 and v_2 before and after the refraction. ($v_1 > v_2$)
2. Time taken for light to travel from B to B′ and A to A′ are the same.
3. $$t = \frac{BB'}{v_1} = \frac{AA'}{v_2}$$
   $$\frac{BB'}{AA'} = \frac{v_1}{v_2}$$
4. The incident rays , the re fracted rays and the normal are lie in the same plane.
5. Angle of incidence , $\angle i = \angle NAL = 90^0 - \angle NBA = \angle BAB'$
6. Angle of reflection, $\angle i = \angle N'B'M' = 90^0 - \angle N'B'A' = \angle A'B'A$
7. For the right angle triangles , $\Delta ABB'$ and $\Delta A A'B'$
   $$\frac{\text{Sin } i}{\text{Sin } r} = \frac{BB'/AB'}{AA'/AB'} = \frac{BB'}{AA'} = \frac{v_1}{v_2} = \frac{c/v_2}{c/v_1}$$
8. Refractive index of the medium : $n_1 = \frac{c}{v_1}$; $n_2 = \frac{c}{v_2}$
   $$\frac{n_2}{n_1} = \frac{c}{v_2}\,\frac{v_1}{c}$$
   $$\frac{n_2}{n_1} = \frac{v_1}{v_2}$$
9. Snell's law in ratio form : $\frac{\text{Sin } i}{\text{Sin } r} = \frac{n_2}{n_1}$
10. Snell's law in product form : $n_1 \text{ Sin } i = n_2 \text{ Sin } r$

Hence , the laws of refraction are proved.

---

3. Obtain the equation for resultant intensity due to interference of light.

Interference :

The phenomenon of superposition of two light waves which produces increases in intensity at some points and decreases in intensity at some points is called " interference of light "

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Theory :

Let us consider two light waves from the two sources S_1 and S_2 meeting at a point P .

1. The wave from S_1 at an instant t at P is : $y_1 = a_1 \sin \omega t$

2. The wave from S_2 at an instant t at P is : $y_2 = a_2 \sin (\omega t + \phi)$

3. Amplitudes ⟶ a_1 and a_2 ; Angular frequency ⟶ ω ; Phase difference ⟶ ϕ ;

Diagram :

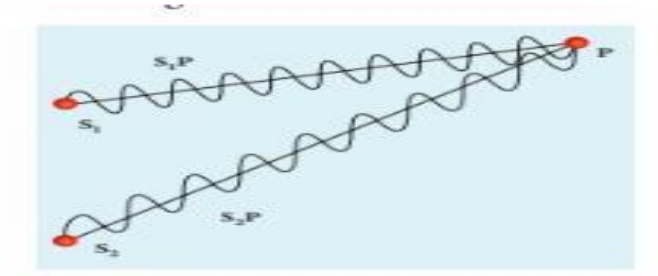

Figure 7.6 Superposition principle

Resultant Displacement : $y = y_1 + y_2$

$$y = a_1 \sin \omega t + a_2 \sin (\omega t + \phi)$$

$$y = a_1 \sin \omega t + a_2 (\sin \omega t \cos \phi + \cos \omega t \sin \phi)$$

$$y = a_1 \sin \omega t + a_2 \sin \omega t \cos \phi + a_2 \cos \omega t \sin \phi$$

$$y = \sin \omega t (a_1 + a_2 \cos \phi) + a_2 \sin \phi \cos \omega t \text{ --------------------- } (1)$$

Let us consider $a_1 + a_2 \cos \phi = A \cos \theta$ and $a_2 \sin \phi = A \sin \theta$ --------- (2)

Sub eqn (2) in eqn (1)

$$y = A \sin \omega t \cos \theta + A \cos \omega t \sin \theta$$

$$y = A (\sin \omega t \cos \theta + \cos \omega t \sin \theta)$$

$$\boxed{y = A \sin (\omega t + \theta)} \text{ ----------------------------- } (3)$$

Resultant Amplitude :

Squaring and adding eqn (2)

$$(a_1 + a_2 \cos \phi)^2 + a_2^2 \sin^2 \phi = A^2 \cos^2 \theta + A^2 \sin^2 \theta$$

$$a_1^2 + a_2^2 \cos^2 \phi + 2 a_1 a_2 \cos \phi + a_2^2 \sin^2 \phi = A^2 (\cos^2 \theta + \sin^2 \theta)$$

$$a_1^2 + a_2^2 \cos^2 \phi + a_2^2 \sin^2 \phi + 2 a_1 a_2 \cos \phi = A^2$$

$$a_1^2 + a_2^2 (\cos^2 \phi + \sin^2 \phi) + 2 a_1 a_2 \cos \phi = A^2$$

$$a_1^2 + a_2^2 + 2 a_1 a_2 \cos \phi = A^2$$

$$A^2 = a_1^2 + a_2^2 + 2 a_1 a_2 \cos \phi$$

$$\boxed{A = \sqrt{a_1^2 + a_2^2 + 2 a_1 a_2 \cos \phi}}$$

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Max Amplitude : $A_{max} = \sqrt{(a_1 + a_2)^2}$ when $\phi = 0, \pm 2\pi, \pm 4\pi, ...$

Min Amplitude : $A_{min} = \sqrt{(a_1 - a_2)^2}$ When $\phi = \pm\pi, \pm 3\pi, \pm 5\pi ......$

Resultant Intensity : " Intensity of light is proportional to square of amplitude "

$I \propto A^2$	$I_1 \propto a_1^2$	$I_2 \propto a_2^2$
$A^2 = I$	$a_1^2 = I_1$	$a_2^2 = I_2$
$A = \sqrt{I}$	$a_1 = \sqrt{I_1}$	$a_2 = \sqrt{I_2}$

Resultant Intensity : $I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos\phi$

Max Intensity : $I_{max} = (a_1 + a_2)^2$ Where $\phi = 0, \pm 2\pi, \pm 4\pi, ...$

$I_{max} = I_1 + I_2 + 2\sqrt{I_1 I_2}$

Max intensity is called " Constructive interference "

Min Amplitude : $I_{min} = (a_1 - a_2)^2$ Where $\phi = \pm\pi, \pm 3\pi, \pm 5\pi, ...$

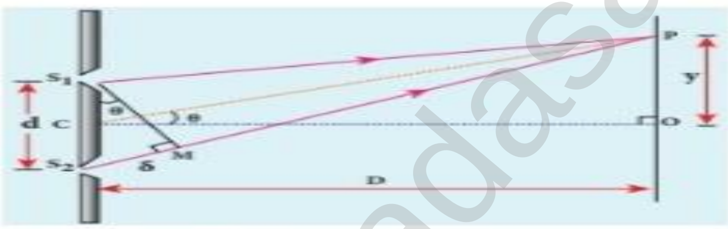
$I_{max} = I_1 + I_2 - 2\sqrt{I_1 I_2}$

Min intensity is called " Destructive interference "

---

4. Explain the Young's double slit experimental setup and obtain the equation for path difference.

Diagram :



Young's double slit arrangement to find path difference

Experimental Setup :

1. Thomas Young used an opaque screen with two openings.
2. This two openings is called double slit S_1 and S_2 .
3. S_1 and S_2 kept equidistance from a source S.
4. The width of each slit is about 0.03 mm.
5. They are separated by a distance of about 0.3 mm.
6. S_1 and S_2 are equidistant from source S .
7. Light waves S_1 and S_2 Same wavefront * In - phase * Coherent source * Obtain interference pattern.
8. Screen is placed 1 m from the slits , alternate bright and dark fringes appeared.
9. These are called interference fringes and bands.
10. These two waves constructively interfere and bright fringe is observed at O.
11. When one slit is closed , fringes disappear and there is uniform illumination on the screen.

Theory :

- Let d be the distance between the double slits S_1 and S_2.
- They act as coherent source of wavelength λ .
- A screen is placed parallel to double slit at a distance D.
- The mid – point of S_1 and S_2 is C .
- The mid – point of the screen is O .
- P is any point at a distance y from O.
- Waves from S_1 and S_2 either in – phase or out – of - phase .

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Path difference Derivation :

1. $\delta = S_2P - S_1P = S_2M$ ---------- (1)

2. From right angle triangle $\Delta\ S_1 S_2 M$

$$\sin\theta = \frac{S_2M}{S_1S_2}$$

$$S_2M = d\sin\theta \quad (S_1S_2 = d)$$
$$\delta = d\sin\theta$$
$$\delta = d\,\theta \quad \text{---------- (2)}$$

3. From right angle triangle Δ O C P

$$\tan\theta = \frac{OP}{CO}$$
$$\tan\theta = \frac{y}{D}$$
$$\theta = \frac{y}{D} \quad \text{--------- (3)}$$

4. Sub eqn (3) in eqn (2)

$$\delta = \frac{d\,y}{D}$$

5. Path Difference :

$$\boxed{\delta = \frac{d\,y}{D}}$$

6. **Condition for bright fringe (or) maxima :**

- Bright Fringe ⟶ Constructive interference
- Path difference $\delta = n\lambda$ where $n = 0, 1, 2, 3$ …….
- $\delta = \frac{d\,y}{D} = n\lambda$
- $y = \frac{n\lambda D}{d}$

$$\boxed{y_n = \frac{n\lambda D}{d}}$$

7. **Condition for Dark fringe (or) minima :**

- Dark Fringe ⟶ Destructive interference
- Path difference $\delta = (2n-1)\frac{\lambda}{2}$ where $n = 1, 2, 3$ …….
- $\delta = \frac{d\,y}{D} = (2n-1)\frac{\lambda}{2}$

$$\boxed{y_n = \frac{(2n-1)}{2}\frac{\lambda D}{d}}$$

---

5. Obtain the equation for bandwidth in Young's double slit experiment.

Theory :

- Let d be the distance between the double slits S_1 and S_2.
- They act as coherent source of wavelength λ .
- A screen is placed parallel to double slit at a distance D.The mid – point of S_1 and S_2 is C .
- The mid – point of the screen is O .
- P is any point at a distance y from O.
- Waves from S_1 and S_2 either in – phase or out – of - phase .

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Diagram :

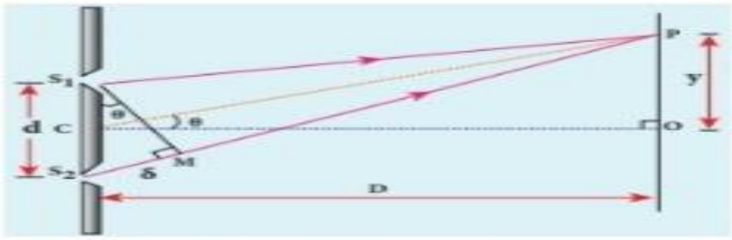

Figure 7.13 Young's double slit arrangement to find path difference

Equation for bandwidth :

The bandwidth β is defined as the distance between any two consecutive bright (or) dark fringes.

Consecutive Bright Fringes:

$$y_n = \frac{n\lambda D}{d}$$

$$y_{(n+1)} = \frac{(n+1)\lambda D}{d}$$

$$\beta = y_{(n+1)} - y_n$$

$$\beta = \left(\frac{(n+1)\lambda D}{d}\right) - \left(\frac{n\lambda D}{d}\right)$$

$$\beta = \frac{n\lambda D}{d} + \frac{\lambda D}{d} - \frac{n\lambda D}{d}$$

$$\beta = \frac{\lambda D}{d}$$

Consecutive Dark Fringes:

$$y_n = \frac{(2n-1)}{2}\frac{\lambda D}{d} = \frac{2n\lambda D}{2d} - \frac{\lambda D}{d} = \frac{n\lambda D}{d} - \frac{\lambda D}{d}$$

$$y_{(n+1)} = \frac{(2(n+1)-1)}{2}\frac{\lambda D}{d} = \frac{(2n+2-2)}{2}\frac{\lambda D}{d} = \frac{n\lambda D}{d}$$

$$\beta = y_{(n+1)} - y_n$$

$$\beta = \frac{n\lambda D}{d} - \left(\frac{n\lambda D}{d} - \frac{\lambda D}{d}\right)$$

$$\beta = \frac{n\lambda D}{d} - \frac{n\lambda D}{d} + \frac{\lambda D}{d}$$

$$\beta = \frac{\lambda D}{d}$$

---

6. Discuss the interference in thin films and obtain the equation for constructive and destructive interference for transmitted and reflected light.

Theory :

1. Let us consider a thin film of transparent material refractive index μ and thickness d.
2. A parallel beam of light is incident on the film at an angle i .
3. The wave is divided into two parts at the point of incidence , as reflected and refracted lights.
4. The refracted part which enters into the film again gets divided at the lower surface into two parts.
   - One is transmitted out of the film . Other is reflected back into the film.

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5. The reflected as well as refracted parts are further formed as multiple reflections take place inside the film.
6. The interference occurs in both the reflected and transmitted light.

Diagram :

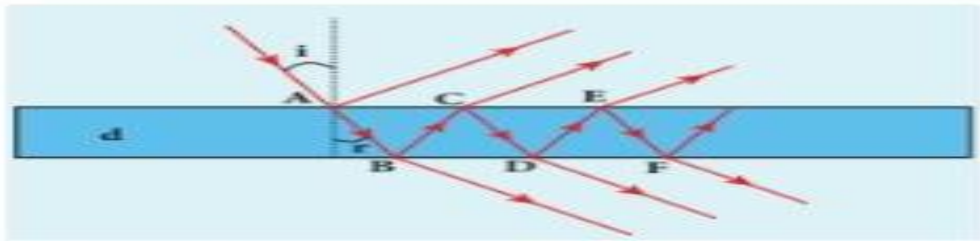

Figure 7.16 Interference in thin films

S.NO	For Transmitted light	For Reflected light
1.	Path difference between B and D.	Path difference between C and A.
2.	The extra path travelled by the wave B C + C D	The additional path travelled by the wave A B + B C
3.	The extra path travelled by the wave is twice thickness of the film.	The extra path travelled by the wave is twice thickness of the film.
4.	For near normal incidence and small thickness then the distance be , $BC + CD = 2d$	For near normal incidence and small thickness then the distance be , $AB + BC = 2d$
5.	As this extra path is traversed inside the refractive index μ , the optical path difference $\delta = 2\mu d$	As this extra path is traversed inside the refractive index μ , the optical path difference $\delta = 2\mu d$
6.	For constructive interference $2\mu d = n\lambda$	For constructive interference $2\mu d + \frac{\lambda}{2} = n\lambda$
7.	For destructive interference $2\mu d = (2n-1)\frac{\lambda}{2}$	For destructive interference $2\mu d + \frac{\lambda}{2} = \frac{(2n+1)\lambda}{2}$

7. Discuss the diffraction at single slit and obtain the condition for nth minimum.

Theory :

- Let a parallel beam of light fall normally on a single slit AB of width a.
- The diffracted beam falls on a screen kept at a distance D from the slit.
- The centre of the slit is C and straight line through C meets at screen at O.
- Consider any point P on the screen and all the light reaching the point P from different points on the slit make an angle θ with the normal CO.
- The point P is the geometrically shadowed region up to which central maximum spread due to *diffraction.*

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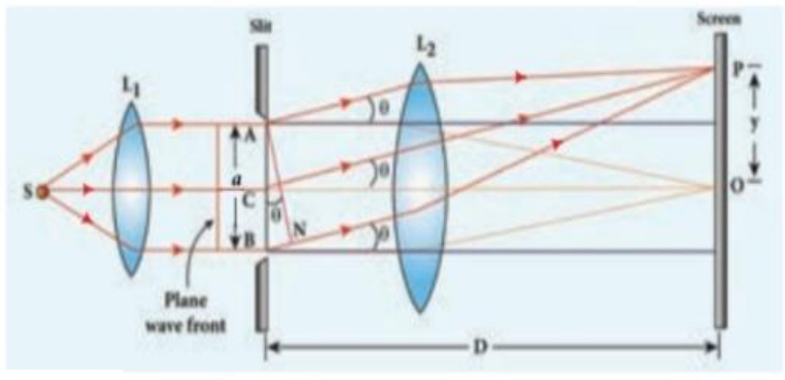
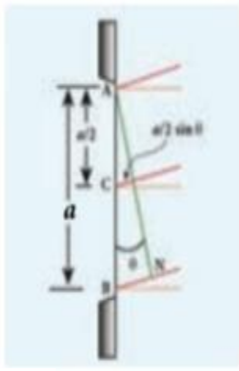
Diagram :



Diffraction at single slit



Corresponding points

Condition for the point P to be Minima :

- The basic idea to divide the slit into *even* number of smaller parts.
- Add their contribution at P with path difference takes place at that point to make it *minimum.*

Condition for P to be first minimum :

- Let us divide the slit AB into *two* halves AC and CB .
- The width of each part is *a / 2.*
- The different points on the slit which are separated by the same width a/2 called as *corresponding points.*
- The light waves from different points interfere *destructively* to make it a *minimum.*

Path Difference : $\delta = \frac{a}{2} \sin\theta$

$\frac{a}{2} \sin\theta = \frac{\lambda}{2}$

$$a \sin\theta = \lambda$$

Condition for P to be second minimum :

- Let us divide the slit AB into *four* equal parts .
- The width of each part is *a / 4.*

Path Difference : $\delta = \frac{a}{4} \sin\theta$

$\frac{a}{4} \sin\theta = \frac{\lambda}{2}$

$$a \sin\theta = 2\lambda$$

Condition for P to be third minimum :

- Let us divide the slit AB into *six equal parts* AC and CB .
- The width of each part is *a / 6.*

Path Difference : $\delta = \frac{a}{6} \sin\theta$

$\frac{a}{6} \sin\theta = \frac{\lambda}{2}$

$$a \sin\theta = 3\lambda$$

Condition for P to be nth minimum :

- Let us divide the slit into 2n number of (even number) equal parts makes as minimum .
- The width of each part is *a / 2n.*

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Path Difference : $\delta = \frac{a}{2n} \sin\theta$

$\frac{a}{2n} \sin\theta = \frac{\lambda}{2}$

$a \sin\theta = n\lambda$

Condition for the point P to be Maxima :

- The basic idea to divide the slit into *odd* number of equal parts.
- One part remains un – cancelled making the point P appear *bright.*

Condition for P to be first maximum : $\frac{a}{3} \sin\theta = \frac{\lambda}{2}$ (or) $a \sin\theta = \frac{3\lambda}{2}$

---

8. Discuss the diffraction at a grating and obtain the condition for the m^th maximum.

Diffraction at grating :

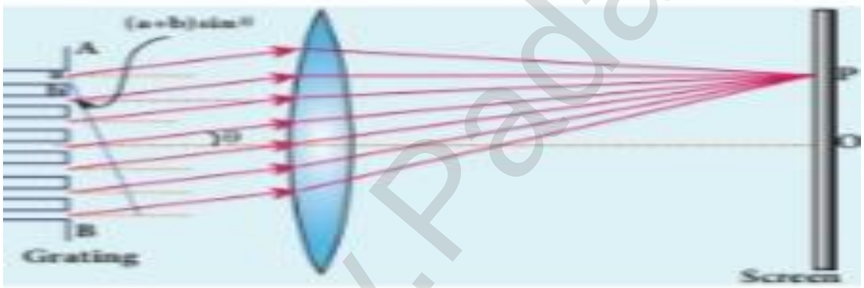
- A grating has multiple slits equal widths of comparable size to the wavelengths of diffracting light.
- A grating is a plane sheet of transparent material on which opaque rulings are made.
- Grating contains about 6000 lines per centimetre.
- The transparent space between the rulings act as slit of width a and the rulings act as obstacles having definite width b.

Grating element :

- The combined width of a ruling and a slit is called grating element e.

The points on the slit separated by a distance equal to the grating element are called *corresponding points.*

Diagram :



Diffraction grating experiment

Theory :

- A plane transmission grating is represented as AB.
- Let plane wavefront of monochromatic light with wavelength λ be incident on the grating.
- As the width of the slit is comparable to that of wavelength , the incident light undergoes diffraction.
- A diffraction pattern is obtained on the screen when the diffracted waves are focussed on a screen using a convex lens.
- Let us consider a point P at an angle θ .

Path Difference : $\delta = (a + b) \sin\theta$

Condition for P will be maximum :

$\delta = m\lambda = (a + b) \sin\theta$

$(a + b) \sin\theta = m\lambda$

Condition for P to be zero^th maximum m = 0

$(a + b) \sin\theta = 0$

Condition for P to be first maximum m = 1

$(a + b) \sin\theta_1 = \lambda$

Condition for P to be second maximum m = 2

$(a + b) \sin\theta_2 = 2\lambda$

Condition for P to be mth maximum

$(a + b) \sin\theta = m\lambda$

$$\sin\theta = \frac{1}{a+b} m\lambda$$

$$N = \frac{1}{a+b}$$

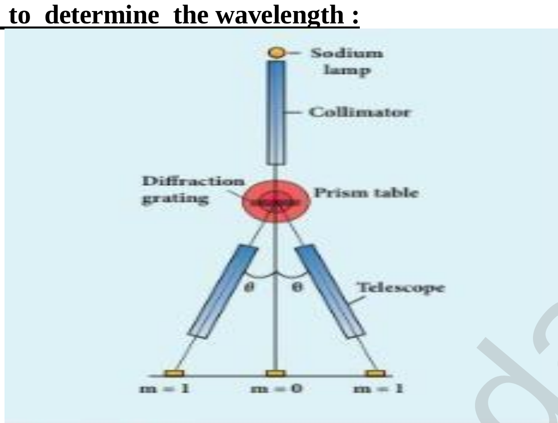
N gives the number of grating elements or rulings drawn per unit width of the grating.

_Condition for P to be m^th maximum $\sin\theta = N m \lambda$

---

9. Discuss the experiment to determine the wavelength of monochromatic light using diffraction grating.

Experiment to determine the wavelength :



Theory :

- The wavelength of a spectral line accurately determined with the help of *grating*.
- For that we need to use an instrument called *spectrometer.*
- After preliminary adjustments , the slit of *collimator* is illuminated by monochromatic light.
- The *telescope* is brought in line with collimator to view the image of the slit.
- The given grating is then mounted on the prism table .
- The telescope is turned to one side until the first order diffraction .
- Reading of the position of the telescope is noted .
- The difference between two readings gives 2θ .
  Half of its valve gives θ.

Wavelength of light : $\lambda = \frac{\sin\theta}{N m}$

- N is the number of rulings per meter in the grating .
- m is the order of the diffraction image.

---

10 . Discuss the experiment to determine the wavelength of different colours using diffraction grating.

Theory :

- The diffraction pattern for white light consists of a white central maximum.
- The continuous coloured diffraction pattern on its both sides.
- The central maximum is white as all the colours constructively meet at centre with no path difference.
- As θ increases , the path differences fulfils the condition for maxima for maxima of different orders for all colours from violet to red.

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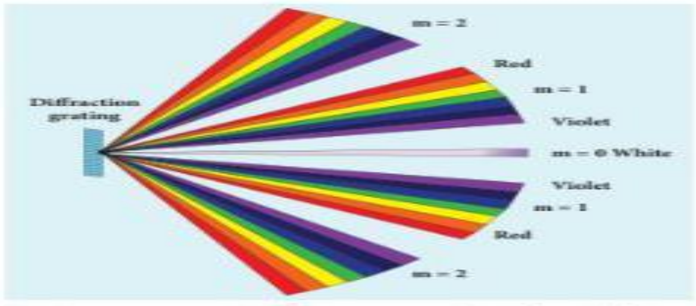
- It produces a spectrum of diffraction pattern from violet to red on either side of central maximum .
- By measuring the angle at which these colours appear for various orders of diffraction , the wavelength of different colours could be calculated.

Diagram :



Formula :

$$\lambda = \frac{\sin\theta}{N\ m}$$

- N is the number of rulings per meter in the grating .
- m is the order of the diffraction image.

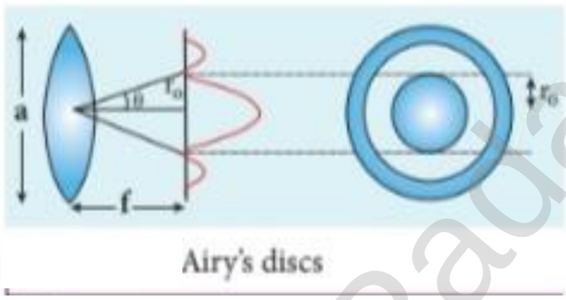
---

11. Obtain the equation for resolving power optical instruments .

Resolving power of optical instrument :

The ability of an optical instrument to distinguish the two closely adjacent objects (or) two points on the same object is said to be " *resolving power* " of the instrument.

Diagram :



Theory :

1. The effect of diffraction in the sharpness of the image formed.
2. There is always spread of central maximum in the image for every point of the object acts as a point source.
3. The condition for central maximum produced by rectangular slit is given by $a \sin\theta = \lambda$
4. circular slit produces diffraction pattern of concentric circles & known as *airy disc's*
5. Most of the optical instruments form images of objects only through circular slits

Condition for central maximum : $a \sin\theta = 1.22\ \lambda$

- The numerical value 1.22 appears in the expression for central maximum.
- Central maximum or first minimum formed by circular slits.

Derivation :

1. For small angles , $\sin\theta = \theta$
2. $a \sin\theta = 1.22\ \lambda$
3. $a\ \theta = 1.22\ \lambda$
4. $\theta = \frac{1.22\ \lambda}{A}$ ------------------ (1)

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5. From diagram ,

$$\theta = \frac{r_0}{f}$$

$$r_0 = \theta f \quad \text{-------------------} \; (2)$$

6. sub eqn (1) in eqn (2)

$$r_0 = \frac{1.22 \lambda f}{a}$$

Rayleigh' criterion :

The two points on an image are said to be just resolved when the central maximum of one diffraction pattern coincides with the first minimum of the other.

Spatial resolution or Angular resolution :

The distance between two central maxima must be at least r_0 .

$$\boxed{r_0 = \frac{1.22 \lambda f}{a}}$$

---

12. Discuss about the simple microscope and obtain the equation for magnification for near point focusing and normal focusing.

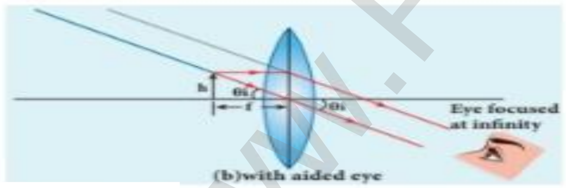
Simple Microscope :

1. A simple microscope is a single magnifying (convex) lens of small focal length .
2. It produce an erect , magnified and virtual image of the object.
3. The object be placed within the focal length f on one side of the lens and viewed through the other side of it.
4. The nearest point where an eye can clearly see is called *near point* and the farthest point up to which an eye can clearly see is called the *far point.*

Near point focusing :

1. The eye is least strained when image is formed at near point i.e 25 cm.
2. The near point is also called as *least distance* of distinct vision .
3. Object distance u should be less than f.
4. Image distance is the near point D.

Diagram :



Normal focusing

Derivation :

1. Magnification $m = \frac{v}{u}$

Distances are measured to left of the lens . v = - D and u = - u

$$m = \frac{-D}{-u}$$

$$\boxed{m = \frac{D}{u}}$$

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2. Lens equation

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

Multiple the above eqn by v

$$\frac{v}{v} - \frac{v}{u} = \frac{v}{f}$$

$$1 - m = \frac{v}{f}$$

$$m = 1 - \frac{v}{f}$$

$$m = 1 - \frac{(-D)}{f} \quad (v = -D)$$

$$\boxed{m = 1 + \frac{D}{f}}$$

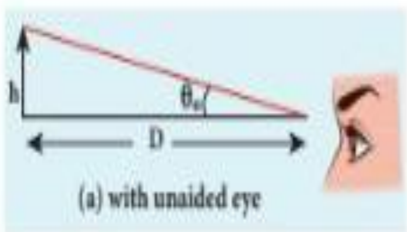
Normal Focusing :

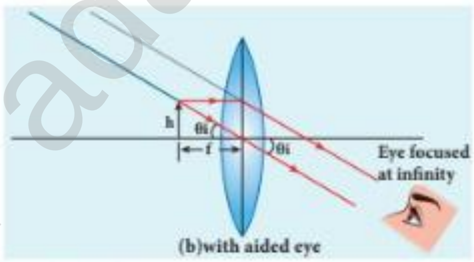
- The eye is most relaxed when the image is formed at infinity .
- The focusing is called normal focusing when the image is formed at infinity.

Angular Magnification :

The ratio of angle θ_i subtended by the image with aided eye to the angle θ_0 subtended by the object with unaided eye.

Diagram :





Derivation :

1. For unaided eye : $\tan\theta_0 = \theta_0 = \frac{h}{D}$

2. For aided eye : $\tan\theta_i = \theta_i = \frac{h}{f}$

3. Angular magnification : $m = \frac{\theta_i}{\theta_0}$

$$m = \frac{h/D}{h/f}$$

$$\boxed{m = \frac{D}{f}}$$

- Magnification of normal focusing is one less than that of near point focusing .
- Viewing is more comfortable in normal focusing than near point focusing.
- For large values of D / f , the difference between the two magnification is negligibly small.

13. Explain about compound microscope and obtain the equation for the magnification.

Compound Microscope :

- **Compound microscope consists of objective lens and eye piece.**

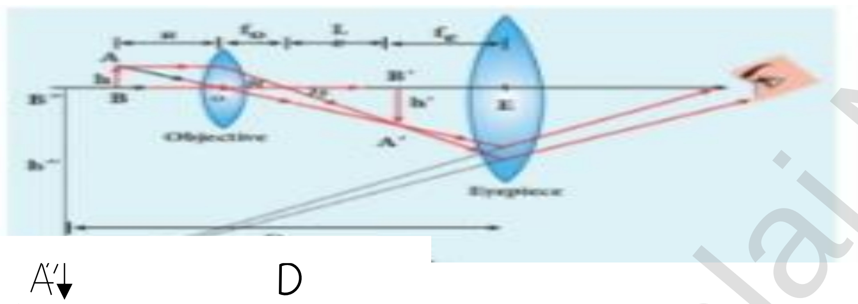
Objective :

- **The lens near the object is called as *objective.***
- **It forms a real , inverted and magnified image of the object.**

Eye Piece :

- **The object for the lens closer to the eye called as *eye piece.***
- **The eye piece serves as a simple microscope that produces finally an enlarged and virtual image.**

Diagram :



Final Image :

- **The final inverted image formed by the objective is to be adjusted within the focus of the eye piece .**
- **So that the final image is formed nearly at infinity (or) at the near point.**
- **The final image is inverted with respect to the object.**

Magnification for objective :

1. $m = \frac{h'}{h}$
2. $\tan\beta = \frac{h}{f_0} = \frac{h'}{L}$
3. $\frac{h'}{h} = \frac{L}{f_0}$
4. $\boxed{m_0 = \frac{L}{f_0}}$

Tube Length:

- **Distance L between the focal point of the eye piece to focal point of the objective.**
- **This is called the tube length of the microscope as f_0 and f_e are smaller than L.**

Magnification for eye piece : $\boxed{m_e = 1 + \frac{D}{f_e}}$

i) Near Point Focusing :

$$m = m_0 \; m_e$$

$$m = \left(\frac{L}{f_0}\right)\left(1 + \frac{D}{f_e}\right)$$

ii) Normal Focusing :

$$m = \left(\frac{L}{f_0}\right)\left(\frac{D}{f_e}\right)$$

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14. Obtain the equation for resolving power of microscope .

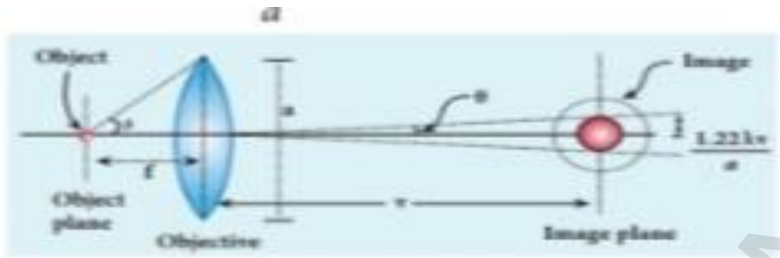
Microscope :

- A microscope is used to see details of the object under observation .
- Good microscope should not only magnify the object.
- Also resolve the two points on an object which are separated by small distance.
- Small distance d_{min} is the resolution and reciprocal is the resolving power.

Spatial Resolution :

Radius of central maximum $r_0 = \frac{1.22\ \lambda f}{a}$

Diagram :



Resolving power of microscope

Derivation :

1. Object distance is more than focal length f and image is formed at v. (f = v)

$$r_0 = \frac{1.22\ \lambda f}{a} = \frac{1.22\ \lambda v}{a}$$

2. If the two points on the object to be resolved is d_{min} then magnification , $m = r_0 / d_{min}$

3. $$d_{min} = \frac{r_0}{m}$$

4. $$d_{min} = \frac{1.22\ \lambda v}{a\ m}$$

5. $$d_{min} = \frac{1.22\ \lambda v}{a\ (v / u)}$$

6. $$d_{min} = \frac{1.22\ \lambda u}{a}$$

7. $$d_{min} = \frac{1.22\ \lambda f}{a} \qquad (u = f)$$

8. On the object side ,

$$2 \tan \beta = 2 \sin \beta = \frac{a}{f}$$

$$a = 2 f \sin \beta$$

9. $$d_{min} = \frac{1.22\ \lambda f}{2 f \sin \beta}$$

$$d_{min} = \frac{1.22\ \lambda}{2 \sin \beta}$$

10. To further reduce the value of d_{min} the optical path of the light is increased by immersing the objective of the microscope into bath containing oil of refractive index n.Such an objective is called oil immersed objective.

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$$d_{min} = \frac{1.22\ \lambda}{2\ n \sin \beta}$$

11. The term n sin β is called *numerical aperture* *N A.*

$$d_{min} = \frac{1.22\ \lambda}{2\ (N A)}$$

12. Resolving power R_M of microscope is ,

$$R_M = \frac{1}{d_{min}} = \frac{2\ (N A)}{1.22\ \lambda}$$

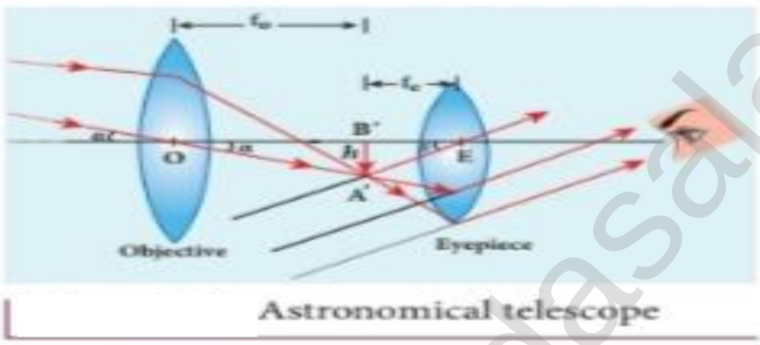
---

15. Discuss about astronomical telescope.

Astronomical Telescope :

1. An astronomical telescope is used to get the magnification of distant astronomical objects like stars , planets , moon etc.
2. The image formed by astronomical telescope will be inverted.
3. It has an objective of long focal length and much larger aperture than eye piece.
4. Light from a distant object enters the objective and a real image is formed in the tube at its focal point.
5. The eye piece magnifies this image producing final inverted image.

Diagram :



Astronomical telescope

Magnification in astronomical telescope :

It is the ratio of the angle β subtended by the image to the angle α subtended by the object with the principal axis .

$$m = \frac{\beta}{\alpha}$$

- From diagram , $\alpha = \frac{h}{f_0}$ $\beta = \frac{h}{f_e}$
- $m = \frac{h}{f_e} \frac{f_0}{h}$
- $m = \frac{f_0}{f_e}$

Length of the telescope : $L = f_0 + f_e$

---

16. Mention different parts of spectrometer and explain the preliminary adjustments.

Spectrometer :

- It is an optical instrument used to analyse the spectra of different sources of light.
- To measure the wavelength of different colours .
- To measure the refractive indices of materials of prisms.

Parts of spectrometer :

1. Collimator 2. Prism Table 3. Telescope

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1.**Collimator :**

1. To produce parallel beam of light .
2. It is rigidly fixed to the base.
3. It has a convex lens and vertical slit.

2. Prism Table :

1. Used for mounting the prism , grating .
2. It consists of two circular discs with three levelling screws.
3. The position can be read from two verniers V_1 and V_2.
4. It can be fixed at any desired height.

3. Telescope :

1. It is an astronomical type.
2. It consists of an eye piece provide with cross wire.
3. And consists of objective at other end.
4. It is attached to a circular scale.

Preliminary adjustments of spectrometer

1.**Adjustment of the eyepiece :**

The eyepiece is moved to and fro until the cross wire are clearly seen.

2.**Adjustment of the telescope :**

The telescope is adjusted to receive parallel rays by focusing it to a distant object to get a clear image on the cross wire.

3.**Adjustment of the collimator :**

The collimator is adjusted until a clear image of the slit is seen at the cross wire.

4. **Levelling of the prism table :**

By adjusting the levelling screws and is ensured by using sprit level.

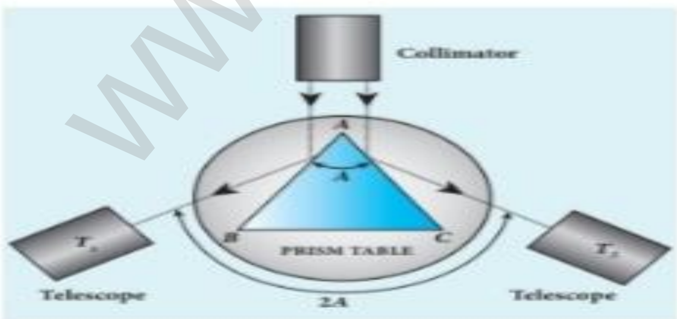
---

17. Explain the experiment determination of refractive index of the material of the prism using spectrometer.

Refractive index of material :

It can be determined by measuring the angle of the prism A and the angle of minimum deviation D.

1. Angle of the prism A :



Angle of prism

1. The prism is placed on the prism table with its refracting angle A facing the collimator.
2. The slit is illuminated by sodium light (Monochromatic light).
3. The parallel rays coming from the collimator fall on the two faces AB and AC and get reflected.

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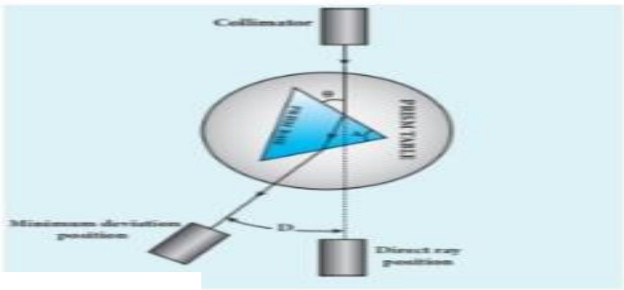
4. Telescope is rotated to the position T_1 and T_2 to capture the reflected rays and the two readings are noted.
5. The difference between these two readings gives rotated by the telescope.
6. It is twice the angle of the prism and half of this value gives the angle of prism.

2. Angle of minimum deviation D :



Angle of minimum deviation

1. The prism is placed on the prism table so that the light from the collimator falls on a refracting and the refracted image is observed through telescope.
2. The prism table alone is now rotated so that the angle of deviation decreases.
3. A stage comes when the image stops and returns on further rotation of the prism table.
4. This is ensured by looking through the telescope simultaneously.
5. The reading in this position gives the minimum deviation position.
6. The prism is removed and the telescope is turned to receive direct ray and the reading is noted.
7. The difference between two readings gives the angle of minimum deviation D .

Refractive Index of the prism :

$$n = \frac{\sin \frac{A + D}{2}}{\sin \frac{A}{2}}$$

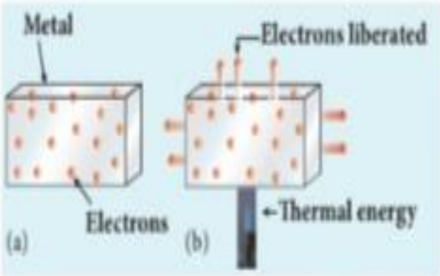
LESSON 8

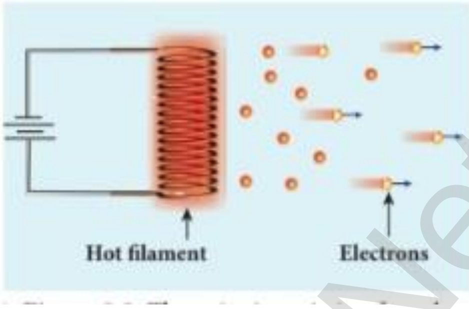
1. What do you mean by electron emission ? Explain briefly various methods of electron emission.

Electron Emission : The liberation of electrons from any surface of substance .

1. Thermionic Emission :

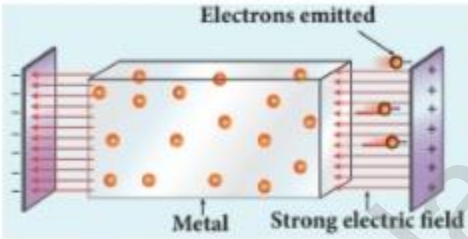
1. When a metal is heated to high temperature free electrons get sufficient energy.
2. After getting thermal energy , free electrons emitted from the metallic surface.
   - Example : Cathode ray tube , X ray tube.





2. Field Emission :

1. When a strong electric field is applied across the metal pulls the free electron.
2. Free electrons over come the surface barrier of the metal.
   - Example : Field emission display.



3.Photo Electric Emission :

1. When an em radiation of suitable frequency incident on metal surface.
2. After getting sufficient energy , free electrons emitted from the metallic surface.
   - Example : Photo Diodes , Photo Electric cells.

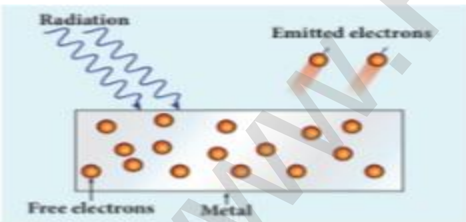


Figure 8.4 Photo electric emission

4. Secondary Emission :

1. When a beam of fast moving electrons strikes on metal surface.
2. After getting sufficient energy , secondary emission of electrons occurs.
   - Example : Photo multiplier tube.

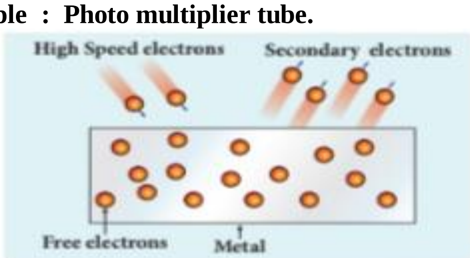


Figure 8.5 Secondary emission of electrons

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2. Briefly discuss the observations of Hertz , Hallwachs and Lenard.

1. Hertz observation :

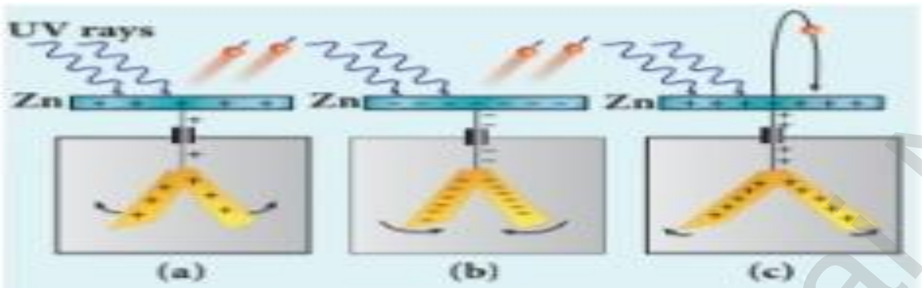
1. Hertz generated and detected electromagnetic wave.
2. High voltage applied between two metallic sphere.
3. Tiny spark produced and cant observed .
4. It was exposed to uv light and noticed by detector.
5. Electrons on the outer surface are emitted.

2. Hallwachs Observation :

Hallwachs confirmed that strange behaviour of spark due to uv light.

a) Uncharged Zinc plate :

Irradiated by uv light from an arc lamp it becomes positively charged and leaves will open.



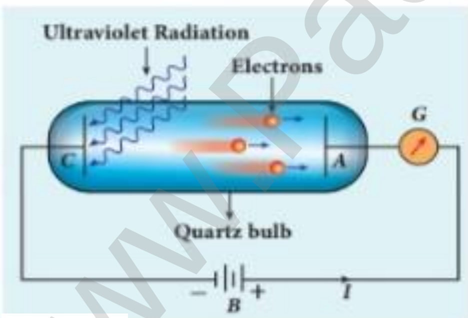
b) Negatively charged Zinc plate :

Irradiated by uv light from an arc lamp , the leaves come closer as the charges leaked away quickly.

c) Positively charged Zinc plate :

Zinc plate becomes more positive upon uv rays and leaves will open further.

3. Lenard's' Observation :



Experimental setup of Lenard

1. Lenard studied the electron emission phenomenon.
2. Consists of two metallic plates A and C .
3. They are placed in an evacuated quartz bulb.
4. Galvanometer and battery are connected.
5. When uv light is incident on plate C , current flows in the circuit.
6. If the positive plate is irradiated by uv light , no current is observed in the circuit.

From these observation :

1. When uv light falls on the negative plate , electrons are ejected from it which are attracted by positive plate A.
2. On reaching the positive plate through the evacuated bulb , the circuit is completed and the current flows in it.
3. The uv light falling on the negative plate causes the electron emission from the surface of the plate.

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3. Explain the effect of potential difference on photoelectric current.

Experiment :

To study the effect of potential difference

1. Frequency and intensity of incident light are kept constant.
2. Initially potential A is kept positive w.r.t C .

Saturation Current :

1. If the potential of A is increased , photo current also increases.
2. At one stage photocurrent reaches saturation current.
3. Photo electrons from C collected by A.

Retarding Potential :

1. If negative potential is applied to A w.r.t C.
2. Current does not immediately drop to zero.
3. Photo electrons emitted with different K.E.

Gradually increasing negative potential :

1. Photo current starts to decrease.
2. At one stage photocurrent becomes zero.
3. At particular negative potential V_0.

Stopping potential :

1. Value of negative potential given to collecting electrode A.
2. It is sufficient to stop most energetic photo electrons emitted.
3. And make the photo current zero.
4. It is known as " stopping / cut – off potential "

Graph :

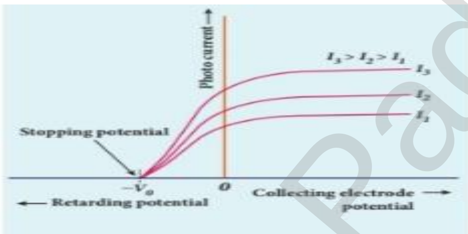

Figure 8.10 Variation of photocurrent with potential difference

Kinetic Energy :

$$K_{max} = \frac{1}{2} m v^2_{max} = e V_0$$

$$v^2_{max} = \frac{2 e V_0}{m}$$

$$v_{max} = \sqrt{\frac{2 e V_0}{m}} = \sqrt{\frac{2 \times 1.602 \times 10^{-19} \times V_0}{9.1 \times 10^{-31}}}$$

$$v_{max} = 5.93 \times 10^5 \sqrt{V_0}$$

$$K_{max} = e V_0 \text{ (in joule)}$$

$$K_{max} = V_0 \text{ (in eV)}$$

1.The intensity of the incident light is increased , saturation current also increases but V_0 remains constant.
2. For a given frequency of the incident light , stopping potential is independent of intensity of incident light.
3. Maximum K.E of the photoelectrons is independent of intensity of the incident light.

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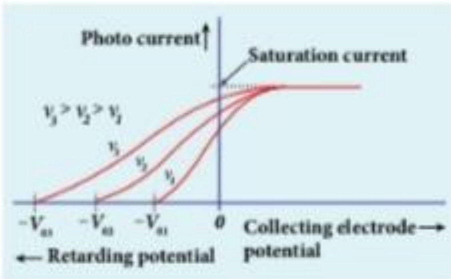
4. Explain how frequency of incident light varies with stopping potential.

Theory :

To study the effect of frequency

1. Intensity of incident light are kept constant.
2. Photocurrent vary with potential.
3. Stopping potential vary with frequency.
4. Greater frequency , larger stopping potential.
5. If frequency increased , K.E of photo electrons increased.
6. Retarding potential needed to stop the photo electrons.

Variation of photo current with potential for different frequency:



Threshold Frequency :

1. Below certain frequency , no electrons emitted.
2. Hence , stopping potential is zero.
3. Frequency increases above threshold frequency ,
4. Stopping potential varies linearly with frequency.

Variation of Stopping potential with frequency for two metals:

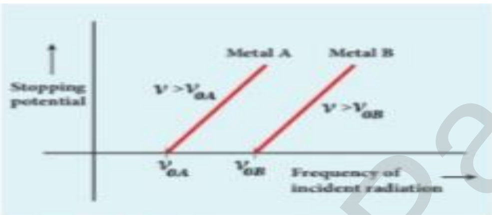


Figure 8.12 Variation of stopping potential with frequency of the incident radiation for two metals

---

5. List out the laws of photo electric effect . (or) 9. Explain experimentally observed facts of photo electric effect with the help of Einstein's explanation.

1. The emission of photo electrons takes place only if the frequency of incident light is greater than a certain minimum frequency is called " Threshold frequency "
2. Number of photo electrons is proportional to intensity of incident light.
3. Saturation current is directly proportional to intensity of incident light.
4. Maximum K. E is directly proportional to frequency of incident light.
5. Maximum K. E is independent of intensity of incident light.
6. There is no time lag between incidence of light and ejection of photo electrons.

---

6. Explain why photoelectric effect cannot be explained on the basis of wave nature of light.

1. Greater the intensity of incident light , Greater the kinetic energy of liberated electrons. But experiment shows that max K.E of photo electrons does not depend on intensity of incident light.
2. If sufficient intense beam of light incident on the surface , electrons liberated from target however low frequency of radiation. It is not possible below certain minimum frequency of incident radiation (Threshold frequency).
3. Each electrons need some time to get energy sufficient to overcome the work function.
4. Photo electric emission is almost instantaneous process. The time lag is less than 10^{-9} s after the surface is illuminated.

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7. Explain the quantum concept of light.

$$E_n = n h \gamma$$

1. Max Planck proposed quantum concept to explain thermal radiation emitted by black body shape of radiation curves.

2. Matter is composed of large number of oscillating particles which vibrate with different frequency.

3. Each atomic oscillator which vibrates with its characteristics frequency emits or em radiation of same frequency.

4. If an oscillator vibrates with frequency its energy have only certain discrete values.

5. The oscillator emit or absorb energy in small packet or quanta and energy of each quanta is $h\gamma$ .This implies that energy of oscillator is quantized so energy is not continuous one. This is called as " quantization of energy ".

8.Obtain Einstein photo electric equation with necessary explanation.

Photo Electric Effect :

The ejection of electrons from a metal surface when illuminated by light or with em radiation of suitable wavelength is called " Photoelectric effect "

Photo electric equation :

$$h\gamma = h\gamma_0 + \frac{1}{2} m v^2$$

Theory

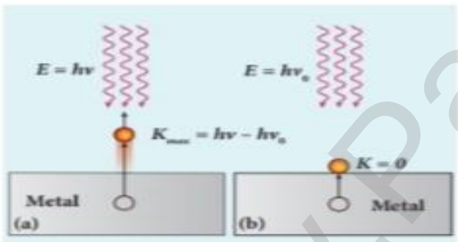
1. When photon of energy $h\gamma$ is incident on a metal surface , it is completely absorbed by single electron is ejected .

2. In this process ,

i) Part of energy is used in overcoming the potential barrier of metal surface. Photo electric work function Φ_0.
ii) Remaining energy as kinetic energy of the ejected electron.

$$\text{Kinetic Energy} = \frac{1}{2} m v^2$$

Emission of photo electron :



3. From law of conservation of energy : $h\gamma = \Phi_0 + \frac{1}{2} m v^2$

- m ⟶ mass of the electron
- v ⟶ velocity of the electron

4. If reduce the frequency of incident light , K.E of photo electrons also reduced. The photo electrons emitted with zero K.E at frequency γ_0 . γ_0 is Threshold frequency. $h\gamma_0 = \Phi_0$

5. **Photo electric equation :**

$$h\gamma = h\gamma_0 + \frac{1}{2} m v^2$$

6. **Maximum kinetic energy :**

$$K_{max} = \frac{1}{2} m v^2_{max}$$

$$h\gamma = h\gamma_0 + \frac{1}{2} m v^2$$

$$h\gamma = \Phi_0 + K_{max}$$

$$K_{max} = h\gamma - \Phi_0$$

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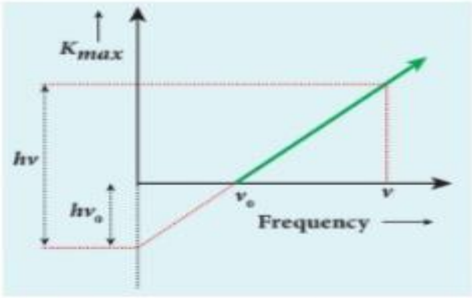
7. K_{max} vs v graph :

A graph between maximum kinetic energy K_{max} of photo electron , frequency γ of the incident light is straight line.



K_{max} vs ν graph

---

10. Give the construction and working of photo emissive cell.

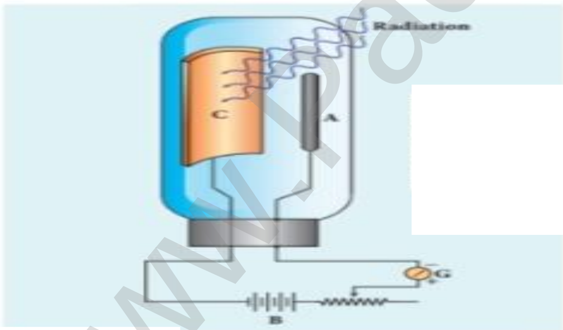
Construction :

1. Consists of an evacuated glass or quartz bulb.
2. Two metallic electrodes are cathode and anode.
3. Cathode (C) is semi cylindrical shape.
4. It is coated with photo sensitive material.
5. Anode (A) is a thin rod or wire.
6. Potential difference applied between A and C through galvanometer.

Working :

1. Cathode is irradiated with suitable radiation.
2. The electrons are emitted from it.
3. These electrons are attracted by anode.
4. Hence , the current is produced.
5. It is measured by the galvanometer.

Photo cell



Construction of photo cell

Magnitude of current depends on

1. Intensity of incident radiation.
2. Potential difference between anode and cathode.

Applications of photo cells :

1. Used as switches and sensors.
2. Used to measure intensity of light.
3. Used for reproduction of sound in motion pictures.
4. Used in automatic lights turn on when it gets dark.
5. Used in street lights switch on and switch off according to night or day.
6. Used as timers to measure the speeds of athletes during a race.

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11. Derive an expression for de Broglie wavelength of electrons.

1. According to de Broglie hypothesis , All material particles like electrons , protons and neutrons in motion associated with waves. These waves are called as " de Broglie waves " or " matter waves " .

2. Momentum of photon : $p = \frac{h\gamma}{c} = \frac{h}{\lambda}$

3. de Broglie wavelength : $\lambda = \frac{h}{mv} = \frac{h}{p}$

4. Kinetic Energy = Potential Difference

$$\frac{1}{2} m v^2 = e V$$

$$v = \sqrt{\frac{2 e V}{m}}$$

m ⟶ mass of the electron
V ⟶ Potential difference .

5. $$\lambda = \frac{h}{m v} = \frac{h}{m\sqrt{\frac{2 e V}{m}}} = \frac{h}{\sqrt{2 e m V}}$$

6. $$\lambda = \frac{6.626 \times 10^{-34}}{\sqrt{2 V \times 1.6 \times 10^{-19} \times 9.11 \times 10^{-31}}}$$

7. $$\lambda = \frac{12.27 \times 10^{-10}}{\sqrt{V}} = \frac{12.27}{\sqrt{V}} A^0$$

8. $$\lambda = \frac{h}{\sqrt{2 e m V}} = \frac{h}{\sqrt{2 m K}}$$

---

12. Briefly explain the principle and working of electron microscope.

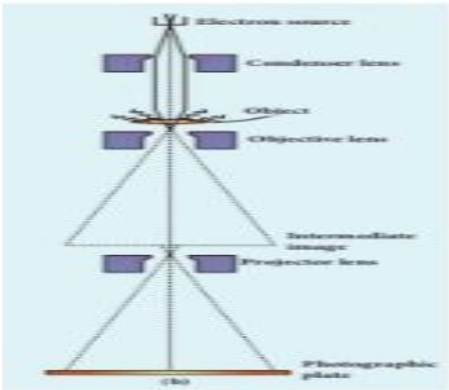
Principle :
1. This is direct application of wave nature of particle.
2. Wave nature of electron is used in electron microscope.

* **Resolving Power**
1. It is inversely proportional to the wavelength of the radiation.
2. Higher magnification and resolving power obtain for shorter wavelength.

* **Wave length**
1. Louis de Broglie wave length of electron is very much less than that of the visible light used in optical microscope.
2. Louis de Broglie wave length of electron is very much higher resolving power than optical microscope.

* **Magnification**
Electron microscope giving magnification more than 2,00,000 times are common in research laboratories.

Diagram :



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Working :

1. Working of an electron microscope is similar to an optical microscope .
2. It focus the electron beam is done by electrostatic or magnetic lens.
3. It is passed through electric or magnetic fields undergoes divergence or convergence.
4. The electrons emitted from source is accelerated by high potential.
5. The beam is made parallel by magnetic condenser lens.
6. When the beam passes through the sample whose needed magnified image is needed.
7. Magnified image is obtained on the screen by using magnetic objective lens and magnetic projector lens.
8. These electron microscopes are used in all branches of science .

---

13. Describe briefly Davisson - Germer experiment which demonstrated the wave nature of electrons.

Davisson - Germer Experiment :

1. de Broglie hypothesis of matter waves was experimentally confirmed
2. Davisson – Germer demonstrated that electron beams are diffracted when they fall on crystalline solids.
3. Crystal acts as 3 – D diffraction grating.
4. Electron waves incident on the crystal.
5. It diffracted off in certain specific directions.

Working :

1. The electrons scattered by Ni atoms in different directions.
2. They are received by electron detector .
3. I t measures the intensity of scattered electron beam.
4. The detector is capable of rotation.
5. The angle between incident beam and the scattered beam be changed.
6. The intensity of scattered electron beam is measured as the function of angle ϴ.

Variation of intensity of diffracted electron beam with angle ϴ

1. For the accelerating voltage of 54 V scattered wave shows peak or maximum at an angle 50^0 .
2. From the known value of interplanar spacing of nickel , the wavelength of the electron wave was experimentally calculated as 1.65 A^0 .

Apparatus for the experiment :

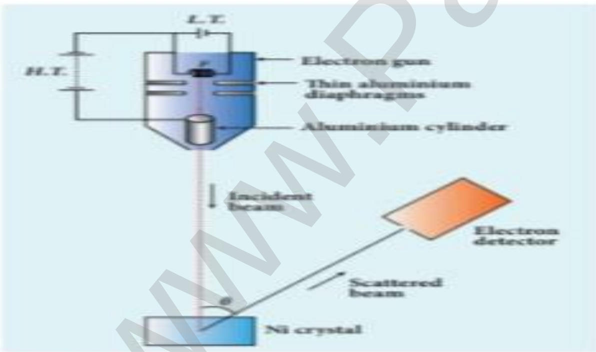

Figure 8.17 Experimental set up of Davisson – Germer experiment

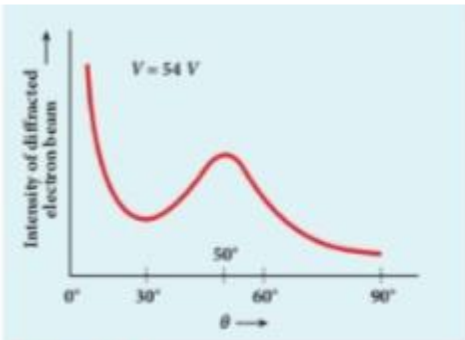

Figure 8.18 Variation of intensity of diffracted electron beam with the angle θ

3. de Broglie wavelength

$$\lambda = \frac{12.27}{\sqrt{V}} A^0 = \frac{12.27}{\sqrt{54}} A^0 = 1.67 \; A^0$$

4. This value agrees with the experimentally observed wavelength of 1.65 A^0 .

5. Thus this experiment directly verifies de Broglie's hypothesis of the nature of moving particles.

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14 . List out the characteristics of photons.

1. The photons of light of frequency γ and wavelength λ will have energy : $E = h\gamma = \frac{hc}{\lambda}$

2. The photons travel with speed of light and its momentum. $p = \frac{h}{\lambda} = \frac{h\gamma}{c}$

3. Photos are electrically neutral they are unaffected by electric and magnetic fields.
4. The energy of a photon is determined by the frequency of the radiation not by intensity. Intensity has no relation with energy of photon.
5. When a photon interacts with matter , the total energy , total linear momentum and angular momentum are conserved. Number of photons may not be conserved.

---

15. Give the applications of photo cells.

1. Used as switches and sensors.
2. Used to measure intensity of light.
3. Used for reproduction of sound in motion pictures.
4. Used in automatic lights turn on when it gets dark.
5. Used in street lights switch on and switch off according to night or day.
6. Used as timers to measure the speeds of athletes during a race.

---

16. How do we obtain characteristics X – ray spectra?

X – ray spectra :

- X - rays are produced when fast moving electrons strike the metal target.
- The intensity of X – rays when plotted against its wavelength gives a curve .
- It is called as " X – ray spectra "

Characteristics X – ray spectra :

X - ray spectra show some well - defined wavelength when the target is hit by fast electrons. The spectrum showing these peaks is called " characteristics X – ray spectrum". This X – ray spectrum is due to the electronic transition within the atoms.

Process :

1. When an energetic electron penetrates into the target atom.
2. It can remove some of K – shells electron.
3. Electrons from outer orbits jump to fill up the vacancy in K – shell.
4. During the downward transition , the energy difference between the levels.
5. Such wavelength , Characteristics of the target , constitute line spectrum.

K – series :

K- series of lines in the X – ray spectrum due to electronic transitions from L , M , N levels to K – levels.

L – series :

L – series originates when an L – electron is knocked out the atom and the vacancy is filled by electronic transitions from M , N , O to the L - level and so on.

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17. Write the applications of X – ray.

1. Medical Diagnosis :

- It pass through flesh more easily than bones.
- It contain deep shadow of bone .
- It contain light shadow of flesh.
- Used to detect fracture , diseased organ.

2.Medical Therapy :

- Used to kill diseased tissue.
- Used to cure skin disease.
- Used to cure malignant tumour.

3. Industry :

- Used to check the flaws in welded joints, motor tyre , tennis ball.
- Used to detect contraband goods .

4. Scientific Research :

- Used to study structure of crystalline structure.
- Used to study arrangement of atoms and molecules in crystal.

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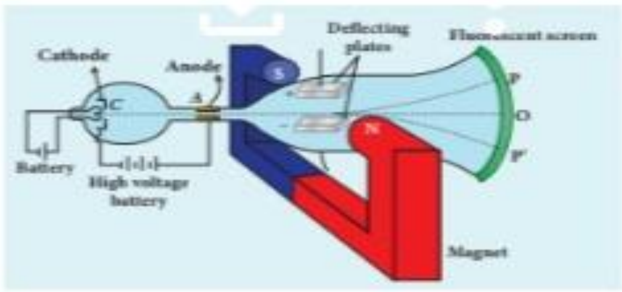
LESSON 9

1. Explain the J.J . Thomson experiment to determine the specific charge of electron.

Diagram :



Principle : In the presence of electric and magnetic fields , the cathode rays were deflected.

Determination : Specific charge (charge per unit mass) of the cathode rays is measured.

Arrangement :

1. A highly evacuated discharge tube is used
2. Cathode rays produced at cathode.
3. Anode disc provided with pin hole.
4. Parallel metal plates at high voltage.
5. Gas discharge tube kept between magnet pole.
6. Both electric & magnetic fields are acts perpendicular to each other.
7. When the cathode rays strike the screen , they produce scintillation & bright spot is observed.
8. This is achieved by coating the screen by zinc sulphide.

i) Velocity of cathode rays :

- Electric field = Magnetic field
- $eE = eBv$

$$v = \frac{E}{B}$$

ii) Specific Charge :

- Potential Energy = Kinetic Energy
- $eV = \frac{1}{2} m v^2$
- $\frac{e}{m} = \frac{v^2}{2V}$
- $\frac{e}{m} = \frac{1}{2V} \frac{E^2}{B^2}$
- $\frac{e}{m} = 1.7 \times 10^{11} \ \text{kg}^{-1}$

---

2. Discuss the Millikan's oil drop experiment to determine the charge of an electron.

Principle :

By adjusting electric field suitably , the motion of oil drop inside the chamber can be controlled.

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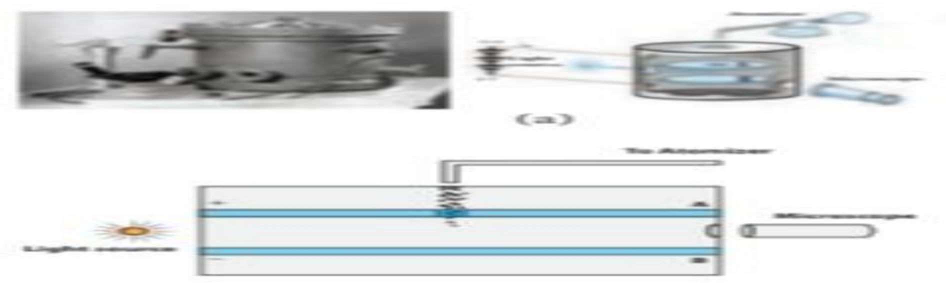
Experimental Arrangement :



Construction :

1. Consists of two horizontal circular metal plates A and B.
2. Each with diameter 20 cm are separated by a small distance 1.5 cm.
3. These two parallel plates are enclosed in a chamber with glass walls.
4. Plates A and B are maintained at high potential difference.
5. Such that the electric field acts downward.
6. A small hole in the upper plate.
7. Atomizer is used to spray the liquid.
8. Highly non volatile liquid (Glycerine) is sprayed.

Free Body Diagram :

Forces acts on oil droplet :

1. Gravitational force $F_g = m g$
2. Electric force $F_e = q E$
3. Buoyant force F_b
4. Viscous force F_v

a) Determination of radius of droplet

i) Without Electric field

1. Density of the oil drop : $\rho = m / v$

2. Volume of the oil drop : $V = \frac{4}{3} \pi r^3$

3. Mass of the oil drop : $m = \frac{4}{3} \pi r^3 \rho$

4. Gravitational force : $F_g = \frac{4}{3} \pi r^3 \rho g$

5. Upthrust force : $F_b = \frac{4}{3} \pi r^3 \sigma g$

6. Viscous force : $F_v = 6 \pi r v \eta$

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Force balancing equation :

$$F_g = F_b + F_v$$

$$\frac{4}{3}\pi r^3 \rho g = \frac{4}{3}\pi r^3 \sigma g + 6\pi r v \eta$$

$$\frac{4}{3}\pi r^3 \rho g - \frac{4}{3}\pi r^3 \sigma g = 6\pi r v \eta$$

$$\frac{4}{3}\pi r^3 (\rho - g) g = 6\pi r v \eta$$

$$\frac{2}{3} r^2 (\rho - \sigma) g = 3 v \eta$$

$$r^2 = \frac{9 v \eta}{2(\rho - \sigma) g}$$

$$\boxed{r = \left(\frac{9 v \eta}{2(\rho - \sigma) g}\right)^{1/2}}$$

b) Determination of electric charge with electric field

$$F_e + F_b = F_g$$

$$q E + \frac{4}{3}\pi r^3 \sigma g = \frac{4}{3}\pi r^3 \rho g$$

$$q E = \frac{4}{3}\pi r^3 \rho g - \frac{4}{3}\pi r^3 \sigma g$$

$$q E = \frac{4}{3}\pi r^3 (\rho - \sigma) g$$

$$q E = \frac{4}{3}\pi r r^2 (\rho - \sigma) g$$

$$q = \frac{4\pi}{3E}\left(\frac{9 v \eta}{2(\rho - \sigma) g}\right)^{1/2}\left(\frac{9 v \eta}{2(\rho - \sigma) g}\right)(\rho - \sigma) g$$

$$q = \frac{18\pi}{E}\left(\frac{\eta^3 v^3}{2(\rho - \sigma) g}\right)^{1/2}$$

Value of q is -1.6×10^{-19} C

3.Derive the energy expression for an electron is the hydrogen atom using Bohr atom model.

Potential energy of the n^{th} orbit is

$$U_n = \frac{1}{4\pi\epsilon_0}\frac{(+Ze)(-e)}{r_n}$$

$$U_n = \frac{-1}{4\pi\epsilon_0}\frac{Ze^2}{r_n}$$

$$r_n = \frac{\epsilon_0 h^2}{\pi m e^2}\frac{n^2}{Z}$$

$$U_n = \frac{-1}{4\pi\epsilon_0}\frac{Ze^2}{\epsilon_0 h^2 n^2} \times \pi m e^2 Z$$

$$U_n = -\frac{1}{4\epsilon_0^2}\frac{Z^2 m e^4}{h^2 n^2}$$

Kinetic energy of e^- in n^{th} orbit

$$K.E = \frac{1}{2} m v_n^2$$

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Angular momentum : $m v_n r_n = l_n = \frac{nh}{2\pi}$

$$v_n = \frac{1}{m r_n} \frac{nh}{2\pi}$$

$$v_n = \frac{\pi m e^2 Z}{m \epsilon_0 h^2 n^2} \frac{nh}{2\pi}$$

$$v_n = \frac{Z e^2}{2 \epsilon_0 h n}$$

Sub v_n value in kinetic energy eqn

$$K.E_n = \frac{1}{2} m \left(\frac{Z e^2}{2 \epsilon_0 h n} \right)^2$$

$$\boxed{K.E_n = \frac{m e^4 Z^2}{8 \epsilon_0^2 h^2 n^2}}$$

Total Energy :

$$E_n = K.E_n + U_n$$

$$E_n = K.E_n - 2 K.E_n \quad (U_n = - 2 K.E_n)$$

$$E_n = - K.E_n$$

$$E_n = \frac{- m e^4 Z^2}{8 \epsilon_0^2 h^2 n^2}$$

For hydrogen atom Z = 1

$$\boxed{E_n = \frac{- m e^4}{8 \epsilon_0^2 h^2 n^2} \text{ joules}}$$

$$E_n = 13.6 \frac{1}{n^2} \text{ eV}$$

- For the first orbit (Ground state) E_1 = -13.6 e V
- For the second orbit (First excited state) E_2 = - 3.4 e V
- For the third orbit (second excited state) E_3 = - 1.51 e V

4.Discuss the spectral series of hydrogen atom.

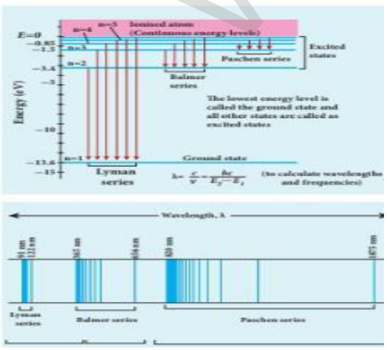
Wavelength of spectral lines

$$\boxed{\frac{1}{m^2} = R \left(\frac{1}{\lambda} - \frac{1}{n^2} \right) = \bar{\gamma}}$$

$\bar{\gamma}$ ⟶ **Wave number (Inverse of wavelength)**

R ⟶ **Rydberg constant 1.09737 X 10^7 m^{-1}**

Spectral series of hydrogen atom



n	m	Series Name	Region
1	2,3,4.....	Lyman	Ultraviolet
2	3,4,5.....	Balmer	Visible
3	4,5,6.....	Paschen	Infrared
4	5,6,7......	Brackett	Infrared
5	6,7,8.....	Pfund	Infrared

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1. Lyman series

- For n = 1 and m = 2, 3, 4
- It lies in ultra violet region.
- Wave number or wavelength

$$\bar{\gamma} = \frac{1}{\lambda} = R \left(\frac{1}{1^2} - \frac{1}{m^2} \right)$$

2. Balmer series

- For n = 2 and m = 3, 4 ,5
- It lies in visible region.
- Wave number or wavelength

$$\bar{\gamma} = \frac{1}{\lambda} = R \left(\frac{1}{2^2} - \frac{1}{m^2} \right)$$

3. Paschen series

- For n = 3 and m = 4 , 5 , 6
- It lies in infra red region.
- Wave number or wavelength

$$\bar{\gamma} = \frac{1}{\lambda} = R \left(\frac{1}{3^2} - \frac{1}{m^2} \right)$$

4. Bracket series

- For n = 4 and m = 5, 6, 7
- It lies infra red region.
- Wave number or wavelength

$$\bar{\gamma} = \frac{1}{\lambda} = R \left(\frac{1}{4^2} - \frac{1}{m^2} \right)$$

5. Pfund series

- For n = 5 and m = 6, 7, 8
- It lies in infra red region.
- Wave number or wavelength

$$\bar{\gamma} = \frac{1}{\lambda} = R \left(\frac{1}{5^2} - \frac{1}{m^2} \right)$$

---

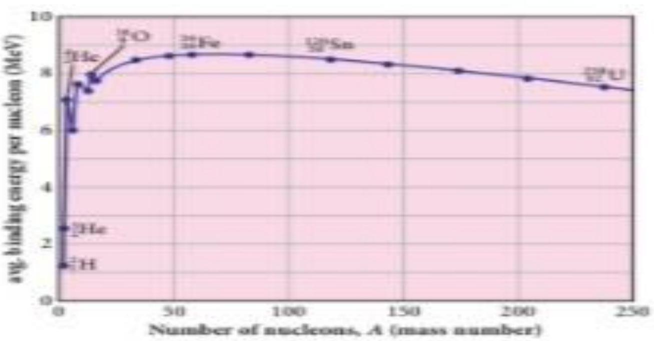
5. Explain the variation of average binding energy with the mass number using graph and discuss about its feature.

Average binding energy per nucleon

The average binding energy per nucleon is the energy required to separate single nucleon from the particular nucleus.

$$\overline{BE} = \frac{[\, Z\, m_H + N\, m_n - M_A \,]\, c^2}{A}$$

BE Curve



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Important Features:

1. BE rises as mass number increases , until it reaches maximum value of 8.8 M e V for A = 56 and then it slowly decreases.

2. BE value is about 8.5 M e V for nuclei having mass number lying between A = 40 and 120 . These elements are comparatively more stable and not radioactive.

3. For higher mass numbers , the curve drops slowly and BE for uranium is about 7.6 M e V . Such nuclei are unstable and exhibit radioactive.

- If two light nuclei with A < 28 combine with nucleus A < 56
- BE per nucleon is more final nucleus than initial nucleus.
- Large amount of energy released.
- It is the basis of nuclear fusion.
- It is the principle of hydrogen atom.

4. If a nucleus of heavy element is split into two or more nuclei of medium value A , energy released would be large.

- Atom bomb is based on this principle.
- Huge energy comes from this fission when it is controlled.

---

6. Explain the detail in nuclear force.

Nuclear Force :

- Nucleus of the atoms contains protons and neutrons.
- They are separated by a distance of about few fermi (10^{-15} m) .
- They must exert on each other very strong repulsive force.

Electrostatic repulsive force :

$$F = K \times \frac{q^2}{r^2}$$

$$F = 9 \times 10^9 \times \frac{(1.6 \times 10^{-19})^2}{(10^{-15})^2} = 230 \text{ N}$$

Acceleration experienced by proton

$$a = \frac{F}{m} = \frac{230 \text{ N}}{1.67 \times 10^{-27}} = 1.4 \times 10^{29} \text{ ms}^{-2}$$

1. Nearly 10^{28} times greater than acceleration due to gravity.
2. If the protons in the nucleus experience only the electrostatic force, then nucleus fly apart in an instant.
3. There must be a strong attractive force between protons to overcome the repulsive coulombic force.
4. This attractive force which holds the nucleons is called strong nuclear force.

Properties of Nuclear force :

1. **Nuclear force is of very short range.**

   1. Repulsive coulomb force or attractive force between two protons are weaker than nuclear force.
   2. Nuclear force is the strongest force.

2. **Nuclear force is attractive one.**

   1. Equal strength between proton – proton , proton – neutron , neutron – neutron.
   2. Nuclear force does not act an the electrons.
   3. So , it does not alter the chemical properties of the atom.

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7. Discuss the alpha decay process with example.

Alpha Decay Process :

1. When an unstable nucleus decay by emitting an α - particle $^{4}He_{2}$ nucleus is known as " Alpha decay process "
2. It loses two protons and two neutrons .
3. Atomic number Z decreases by 2.
4. Mass number A decreases by 4.

$$^{A}X_{Z} \longrightarrow {}^{A-4}X_{Z-2} + {}^{4}He_{2}$$

X ⟶ Parent nucleus

Y ⟶ Daughter nucleus

5. Example : Decay of Uranium to Thorium with emission of α - particle.

$$^{238}U_{92} \qquad {}^{234}Th_{92} + {}^{4}He_{2}$$

6. Total mass of daughter nucleus and $^{4}He_{2}$ nucleus is always less than that of parent nucleus.

7. Difference in mass : $\Delta m = m_X - m_Y - m_\alpha$

8. Disintegration Energy : $Q = (m_X - m_Y - m_\alpha) c^2$

9. $Q > 0$, Spontaneous decay occur.

10. $Q < 0$, cannot spontaneous decay.

---

8. Discuss the beta decay process with examples.

Beta Decay :

1. A radioactive nucleus emits electron or positron.
2. The positron is an anti – particle of an electron.
3. Its mass is same as that of electron.
4. Its charge is opposite to that of electron.
5. Both positron and electron are referred to as beta particles.

β^- Decay :

1. If electron is emitted , it is called " β^- Decay "
2. Atomic number of nucleus increase by one but its mass number remains same.

Representation of β^- Decay

Element X becomes by Y by giving out an electron and an anti neutrino.

- $^{A}X_{Z} \longrightarrow {}^{A}Y_{Z+1} + e^- + \overline{\gamma}$
- $^{14}C_{6} \longrightarrow {}^{14}N_{7} + e^- + \overline{\gamma}$

B^+ Decay :

1. If positron is emitted , it is called " β^+ Decay "
2. Atomic number of nucleus decrease by one but its mass number remains same.

Representation of β^- Decay

Element X becomes by Y by giving out an positron and neutrino.

- $^{A}X_{Z} \longrightarrow {}^{A}Y_{Z-1} + e^+ + \gamma$
- $^{22}Na_{11} \longrightarrow {}^{22}N_{10} + e^+ + \gamma$

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9.Discuss the gamma emission process with example.

1. In α and β decay , the daughter nucleus is in the excited state most of the time.
2. Life time of excited state is 10^{-11} s.
3. Excited state nucleus return to ground state or lower energy state by emits highly energetic photons called " γ rays "
4. Atom is in excited state returns to ground state by emits photons of energy in the order of few e V.
5. If it emits highly energetic photon of energy in the order of M e V.

6. <u>Representation of gamma emission</u>

$${}^{A}X^{*}_{Z} \longrightarrow {}^{A}X_{Z} + \text{Gamma rays}$$

* asterisk means excited state nucleus.

. There is no change in the mass number or atomic number of nucleus.

<u>Example :</u>

Boron (${}^{12}B_{5}$) has two beta decay mode.

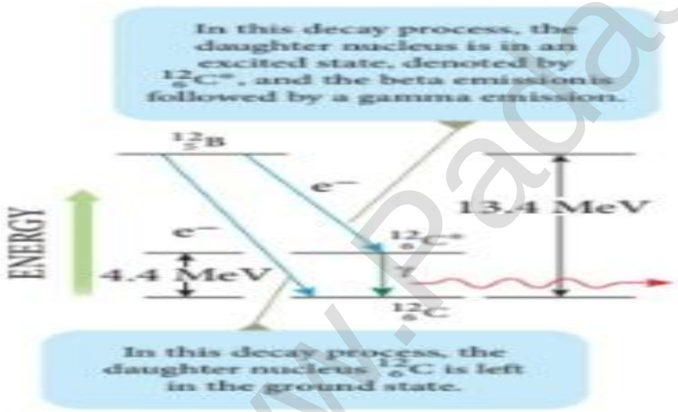
- ${}^{12}B_{5} \longrightarrow {}^{12}C_{6} + e^{-} + \bar{\gamma}$
- ${}^{12}C^{*}_{6} \longrightarrow {}^{12}C_{6} + \gamma$

<u>Explanation :</u>

1. It undergoes beta decay directly into ground state carbon (${}^{12}C_{6}$) by emitting an electron of maximum of energy.

2. It undergoes beta ray emission to an excited state of carbon (${}^{12}C^{*}_{6}$) by emitting an electron of maximum energy 9.0 M e V followed by gamma decay to ground state by emitting photon of energy 4.4 M e V.

<u>Gamma Emission :</u>



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10. Obtain the law of radioactivity.

1. Bulk material of radioactive sample which contains vast number radioactive nuclei.
2. Not all the radioactive nucleus in a sample decay at the same time.
3. It decays over a period of time and this decay is random process.
4. We can calculate approximately how many nuclei in sample are decayed over a period of time.
5. At any instant t , the number of decays per unit time called rate of decay (dN / dt) is proportional to the number of nuclei (N) at the same instant.

<u>Derivation :</u>

1. $\frac{dN}{dt} \propto N$

2. $\frac{dN}{dt} = -\lambda N$

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3. $\lambda \longrightarrow$ Decay constant

4. Negative sign implies that N decrease with time.

5. $\frac{dN}{N} = -\lambda\, dt$

6. $\int_{N_0}^{N} \frac{dN}{N} = -\lambda \int_{0}^{t} dt$

7. $[\ln N]_{N_0}^{N} = = -\lambda t$

8. $\frac{N}{N_0} = e^{-\lambda t}$

9. $N = N_0 \, e^{-\lambda t}$

10. This is called as " law of radioactive decay ".

11. Number of atoms decreases exponentially over the time .

12. Infinite time is needed for decay of all the atoms.

---

11. Discuss the properties of neutrino and role in beta decay.

Neutrino role in beta decay:

1. During beta decay , a neutrino in the parent nucleus is converted into the daughter nuclei by emitting only electron.

$$^{A}X_{Z} \longrightarrow \; ^{A}Y_{Z+1} + e^-$$

2. Kinetic energy of electron coming out of the nucleus did not match with the experimental results.
3. In alpha decay , the alpha particles takes only discrete energies but in beta decay the beta particles has continuous range of energies.
4. The conservation of energy and momentum gives single value of energy for electron and recoiling nucleus.
5. In 1931 , Pauli explained the particle emitted in beta decay process.
6. Fermi named this particle as " neutrino ".
7. In 1956 , neutrino was detected by Fredrick reins and clyde cowan.
8. In 1995 , Rein received Nobel prize for this discovery.

Properties of neutrino:

1. It has zero charge.
2. It has an anti particle called anti neutrino.
3. It has very small mass.
4. It interacts very weakly with the matter.
5. It is very difficult to detect it.
6. In every second, trillions of neutrinos coming from the sun are passing through our body without causing interaction.

---

12. Explain about carbon dating.

1. Application of beta decay is radioactive dating or carbon dating.
2. The age of an ancient object can be calculated.
3. All living organisms absorb CO_2 from air to synthesize organic molecules.
4. In absorbed CO_2 , major part contains $^{12}C_6$.
5. And contains very small fractions 1.3 X 10^{-12} contains radio active $^{14}C_6$.

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6. $^{14}C_6$ whose half life is 5730 years.
7. Carbon -14 in the atmosphere is always decaying.
8. Cosmic ray from outer space are bombarding the atoms in the atmosphere which produces $^{14}C_6$.
9.The continuous production and decay of $^{14}C_6$ in the atmosphere keep the ratio of $^{14}C_6$ to $^{12}C_6$ always constant.
10. Our human body , tree or any living organism continuously absorb Co_2 from the atmosphere , the ratio of $^{14}C_6$ to $^{12}C_6$ nearly constant.
11. When the organism does , it stops absorbing Co_2 .
12. Since $^{14}C_6$ starts to decay , the ratio of $^{14}C_6$ to $^{12}C_6$ in dead organism or specimen decreases over the years.
13. The ratio $^{14}C_6$ to $^{12}C_6$ in the ancient tree pieces excavated is known , then the age of the tree pieces can be calculated. Example : Keezhadi excavation

---

13. Discuss the process of nuclear fission and its properties.

1. The process of breaking up of the nucleus of a heavier atom into two smaller nuclei with the release of a large amount of energy is called " nuclear fission "

2. <u>Example :</u>

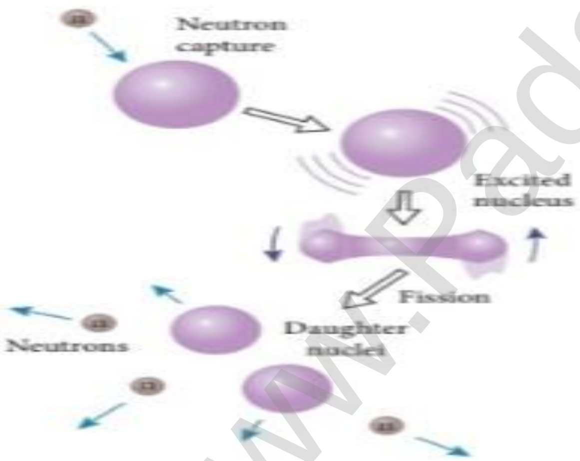
$$^{235}U_{92} + {}^{1}n_0 \longrightarrow {}^{235}U^*_{92} \longrightarrow {}^{141}Ba_{56} + {}^{92}Kr_{36} + 3\,{}^{1}n_0 + Q$$

$$^{235}U_{92} + {}^{1}n_0 \longrightarrow {}^{235}U^*_{92} \longrightarrow {}^{140}Xe_{54} + {}^{94}Sr_{38} + 2\,{}^{1}n_0 + Q$$

3. When a slow neutron is absorbed by the uranium nucleus , the mass number increases by one and goes to an excited state $^{235}U^*_{92}$.

4. Excited state does not last longer than 10^{-12} s.
5. It decay into two daughter nuclei along with the release of 2 or 3 neutrons.
6. In each reaction , on an average 2.5 neutrons are emitted.

<u>Diagram :</u>



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14. Discuss the process of nuclear fusion and how energy is generated in stars ?

1. When two or more light nuclei ($A < 20$) combine to form a heavier nucleus , then it is called " Nuclear fusion "
2. The mass of the resultant nucleus is less than sum of the masses of original light nuclei.
3.The mass difference appears as energy.
4. The nuclear fusion never occurs at room temperature unlike nuclear fission.
5.It is because when two light nuclei come closer to combine , strongly repelled by the coulomb repulsive force.
6. To over come repulsive force , two light nuclei must have enough K.E to move closer to each other.
7. Nuclear force becomes effective if the temperature greater than 10^7 K.
8. At 10^7 K lighter nuclei start fusing to form heavier nuclei is called thermo nuclear fusion reaction.

<u>Energy generation in stars :</u>

1. In most of the stars including our sun hydrogen atoms fuse into helium and helium fuse into heavier elements.

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2. The early stage of a star is in the form of cloud and dust.
3. Due to own gravitation pull , these clouds fall inward.
4. Gravitational potential energy is converted in to kinetic energy and finally into heat.
5. When the temperature is high enough to initiate the thermos nuclear fusion.
6. They start to release enormous energy which tends to stabilize the star and prevents it from further collapse.
7. Sun's interior temperature is around 1.5 X 10^7 K.
8.In sun ,6 X 10^{11} kg of hydrogen is converted into helium every second.
9. Sun has enough hydrogen such that these fusion reactions for 5 billion years.
10. When hydrogen burn out , sun enter into new phase called red gaint where helium fuse to become carbon.

According to Hans Bethe , the sun is powered by proton – proton cycle of fusion reaction.

$$^1H_1 + {}^1H_1 \rightarrow {}^2H_1 + e^+ + \gamma$$

$$^1H_1 + {}^2H_1 \rightarrow {}^3He_2 + \gamma$$

$$^3He_2 + {}^3He_2 \rightarrow {}^4He_2 + {}^1H_1 + {}^1H_1$$

Over all energy produced is about 27 M e V.

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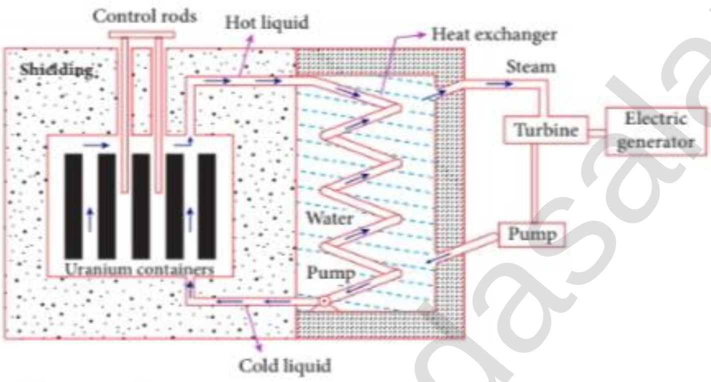
15. Describe the working of nuclear reactor with block diagram.

Block diagram of nuclear reactor :



Nuclear reactor:

1. It is a device in which the nuclear fission takes place.
2. It is self – sustained controlled manner.
3. The energy produced is used for research purpose.
4. It is used for power generation.
5. First nuclear reactor was built by Enrico Fermi in 1942.

Main parts of nuclear reactor:

1. Fuel :

1. It is fissionable material. Ex : Uranium , Plutonium
2. Uranium contains only 0.7 % of $^{235}U_{92}$ and 99.3 % are only $^{238}U_{92}$.
3. $^{238}U_{92}$ contains at least 2 % to 4 % of $^{235}U_{92}$.
4. Neutron source is need for chain reaction . Ex : Beryllium with plutonium.
5. During fission of $^{235}U_{92}$, fast neutrons are emitted.
6. Slow neutrons need for nuclear reactor.

2. Moderator :

1. Used to convert fast neutron into slow neutrons.
2. Light nuclei undergo collision with fast neutron and speed of neutron is reduced.
3. This is the reason for using light nuclei used as a moderator.
4. Example : Heavy water (D_2O) , Graphite.

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3. Control Rods:

1. They are used to adjust reaction rate.
2. During each fission 2.5 neutrons emitted
3. To have controlled chain reactions , only one neutron is allowed to cause fission .
4. Remaining neutrons absorbed by control
5. Example : Cadmium , Boron

4.Shielding

Nuclear reactor surrounded by concrete wall of thickness of about 2 to 2.5 m for protection against harmful radiation.

5. Coolin system :

1. It removes heat generator in reactor.
2. Ex: Ordinary waver, Heavy water and Liquid sodium.
3. Coolant have large boiling point under high pressure.
4. It carries away the heat to the steam generator through heat exchanger.
5. The steam runs the turbines which produces electricity in power reactor.

---

16. Explain in detail four fundamental forces in nature.

1. Gravitational Force:

1. We live on earth because of earth's gravitational attraction on our body.
2. Our planets are bound to the sun through gravitational force of sun.

Ex: Force b\w two masses.

2. Electromagnetic Force:

We are standing on the surface of earth because of electromagnetic force between atoms of surface of the earth and atoms in our foot.

Ex: Force b\w two charges.

3. Strong Force:

1. The atoms in our body are stable because of strong nuclear force.
2. Strong nuclear force exist b\w two nucleons.

Ex: Responsible for stability of nucleus.

4. Weak force:

1. The lives of species on earth depend on the solar energy form the sun and it is due to weak force.
2. It plays vital role during nuclear fusion reactions going on in the core of the sun.
3. It plays important role in beta decay and energy production in stars.
4. During the fusion of hydrogen into helium in sun , neutrons & enormous radiation produced through weak force.

---

17. Briefly explain the elementary particles present in nature.

Elementary Particles :

1. An atom has a nucleus surrounded by electrons and nucleus is made up of protons and neutrons.
2. Protons and neutrons and electrons are fundamental building blocks of matter.
3. Murray Gellman and George Zweig theoretically proposed that protons &neutrons are not fundamental particles.

Quarks:

1. They are made up of quarks.
2. These quarks are now considered elementary particles of nature.
3. In 1968, Quarks were discovered by Stanford Linear accelerator centre SLAC, USA.

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Types of quark:

There are six quarks namely up, down, charm, strange, top and bottom and their antiparticles. All these quarks have fractional charges.

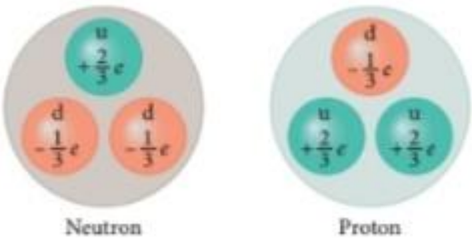
For Examples:

Charge of up quark $+\frac{2}{3}e$; Charge of down quark $-\frac{1}{3}e$

According to Quark model

Proton is made up of two up quarks and one down quark. Neutron is made up of one up quark and two down quarks.

Constituents of Nucleons:



The study of elementary particles is called particle physics. It is an active area of research even now more than 20 Nobel prizes awarded for particle physics.

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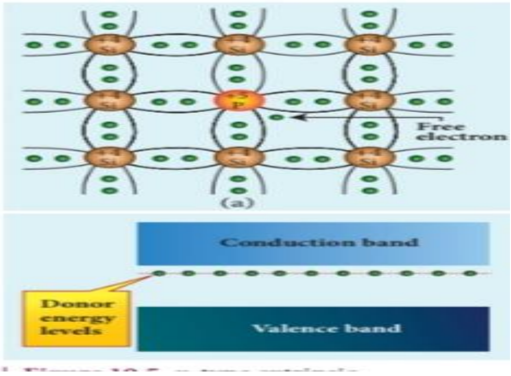
Lesson 10

1.Elucidate the formation of n-type extrinsic semiconductors.

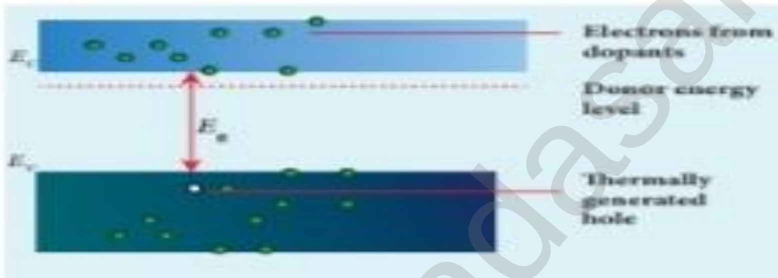
Diagram :



Formation of n- type extrinsic semiconductors:

1. By doping pure silicon crystal with pentavalent impurity atoms. Ex : phosphorus , arsenic , antimony
2.The dopant has five valence electron.
3.Silicon atom has four valence electrons.
4.Four of the five valence electron of the impurity atom form covalent bonds with four silicon atoms.

5.Fifth valence electron of the impurity atom is loosely attached with nucleus .
6.Fifth electron from the dopant is found just below the conduction band edge is called donor energy level.



7.At room temperature or by an external electric field loosely bound electrons lead to conduction.
8.Energy required for an electron to jump from valence band to conduction band.

- **0.7 e V for Ge** * **1.1 e V for Si**

9. Energy required to set free donor electron. * 0.01 e V for Ge * 0.05 e V for Si

10. The V group pentavalent impurity atom donates electrons to conduction band and are called " donor impurities "
11. Each impurity atom provides one extra electron to conduction band in addition to thermally generated electrons.
12. These thermally generated electrons leave holes in valence in valence band.
13. Majority Carrier : Electrons Minority Carrier : Holes

---

2. Explain the formation of depletion region and barrier potential in PN junction diode.

Diagram :

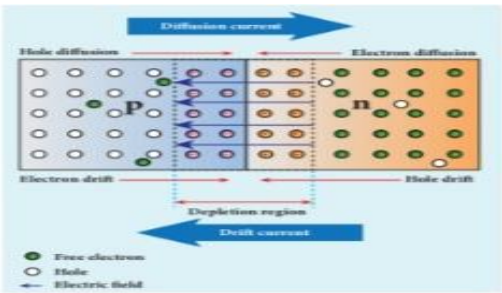


Figure 10.9 Formation of p–n junction

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Formation of depletion region:

1. P N Junction :

- Doped semiconductor one side is p – type.
- Doped semiconductor other side is n – type.
- The contact surface between two side is called " p – n junction "

2.Diffusion :

- Free electron diffuse from n- side to p- side.
- Holes diffuse from p – side to n- side.

3.Diffusion Current :

The diffusion of the majority charge carriers across the junction gives rise to an electric current

4. Positive ion :

When an electron leaves n – side , and pentavalent atom in the n- side becomes " positive ion ".

5. Negative ion :

When free electron migrating into p – side , and recombines with a hole then trivalent becomes " negative ion ".

6. Depletion Region :

Thin region near the junction which is free from charge carriers is called " depletion region" .

7.Electric field :

- An electric field is set up between n- side and p-side.
- This electric field makes electrons in the n-side inti p- side.

8.Drift Current :

The electric current produced due to the motion of minority charge carriers by the electric field is known as " Drift velocity "

9.Diffusion & Drift current :

- The diffusion current and drift current flow in opposite directions.
- Drift current is less than diffusion current .
- Diffusion of electron or hole increases electric field and increase drift current.

10. P n junction

At equilibrium , there is no electric current across the junction . Thus p-n junction is formed.

Junction potential & Barrier potential

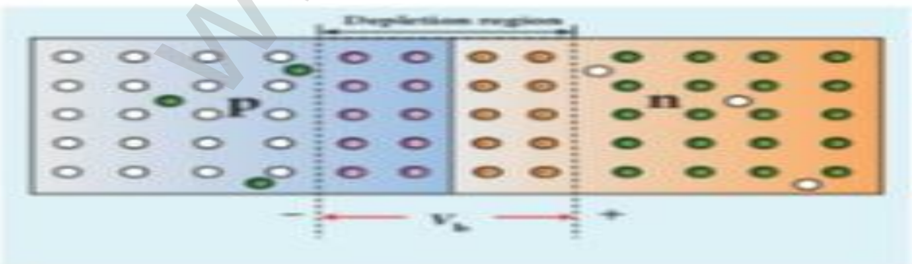

Figure 10.10 Barrier potential formed across the junction

1. Movement of charge carrier across the junction takes place only to certain point.
2. Beyond which depletion layer acts like barrier to further diffusion of free charges across the junction.
3. Immobile ions on both sides establish an electric potential difference across junction.

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4. Electron trying to diffuse into the interior of the depletion region encounters wall of negative ions repelling it backwards.
5. If the free electron has enough energy to break the wall and enter into p-region where it can recombine with hole and create another negative ion.
6. Increasing electric potential difference across depletion region to reach equilibrium.
7. Internal repulsion of depletion layer stops further diffusion of free electrons across the junction.
8. This difference is potential across the depletion layer is called " Barrier potential "
9. At 25^0 c this barrier potential is approximately 0.7 V for silicon , 0.3 V for germanium

---

3. Draw the circuit diagram of a half wave rectifier and explain its working.

Half wave rectifier circuit :

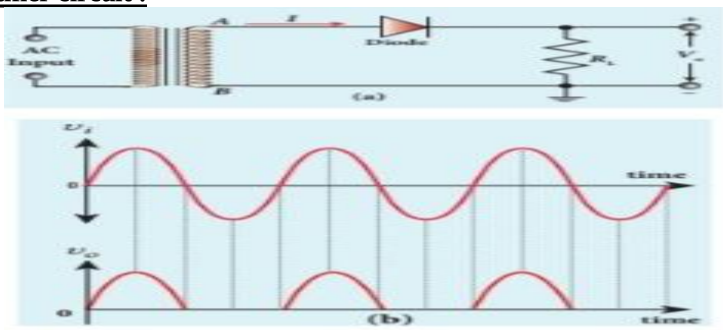

Figure 10.17 (a) Half wave rectifier circuit (b) Input and output waveforms

Half wave rectifier :

1. It consists of transformer , p-n junction diode and resistor.
2. One half of the input wave is rectified and other half is blocked.
3. p-n junction diode act as a rectifier diode.
4. Not steady DC voltage but pulsating wave.
5. Steady voltage obtained filter circuit & voltage regulator circuit.

Working :

1. In a half wave rectifier circuit , either a positive half or the negative of the AC input is passed through by the diode while the other half is blocked.
2. There are two types of half cycle in half wave rectifier.

Efficiency :

1. Ratio of the output Dc power to the AC input power supplied to the circuit.
2. Its value for half wave rectifier is 40.6 %

Types of half cycle :

S.NO	During positive half cycle	During negative half cycle
2.	Diode is forward biased.	Diode is reverse biased.
3.	Diode will conduct.	Diode does not conduct.
4.	Current flows through load resistance R_L .	No current passes through load resistance R_L .
5.	Voltage developed across R_L .	No voltage drop across R_L .

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4. Explain the construction and working of a full wave rectifier.

Full wave rectifier :

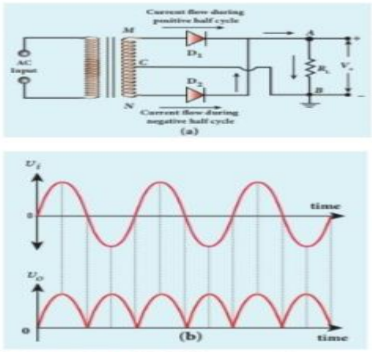

Figure 10.18 (a) Full wave rectifier circuit (b) Input and output waveforms

Theory :

1. It consists of two p-n junction diodes, centre tap transformer and load resistor R_L .
2. The centre is usually taken as the ground or zero voltage reference point.

Types of cycle:

S.NO	i) During positive half cycle :	ii) During negative half cycle :
1.	• Terminal M is positive potential . • Terminal N is negative potential . • C is at zero potential.	• Terminal M is negative potential . • Terminal N is positive potential . • C is at zero potential.
2.	Diode D_1 is forward bias and it conducts.	Diode D_2 is forward bias and it conducts.
3.	Diode D_2 is reverse bias and does not conduct.	Diode D_1 is reverse bias and does not conduct.
4.	Current flows along the path MD_1ABC.	Current flows along the path ND_2ABC.

Working :

- **During both positive and negative half cycles of the input signal , the current flows through the load in the same direction.**
- **Though both half cycles of AC input are rectified , the output is still pulsating in nature.**

Efficiency :

- **The efficiency of full wave rectifier is twice that of half wave rectifier.**
- **It is found to be 81.2 % efficiency .**
- **It is because of power losses in the winding , the diode and the load resistance.**

---

5. What is an LED ? Give the principle of its operation with a diagram.

Light Emitting Diode :

1. **LED is a p-n junction diode which emits visible or invisible light when it is forward biased.**
2. **Electrical energy is converted into light energy , this process is also called as " electroluminescence ".**

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Symbol of LED :

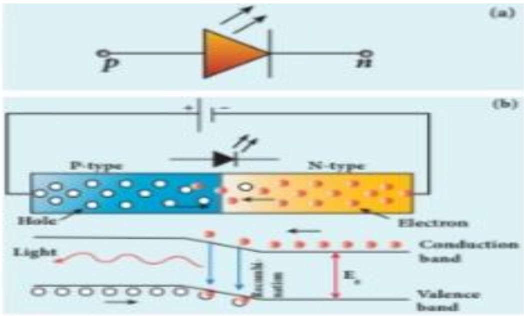

Figure 10.22 (a) Circuit symbol of LED (b) Schematic diagram to explain recombination process

Construction :

1. When p-n junction is forward biased , the conduction band electrons on n-side and valance band holes on p-side diffuse across the junction .
2. When they cross the junction , they become excess minority carriers.
3. These excess minority carrier recombine with oppositely charged majority carriers in the respective regions.
4. The electrons in the conduction band recombine with the holes in the valence band.

Recombination process :

1. During recombination process , energy is released in the form of light or heat.
2. For radiative recombination , photon energy hγ is emitted.
3. For non – radiative recombination , energy is liberated in the form of heat.
4. Colour of the light is determined by the energy band gap of the material.
5. Example : Si C ⟶ Blue Ga As P ⟶ Red

AL Ga P ⟶ Green Ga In N ⟶ White

Application of LED :

1. Seven segment displays 2. Traffic signals 3.Air conditioner

4.Remote control of television 5. Indicator lamps on science lab.

---

6. Write notes on photo diode.

1. A p-n junction diode which converts an optical signal into electric signal is known as " photo diode "
2. Operation of photo diode is exactly inverse to that of LED.
3. Photo diode works in reverse bias condition.

Symbol of Photo Diode:

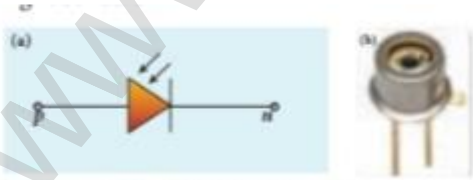

Figure 10.23 (a) Circuit symbol (b) Schematic view of photodiode

Construction :

1. It consists of p-n junction semiconductor made of photosensitive material.
2. It has small transparent window that allows light to be incident on the p-n junction.
3. Photo diodes can generate current when the p-n junction is exposed to light and hence are called as " light sensors "

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Working :

i When light incident on diode :

1. If sufficient energy hγ strikes the depletion region of diode.
2. Valence band electron elevated to the conduction band abd holes are developed.
3. It creates electron – hole pair depends on intensity of incident light.
4. Electric field created by reverse voltage.
5. Hole move towards n- side and electron towards p- side.
6. It constitute photo current.

ii When there is no incident light on diode :

1. There exists a reverse current which is negligible.
2. This reverse current in the absence of any incident light is called " dark current "
3. It is due to thermally generated minority carriers.

Applications :

1. Alarm system 2. Photo conductor 3. Smoke detector 4. Compact disc player 5. Medical applications

---

7. Explain the working principle of a solar cell. Mention its application.

Solar Cell :

1. A solar cell also known as photovoltaic cell.
2. It works on the principle of photo voltaic effect.
3. The p-n junction of solar cell generates emf when solar radiation falls on it.

Construction :

1. Electron – hole pairs are generated due to the absorption of light photons near the junction.
2. The charge carriers are separated due to electric field of depletion region.
3. Electrons move towards n-type Si layer.
4. Holes move towards p-type Si layer.
5. Electrons and holes are collected by the front and back electrical contact.
6. Potential difference is developed across solar cell.
7. When an external load is connected to solar cell , photo current flows through the load.
8. Many solar cells are connected together series or parallel form " solar panel " .
9. Solar panels are connected with each together to form " solar arrays "

Cross sectional view of a solar cell :

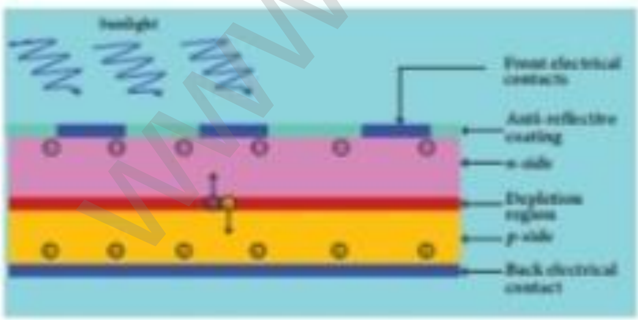

Figure 10.24 Cross-sectional view of a solar cell

Applications Solar cells :

1. Calculator , watch , toy 2. Satellite and space applications.

3. Solar panel used for commercial production of electricity.

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8. Sketch the static characteristics of a common emitter transistor and bring out the essential features of input and output characteristics.

Bias supply voltages :

V_{BB} and V_{CC} bias the base - emitter junction and collector – emitter junction respectively.

Junction Potential :

V_{BE} ⟶ Base Emitter voltage

V_{CE} ⟶ Collector Emitter voltage

Current

I_B ⟶ Base current

I_E ⟶ Emitter current

I_C ⟶ Collector current

Rheostat R_1 and R_2 vary base and collector current.

Circuit diagram :

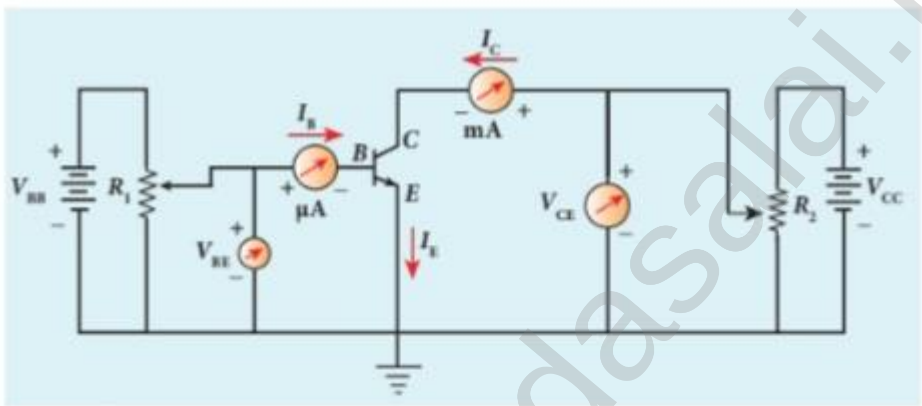

Figure 10.30 NPN transistor in common emitter configuration

Static characteristics of BJT:

i) Input characteristics ii) Output characteristics iii) Transfer characteristics

i) Input Characteristics :

- **Relationship between I_B and V_{BE} at constant V_{CE}**
- **For particular V_{CE} increase V_{BE} and note the value of I_B.**

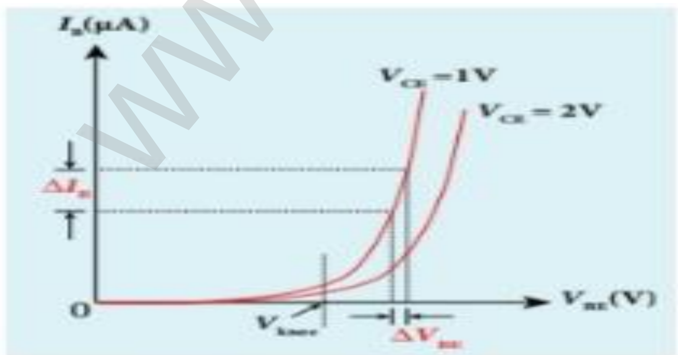

Figure 10.31 Input characteristics

1. Forward characteristics of an ordinary p-n junction diode.

2. Threshold voltage or knee voltage V_{Knee} 0.7 V for Silicon and 0.3 V for Germanium

3. Collector – emitter voltage increases

- **Decreases base current.**
- **Increases width of depletion region.**
- **Reduces effective base width.**

4. Input Impedance

$$r_i = \left(\frac{\Delta V_{BE}}{\Delta I_B}\right)_{V_{CE}}$$

Ratio of change in base emitter voltage to change in base current at constant collector emitter voltage.

ii) output Characteristics :

- **Relationship between I_C and V_{CE} at constant I_B.**

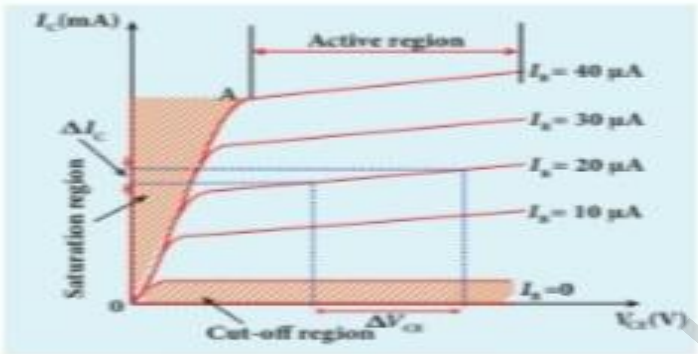

Figure 10.32 Output characteristics

i Saturation Region

1. V_{CE} increase above 0 V , I_C increases and reach saturation value at particular value of V_{CE} called " knee voltage ".
2. O A called as saturation region .
3. Transistor always operated above knee voltage.

ii Cut off Region

1. Small collector current exists for I_B = 0 .
2. Region below I_B = 0 called cut – off region.
3. Collector current is cut – off.

iii Active Region

1.Central region of curve is called " Active region ".
2. BE junction is forward bias.
3. CB junction is reverse bias.
4.Used for voltage , current and power amplification.

iv Breakdown Region

1.V_{CE} is increase , I_C increase .
2. It leads to junction breakdown of transistor.
3.Avalanche breakdown damage transistor.

v Output Impedance

$$r_o = \left(\frac{\Delta V_{CE}}{\Delta I_C}\right)_{I_B}$$

Ratio of change in collector emitter voltage to change in collector current at constant collector base current.

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9.Transistor functions as a switch . Explain.

Circuit Diagram

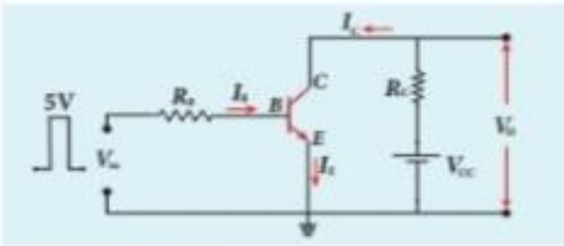

Figure 10.35 Transistor as a switch

Transistor functions as a switch

1.Transistor functions like an electronic switch that helps to turn ON or OFF a given circuit by a small control signal.
2. A small control signal which keeps the transistor either in saturation region or in cut – off region.
3. A transistor in saturation region act as a closed switch.
4. A transistor in cut – off region acts an open switch.

Working :

S.NO	When the input is low : Say 0 V	When the input is high : Say + 5 V
1.	Base Current is zero.	Base Current is increases.
2.	Collector current is zero.	Collector current increases to maximum.
3.	Voltage drop across R_C is zero.	Voltage drop across R_C increases.
4.	No current flows through it.	Maximum current flows through it.
5.	Output voltage is high , equal to V_O.	Lowering voltage close to zero. $V_O = V_{CC} - I_C R_C$
6.	It is in cut – off region.	It is in saturation region.
7.	It is said to be switched off.	It is said to be switched ON.
8.	It acts as an open switch.	It acts as an closed switch.

10. Describe the function of a transistor as an amplifier with the neat circuit diagram . Sketch the input and output waveforms.

Amplification :

- **Process of increasing the signal strength , increase in amplitude.**
- **If a large amplification is required , the transistor are cascaded with coupling elements .**
- **Coupling elements like resistors , capacitors , transformer are called "multistage amplifier .**

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Circuit Diagram :

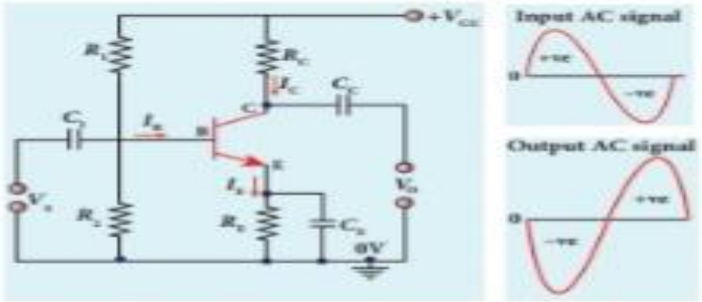

Figure 10.36 (a) Transistor as an amplifier (b) Input and output waveforms showing 180° phase reversal.

Single stage circuit :

- A NPN transistor is connected in the common emitter configuration.
- Q point : Quiescent point which determine the operating point or working point of a transistor.
- Q point is fixed to get maximum signal at the output.

Components :

- R_C ⟶ Load resistance connected in series with collector to measure the output voltage.
- R_1 , R_2, R_3 ⟶ Form the biasing & stabilization circuit.
- C_1 ⟶ Capacitor allows only AC signal.
- C_E ⟶ Bypass capacitor provides low resistance path to amplified AC signal
- V_S ⟶ Sinusoidal input signal

Collector current: $I_C = \beta I_B$ **Collector Emitter Voltage:** $V_{CE} = V_{CC} - I_C R_C$

Working of the amplifier

During Positive Half Cycle	During Negative Half Cycle
1. Input signal V_S increases	1. Input signal V_S decreases
2. Base current increases I_B in μA	2. Base current decreases I_C in μA
3. Collector current increases I_C in Ma	3. Collector current decreases I_C in mA
4. Voltage drop across R_C increases	4. Voltage drop decreases across R_C decreases
5. Collector – Emitter voltage V_{CE} decreases	5. Collector – Emitter voltage V_{CE} increases
6. Output signal is reversed by 180°	6. 180° phase reversal is observed.

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11. Give circuit symbol , logical operation , truth table and Boolean expression of

i) AND gate ii) OR gate iii) NOT gate iv) NAND gate v) NOR gate vi) EX- OR

i) AND gate

(a)

Inputs		Output
A	B	Y=A.B
0	0	0
0	1	0
1	0	0
1	1	1

(b)

Figure 10.41 (a) Two input AND gate (b) Truth table

Boolean expression : **Y = A . B**

Logical Operation :

- **Output is high only when all the inputs are high.**
- **Output is low for rest of the cases.**

ii) OR gate

(a)

Inputs		Output
A	B	Y= A+B
0	0	0
0	1	1
1	0	1
1	1	1

(b)

Figure 10.42 (a) Two input OR gate (b) Truth table

Boolean expression : **Y = A + B**

Logical Operation :

- **Output is high only when either of the inputs or both are high.**

iii) NOT gate

(a)

Inputs	Output
A	$Y=\overline{A}$
0	1
1	0

(b)

Figure 10.43 (a) NOT gate (b) Truth table

Boolean expression : $Y = \overline{A}$

Logical Operation :

- **Output is complement of input .**
- **It is represented with an overbar.**
- **It is also called inverter.**

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iv) NAND gate

Boolean expression : $Y = \overline{A \cdot B}$

Logical Operation :

- Complement of AND operation.
- AND gate followed by a NOT gate.
- Output is zero when all the inputs are high.

(a)

Inputs		Output (AND)	Output (NAND)
A	B	$Z = A.B$	$Y = \overline{A.B}$
0	0	0	1
0	1	0	1
1	0	0	1
1	1	1	0

(b)

Figure 10.44 (a)Two input NAND gate (b) Truth table

v) NOR gate

(a)

Inputs		Output (OR)	Output (NOR)
A	B	$Z = A+B$	$Y = \overline{A+B}$
0	0	0	1
0	1	1	0
1	0	1	0
1	1	1	0

(b)

Figure 10.45 (a) NOR gate (b) Truth table

Boolean expression : $Y = \overline{A + B}$

Logical Operation :

- Complement of OR operation.
- OR gate followed by a NOT gate.
- Output is high when all the inputs are low.

vi) EX-OR gate

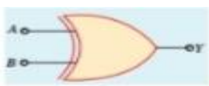
Boolean expression :

$Y = A \oplus B$

$Y = A \cdot \overline{B} + \overline{A} \cdot B$

Logical Operation :

- Output is high when either of two input high.
- Exclusive OR gate is known as EX – OR gate.



(a)

Inputs		Output (Ex-OR)
A	B	$Y = A \oplus B$
0	0	0
0	1	1
1	0	1
1	1	0

(b)

Figure 10.46 (a) Ex-OR gate (b) Truth table

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12. State and prove De Morgon's first and second theorem.

De Morgon's first theorem

The complement of the sum of two logical inputs is equal to the product of its complements.

Proof :

1. The Boolean equation for NOR gate is $Y = \overline{A + B}$
2. The Boolean equation for bubbled AND gate is $Y = \overline{A} . \overline{B}$
3. Both cases generate same outputs for same inputs.
4. NOR gate = Bubbled AND gate
5. $\overline{A + B} = \overline{A} . \overline{B}$

Symbol:

Figure 10.47 NOR gate equals bubbled AND gate

Truth Table :

A	B	$A+B$	$\overline{A+B}$	$\overline{A}$	$\overline{B}$	$\overline{A}.\overline{B}$
0	0	0	1	1	1	1
0	1	1	0	1	0	0
1	0	1	0	0	1	0
1	1	1	0	0	0	0

De Morgon's second theorem

The complement of the product of two logical inputs is equal to the sum of its complements.

Proof :

1. The Boolean equation for NAND gate is $Y = \overline{A . B}$
2. The Boolean equation for bubbled OR gate is $Y = \overline{A} + \overline{B}$
3. Both cases generate same outputs for same inputs.
4. NAND gate = Bubbled OR gate
5. $\overline{A . B} = \overline{A} + \overline{B}$

Symbol :

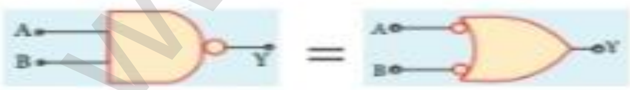

Figure 10.48 NAND gate equals bubbled OR gate

Truth Table :

A	B	$A.B$	$\overline{A.B}$	$\overline{A}$	$\overline{B}$	$\overline{A}+\overline{B}$
0	0	0	1	1	1	1
0	1	0	1	1	0	1
1	0	0	1	0	1	1
1	1	1	0	0	0	0

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13. Explain the amplitude modulation with necessary diagrams.

Definition :

If the amplitude of the carrier signal is modified in proportion to the instantaneous amplitude of the baseband signal , then it is called amplitude modulation.

- **Frequency and phase of the carrier signal remain constant.**
- **Amplitude modulation is used in radio and TV broadcasting.**

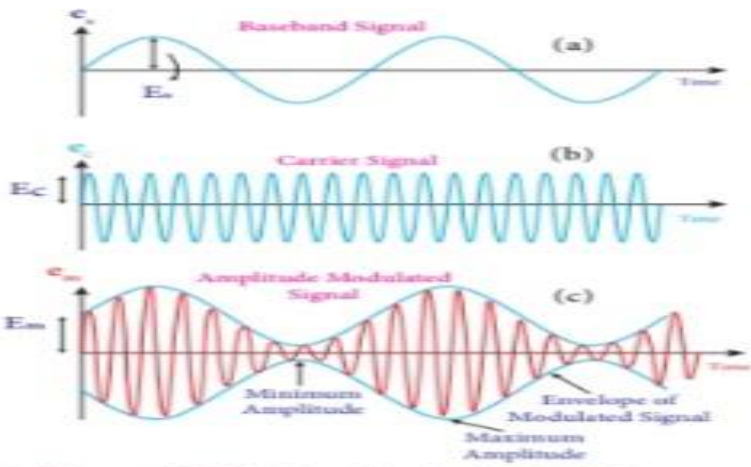

Figure 10.50 Amplitude Modulation (a) Baseband signal (b) Carrier signal (c) Modulated signal

Base band signal

- **Low frequency signal is base band signal.**
- **Base band signal carrier information.**

Carrier Signal

- **High frequency signal called carrier signal.**
- **It is used to carry the base band signal.**

Modulated Signal

The amplitude of the carrier wave is modified in proportion to the amplitude of the base band signal.

Advantage of AM

1. Easy transmission and reception. 2. Lesser bandwidth requirement. 3. It is low cost.

Limitations of AM

1. Noise level is high 2. Low efficiency 3. Small operating range.

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14. Explain the basic elements of communication system with the necessary block diagram.

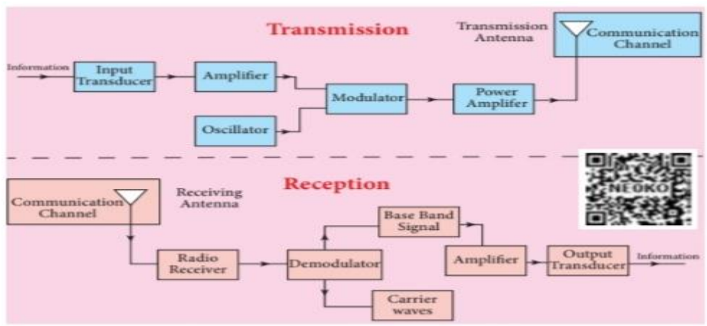

Figure 10.52 Block diagram of transmission and reception of voice signals

1. Information : Information is given as input to the input transducer. Ex : Music , picture , speech

2. Input Transducer : Transducer converts the information into corresponding electrical signal. Ex : Microphone

3. Transmitter : It feeds the electrical signal from the transducer to the communication channel.

- **Amplifier :** Transducer weak output is amplified.
- **Oscillator :** Generates high energy frequency carrier wave.
- **Modulator :** Generates modulated signal by superimpose baseband to carrier signal.
- **Power Amplifier :** Increase power level of the electrical signal to cover large distance.

4. Transmitting Antenna

- Radiates radio signal into space in all direction.
- Travels in the form of em waves.

5. Communication Channel

Used to carry the electrical signal from transmitter to receiver with less noise or direction. Ex : Wire , cable

6. Receiver

Converts EM waves inti RF signal by receiving antenna. Ex : Demodulator , amplifier

7. Repeaters

Used to increase the range or distance through which the signal are sent. It is a combination of transmitter and receiver

Ex : Communication satellite in space

8. Output Transducer

Converts the electrical signal back to its original form such as sound , music , picture. Ex: Loud speaker , picture tube

---

15. Explain the ground wave propagation and space wave propagation of electromagnetic waves through space.

Ground Wave Propagation

1. If the em waves transmitted by the transmitter glide over the earth surface to reach the receiver , then the propagation is called " Ground wave propagation "
2. The corresponding waves are called as " ground waves " or " surface waves".
3. Both transmitting and receiving antenna's must be close to earth's surface.

Uses :

Used in local broadcasting , radio navigation for ship – ship , ship to shore communication and mobile communication.

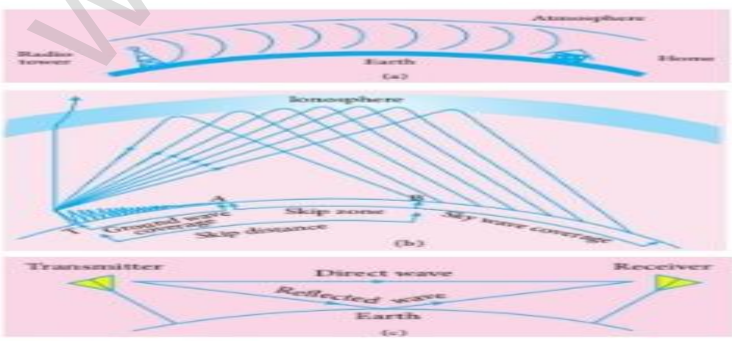

Figure 10.53 Propagation of EM waves (a) Ground wave (b) Sky wave (c) Space wave

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Space Wave Propagation

1. The process of sending and receiving information signal through space is called " Space wave propagation "
2. The em waves of very high frequencies above 30 MHz are called as " Space waves "
3. These waves travel in a straight line from transmitter to receiver.
4. It is used for a line of sight communication [L O S].
5. Like television telecast , satellite communication and RADAR .
6. Range or distance (d) of coverage of the propagation depends on the height (h) of the antenna.

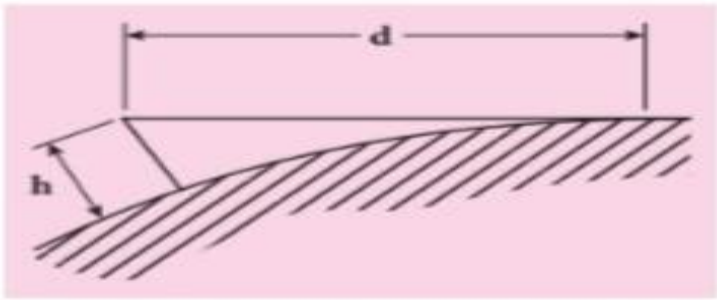

Figure 10.54 Distance of coverage

$$d = \sqrt{2Rh}$$

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16. Fibre optic communication is gaining popularity among the various transmission media – Justify.

Principle : It works on the principle of total internal reflection.

Fibre Optic Communication :

The method of transmitting information from one place to another in terms of light pulses through an optical fibre is called " Fibre optic communication "

Applications :

1. International communication. 2. Inter- city communication . 3. Traffic control & defence application .

Merits :

1. Very thin & weigh less than copper cable. 2. It has much larger band width.

3. Carrying information capacity is larger. 4. immune to electricity interferences.

5. Cheaper than copper cable.

Demerits :

1. It is ab expensive technology. 2.More breakable when compared to copper wires.

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17. List out the advantages and limitations of frequency modulation.

Advantages of FM :

1. Operating range is quite large 2. Transmission efficiency is very high. 3. Large decrease in noise.

4. FM bandwidth covers the entire frequency range which humans can hear.

Limitations of FM :

1. FM requires much wider channel.

2. FM transmitters and receivers are more complex and costly.

3. In FM reception , less area is covered compared to AM.

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18.What is meant by satellite communication ? Give its applications.

Satellite Communication

1. Mode of transmission of the signal between transmitter and receiver via satellite.
2. The message signal from earth station is transmitted to satellite on board via uplink . (frequency band 6 G Hz)
3. Retransmitted to another earth station via downlink. (frequency 4 G Hz)

i) Weather Satellite :

1. Used to monitor the weather and climate of earth.
2. By measuring cloud mass.
3. Satellite enable us to predict rain.
4. Dangerous storms like hurricane cyclone etc.

ii) Communication Satellite :

1. Used to transmit television , radio , internet signal etc.
2. Multiple satellites are used for long distance communication.

iii) Navigation Satellite :

1. Used to determine the geographic location of ships , air craft or any other object.

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