Chapter-1: Electric Charges and Fields

1. Property of Charges:

- Quantisation of charge

$$\boxed{q = Ne}$$

- Additivity of charges

$$\boxed{q_{net} = \sum_{i=1}^{n} q_i}$$

- Conservation of charges

$$\boxed{q_{net}(isolated) = Constant}$$

2. Coulomb's Force

Force between two point charge q_1 and q_2 separated by distance r and placed in vacuum

- In vector Form

$$\boxed{\vec{F} = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{q_1 q_2}{r^2}\hat{r}}$$

- In magnitude form

$$\boxed{F = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{|q_1||q_2|}{r^2}}$$

Also,

$$\boxed{F \propto \frac{1}{r^2}}$$

And,

$$\boxed{F \propto |q_1||q_2|}$$

3. Electric Field Intensity

- Electric field intensity E at a point at distance r due to a point charge q kept in free space

In vector form

$$\boxed{\vec{E} = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{q}{r^2}\grave{r}}$$

In magnitude form

$$E = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{|q|}{r^2}$$

- The net electric field intensity at a point whose position vector is r due to other charges whose positions are r_1, r_2, r_3, -------can be expressed as-

$$\vec{E} = \frac{1}{4\pi\varepsilon}\sum_{i=1}^{n}\frac{q_i(\vec{r}-\vec{r_i})}{|\vec{r}-\vec{r_i}|^3}$$

4. Dipole

- Dipole Moment
  In vector form

$$\vec{p} = 2aq\hat{\imath}$$

  In magnitude form

$$p = 2aq$$

- Net Electric Field Intensity due to a dipole
  At **axial point** at distance r from dipole centre

$$E = \frac{1}{4\pi\epsilon_0}\frac{4aqr}{[r^2 - a^2]^2}$$

  At **Axial point** when r >> a

$$E = \left(\frac{1}{4\pi\varepsilon_0}\right)\left(\frac{2p}{r^3}\right)$$

  This shows that

$$E \propto \frac{1}{r^3}$$

- Net Electric field intensity due to a dipole
  At the **equatorial point** at distance r from dipole centre

$$E = \frac{1}{4\pi\varepsilon_0}\left(\frac{2aq}{[r^2 + a^2]^{\frac{3}{2}}}\right)$$

  At the **equatorial point** when r >> a

$$E = \frac{1}{4\pi\varepsilon_0}\left(\frac{p}{r^3}\right)$$

- Torque in a dipole

  In vector form

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

  In magnitude form

$$\boxed{\tau = pE \sin\theta}$$

- Potential energy in rotating a dipole at an angle θ

  In vector form

$$\boxed{U = -\vec{p}.\vec{E}}$$

  In magnitude form, Potential in the dipole is

$$\boxed{U = -\mathrm{pE}\cos\theta}$$

5. Electric Flux

For uniform field

In vector form

$$\boxed{\varphi_E = \vec{E}.\vec{S}}$$

In magnitude form,

$$\boxed{\varphi = ES\ \cos\theta}$$

6. Charge Densities (continuous charge distribution)

- Linear Charge Density

$$\boxed{\lambda = \frac{q}{L}}$$

- Surface Charge Density

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

- Volume Charge Density

$$\boxed{\rho = \frac{q}{V}}$$

7. Gauss's Law

$$\boxed{\varphi_E = \oint \vec{E}.\overrightarrow{dS} = \frac{q_{in}}{\varepsilon_0}}$$

The flux contributes all charges inside a Gaussian surface, not outside charge

And

$$\boxed{\varphi = \frac{q_{in}}{\varepsilon_0}}$$

8. Electric field intensity due to Infinite Line Charge (linear charge density λ distributed)

- Electric Field Intensity due to Line charge

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

This shows that

$$\boxed{E \propto \frac{1}{r}}$$

9. Electric Field Intensity due to two parallel infinite line charges having $(+\lambda \ and - \lambda)$

- Inside between two at distance r (separation is 2r)

$$\boxed{E = \frac{\lambda}{\pi\epsilon_0 r}}$$

{Towards line (2)}

- Outside (1) at distance r

$$\boxed{E = \frac{\lambda}{3\pi\epsilon_0 r}}$$

{Away from line charge (1)}

- Outside (2) at distance r

$$\boxed{E = \frac{\lambda}{3\pi\epsilon_0 r}}$$

{Towards line charge (2)}

10. Electric field intensity due to an infinite thin plane sheet (Surface charge density σ is distributed)

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

(This shows that E is independent of r.)

11. Electric field intensity due to a charged conductor –charged on both sides (near the conductor)

$$\boxed{E = \sigma/\varepsilon_0}$$

12. Electric field intensity in between and outside two long parallel plane sheet having surface charge densities ± σ

Outside parallel sheets,

$$\boxed{E = 0}$$

Between parallel sheet,

$$\boxed{E = \sigma/\varepsilon_0}$$

13. Electric field intensity due to hollow sphere or spherical shell

(r is the distance of a point inside the sphere from its centre, R is the radius of sphere)

Inside the sphere (r < R)

$$\boxed{E = 0}$$

Outside the sphere, r > R

$$\boxed{E = \frac{1}{4\pi\epsilon_0}\left(\frac{|q|}{r^2}\right)}$$

On its surface r = R

$$\boxed{E = \frac{1}{4\pi\epsilon_0}\left(\frac{|q|}{R^2}\right) = \frac{\sigma}{\epsilon_0}}$$

14. Electric Field due to two concentric spherical shells of radius, say r (inner sphere and 2r (outer sphere), charge distributed +q on inner sphere and – q on outer sphere surface

At distance $r_1 = 1.5$ r $(r < r_1 < 2r)$

$$\boxed{E = \frac{1}{4\pi\epsilon_0}\left(\frac{4q}{9r^2}\right)}$$

At distance $r_2 = 2.5\,r \;\; (r_2 > 2r)$

$$\boxed{E = 0}$$

Chapter-2: Electrostatics Potential and Capacitance

1. Relation between work done, potential energy and potential difference

By the external agent

$$W(i \to f) = U_f - U_i \ = \ \Delta U = V_f - V_i$$

By the conservative force

$$W(i \to f) = U_i - U_f \ = \ -\Delta U = V_i - V_f$$

2. Potential energy of two point charge system (if charges q_1 and q_2 are separated by distance r)

$$U = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r}$$

3. Potential energy of system of charges (due to several charges) (Charges kept at vertices of triangle or square or rectangle or at any geometrical shape.)

$$U = \frac{1}{4\pi\epsilon_0}\left[\frac{q_3 q_2}{r_{32}} + \frac{q_3 q_1}{r_{31}} + \frac{q_2 q_1}{r_{21}}\right]$$

4. Relation between electric potential and potential energy

$$V = \frac{U}{q_0}$$

(If initial point is at ∞ and final point is say f so work done to bring a charge (say q_0) from infinity to a point (say f) by external force or against electric force)

$$V_f - V_\infty = \frac{U_f - U_\infty}{q_0} = W_{\infty \to f}$$

[Here V_∞ and U_∞ are zero as seen that $U \propto \frac{1}{r}$ and $\propto \frac{1}{r}$]

5. Relation between electric potential and electric field intensity

$$dV = -\vec{E}.\overrightarrow{dr}$$

Or,

$$\int_{V_B}^{V_A} dV = -\int_{r_B}^{r_A} \vec{E}.\overrightarrow{dr}$$

6. Electric potential difference say V_{AB} or $V_A - V_B$ in a uniform electric field

$$V_B - V_A = \vec{E}.(\vec{r}_A - \vec{r}_B)$$

7. Electric potential at a point

At distance r due to a point charge q

$$V = \frac{1}{4\pi\epsilon_0}\left(\frac{q}{r}\right)$$

At position vector r due to a point charge q kept at position vector r_0

$$V = \frac{1}{4\pi\epsilon_0}\left(\frac{q}{|\vec{r} - \overrightarrow{r_0}|}\right)$$

At position vector r due to system of charges q_1, q_2, q_3..... kept at positions r_1, r_2, r_3 ....respectively

$$V = \frac{1}{4\pi\epsilon_0}\sum_{i=1}^{n}\frac{q_i}{|\vec{r} - \vec{r_i}|}$$

At distance is same (r) from each charge

$$V = \frac{1}{4\pi\epsilon_0}\left(\frac{q_{net}}{r}\right)$$

At distance r due to continuous charge distribution

$$V = \frac{1}{4\pi\epsilon_0}\int\frac{dq}{r}$$

8. Electric potential in a dipole at any point p, at distance r from the centre of dipole, making angle θ from the dipole axis

$$V_p = \frac{1}{4\pi\epsilon_0}\left(\frac{p\cos\theta}{r^2}\right)$$

- When $\theta = 0^0$, (axial position of dipole)

$$V_p = \frac{1}{4\pi\epsilon_0}\left(\frac{p}{r^2}\right)$$

- When $\theta = 90^0$, (at the equatorial point),

$$\boxed{V = 0}$$

9. Electric potential in case of hollow spherical conductor,

Inside the hollow spherical conductor (r < R) where R is the radius of conductor and q is the charge distributed on the surface of conductor

$$\boxed{V_{inside} = V_{surface} = \frac{1}{4\pi\epsilon_0}\left(\frac{q}{R}\right)}$$

Outside at any point at distance r from the centre of the spherical shell

$$\boxed{V_r = \frac{1}{4\pi\epsilon_0}\left(\frac{q}{r}\right)}$$

10. Electric potential in case of two metallic hollow concentric shells:

If the inner shell A has radius R_1 and charge distributed is q_1 and has outer shell B has radius R_2 and charge distributed is q_2, then potential V_A and V_B are given as

$$\boxed{V_A = \frac{1}{4\pi\epsilon_0}\left(\frac{q_1}{R_1} + \frac{q_2}{R_2}\right)}$$

$$\boxed{V_B = \frac{1}{4\pi\epsilon_0}\left(\frac{q_1}{R_2} + \frac{q_2}{R_2}\right)}$$

Thus, potential difference

$$\boxed{V_A - V_B = \frac{1}{4\pi\epsilon_0} q\left(\frac{1}{R_1} - \frac{1}{R_2}\right)}$$

11. Capacitance C: SI Unit: Farad (F)

Capacitance of a capacitor of charge q and V the potential difference

$$\boxed{C = \frac{q}{V}}$$

A metallic spherical conductor of radius R and charge q on its surface

$$\boxed{C = 4\pi\epsilon_0 R}$$

Of a two concentric metallic hollow spherical conductor of inner and outer shell having radii R_1 and R_2 and charges on inner and outer surface q and –q respectively

$$C = 4\pi\epsilon_0 \frac{R_1R_2}{R_2 - R_1}$$

Of a two co-axial metallic hollow cylindrical conductor placed in free space of inner and outer shell having radii R_1 and R_2 and charge on inner outer surface of sphere is q and charge on outer surface of shell B is –q

$$C = \frac{2\pi\epsilon_0 L}{ln\frac{R_2}{R_1}}$$

12. Parallel Plate Capacitor

Capacitance C when gap is completely filled with dielectric slab

$$C = \frac{\epsilon_0 KA}{d}$$

Capacitance C of n similar plates of equal separation (d) and same plate area (A) connected alternatively

$$C = (n-1)\frac{\epsilon_0 A}{d}$$

Capacitance C of a parallel plate capacitor when a dielectric slab is partially filled in the gap

$$C = \frac{\epsilon_0 A}{d - t + \frac{t}{K}}$$

Special cases:

- If more than one dielectric slabs of different thickness and different constants are placed between the parallel plates capacitor, then

$$C = \frac{\epsilon_0 A}{(d - t_1 - t_2 - \cdots..) + (\frac{t_1}{K_1} + \frac{t_2}{K_2} + \cdots.)}$$

- If a conductor is completely filled in the gap, then t = d and $K = \infty$, then

$$C = \infty$$

- If the conductor is partially filled with thickness t and same area, then

$$C = \frac{\epsilon_0 A}{d - t}$$

- The capacitance will be infinity if one of the plates is earthed..

13. Energy stored in capacitor is given by

$$U = \frac{1}{2}CV^2 = \frac{1}{2}qV = \frac{1}{2}\frac{q^2}{C}$$

14. Energy density

- The energy per unit volume is called the energy density (u).

$$u = \frac{U}{Volume}$$

- Energy density of air capacitor

$$u = \frac{1}{2}\epsilon_0 E^2$$

- Energy density in a dielectric medium (dielectric constant K)

$$u = \frac{1}{2}(\epsilon_0 K E^2)$$

15. Electric field intensity on the –q plate due to positive charge in case of two parallel plates

$$E = \frac{q}{2A\epsilon_0}$$

16. Force of attraction with which both parallel plates (charge q and –q and area A with separation d) attract each other

$$F = \frac{q^2}{2A\epsilon_0}$$

17. Electric field intensity (E) in the dielectric (dielectric constant K) inserted between parallel plates

$$E = \frac{\sigma}{\epsilon} = E_0 - E_i$$

18. In free space between the plates, External electric field (E_0)

$$E_0 = \frac{\sigma}{\epsilon_0}$$

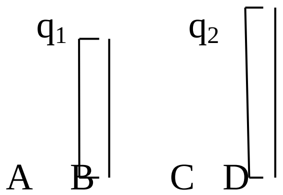
19. Dielectric Constant K

$$K = \frac{E_0}{E}\ or, K = \frac{E_0}{E_0 - E_i}$$

20. Relation between induced charge, charge on plates and dielectric constant K

$$q_i = q\left(1 - \frac{1}{K}\right)$$

21. If the charge on plate 1 is q_1 and on plate 2 is q_2 then charge at each **point** (inner & outer surface of plate-1 and plate-2 respectively are



- Charge on point A and D

$$\boxed{q_A = q_D = \frac{q_1 + q_2}{2}}$$

Where q_1 is

$$\boxed{q_1 = Charge\ at\ point\ A + Charge\ at\ point\ B}$$

And q_2 is

$$\boxed{q_2 = \text{Charge at point C} + \text{Charge at point D}}$$

- Charge at point B

$$\boxed{q_B = \frac{q_1 - q_2}{2}}$$

- Charge at point C

$$\boxed{q_C = -\left(\frac{q_1 - q_2}{2}\right)}$$

22**. Charge redistribution**:

When two conductors of charge q_1 and q_2 on its surfaces and having capacitances as C_1 and C_2 with radii as R_1 and R_2, are connected by a conducting wire, then charges on conductors after joining the wire are in the ratio of their capacities as given-

$$q_1' = C_1V' \ \ and\ q_2' = C_2V'$$

Where

$$\boxed{V_{com} = Common\ potential = \frac{q_1 + q_2}{C_1 + C_2}}$$

Since,

$$\boxed{C \propto R\ So, q_1' = (q_1 + q_2)\left(\frac{R_1}{R_1 + R_2}\right)}$$

23**. Loss of energy during redistribution of charge**

$$\Delta U = U_i - U_f = \frac{C_1 C_2}{2(C_1 + C_2)}((V_1 - V_2)^2)$$

Where,

$$U_i = \frac{1}{2}\left(\frac{q_1^2}{C_1}\right) + \frac{1}{2}\left(\frac{q_2^2}{C_2}\right) \; and \; U_f = \frac{1}{2}\left[\frac{(q_1 + q_2)^2}{C_1 + C_2}\right]$$

24. **Capacitors Combination**

If C_1, C_2 capacitors are connected in

- Series (same charge in each capacitor)

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots \ldots .$$

- Parallel (same potential difference across each capacitor)

$$C = C_1 + C_2 + \cdots \ldots \ldots$$

25. **Relation between Electrical susceptibility and Polarisation**

Polarisation is defined as dipole moment per unit volume and its magnitude is referred to as polarisation density.

Electrical susceptibility is given by

$$\chi = \frac{\vec{p}}{\epsilon_0 \vec{E}}$$

26. **Relation between dielectric constant (K) and electrical susceptibility (χ)**

$$K = 1 + \chi$$

27. **Polarisation density (P)**

$$P = \frac{q_i t}{At} = \frac{dipole\ moment\ in\ the\ slab}{volume} = \frac{q_i}{A} = \sigma_i$$

Where A is the area of dielectric slab, t the thickness of slab, q_i the induced charge in the dielectric slab.

28. **Effect of dielectric on various parameters**

Effect of dielectric

Initially No dielectric and Supply is Connected

Let q_0, V_0, C_0, E_0 and U_0 be the charge, potential difference, capacitance, electric field

Intensity and potential energy stored respectively before dielectric slab is inserted.

Then,

$$\boxed{V_0 = \frac{q_0}{C_0} \; and \; V_0 = E_0 d \; and \; U_0 = \frac{1}{2} C_0 V_0^2}$$

Finally

(i) When supply is disconnected and dielectric slab is inserted:

- Charge (remains same)

$$\boxed{q = q_0}$$

The charge on capacitor plate remains q_0 as battery has been disconnected before the insertion of dielectric slab.

- Electric field (decreased by K times

$$\boxed{E = \frac{E_0}{K}}$$

- Potential difference (decreased by K times)

$$\boxed{V = \frac{V_0}{K}}$$

- Capacitance (increased by K times)

$$\boxed{C = C_0 K}$$

- Potential energy stored (decreased by K times)

$$\boxed{U = \frac{1}{2} C V^2 = \frac{U_0}{K}}$$

Finally

(ii) When battery remains connected across the capacitor

- Potential difference (remains same)

$$\boxed{V = V_0}$$

- Electric field intensity (remains same)

$$\boxed{E = E_0}$$

- Capacitance (increased by K times)

$$\boxed{C = C_0 K}$$

- Charge (increased by K times)

$$\boxed{q = K q_0}$$

- Potential energy stored:

$$\boxed{U = K U_0}$$

Chapter-3: Current Electricity

1. Relation among charge (q) to flow, current (I) and time t

$$\boxed{I = \frac{q}{t} = \frac{ne}{t}}$$

For positive q, current is in forward direction and for negative q, it is in backward direction.

2. Relation between very small charge dq to flow for small time dt

$$\boxed{I = \frac{dq}{dt}}$$

3. Current density (J) is the current (I) distributed uniformly over the cross section area (A)

$$\boxed{J = \frac{I}{A}}$$

Or

$$\boxed{I = \vec{J} \cdot \vec{A}}$$

4. Ohm's law

$$\boxed{I \propto V \ or \ V \propto I \Rightarrow V = RI}$$

$$\boxed{R \propto l, R \propto \frac{1}{A} \ So, R = \rho \frac{l}{A}}$$

5. Effect of temperature on resistance:

If R_1 be the resistance at temperature t_1 and R_2 be the resistance at temperature t_2, then

$$R_2 = R_1(1 + \alpha\Delta t)$$

Where α is the temperature coefficient of resistance and $\Delta t = t_2 - t_1$.

If the temperature is not sufficiently large, as in practical cases, then the equation is

$$\boxed{R_t = R_0(1 + \alpha t) \ or \ \alpha = \frac{R_t - R_0}{R_0 t} = \frac{Change \ in \ resistance}{original \ resistance \ x \ rise \ in \ temperature}}$$

6. Temperature dependence of resistivity

Resistivity of a metal conductor is given by

$$\rho_T = \rho_0[1 + \alpha(T - T_0)]$$

7. Conductance (G) and conductivity (σ):

Conductance (G) is given by reciprocal of resistance and will be written as

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

And conductivity (σ) is given by reciprocal of resistivity and will be written as

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

8. Drift velocity and relaxation time

Drift velocity

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

Drift Speed

$$|\vec{v}_d| = v_d = \frac{eE}{m}\tau$$

9. Relation between average drift velocity, relaxation time and current

$$I = neAv_d$$

$$R = \frac{ml}{ne^2A\tau} = constant$$

10. Relation between resistivity (ρ), number density (n) and relaxation time (τ)

$$\rho = \frac{m}{ne^2\tau}$$

11. Mobility is the magnitude of drift velocity per unit electric field applied

$$\boxed{\mu = \frac{q\tau}{m}}$$

a) Mobility due to charge carrier electrons in a conductor is given by

$$\boxed{\mu_e = e\frac{\tau_e}{m_e}}$$

b) Mobility due to charge carrier holes in a conductor is given by

$$\boxed{\mu_h = e\frac{\tau_h}{m_h}}$$

12. Equivalent Resistance in series

$$\boxed{R = R_1 + R_2 + R_3 - - - -}$$

For two resistors R_1 and R_2 connected in series and the combination is connected with a battery of potential difference across it,
Then

$$\boxed{V_1 = V\left(\frac{R_1}{R_1 + R_2}\right)}$$

And,

$$\boxed{V_2 = V - V_1}$$

Or

$$\boxed{V_2 = V\left(\frac{R_2}{R_2 + R_1}\right)}$$

In series, n resistors, each capacity R

$$\boxed{R_{eqvt} = nR}$$

13. Equivalent Resistance in Parallel

$$\boxed{\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} - - - -}$$

For two resistors R_1 and R_2 connected in parallel and the combination is connected with a battery of potential difference V across it,
Then

$$\boxed{I_1 = I\left(\frac{R_2}{R_1 + R_2}\right)}$$

And,

$$\boxed{I_2 = I - I_1}$$

Or

$$\boxed{I_2 = I\left(\frac{R_1}{R_2 + R_1}\right)}$$

In parallel, n resistors each capacity R

$$\boxed{\frac{1}{R_{eqvt}} = \frac{n}{R} \Rightarrow R_{eqvt} = \frac{R}{n}}$$

14. Power Supplied by a Battery

When the current enters the positive plate of a battery, Then

$$\boxed{P = +EI}$$

15. Power Delivered / Consumed by a Battery

When current enters the negative plate of a battery, Then

$$\boxed{P = -EI}$$

16. Electrical Power (P) and Heat generated across a resistor

Electrical power (P) dissipated or generated across a resistor is given by

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

Heat generated across a resistor is given by

$$\boxed{H = VIt = I^2Rt = \frac{V^2}{R}t}$$

17. Power of two bulbs

Series Connection

$$\boxed{P = \frac{P_1P_2}{P_1 + P_2}}$$

Parallel Connection

$$\boxed{P = P_1 + P_2}$$

18. EMF (E) of cell and internal resistance (r)

$$\boxed{E = \frac{W}{q}}$$

Discharging Equation of a cell

- **In Closed Circuit**

When a load resistance R is connected across the cell, Then

$$\boxed{V < E}$$

And,

$$\boxed{V = E - Ir}$$

For V = IR;

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

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

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

- **If a cell is shorted, then**

$$\boxed{V = 0}$$

And,

$$\boxed{I = \frac{E}{r}}$$

- **In Open Circuit**

$$\boxed{I = 0}$$

Then

$$\boxed{V = E}$$

This shows that

$$\boxed{V \leq E}$$

Charging Equation of a cell

In Closed Circuit

When battery is discharged (it draws the current)

$$V = E + Ir$$

If resistance R is connected in series with a battery which supplies the current and charges the cell then

$$\boldsymbol{I = \frac{V' - E}{r + R}}$$

19. Combination of cells

a) **Series Connection**:

Equivalent emf (same polarity)

$$E_{eq} = E_1 + E_2 + E_3 + - - - - - -$$

Equivalent Internal Resistance

$$r_{eq} = r_1 + r_2 + r_3 + - - -$$

If external resistance R is connected in a closed loop,

$$I = \frac{E_1 + E_2 + E_3 + - - -}{(r_1 + r_2 + r_3 + - - -) + R}$$

So, it can be said that two cells connected in series,

$$Net\ EMF = E_1 + E_2$$

$$I = \frac{Net\ EMF}{Net\ Resistance}$$

(i). N cells of same emf (E) and same internal resistance (r) are connected in series, then

$$I = \frac{nE}{nr + R}$$

(ii). In series connection, there are n cells of each emf E. If polarity of m cells is reversed, then equivalent emf

$$E_{eq} = (n - 2m)E$$

Whereas, total resistance is

$$\boxed{R_{eq} = R + nr}$$

$$\boxed{I = \frac{(n-2m)E}{nr + R}}$$

b) Parallel Combination

- If n cells of emf E_1, E_2, E_3, ---- (polarity of each same) with internal resistance r_1, r_2, r_3---are connected in parallel (with no external resistance R across the combination), then

$$\boxed{\frac{E_{eq}}{r_{eq}} = \frac{E_1}{r_1} + \frac{E_2}{r_2} + \frac{E_3}{r_3} + ----}$$

- Equivalent internal resistance

$$\boxed{\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + ----}$$

- If n cells each emf E (polarity of each same), internal resistance r, are connected in parallel, then
  Equivalent emf

$$\boxed{E_{eq} = E}$$

  Equivalent resistance

$$\boxed{E_{eq} = nr}$$

- If an external resistance R is connected across the parallel combination of n cells with each emf E and internal resistance r, then Current

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

- If two cells or three cells with integral multiple of E connected in parallel and no internal resistance given, then take the average of all as,

$$\boxed{E_{eq} = Average\ value\ of\ all\ emfs}$$

20. Maximum Power Transfer Theorem

Current I will be maximum when

$$\boxed{\sqrt{mR} = \sqrt{nr}}$$

Or,

$$\boxed{R = \frac{nr}{m}}$$

Hence, power transferred to the load is maximum when load resistance = total internal resistance

21. Kirchhoff's Law:

Junction Rule:

The algebraic sum of current at any junction is equal to zero.

$$\boxed{\sum_{junction} I = 0}$$

That is, net current entering the junction = net current leaving the junction

So,

$$\boxed{I_1 + I_2 = I_3 + I_4 + I_5}$$

Kirchhoff's Loop Rule

The net voltage in a closed loop is equal to zero.

$$\boxed{\sum_{closed\ loop} V = 0\ or \sum E_{net} = \sum IR}$$

22. Wheatstone bridge:

Balancing of Wheatstone Bridge.

. That is $I_g = 0$

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

Chapter-4: Moving Charges and Magnetism

1. Magnetic force on a moving charge

$$\boxed{\vec{F}_m = q\vec{v} \times \vec{B}}$$

Or

$$\boxed{F_m = qvB\sin\theta}$$

2. Path of charged particle in uniform magnetic field

- Path is straight line when

$$\boxed{\theta = 0^0 \ Or\ 180^0}$$

- Path is circle when

$$\boxed{\theta = 90^0}$$

- For any other angle, path is helix.

3. Circular path

$$\boxed{\vec{v} \cdot \vec{B} = 0}$$

- Centripetal force = Magnetic force

$$\boxed{m\frac{v^2}{r} = qvB}$$

- Radius of the circular path (r)

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

- Momentum (p)

$$\boxed{p = mv}$$

- Kinetic energy(K)

$$\boxed{p = \sqrt{2mK}}$$

- Time period,

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

- Angular velocity

$$\boxed{\omega = \frac{Bq}{m}}$$

- Frequency

$$\boxed{f = \frac{Bq}{2\pi m}}$$

4. Helical path

- Radius of helical path

$$\boxed{r = \frac{mv\sin\theta}{Bq}}$$

- Time period and

$$\boxed{T = \frac{2\pi m}{qB}}$$

- Frequency of helical path

$$\boxed{f = \frac{1}{T} = \frac{qB}{2\pi m}}$$

- Pitch of the helical path

$$\boxed{p = (v\cos\theta)T = \frac{2\pi mv\cos\theta}{Bq}}$$

5. Magnetic force on a current carrying conductor

- In Vector Form

$$\boxed{\vec{F}_m = I\vec{l} \times \vec{B}}$$

- In Magnitude Form

$$\boxed{F_m = IlB\sin\theta}$$

Here θ is the angle between $\vec{l}\ and\ \vec{B}$ or between direction of current and magnetic field.

6. Lorentz Force

The total force on a charge Q moving in the presence of both electric and magnetic field is given by

$$\boxed{\vec{F} = \vec{F}_e + \vec{F}_m = Q\left(\vec{E} + \vec{v} \times \vec{B}\right)}$$

7. Velocity selector

Path of a charged particle in uniform electric and magnetic field will remain unchanged if,

$$\boxed{\vec{F}_{net} = 0 \text{ or } q(q\vec{E} + q\vec{v} \times \vec{B}) = 0 \text{ or } \vec{E} = -\vec{v} \times \vec{B} \text{ or } \vec{E} = \vec{B} \times \vec{v}}$$

8. Cyclotron

- The frequency of revolution of the particle

$$\boxed{f = \frac{qB}{2\pi m}}$$

- The Energy Gained by Charged particles

$$\boxed{K = \frac{1}{2}mv^2 = \frac{1}{2}\left(\frac{q^2B^2R^2}{m}\right)}$$

9. Magnetic dipole: and Magnetic dipole moment (unit Am)

- Current carrying loop is a magnetic dipole.
- Magnetic dipole moment of magnetic dipole

$$\boxed{M = NIA}$$

- Direction of $\vec{M}$ is the perpendicular to the plane of loop and given by right hand screw law.

10. Potential energy stored in dipole

$$\boxed{U = -\vec{M}.\vec{B} \text{ or } U = -MB\cos\theta}$$

11. Work done in rotating dipole against torque

$$\boxed{W_{\theta_1 \to \theta_2} = U_{\theta_2} - U_{\theta_1} = MB(\cos\theta_1 - \cos\theta_2)}$$

12. Biot-Savart Law

$$\boxed{d\vec{B} = \frac{\mu_0}{4\pi}\left(\frac{I\vec{dl} \times \vec{r}}{r^3}\right) \text{ or } dB = \frac{\mu_0}{4\pi}\left(\frac{Idl\sin\theta}{r^2}\right)}$$

13. Magnetic field of a moving point charge

The magnetic field vector $\vec{B}$ at point P at position vector $\vec{r}$ from the charge q moving with a velocity $\vec{v}$

$$\boxed{\vec{B} = \frac{\mu_0}{4\pi}\left[\frac{q(\vec{v} \times \vec{r})}{r^3}\right] \text{ or } B = \frac{\mu_0}{4\pi}\left(\frac{qv\sin\theta}{r^2}\right)}$$

14. Magnetic field induction at a point due to a straight wire carrying current I

- Magnetic field due at a point due to a straight wire of finite length (wire is held vertically)

$$\boldsymbol{B = \left(\frac{\mu_0 I}{4\pi x}\right)(\sin\alpha + \sin\beta)}$$

- Magnetic field at a point due to a straight wire of infinite length

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

- Magnetic field at a point due a straight wire with one end finite and other end infinite

$$\boldsymbol{B = \frac{1}{2}\left(\frac{\mu_0 I}{2\pi r}\right) = \frac{\mu_0 I}{4\pi r}}$$

- Magnetic field created by long current carrying wire
  - r > R

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

  - r < R

$$\boldsymbol{B = \frac{\mu_0 I r}{2\pi R^2}}$$

15. Magnetic field induction at a point due to a circular wire carrying current I

- Magnetic field on the axis (either x, y or z-axis) of a circular loop (say, if coil placed in y-z plane so, $B_y = 0$, $B_z = 0$ and B_x

$$\boldsymbol{B_x = \frac{\mu_0 I R^2}{2(R^2 + x^2)^{\frac{3}{2}}}}$$

- Magnetic field at the centre (O) of ring (or circular loop)

$$\boldsymbol{B_o = \frac{\mu_0 I}{2R}}$$

- If circular loop has N number of turns then magnetic field at its centre of radius R and carries current I

$$\boldsymbol{B = \frac{\mu_0 N I}{2R}}$$

- Magnetic field when x >> R for N circular loops on axial position

$$B_x = \frac{\mu_0 N I R^2}{2x^3} = \frac{\mu_0 N I}{4\pi}\left(\frac{2\pi R^2}{x^3}\right) = \frac{\mu_0}{4\pi}\left(\frac{2NIA}{x^3}\right) = \frac{\mu_0}{4\pi}\left(\frac{2M}{x^3}\right)$$

- Magnetic field due to an arc of a circle at the centre(O)

$$\boxed{B = \left(\frac{\theta}{2\pi}\right)\frac{\mu_0 I}{2R}}$$

16. Ampere circuital law

$$\boxed{\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{net}}$$

17. Magnetic field induction due to a solenoid carrying current I

- Magnetic field at the axis of a solenoid

$$\boxed{B = \frac{1}{2}\mu_0 nI(\cos\theta_1 - \cos\theta_2)}$$

- Magnetic field at the centre (on the axis) of a long solenoid

$$\boxed{B(centre) = \mu_0 nI}$$

- Magnetic field at ends of a long solenoid

$$\boxed{B(end) = \frac{1}{2}\mu_0 n}$$

18. Magnetic field induction due to a toroid carrying current I: (JEE/NEET Enrichment)

- Magnetic field due to toroid

$$\boxed{B = \frac{\mu_0 NI}{2\pi r} = \mu_0 nI}$$

Where

$$\boxed{n = \frac{N}{2\pi r} = \frac{n}{l}}$$

- Speed of light

$$\boxed{c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}}$$

18. Force between Two Long Parallel Wires

- Force on any one wire due to other parallel wire

$$\boxed{F = \frac{\mu_0}{2\pi}\left(\frac{I_1 I_2 L}{d}\right)}$$

- $\frac{\mu_0}{2\pi} = 2 \times 10^{-7}$H/m

19. Moving coil Galvanometer:

$$\boldsymbol{deflection, \varphi \propto current\ in\ the\ coil\ (I)}$$

Torque-

$$\boldsymbol{\tau = MB\sin\theta = (NIA)B\sin\theta}$$

This torque is balanced by spring in galvanometer, called spring torque or counter torque as in equilibrium,

$$k\varphi = NIAB$$

Here, k is the torsional constant of the spring. So,

$$\boldsymbol{I = \left(\frac{k}{NAB}\right)\varphi}$$

Hence, the current $I \propto \varphi$; $\boldsymbol{Galvanometer\ constant} = \frac{\boldsymbol{k}}{\boldsymbol{NAB}}$

20. Sensitivity of Galvanometer:

- Current sensitivity

  Deflection per unit current is called current sensitivity

$$\boldsymbol{current\ sensitivity = \frac{\varphi}{I} = \frac{NAB}{k}}$$

- Voltage sensitivity

  Deflection per unit P.D. is applied across the coil

$$\boldsymbol{Voltage\ sensitivity = \frac{\varphi}{V} = \frac{\varphi}{IR} = \frac{NBA}{kR}}$$

$$\boldsymbol{Current\ sensitivity = R(Voltage\ sensitivity)}$$

21. Conversion of galvanometer in to an ammeter:

A very low resistance is connected in parallel with a galvanometer

$$\boldsymbol{I_g = I\frac{R_{sh}}{R_{sh} + R_g}}$$

Hence an ammeter is a shunted or low resistance across a galvanometer.
Its effective resistance is,

$$\boldsymbol{R_A = \frac{R_g R_{sh}}{R_g + R_{sh}} < R_{sh}}$$

22. Conversion of galvanometer into a voltmeter

A high resistance is connected in series with galvanometer to make a voltmeter.

$$V = I(R_g + R_s)$$

And total resistance of the circuit (resistance of voltmeter) is given by-

$$\boxed{R_V = R_g + R_s \gg R_g}$$

23. Bohr's Magneton

$$\boxed{\boldsymbol{M = \frac{evr}{2}}}$$

$$M_{min} = \frac{eh}{4\pi m} \text{ is called Bohr's magneton.}$$

Chapter-5: Magnetism and Matter-Formulae

1. Magnetic Dipole Moment

$$\boxed{M = 2lm}$$

2. Magnetic field at an axial point due to a short magnet

$$\boxed{B = \frac{\mu_0}{4\pi}\left(\frac{2M}{r^3}\right)}$$

3. Magnetic field at equatorial position due to a short magnet

$$\boxed{B = \frac{\mu_0}{4\pi}\left(\frac{M}{r^2}\right)}$$

4. A current loop placed in a magnetic field $\vec{B}$ experiences a torque

$$\boxed{\vec{\tau} = \vec{M} \times \vec{B}}$$

5. A magnetic pole strength m placed in a magnetic field $\vec{B}$ experiences a force

$$\boxed{\vec{F} = m\vec{B}}$$

6. Intensity of Magnetisation$(\vec{I})$

$$\boxed{I = \frac{M}{V}}$$

7. Magnetic Intensity or magnetic field strength$(\vec{H})$:

$$\boxed{\vec{B} = \vec{B}_0 + \vec{B}_M \Rightarrow \vec{B} = \mu_0\vec{H} + \mu_0\vec{I}}$$

8. Magnetic permeability

$$\boxed{\mu = \frac{B}{H}}$$

9. Relative magnetic permeability(μ_r)

$$\boxed{\mu_r = \frac{\mu}{\mu_0}}$$

$$\boxed{\mu_r = \frac{B}{B_0}}$$

10. Magnetic susceptibility (χ_m)

$$\boxed{\chi_m = \frac{I}{H}}$$

11. Relation between relative permeability and magnetic susceptibility:

$$\boxed{\mu_r = 1 + \chi_m}$$

12. Curie's Law

$$\boxed{\chi_m \propto \frac{1}{T} \ or \ \chi_m = \frac{C}{T}}$$

13. Curie-Weiss law

$$\boxed{\chi_m = \frac{C}{T - T_C}}$$

14. For Paramagnetic Material

$$\boxed{\mu_r > 1}$$

$$\boxed{\mu > \mu_0}$$

$$\boxed{X_m \ slightly \ positive}$$

$$\boxed{X_m \propto \frac{1}{T}}$$

15. For Diamagnetic Material

$$\boxed{\mu_r < 1}$$

$$\boxed{\mu < \mu_0}$$

$$\boxed{X_m \ slightly \ negative}$$

$$\boxed{X_m \ independent \ of \ temperature}$$

(parallel to temperature axis and negative)

16. For Ferromagnetic Material

$$\boxed{\mu_r \gg 1}$$

$$\boxed{\mu \gg \mu_0}$$

$$\boxed{X_m \propto \frac{1}{T - T_C}}$$

17. Work done to rotate a magnet from θ_1 to θ_2 in the uniform magnetic field

$$\boxed{W = MB(\cos\theta_1 - \cos\theta_2)}$$

Chapter-6: Electromagnetic Induction

1. Magnetic flux

$$\varphi = BS\cos\theta$$

Or

$$\varphi = \vec{B}\cdot\vec{S}$$

2. Gauss's law of magnetism

$$\oint \vec{B}.\overrightarrow{dS} = 0$$

3. Faraday's law of electromagnetic induction

$$e = -N\frac{d\varphi}{dt}$$

4. Induced current

$$i = \frac{e}{R} = \frac{1}{R}\left(\frac{-d\varphi}{dt}\right)$$

5. Motional emf

$$e = vbL\sin\theta$$

(Where θ = angle between conductor velocity and length of conductor from vertical)
If $\theta = 90^0$, then

$$e = vbL$$

6. Current induced in the loop:

$$i = \frac{e}{R} = \frac{vBl}{R}$$

7. Force experienced in the movable conductor of length l carrying current I, is given by

$$F = Ilb\sin 90^0 = IlB = \frac{vBl}{R}(lB) = \frac{B^2l^2v}{R}$$

8. If r is the internal resistance of the battery then, the current in the circuit is,

$$i = \frac{e}{R+r} = \frac{vBl}{R+r}$$

9. Power delivered by the external force:

$$P_{del} = Fv = \frac{B^2l^2v}{R}v = \frac{B^2l^2v^2}{R}$$

10. If a conductor is moving in a circular path with one end fixed at the centre of the circle, then Induced emf across the conductor

$$e = \frac{1}{2}B\omega L^2$$

Or

$$e = \pi f BL^2$$

11. Self-inductance of a coil

$$L = \frac{N\varphi}{I}$$

And

$$L = \left|\frac{-e}{\frac{dI}{dt}}\right|$$

Or

$$e = -L\frac{dI}{dt}$$

PD across a coil

$$v = -e = L\frac{dI}{dt}$$

12. Self-inductance of the solenoid

$$L = \frac{\mu_0 N^2 A}{l}$$

13. Energy (potential energy) stored in an inductor in magnetic field,

$$U = \frac{1}{2}Li^2$$

14. Energy density in magnetic field,

$$u = \frac{U}{V} = \frac{1}{2}\left(\frac{B^2}{\mu_0}\right)$$

15. Mutual Inductance (M):

$$M = \frac{N_2\varphi_2}{I_1}$$

Or

$$e_2 = -M\frac{di_1}{dt}$$

16. Mutual Inductance between two coaxial solenoids

$$M = \frac{\mu_0 N_1 N_2 A}{l}$$

Chapter-7: Alternating Current

1. AC Generator

$$\varphi = BA\cos\theta = BA\cos\omega t$$

$$e = -N\frac{d\varphi}{dt}$$

$$e = E_0 \sin\omega t$$

$$E_0 = NBA\omega = 2\pi f NBA$$

2. Average value of Voltage over half cycle of ac wave

$$V_{av} = \frac{2V_0}{\pi} = 0.637V_0$$

3. Average value of Current over half cycle of ac wave

$$I_{av} = \frac{2I_0}{\pi} = 0.637I_0$$

4. Phase and Phase Difference:

   In the circuit, $V = V_0 \sin(\omega t \pm \varphi_0)$ and $i = I_0 \sin(\omega t \pm \varphi_0)$

   Phase

$$\omega t \pm \varphi_0$$

   (φ_0 = initial phase angle)

   In the circuit, $V = V_0 \sin(\omega t \pm \theta_1)$ and $i = I_0 \sin(\omega t \pm \theta_2)$

   Phase Difference

$$\varphi = (\pm\theta_1) - (\pm\theta_2)$$

   (With respect to current phase)

5. Instantaneous Voltage Equation

$$V = V_0 \sin(\omega t \pm \varphi) \;\; or\; V = V_0 \cos(\omega t \pm \varphi)$$

6. Instantaneous Current Equation

$$i = I_0 \sin(\omega t \pm \varphi) \;\; or\; i = I_0 \cos(\omega t \pm \varphi)$$

   The phase angle ϕ is between voltage and current.

7. Relation between Time Period, Frequency and Angular Frequency

$$T = \frac{2\pi}{\omega} \; or\; \omega = 2\pi f$$

8. Root mean square (rms) value of current over one full cycle

$$I_{rms} = \frac{I_0}{\sqrt{2}} = 0.707\ I_m$$

9. Root mean square (rms) value of voltage over one full cycle

$$V_{rms} = \frac{V_0}{\sqrt{2}} = 0.707 V_m$$

10. Power Factor of the Circuit

$$Power\ factor = \frac{Actual\ Power}{Apparent\ Power} = \cos\varphi = \frac{R}{Z}$$

11. Impedance of the LCR series ac circuit is Z.

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

12. Average Power in the LCR series ac circuit

$$P_{av} = V_{rms} I_{rms} \cos\varphi$$

13. Purely Resistive ac circuit

If

$$V = V_0 \sin\omega t$$

Then

$$i = I_0 \sin\omega t$$

$$Z = R$$

$$R = \frac{V_{rms}}{I_{rms}} = \frac{V_0}{I_0}$$

$$V_R = I_{rms} R$$

$$P_{av} = {I_{rms}}^2 R = \frac{{V_{rms}}^2}{R} = \frac{{I_0}^2 R}{2}$$

14. Purely Inductive ac Circuit

If

$$V = V_0 \sin\omega t$$

Then

$$i = I_0 \sin\left(\omega t - \frac{\pi}{2}\right)$$

$$X_L = \omega L = 2\pi f L$$

$$\boxed{Z = X_L}$$

$$\boxed{V_L = I_{rms}X_L}$$

$$\boxed{P_{av} = 0}$$

$$\boxed{Wattless\ Current = I_{rms}\sin\varphi}$$

15. Purely Capacitive Circuit

If

$$\boxed{V = V_m \sin \omega t}$$

Then

$$\boxed{i = I_m \sin\left(\omega t + \frac{\pi}{2}\right)}$$

$$\boxed{X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}}$$

Or

$$\boxed{C = \frac{1}{2\pi f X_C}}$$

$$\boxed{V_C = I_{rms}X_C}$$

$$\boxed{Z = X_C}$$

16. R-L circuit

If

$$\boxed{V = V_m \sin \omega t}$$

Then

$$\boxed{i = I_m \sin(\omega t - \varphi)}$$

$$\boxed{Z = \sqrt{R^2 + {X_L}^2}}$$

$$\boxed{V = \sqrt{{V_R}^2 + {V_L}^2}}$$

$$\tan\varphi = \frac{X_L}{R} = \frac{\omega L}{R}$$

17. R-C circuit

If

$$V = V_m \sin\omega t$$

Then

$$i = I_m \sin(\omega t + \varphi)$$

$$z = \sqrt{R^2 + X_C{}^2}$$

$$\tan\varphi = \frac{X_C}{R} = \frac{1}{\omega CR}$$

18. In phasor representation in R-L circuit (inductive circuit),

$$\bar{Z} = R + jX_L$$

Or

$$\bar{V} = V_R + jV_L$$

LCR ac series circuit (also called Adaptor circuit)

RMS values of

$$V_R = I_{rms}R$$

$$V_L = I_{rms}X_L$$

$$V_C = I_{rms}X_C$$

Applied Voltage

$$V_{applied} = I_{rms}Z = \sqrt{V_R{}^2 + (V_L - V_C)^2}$$

For Inductive LCR series ac circuit,

If

$$V = V_0 \sin\omega t$$

Then

$$i = I_0 \sin(\omega t - \varphi)$$

For Capacitive LCR series ac circuit,

If

$$\boxed{V = V_0 \sin \omega t}$$

Then

$$\boxed{i = I_0 \sin(\omega t + \varphi)}$$

19. Resonance in LCR series ac circuit

Resonant frequency

$$\boxed{\omega_r = \frac{1}{\sqrt{LC}}}$$

Resonance Condition

$$\boxed{\omega = \omega_r}$$

$$\boxed{X_L = X_C}$$

$$\boxed{V_L = V_C}$$

20. Quality factor Q is defined as

$$\boxed{Q = \frac{Resonant\ frequency}{Bandwidth} = \frac{\omega_r}{\omega_2 - \omega_1}}$$

21. Quality factor at resonance is

$$\boxed{Q = \frac{\omega_r}{\omega_2 - \omega_1} = \frac{\omega_r L}{R}}$$

22. Quality factor can be in another form as,

$$\boxed{Q = \frac{1}{R}\left(\sqrt{\frac{L}{C}}\right)}$$

23. Transformer:

Transformation ratio

$$\boxed{\frac{e_s}{e_p} = \frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{\eta I_p}{I_s}}$$

For an ideal transformer, there is no loss of power.

$$\boxed{\frac{e_s}{e_p} = \frac{N_s}{N_p} = \frac{i_p}{i_s}}$$

Efficiency of a Transformer

$$\boxed{Efficiency(\eta) = \frac{Output\ Power}{Input\ Power \times Power\ Factor}}$$

Chapter-8: Electromagnetic Waves

1. Displacement Current

$$\boxed{I_d = \epsilon_0 \frac{d\varphi_E}{dt}}$$

For a suitable uniform-field situation:

$$\boxed{I_d = \epsilon_0 A \frac{dE}{dt}}$$

2. For EM Wave, Direction of Oscillations and Propagation of wave

$$\boxed{\vec{E} \times \vec{B} = \vec{v}}$$

3. Electromagnetic Wave

In vacuum, the speed of electromagnetic waves

$$\boxed{c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}}$$

For an electromagnetic wave travelling through vacuum,

$$\boxed{E_0 = cB}$$

Therefore,

$$\boxed{c = \frac{E_0}{B_0}}$$

4. Frequency and Wavelength

For every electromagnetic wave,

$$\boxed{c = f\lambda}$$

$$\boxed{\lambda = \frac{c}{f}}$$

And

$$\boxed{f = \frac{c}{\lambda}}$$

5. Frequency–Wavelength–Energy Relationship

Photon Energy

$$\boxed{E = hf}$$

$$\boxed{E = \frac{hc}{\lambda}}$$

6. Photon Momentum

$$\boxed{p = \frac{E}{c}}$$

$$\boxed{p = \frac{hf}{c}}$$

$$\boxed{p = \frac{h}{\lambda}}$$

7. Energy Transported by Electromagnetic Waves

Electric and Magnetic Energy Density

For the electric field:

$$\boxed{u_E = \frac{1}{2}\epsilon_0 E^2}$$

For the magnetic field:

$$\boxed{u_B = \frac{1}{2}\left(\frac{B^2}{\mu_0}\right)}$$

For an electromagnetic wave in vacuum:

$$\boxed{u_E = u_B}$$

8. Intensity

$$\boxed{I = \frac{Energy}{Area \times time}}$$

$$\boxed{I \propto {E_0}^2}$$

$$\boxed{I \propto {B_0}^2}$$

9. Radiation Pressure

For complete absorption:

$$\boxed{P = \frac{I}{c}}$$

For complete reflection,

$$\boxed{P = \frac{2I}{c}}$$

10. Poynting Vector

$$\boxed{\vec{S} = \frac{1}{\mu_0}\left(\vec{E} \times \vec{B}\right)}$$

Chapter-9: Ray Optics

Reflection of Light Through a Spherical Mirror

1. Relation between radius of Curvature and focal length

$$\boxed{R = 2f}$$

2. Relation between object distance, image distance and focal length

Mirror Formula

$$\boxed{\frac{1}{v} + \frac{1}{u} = \frac{1}{f}}$$

Magnification (Linear or transverse or lateral}

$$\boxed{m = \frac{h_I}{h_o} = -\frac{v}{u}}$$

Refraction of Light through a Spherical Lens

4. Relation between object distance, image distance and focal length

Lens Formula

$$\boxed{\frac{1}{v} - \frac{1}{u} = \frac{1}{f}}$$

Magnification Formula

$$\boxed{m = \frac{h_I}{h_0} = \frac{v}{u}}$$

Refraction of Light Through One Plane Surface

5. Snell's law

$$\boxed{\mu_1 \sin\theta_1 = \mu_2 \sin\theta_2}$$

6. Absolute Refractive Index

$$\boxed{\mu = \frac{speed\ of\ light\ in\ vacuum}{speed\ of\ light\ in\ medium} = \frac{c}{v}}$$

7. Relative Refractive Indices

$$\boxed{\mu_{21} = \frac{\mu_2}{\mu_1}, \mu_{12} = \frac{\mu_1}{\mu_2}}$$

Or

$$\boxed{Refractive\ index\ of\ medium - 2\ with\ respect\ to\ medium - 1 = \frac{\mu_2}{\mu_1} = \mu_{21}}$$

And

$$\boxed{Refractive\ index\ of\ medium - 1\ with\ respect\ to\ medium - 2 = \frac{\mu_1}{\mu_2} = \mu_{12}}$$

8. Relation between refractive index (μ) and speed of light (v)

$$\boxed{\mu v = constant}$$

Or

$$\boxed{\mu_1 v_1 = \mu_2 v_2}$$

9. Relation between refractive index and wavelength of light

$$\boxed{\mu\lambda = constant}$$

Or

$$\boxed{\mu_1 \lambda_1 = \mu_2 \lambda_2}$$

10. Relation between refractive index, real depth and apparent depth

$$\boxed{Apparent\ depth = \frac{Real\ depth}{\mu}}$$

Or

$$\boxed{Apparent\ depth = \frac{Real\ depth}{\frac{\mu}{\mu_0}}}$$

11. Lateral Displacement

$$\boxed{\mathrm{d} = \mathrm{t}\frac{\sin(i-r)}{\cos r}}$$

Or

$$\boxed{d = t\sin i\left[1 - \frac{\cos i}{(\mu^2 - sin^2 i)^{\frac{1}{2}}}\right]}$$

12. Critical Angle

$$\boxed{\sin i_C = \frac{\mu_R}{\mu_D}}$$

Where,

μ_R = Refractive index of rarer medium and

μ_D = Refractive index of denser medium

Refraction of Light through Curved Spherical Lenses

13. When light travels from rarer medium to denser medium

$$\boxed{\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}}$$

14. When light travels from rarer medium to denser medium

$$\boxed{\frac{\mu_1}{v} - \frac{\mu_2}{u} = \frac{\mu_1 - \mu_2}{R}}$$

Lens Maker Formula

15. When same medium μ_1 around a lens of refractive index (μ_2)

$$\boxed{\frac{1}{f} = \left(\frac{\mu_2}{\mu_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)}$$

16. When air $(\mu_1 = 1)$ around a lens

$$\boxed{\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)}$$

17. One medium refractive index (μ_1) to face surface-1 of radius of curvature R_1, lens refractive index μ_2 and towards second face surface-2, refractive index μ_3, that is, light is travelling from rarer medium (μ_1) to denser medium $(lens\ \mu_2)$ and then to rarer medium (μ_3)
Then

$$\boxed{\frac{\mu_3}{f} = \left(\frac{\mu_2 - \mu_1}{R_1}\right) + \left(\frac{\mu_3 - \mu_2}{R_2}\right)}$$

18. Power of a lens

$$\boxed{P = \frac{1}{f}}$$

Combined Focal Length of Two or More Thin Lenses in Contact

19. Combined focal length of two thin lenses in contact

$$\boxed{\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}}$$

20. Combined focal length of more than two thin lenses in contact

$$\boxed{\frac{1}{f} = \sum_{i=1}^{n} \frac{1}{f_i}}$$

Or

$$\boxed{\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3} + -------}$$

21. Combined Power of two thin lenses in contact

$$\boxed{P = P_1 + P_2}$$

22. Combined Magnification

$$\boxed{m = m_1 \times m_2}$$

Refraction of Light through a Equilateral Triangular Prism

23. Deviation angle in equilateral

$$\boxed{\delta = i + e - A}$$

24. Minimum deviation angle

$$\boxed{\delta_{min} = 2i - A = 2e - A}$$

25. Refractive index at minimum deviation angle

$$\mu = \frac{\sin\left(\frac{A+\delta_{min}}{2}\right)}{sin\left(\frac{A}{2}\right)}$$

Optical Instruments

Simple Microscope

26. Magnifying Power when final image is formed at least distance of distinct Vision (D)

$$M_D = 1 + \frac{D}{f_e}$$

27. Magnifying Power when final image is formed infinity (normal adjustment)

$$M_\infty = \frac{D}{f_e}$$

Compound Microscope

28. Magnifying Power when final image is formed at least distance of distinct Vision (D)

$$M_D = -\frac{v_0}{u_0}\left(1 + \frac{D}{f_e}\right)$$

29. Tube length (distance between two lenses) in case of final image at D

$$L_D = v_0 + |u_e|$$

30. Magnifying Power when final image is formed infinity (normal adjustment)

$$M_\infty = -\frac{v_0}{u_0} \times \frac{D}{f_e}$$

31. Tube length (distance between two lenses) in case of final image at infinity

$$L_\infty = v_0 + f_e$$

32. Magnifying Power when final image formed at near point

$$M_{near\ point} = -\frac{L}{f_0}\left(1 + \frac{D}{f_e}\right)$$

Astronomical Refractive Telescope

33. Magnifying Power when final image formed at least distance of distinct vision

$$M_D = -\frac{f_0}{f_e}\left(1 + \frac{f_e}{D}\right)$$

34. Magnifying Power when final image is formed at infinity

$$M_\infty = -\frac{f_0}{f_e}$$

35. Tube length when final image formed at least distance of distinct vision

$$\boxed{L_D = f_0 + |u_e|}$$

36. Tube length when final image formed at infinity

$$\boxed{L_\infty = f_0 + f_e}$$

Chapter -10: Wave Optics

1. BASIC WAVE RELATIONS

Wave velocity

$$v = f\lambda$$

Frequency

$$f = \frac{1}{T}$$

Time period

$$T = \frac{1}{f}$$

Angular frequency

$$\omega = 2\pi f$$

Therefore:

$$\omega = \frac{2\pi}{T}$$

and:

$$T = \frac{2\pi}{\omega}$$

Wave number

$$k = \frac{2\pi}{\lambda}$$

Therefore:

$$\lambda = \frac{2\pi}{k}$$

Relation between velocity, angular frequency and wave number

$$v = \frac{\omega}{k}$$

2. EQUATION OF A PROGRESSIVE WAVE

A sinusoidal progressive wave can be represented as:

$$y = A\sin(kx - \omega t + \varphi)$$

Where: A = amplitude, k = wave number, ω = angular frequency, φ = initial phase

3. PHASE DIFFERENCE

Phase difference corresponding to path difference Δ:

$$\varphi = \frac{2\pi\Delta}{\lambda}$$

Therefore:

$$\Delta = \frac{\lambda\varphi}{2\pi}$$

Important cases:

If: $\Delta = \lambda$

Then: $\varphi = 2\pi$

If: $\Delta = \lambda/2$
Then: $\varphi = \pi$
If: $\Delta = \lambda/4$
Then: $\varphi = \pi/2$

---

4. WAVEFRONT

Definition

Wavefront is an imaginary surface joining all points of a wave which are in the same phase.

Important relation

Ray of light is perpendicular to Wavefront.

Types of wavefront

1. Spherical wavefront
2. Cylindrical wavefront
3. Plane wavefront

Distance between two successive wavefronts

$$\boxed{\lambda}$$

---

5. HUYGENS' PRINCIPLE

Every point on a wavefront acts as a source of secondary wavelets.
After time dt, radius of each secondary wavelet is:

$$\mathbf{r = v\,dt}$$

Where: v = wave velocity, dt = time interval

---

6. REFLECTION OF LIGHT

According to Huygens' construction:

$$\mathbf{i = r}$$

Where: i = angle of incidence, r = angle of reflection, **Laws of reflection**
The incident ray, reflected ray and normal lie in the same plane.

---

7. REFRACTION OF LIGHT

Refractive index

$$\boxed{\mu = \frac{c}{v}}$$

Where: c = speed of light in vacuum, v = speed of light in medium

---

8. SNELL'S LAW

For refraction from medium 1 to medium 2:

$$\boxed{\mu_1 \sin i = \mu_2 \sin r}$$

Therefore:

$$\boxed{\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1}}$$

---

9. RELATIVE REFRACTIVE INDEX

Relative refractive index of medium 2 with respect to medium 1:

$$\boxed{\mu_{21} = \frac{\mu_2}{\mu_1}}$$

Also:

$$\boxed{\mu_{21} = \frac{v_1}{v_2}}$$

and:

$$\boxed{\mu_{21} = \frac{\lambda_1}{\lambda_2}}$$

10. WAVELENGTH IN A MEDIUM

For light entering a medium of refractive index μ:

$$\boxed{\lambda_m = \frac{\lambda_0}{\mu}}$$

Where: λ_0 = wavelength in vacuum; λ_m = wavelength in medium
Important:

Frequency remains unchanged.

Therefore:

$$\boxed{f_m = f_0}$$

But generally:

$$\boxed{v_m \neq v_0}$$

and:

$$\boxed{\lambda_m \neq \lambda_0}$$

11. PRINCIPLE OF SUPERPOSITION

For two waves:

$$y = y_1 + y_2$$

For n waves:

$$y = y_1 + y_2 + y_3 + \dots + y_n$$

12. INTENSITY AND AMPLITUDE RELATION

$$\boxed{I \propto A^2}$$

13. RESULTANT AMPLITUDE

For two waves of amplitudes a_1 and a_2 with phase difference φ:

$$\boxed{A = \sqrt{{a_1}^2 + {a_2}^2 + 2a_1a_2\cos\varphi}}$$

Same phase

If: $\varphi = 0$
Then: **Amax = $a_1 + a_2$**

Opposite phase

If: $\varphi = \pi$
Then: **Amin = $|a_1 - a_2|$**

14. INTERFERENCE OF LIGHT

Interference is the redistribution of intensity produced by superposition of coherent light waves.

Coherent sources

Two sources are coherent if they have:

- Same frequency
- Constant phase difference

15. RESULTANT INTENSITY

For two coherent waves:

$$\boxed{I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\varphi}$$

where: φ = phase difference

16. MAXIMUM INTENSITY

For constructive interference:

φ = 2nπ

Therefore:

$$\boxed{I_{max} = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2}$$

17. MINIMUM INTENSITY

For destructive interference:

φ = (2n - 1)π

Therefore:

$$\boxed{I_{min} = \left(\sqrt{I_1} - \sqrt{I_2}\right)^2}$$

18. EQUAL-INTENSITY INTERFERENCE

If: $I_1 = I_2 = I_0$

Then:

$$\boxed{I_r = 4I_0 cos^2\left(\frac{\varphi}{2}\right)}$$

Maximum intensity

$$\boxed{I_{max} = 4I_0}$$

Minimum intensity

$$\boxed{I_{min} = 0}$$

19. CONDITIONS OF INTERFERENCE

Constructive Interference

Phase condition:

$$\boxed{\varphi = 2n\pi}$$

Path condition:

$$\boxed{\Delta = n\lambda}$$

Where, n = 0, $\pm 1;\ \pm 2;\ \pm 3;\ ----$

Result:

Bright fringe

Destructive Interference

Phase condition:

$$\boxed{\varphi = (2n - 1)\pi}$$

Path condition:

$$\boxed{\Delta = (2n - 1)\frac{\lambda}{2}}$$

Result:

Dark fringe

where:

n = ±1; ±2; ±3; − − − − −

20. VISIBILITY OF FRINGES

Visibility:

$$\boxed{V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}}$$

For two interfering waves:

$$\boxed{V = \frac{2\sqrt{I_1 I_2}}{I_1 + I_2}}$$

For equal intensities:

$$\boxed{V = I}$$

Thus, maximum visibility occurs when:

$$\boxed{I_1 = I_2}$$

21. YOUNG'S DOUBLE-SLIT EXPERIMENT

Let:

d = separation between two slits

D = distance between slits and screen

λ = wavelength of light

y = distance of point P from central axis

Usually:

D >> **d**

22. PATH DIFFERENCE IN YDSE

Exact geometrical relation:

$$\boxed{\Delta = d \sin\theta}$$

For small angle: sinθ ≈ tanθ and:

tanθ = y/D

Therefore:

$$\boxed{\Delta = \frac{\mathrm{yd}}{\mathrm{D}}}$$

23. BRIGHT FRINGE IN YDSE

Condition: **Δ = nλ**

Therefore:

$$\boxed{y_{bright} = \frac{nD\lambda}{d}}$$

For central bright fringe:

n = 0

Therefore:

$$y_0 = 0$$

24. DARK FRINGE IN YDSE

Condition:

Δ = (2n - 1)λ/2

Therefore:

$$\boxed{y_{dark} = \frac{(2n-1)D\lambda}{2d}}$$

25. FRINGE WIDTH

Fringe width is the distance between two successive bright fringes or two successive dark fringes.

$$\boxed{\beta = \frac{D\lambda}{d}}$$

Therefore:

$\beta \propto \lambda$

$\beta \propto D$

$\beta \propto 1/d$

26. ANGULAR FRINGE WIDTH

Angular fringe width:

$$\boxed{\Delta\theta = \frac{\lambda}{d}}$$

Relation between linear and angular fringe width:

$$\boxed{\beta = D\Delta\theta}$$

β = DΔθ

27. YDSE IN A MEDIUM

If refractive index of medium is μ:

$$\boxed{\mu_m = \frac{\lambda_0}{\mu}}$$

Therefore:

$$\boxed{\beta_m = \frac{\beta_0}{\mu}}$$

Thus: $\beta_m < \beta_0$ for $\mu > 1$.

28. YDSE RATIO FORMULA

For two different situations:

$\beta_1 = \lambda_1 D_1/d_1$

$\beta_2 = \lambda_2 D_2/d_2$

Therefore:

$$\boxed{\frac{\beta_2}{\beta_1} = \frac{D_2\lambda_2 d_1}{D_1\lambda_1 d_2}}$$

This is particularly useful for NEET/JEE numerical problems.

29. DIFFRACTION OF LIGHT
Diffraction is the bending or spreading of light waves around obstacles or through narrow apertures.
Diffraction becomes appreciable when:

$$\boxed{a \approx \lambda}$$

Where:
a = slit width

---

30. SINGLE-SLIT DIFFRACTION
For a single slit of width a:
Path difference:

$$\boxed{\Delta = a \sin\theta}$$

---

31. CONDITION FOR MINIMA
General condition:
$a \sin\theta = m\lambda$
Where:
m = 1, 2, 3,--------
For first minimum:
$a \sin\theta_1 = \lambda$
For small angle:
$\theta_1 \approx \lambda/a$

---

32. ANGULAR WIDTH OF CENTRAL MAXIMUM
First minimum occurs at approximately:
$\theta_1 \approx \lambda/a$
Therefore, central maximum extends from $-\theta_1$ to $+\theta_1$.
Hence:

$$\boxed{\Delta\theta \approx \frac{2\lambda}{a}}$$

---

33. LINEAR WIDTH OF CENTRAL MAXIMUM
For a screen at distance D:

$$\boxed{W = \frac{2D\lambda}{a}}$$

Therefore:
$W \propto \lambda$
$W \propto D$
$W \propto 1/a$

Important concept
Narrower slit → Greater diffraction
Wider slit → Smaller diffraction

---

34. INTERFERENCE vs DIFFRACTION
Interference
$\beta = \lambda D/d$
where d = separation between coherent slits.

Diffraction

$W = 2\lambda D/a$

Where a = width of single slit.

Remember:

d → YDSE slit separation

a → Diffraction slit width

---

35. POLARISATION

Polarisation is the phenomenon of restricting vibrations of a transverse light wave to a particular direction.

Important conclusion

Polarisation proves the transverse nature of light.

---

36. MALUS' LAW

If plane-polarised light of intensity I_0 falls on an analyser at angle θ:

$$\boxed{I = I_0 cos^2\theta}$$

---

37. SPECIAL CASES OF MALUS' LAW

At:

$\theta = 0°$

$I = I_0$

At:

$\theta = 30°$

$I = 3I_0/4$

At:

$\theta = 45°$

$I = I_0/2$

At:

$\theta = 60°$

$I = I_0/4$

At:

$\theta = 90°$

$I = 0$

---

38. UNPOLARISED LIGHT THROUGH A POLARISER

For ideal polariser:

$I = I_0/2$

where I_0 is the intensity of incident unpolarised light.

---

39. POLARISER + ANALYSER

For unpolarised light of intensity I_0:

After polariser:

$I_1 = I_0/2$

After analyser:

$I = (I_0/2) \cos^2\theta$

---

40. CROSSED POLAROIDS

If:

$\theta = 90°$

then:

$I = (I_0/2)\cos^2 90°$

Therefore:

$\mathbf{I = 0}$

---

41. THREE-POLAROID ARRANGEMENT

If first and third Polaroids are crossed and the middle Polaroid makes angle θ with the first:

$\mathbf{I = (I_0/8)\sin^2 2\theta}$

Maximum transmission occurs at:

$\mathbf{\theta = 45°}$

Maximum intensity:

$\mathbf{I_{max} = I_0/8}$

---

42. BREWSTER'S LAW

At the polarising angle i_p:

$\mathbf{\mu = \tan i_p}$

For light travelling from medium 1 to medium 2:

$\mathbf{n_2/n_1 = \tan i_p}$

---

43. BREWSTER ANGLE CONDITION

At Brewster angle:

$\mathbf{i_p + r = 90°}$

Therefore:

Reflected ray ⊥ Refracted ray

---

44 IMPORTANT UNIT CONVERSIONS

1 nm = 10^{-9} m

1 μm = 10^{-6} m

1 mm = 10^{-3} m

1 cm = 10^{-2} m

Therefore, in numerical problems, wavelength and distances should generally be converted into metres before substitution.

Chapter-11: Dual Nature of Radiation and Matter

1. For photoemission to take place, either of the following conditions must be satisfied:

$$\boxed{E \geq W \;\; or \;\; f \geq f_0 \;\; or \;\; \lambda \leq \lambda_0}$$

2. Energy of a photon (E)

$$\boxed{E = \frac{hc}{\lambda} = hf}$$

3. Effect of intensity of light on photoelectric current
   Intensity ∝ photoelectric current ∝ number of photo electrons emitted per sec

$$\boxed{\propto \frac{1}{distance^2}}$$

4. Maximum kinetic energy of emitted electrons

$$\boxed{K_{max} = eV_0 = \frac{1}{2}m{v_{max}}^2}$$

   Where
   - m is the mass of photoelectron,
   - V_{max} is the maximum velocity of photoelectrons.
   - V_0 is stopping potential or cut-off potential
5. Einstein's photoelectric equation
   Work function

$$\boxed{W = hf_0}$$

   As per the law of conservation of energy

$$\boxed{E = W + \frac{1}{2}m{v_{max}}^2 = W + K_{max}}$$

   Where, E = Energy of Incident light on photosensitive plate
   Einstein photoelectric equation

$$\boxed{K_{max} = hf - W}$$

6. Relation between maximum kinetic energy and frequency

$$\boxed{K_{max} = h(f - f_0)}$$

7. Relation between stopping potential and frequency

$$\boxed{eV_0 = h(f - f_0)}$$

   Or

$$\boxed{V_0 = \frac{h}{e}(f - f_0)}$$

   Where

$$\boxed{f = \frac{c}{\lambda}}$$

$$\boxed{f_0 = \frac{c}{\lambda_0}}$$

8. De-Broglie wave equation:
   Einstein's mass energy relationship

$$\boxed{E = mc^2}$$

   De-Broglie's wave equation

$$\boxed{\lambda = \frac{h}{mc} = \frac{h}{p}}$$

   Where p (=mc) is the momentum of the photon.

9. For material particles like electrons, protons, neutrons wavelength λ

$$\boxed{\lambda = \frac{h}{p} = \frac{h}{mv}}$$

10. de-Broglie wavelength of an electron

$$\boxed{\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mK}} = \frac{h}{\sqrt{2meV}} = \frac{12.27}{\sqrt{V}}}$$

11. de-Broglie wavelength for any charge particle,

$$\boxed{\lambda = \frac{h}{\sqrt{2mK}} = \frac{h}{\sqrt{2mqV}}}$$

12. de-Broglie wavelength for other charged particle (except electron) (λ is in Angstrom)
    For proton,

$$\boxed{\lambda = \frac{0.286}{\sqrt{V}}}$$

    For deuteron,

$$\boxed{\lambda = \frac{0.2o2}{\sqrt{V}}}$$

    For α-particle,

$$\boxed{\lambda = \frac{0.101}{\sqrt{V}}}$$

Ch-12: Atoms

1. Distance of closest approach-Estimation of nuclear size

$$\boxed{r_0 = \frac{Ze^2}{m\pi\epsilon_0 v^2}}$$

Where, r_0 = distance of closest approach, Z= atomic number, v = velocity of $\alpha -$ particle

---

2. Impact parameter:

Relation between Impact parameter b and the scattering angle θ

$$\boxed{b \propto cot\left(\frac{\theta}{2}\right)}$$

For a head-on collision, the impact parameter

$$\boxed{b = 0}$$

(Scattering angle θ = 180^0. α-particle is reversed back along its original path.)

---

3. Postulates of Bohr's theory of hydrogen atom

Quantum condition: Angular momentum is the integral multiple of h/2 π.

$$\boxed{L_n = mvr = \frac{nh}{2\pi}}$$

Where, n = 1, 2, 3, ----are principal quantum number.

Frequency condition

Frequency of the emitted radiation

$$\boxed{f = \frac{E_2 - E_1}{h}}$$

Where, $h = Planck's\ constant$

---

4. Radius of electron: n^{th} radius of electron;

$$\boxed{r_n = \frac{\epsilon_0 n^2 h^2}{\pi m Z e^2}}$$

Or

$$\boxed{r_n \propto \frac{n^2}{Z}}$$

[Where, n = no. of orbit, Z = atomic number, m=mass of one electron, e = charge of one electron, h = Planck's constant, ϵ_0 = Permittivity of free space

For, H-atom, Z = 1; For Hydrogen like atom: For He^+,Z = 2, for Li^{++},Z = 2, For Be^{+++}, Z = 4]

For Hydrogen atom, n^{th} radius is,

$$\boxed{r_n = r_1 n^2 \ or \ r_n \propto n^2}$$

Where r_1 = 0.53 Ǎ (1 Ǎ= 10^{-10} m)

The lowest radius r_1

$$r_1 = \frac{\epsilon_0 h^2}{\pi m e^e}$$

The ratio of radii of electron in H atom

$$r_1 : r_2 : r_3 - -- = 1 : 4 : 9 - - -$$

5. **Speed of nth orbit in Bohr's model of hydrogen atom**

$$v_n = \frac{e^2}{2\epsilon_0 nh}$$

Or

$$v_n = \frac{v_1}{n}$$

Or

$$v_1 \propto \frac{1}{n}$$

Where,

$$v_1 = \frac{e^2}{2\epsilon_0 h} = \frac{c}{137} = 2.19 \times \frac{10^6 m}{s} = Maximum\ Speed$$

And, $c = speed\ of\ light\ in\ vacuum$

6. **Speed of nth orbit in Bohr's model of hydrogen like atom**

$$\boldsymbol{v_n = \frac{Ze^2}{2\epsilon_0 nh}}$$

7. **Fine structure constant**

$$\alpha = \frac{e^2}{2\epsilon_0 ch}, so\ v = \alpha \frac{c}{n}$$

8. **Energy of the electron of H atom**:

The total energy in the n^th orbit is the sum of kinetic energy and potential

$$E_n = -\frac{me^4}{8\epsilon_0{}^2 n^2 h^2}$$

Where

$$E_n = \frac{E_1}{n^2} = \frac{-13.6}{n^2} = \frac{-Rhc}{n^2} \quad (in\ eV)$$

9. **Absorption of energy**: When the electron in the atom can jump from lower orbit to higher orbit, it absorbs energy.
10. **Emission of energy**: When an electron jumps from higher to lower orbit, it emits energy.

Energy of photon is equal to the difference of two orbits. $[E_i - E_f = hf]$

11. **Ground state and ground state energy**: The energy associated with ground state (n = 1)
12. **Ionization energy**: It is the energy required to make the electron jump from present orbit to the infinite orbit.

$$E_{ionisation} = E_\infty - E_n = 0 - (E_n) = 13.6\ eV$$

13. **Energy needed to remove the electron from any energy level means Ionisation Energy**.
(Minimum energy required to free the electron from ground state of the hydrogen atom is 13.6 eV, it is called ionization energy.)

14. **Ionization Potential**:

$$Ionisation\ Potential = \frac{Ionisation\ energy}{e}$$

15. **Excitation energy**: If lower state energy is E_{n_1} and higher state energy is E_{n_2}, then excitation energy:

$$\Delta E_{n_1 n_2} = E_{n_2} - E_{n_2}$$

16. Excitation Potential

$$Excitation\ Potential = \frac{Excitation\ energy}{e}$$

17. **Wavelength of photon emitted in De-excitation**:

$$E = hf = \frac{hc}{\lambda} = E_i - E_f$$

$$E_n = -\frac{Rhc}{n^2} = -\frac{13.6}{n^2}$$

Where,

$$Rhc = 13.6\ eV$$

18. Rydberg formula: In General

$$\frac{1}{\lambda} = Z^2 R\left[\frac{1}{{n_1}^2} - \frac{1}{{n_2}^2}\right]$$

Energy of the emitted radiation (H atom), For H-spectrum, wave number = 1/λ related as

$$\frac{1}{\lambda} = R\left[\frac{1}{{n_f}^2} - \frac{1}{{n_i}^2}\right]$$

[For **Lyman series**: $n_f = 1, n_i = 2, 3, 4, --$ for **Balmer series:** $n_f = 2, n_i = 3, 4, 5,$,-- for **Paschen series**: $n_f = 3, n_i = 4, 5, 6, -----$; for Bracket series: $n_f = 4, n_i = 5, 6, 7, ----$ for p-Fund series: $n_f = 5, n_i = 6, 7, 8, -----$;

$$E = Rhc\left[\frac{1}{{n_1}^2} - \frac{1}{{n_2}^2}\right]$$

Here Rhc = -13.6 eV; $1eV = 1.6 \times 10^{-19}\ J$

Chapter-13: Nuclei

1. Nuclear Composition

A nucleus contains:

- **Z protons**
- **N neutrons**

Total number of nucleons:

$$\boldsymbol{A = Z + N}$$

Therefore:

$$\boldsymbol{N = A - Z}$$

Where:

- A = mass number
- Z = atomic number
- N = neutron number

Nuclear notation

$$\boldsymbol{{}^{A}_{Z}X}$$

---

2. Isotopes, Isobars and Isotones

Isotopes

Same atomic number:

$$\boldsymbol{Z_1 = Z_2}$$

$Z_1 = Z_2$

Different mass numbers:

$$\boldsymbol{A_1 \neq A_2}$$

Isobars

Same mass number:

$$\boldsymbol{A_1 = A_2}$$

Different atomic numbers:

$$\boldsymbol{Z_1 \neq Z_2}$$

Isotones

Same neutron number:

$$\boldsymbol{N_1 = N_2}$$

Since:

N = A − Z

---

3. Nuclear Radius

The nuclear radius is:

$$\boldsymbol{R = R_0 A^{1/3}}$$

Where:

$R_0 \approx 1.2 \times 10^{-15}$ m

or:

$R_0 \approx 1.2$ fm

and:
1 fm = 10^{-15} m
Therefore:

$$\boxed{R \propto A^{1/3}}$$

Radius Ratio

For two nuclei:

$$\boxed{\frac{R_1}{R_2} = \left(\frac{A_1}{A_2}\right)^{1/3}}$$

Useful results
If: $A_2 = 8A_1$
Then: $R_2 = 2R_1$
If: $A_2 = 27A_1$
Then: $R_2 = 3R_1$

---

4. Nuclear Volume

Assuming the nucleus is approximately spherical:

$$\boxed{V = (4/3)\pi R^3}$$

Using:
R = $R_0 A^{1/3}$
We get:

$$\boxed{V = (4/3)\pi {R_0}^3 A}$$

Therefore:

$$\boxed{V \propto A}$$

---

5. Nuclear Density

Nuclear density:

$$\boxed{\rho = \frac{M}{V}}$$

Approximate nuclear mass:
M ≈ mA
Therefore:
$\rho = Am / [(4/3)\pi R_0^3 A]$
Hence:

$$\boxed{\rho = \frac{3m}{4\pi {R_0}^3}}$$

Therefore:

$$\boxed{\rho \approx Constant}$$

The order of nuclear density is:
$\rho \approx 10^{17}$ kg m^{-3}

Important conclusion

Nuclear density is approximately independent of mass number A.

---

6. Nuclear Force

Important properties:

- very strong
- short range
- attractive at intermediate distances
- repulsive at extremely small distances
- approximately charge independent
- saturation property

Typical nuclear-force range:

$$\boxed{\approx 1 - 2\, fm}$$

---

7. Mass Defect

If nuclear masses are given:

$$\boxed{\Delta m = Zm_p + Nm_n - M_{nucleus}}$$

Since:

N = A − Z

We can write:

$$\boxed{\Delta m = Zm_p + (A - Z)m_n - M_{nucleus}}$$

---

8. Mass Defect Using Atomic Masses

If the mass of the **neutral atom** is given:

$$\boxed{\Delta m = Zm_H + Nm_n - M_{atom}}$$

Where:

- m_H = mass of hydrogen atom
- m_n = neutron mass
- m_{atom} = atomic mass

This formula automatically accounts for the electron masses.

Important

Nuclear masses given → use m_p

Atomic masses given → use M_H

---

9. Einstein Mass-Energy Relation

The fundamental relation is:

$$\boxed{E = mc^2}$$

For mass defect:

$$\boxed{B.E = \Delta mc^2}$$

Where, B.E. is nuclear binding energy.

---

10. Atomic Mass Unit Conversion

1 u = 1.6605×10^{-27} kg

Therefore:

1 u × c^2 ≈ 931.5 MeV

Hence:

$1\ u\ c^2 = 931.5$ MeV

For numerical calculations:

$$\boxed{\boldsymbol{B.E.(MeV) = \Delta m(in\ u) \times 931.5}}$$

11. Binding Energy

Binding energy is:

B.E. = Δmc^2

If Δm is in kg:

B.E. in joules = $\Delta m \times c^2$

If Δm is in u:

B.E. in MeV = $\Delta m \times 931.5$

12. Binding Energy Per Nucleon

The binding energy per nucleon is:

$$\boxed{\boldsymbol{\frac{B.E.}{A} = \frac{Total\ B.E.}{A}}}$$

Therefore:

Total B.E. = A × (B.E. per nucleon)

Unit:

MeV/nucleon

Important

Higher B.E./A generally indicates stronger average nuclear binding.

13. Binding Energy Curve

The binding energy per nucleon:

- is relatively low for very light nuclei,
- increases rapidly for light nuclei,
- reaches a maximum near the iron/nickel region,
- decreases gradually for heavy nuclei.

Maximum region:

$A \approx 56$–62

Approximate maximum:

B.E./A ≈ 8.8 MeV/nucleon

14. Nuclear Stability

For light stable nuclei:

$$\boxed{\boldsymbol{\frac{N}{Z} \approx 1}}$$

For heavy stable nuclei:

$$\boxed{\boldsymbol{\frac{N}{Z} > 1}}$$

The stable nuclei lie approximately within a:

Band of Stability

15. Nuclear Reaction Energy / Q-Value

For a nuclear reaction:

Reactants → Products + Energy
Tthe energy released is:

$$\boldsymbol{Q = (M_{initial} - M_{final})c^2}$$

If the mass difference is expressed in atomic mass units:

Q(MeV) = Δm(u) × 931.5

Binding-Energy Method

Alternatively:

$$\boldsymbol{Q = B.E._{products} - B.E._{reactants}}$$

Therefore:
Q > 0 → energy released
Q < 0 → energy absorbed

---

16. Energy Conversion

Useful conversions:
1 eV = 1.602 × 10^{-19} J
1 keV = 10^3 eV
1 MeV = 10^6 eV
Therefore:

1 MeV = 1.602 × 10^{-13} J

---

17. Alpha Decay

General equation:

$$\boxed{{}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He}$$

Therefore:
A → A − 4
Z → Z − 2

---

18. Beta-Minus Decay

Basic nuclear process:
n → p + e^- + $\bar{\nu}$
General equation:

$${}^{A}_{Z}X \rightarrow {}_{Z+1}{}^{A}Y + e^{-} + \bar{\nu}$$

Therefore:
A remains unchanged
Z → Z + 1

---

19. Beta-Plus Decay

Basic nuclear process:
p → n + e^+ + ν
General equation:

$$\boxed{{}^{A}_{Z}X \rightarrow {}_{Z-1}{}^{A}Y + e^{+} + \nu}$$

Therefore:
A remains unchanged
$Z \rightarrow Z - 1$

---

20. Gamma Decay

Gamma emission:
A unchanged
Z unchanged
Only the nuclear energy state changes.
Symbolically:
$X \rightarrow X + \gamma^*$
Where X* represents an excited nucleus.

---

21. α, β and γ — Quick Formula Table

Radiation	Mass/Charge	Change in A	Change in Z
α	^4_2He	−4	−2
β^-	e^-	0	+1
β^+	e^+	0	−1
γ	photon	0	0

---

22. Nuclear Fission

General idea:

Heavy nucleus → lighter nuclei + neutrons + energy

For U-235, a representative fission channel is:
$^{235}_{92}U + ^1_0n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^1_0n$ + Energy
The exact fission products can vary.
Typical energy released per fission:
≈ 200 MeV

23. Nuclear Chain Reaction

One fission can produce additional neutrons.
These neutrons can cause further fissions.
Therefore:
Fission → Neutrons → More fission → More neutrons
This is a:
Nuclear chain reaction

---

24. Critical Mass

The minimum amount of fissile material required under specified conditions to maintain a self-sustaining chain reaction is called:

Critical mass

It depends on factors such as:

- material,
- geometry,
- density,
- neutron leakage,
- surrounding materials.

---

25. Nuclear Reactor

A nuclear reactor maintains a:

Controlled nuclear chain reaction

Main components:

Fuel → Moderator → Control Rods → Coolant → Shielding

Functions

Fuel → undergoes fission
Moderator → slows neutrons
Control rods → absorb neutrons
Coolant → removes heat
Shielding → reduces radiation exposure

---

26. Nuclear Fusion

General idea:

Light nuclei → heavier nucleus + energy

Important example:

$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + 17.6\ \text{MeV}$

This is the deuterium-tritium fusion reaction.

---

27. Energy from Fusion/Fission

For any nuclear reaction:

$Q = \Delta mc^2$

or:

$Q = \Delta m \times 931.5\ \text{MeV}$

Energy release can also be calculated from binding energies:

Q = B.E._products − B.E._reactants

---

28. Fission vs Fusion — Formula-Level Summary

Fission

Heavy → Medium

B.E./A generally increases.

Therefore:

Energy released

Fusion

Light → Heavier

B.E./A can increase toward the maximum.

Therefore:

Energy released

---

29. Most Important Proportionalities

Quantity	Relation
Nuclear radius	$R \propto A^{1/3}$
Nuclear volume	$V \propto A$
Nuclear density	$\rho \approx$ constant
Binding energy	B.E. $\propto \Delta m$

---

30. Constants for Chapter 13

Constant	Value
Speed of light, c	**3.00×10^{8} m/s**
1 fm	**10^{-15} m**
Nuclear radius constant R_0	**≈ 1.2 fm**
1 u	**1.6605×10^{-27} kg**
1 u c^2	**931.5 MeV**
1 eV	**1.602×10^{-19} J**
1 MeV	**1.602×10^{-13} J**

Chapter 14 — Semiconductor and Electronics Devices

1.1 Semiconductor Fundamentals

1. Conductivity

$$\sigma = e(n\mu_e + p\mu_h)$$

Where:

- σ = electrical conductivity
- n = electron concentration
- p = hole concentration
- μ_e = electron mobility
- μ_h = hole mobility
- e = electronic charge

For an intrinsic semiconductor:

$$\sigma_i = en_i(\mu_e + \mu_h)$$

2. Resistivity

$\rho = 1/\sigma$

Therefore,

$$\rho = \frac{1}{e(n\mu_e + p\mu_h)}$$

3. Current density

$J = \sigma E$

Therefore,

$$J = e(n\mu_e + p\mu_h)E$$

4. Mobility

$$\mu = \frac{v_d}{E}$$

Where:

- v_d = drift velocity
- E = electric field

1.2 Intrinsic Semiconductor

For an intrinsic semiconductor:

$$n = p = n_i$$

Where: n_i is intrinsic carrier concentration.

The mass-action relation is:

$$np = {n_i}^2$$

For intrinsic semiconductor:

$${n_i}^2 = n_i \times n_i$$

1.3 Extrinsic Semiconductor

n-type semiconductor

Donor impurity → pentavalent impurity

Examples:

P, As, Sb, Bi

Majority carriers:

Electrons

Minority carriers:

Holes

For strongly doped n-type semiconductor:

$$\boxed{n \approx N_D}$$

And

$$\boxed{p = \frac{{n_i}^2}{N_D}}$$

Where: N_D = donor concentration

---

p-type semiconductor

Acceptor impurity → trivalent impurity

Examples:

B, Al, Ga, In

Majority carriers: Holes

Minority carriers: Electrons

For strongly doped p-type semiconductor:

$$\boxed{p \approx N_A}$$

And

$$\boxed{n \approx \frac{{n_i}^2}{N_A}}$$

Where N_A = acceptor concentration.

Charge neutrality condition

$$\boxed{n + N_A = p + N_D}$$

This is an important numerical relation.

1.4 Energy Band Gap

For a semiconductor:

$$\boxed{E_g = E_C - E_V}$$

Where:

- E_C = conduction-band energy
- E_V = valence-band energy
- E_g = forbidden energy gap

Typical values:

Si: $E_g \approx 1.1eV$

Ge: $E_g \approx 0.7eV$

1.5 p–n Junction

When p-type and n-type semiconductors are joined:

- electrons diffuse from n → p

- holes diffuse from p → n
- recombination occurs near junction
- immobile ions remain
- depletion region develops
- electric field is established
- potential barrier is formed

Approximate barrier potential at room temperature:

For Si: $V_B \approx 0.7\ V$

For Ge: $V_B \approx 0.3\ V$

Important concept

At equilibrium:

Diffusion current = Drift current

Therefore,

Net current = 0

1.6 p–n Junction Biasing

Forward bias

p-side → positive terminal

n-side → negative terminal

Effects:

- depletion width decreases
- barrier potential decreases
- current increases significantly

Reverse bias

p-side → negative terminal

n-side → positive terminal

Effects:

- depletion width increases
- barrier potential increases
- only a small reverse saturation current flows before breakdown

---

1.7 Diode V–I Characteristics

For a diode:

I = f(V)

Static resistance

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

Dynamic resistance

$$\boxed{r_d = \frac{\Delta V}{\Delta I}}$$

The dynamic resistance is the slope-related small-signal resistance around an operating point.

Cut-in/Knee voltage

For silicon:

$$\boxed{V_\gamma \approx 0.7\ V}$$

For germanium:

$$\boxed{V_\gamma \approx 0.3\ V}$$

Diode equation — JEE extension

$$\boxed{I = I_0 \left[e^{\left(\frac{V}{\eta V_T}\right)} - 1 \right]}$$

Where:

- I_0 = reverse saturation current
- η = ideality factor
- V_T = thermal voltage

At room temperature:

$V_T \approx 26$ mV

1.8 Rectification

Rectification means conversion of:

AC → pulsating DC

Two important types:

1. Half-wave rectifier
2. Full-wave rectifier

1.9 Half-Wave Rectifier

For ideal half-wave rectifier:

Average/DC current

$$\boxed{I_{dc} = \frac{I_m}{\pi}}$$

RMS current

$$\boxed{I_{rms} = \frac{I_m}{2}}$$

Average/DC voltage

$$\boxed{V_{dc} = \frac{V_m}{\pi}}$$

RMS voltage

$$\boxed{V_{rms} = \frac{V_m}{2}}$$

Rectification efficiency

$$\boxed{\eta_{max} \approx 40.6\%}$$

Ripple factor

$$\boxed{r \approx 1.21}$$

Output frequency

$$\boxed{f_{out} = f}$$

Where, f is input AC frequency.

1.10 Full-Wave Rectifier

For an ideal full-wave rectifier:

Average/DC current

$$\boxed{I_{dc} = \frac{2I_m}{\pi}}$$

RMS current

$$\boxed{I_{rms} = \frac{I_m}{\sqrt{2}}}$$

Average/DC voltage

$$\boxed{V_{dc} = \frac{2V_m}{\pi}}$$

RMS voltage

$$\boxed{V_{rms} = \frac{V_m}{\sqrt{2}}}$$

Maximum rectification efficiency

$$\boxed{\eta_{max} \approx 81.2\%}$$

Ripple factor

$$\boxed{r \approx 0.482}$$

Output frequency

$$\boxed{f_{out} = 2f}$$

This is an important difference from a half-wave rectifier.

1.11 Peak Inverse Voltage (PIV)

Centre-tapped full-wave rectifier

PIV per diode:

$$\boxed{PIV = 2V_m}$$

Bridge rectifier

PIV per diode:

$$\boxed{PIV = V_m}$$

Note: The exact symbol V_m must be interpreted according to the transformer/circuit definition being used.

1.12 Capacitor Filter

A capacitor connected across the load reduces the ripple in rectified output.
Basic idea:

Large capacitance → better smoothing

For a simple capacitor filter, approximately:

$$\boxed{V_{ripple} \propto \frac{1}{fC}}$$

Thus:

- larger C → smaller ripple
- larger f → smaller ripple

For the same load conditions, a full-wave rectifier gives a higher ripple frequency than a half-wave rectifier.
