Electric Charges and Fields

Electric charges

Electric field lines
- Always normal to conducting surface
- Lines originating from +ve charge
- Terminating at –ve charge
- Never intersect each other
- Do not form closed loop
- Are imaginary lines.

Quantization of charge
All charges must be a multiple of charge (e)

$Q = ne$

Where n is an integer

- Two kinds of charges + ve and – ve
- S.I. unit is Coulomb (C)
  1 C = charge flowing through a wire in 1s if current in it is 1A
- $e = 1.602 \times 10^{-19}$C.

Conservation of charge
It is not possible to create or destroy net charge of an isolated system.

Applications of Gauss' Law
- Electric Field due to linear charge distribution
  $E = \lambda/2\pi \varepsilon_0 r$,
  λ = linear charge density
- Electric Field due to a plane sheet of charge
  $E = \sigma/2\varepsilon_0$,
  σ = charge per unit area
- Electric Field due to a charged conducting plate
  $E = \sigma/\varepsilon_0$,
  σ = charge per unit area
- Electric Field inside a conductor $= 0$

Electric field due to uniformly charged spherical shell at :
- Outside point,
  $E = Q/4\pi\varepsilon_0 r^2$
- Internal point,
  $E = 0$
- The surface,
  $E = Q/4\pi\varepsilon_0 R^2$

Electric flux
$\Delta\phi = \vec{E}.\Delta\vec{S}$, $\Delta\vec{S}$ = area vector
$\vec{E}$ = electric field

$\phi = \int \vec{E}.\vec{ds}$

Electric Field

Electric field due to point charge
$\vec{E} = \dfrac{\vec{F}}{q} = k\dfrac{Q}{r^2}$ (N/C)

- Due to discrete distribution of charges
  $\vec{E} = \sum_{i}^{n} \vec{E}_i$
- Due to continuous distribution of charge
  $\vec{E} = k\int \dfrac{dQ}{r^3}\vec{r}$
  $|\vec{E}| = k\int \dfrac{dQ}{r^2}$

Coulomb's Law
- Force between two charged particles
  $\vec{F} = \dfrac{k\, q_1\, q_2 \vec{r}}{r^3} = \dfrac{k q_1\, q_2 \hat{r}}{r^2}$, force is attractive when q_1 and q_2 are of opposite sign, otherwise repulsive
  $|\vec{F}| = \dfrac{k\, q_1\, q_2}{r^2}$
  $k = \dfrac{1}{4\pi\varepsilon_0} \approx 9 \times 10^9 \, Nm^2C^{-2}$
- Force between multiple charges
  $\vec{F}_1 = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14} + \vec{F}_{15} + ... = \dfrac{q_1}{4\pi\varepsilon_0}\sum_{i=2}^{n}\dfrac{q_i}{r_{1i}^2}\hat{r}_{1i}$

where $\hat{r}$ is the unit vector along charge particle under consideration
$\hat{r}_{1i}$ = distance between 1st and i^{th} particle

"The electric force with which two charges attract or repel one another are not affected by the presence of other charges". It is known as Superposition Principle.

In 1985, Charles Augustin de Coulomb gave Coulomb's law

Electric Dipole moment, $\vec{p} = q\vec{d}$
- Electric field due to dipole at axial position,
  $\vec{E} = \dfrac{1}{4\pi\,\varepsilon_0}\left(\dfrac{2p}{r^3}\right)\hat{r}$
- Electric field due to dipole at an equatorial position,
  $|E| = \dfrac{1}{4\pi\,\varepsilon_0}\left(\dfrac{P}{r^3}\right)$
- Torque on an electric dipole placed in an electric field $(\vec{E})$
  $\vec{\tau} = \vec{p} \times \vec{E} = p\,E\sin\theta$

Gauss' Theorem
$\oint \vec{E}.\vec{ds} = q_{in}/\varepsilon_0 = \phi$

where, q_{in} = net charge enclosed
ϕ = flux through a closed surface

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- First Level
- Second Level
- Third Level

Electrostatic Potential and Capacitance

Electric potential

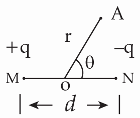
- Work done per unit test charge by an external agent in moving the test charge from reference point to the desired point. Its SI unit is J/C
  $V_0 = W/q_0$.

Electric potential due to a point charge: $V_P = Q/4\pi\varepsilon_0 r$

Potential due to a system of charges: $V = \frac{1}{4\pi\varepsilon_0}\sum \frac{Q_i}{r_i}$

Potential due to a dipole:

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



Where, $p = qd$

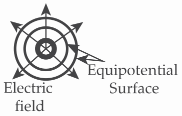
$\theta = \angle AON$

At $\theta = 0°$, $V = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^2}$ [at axial position]

At $\theta = 90°$, $V = 0$ [at equitorial position]

Equipotential surface

- Potential is same at all the points of the surface.
- Component of electric field parallel to an equipotential surface is zero.



Electric potential energy

- It is negative count of work done by the electric force as the configuration of the system changes.
- $Ur_2 - Ur_1 = -W = \frac{q_1 \cdot q_2}{4\pi\varepsilon_0}\left(\frac{1}{r_2} - \frac{1}{r_1}\right)$
- If the separation between charges is 'r', then $U_{(r)} = \frac{q_1 \cdot q_2}{4\pi\varepsilon_0 r}$
- Potential Difference,
  $V_B - V_A = \frac{U_B - U_A}{q}$
  $U_B - U_A$ = Change in Potential energy
  q = Test charge

In 1774, Alessandro Volta wrote treatise "on the forces of attraction of electric fire".

Capacitance, $C = \frac{Q}{V}$

Capacitance of a parallel plate capacitor,
$C = \kappa\varepsilon_0 A/d$, κ = dielectric constant

Parallel grouping of capacitors,
$C = C_1 + C_2 + C_3 + ---- + C_n$
for two capacitors, $C = C_1 + C_2$

Energy stored in a capacitor,
$U = \frac{1}{2}CV^2 = \frac{Q^2}{2C} = 1/2\, QV$

Series grouping of capacitors,
$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ---- + \frac{1}{C_n}$

For two capacitors, $C = \frac{C_1 C_2}{C_1 + C_2}$

Capacitance when dielectric slab is inserted between the plates
$C = \kappa\varepsilon_0 A/[\kappa d - x(\kappa - 1)]$
where, x = thickness of the slab inserted

Capacitance of a spherical capacitor,
$C = 4\pi\varepsilon_0 / \left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

For isolated sphere,
$C = 4\pi\varepsilon_0 R$

Dielectric

- Force $F = \frac{q_1\, q_2}{4\pi\kappa\varepsilon_0 r^2}$, κ = dielectric constant of medium
- A dielectric is an electrical insulator that can be polarized by "application of" electric field.

Conductors & Insulators

Conductors	Insulators
A material which when placed in an electric field, the free electrons move in a direction opposite to the field.	A material in which electrons are tightly bound, and when exposed in an electric field, electrons do not move i.e.,having no free electrons.

Properties of electric field

- Electric field inside a conductor is always zero.
- Electric field is always perpendicular to the charged surface.
- In static state, there will be no additional charge in a conductor.

Potential energy of a dipole

$dU = pE\sin\theta d\theta$

If we choose P.E. of dipole to be zero when $\theta = 90°$, then

$U_\theta - U_{90°} = \int_{90°}^{\theta} pE\sin\theta\, d\theta$

If it is rotated through angle θ against the torque,

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

Trace the Mind Map
- First Level
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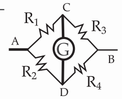
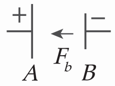
Current Electricity

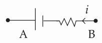
- **Electric Current**
  - Rate of flow of charge through an area,
    $$i = \frac{Q}{t}$$
    $$i = \int \vec{J}.d\vec{S}$$
- **Current density**
  - $\vec{J} = \frac{\Delta i}{\Delta s \cos\theta} = \sigma E$
  - ΔS = Area of cross-section
  - θ = Angle between Area vector and current flow
  - σ = Conductivity
- **Drift velocity**
  - $v_d = \frac{i}{neA} = \frac{J}{ne}$
- **Mobility**
  - $\mu = \frac{v_d}{E} = \frac{e\tau}{m}$
  - τ = Average collision time
- **Ohm's Law**
  - $J = \sigma E$ or $V = IR$
- **Resistivity**
  - $\rho = \frac{1}{\sigma}\,\Omega\,m$
- **Conductivity**
  - $\sigma = J/E$
- **Grouping of Resistors**
  - In series combination
    $R_{eq} = R_1 + R_2 + R_3 + \text{- - -} + R_n$
    For two resistors,
    $R_{eq} = R_1 + R_2$
  - In parallel combination
    $$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \text{- - -} + \frac{1}{R_n}$$
    For two resistors
    $$R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$$
- **Temperature Dependence of Resistance**
  - $R = R_0\,[1 + \alpha\,(T - T_0)]$
  - $\rho = \rho_0\,[1 + \alpha\,(T - T_0)]$
  - R = Resistance at temperature T
  - R_0 = Resistance at temperature T_0
  - α = Temperature coefficient of resistance
- **Wheatstone Bridge**
  - Condition for balanced wheatstone bridge
    If, $\frac{R_1}{R_2} = \frac{R_3}{R_4}$



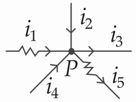
  - $V_c = V_D$
    No current through G i.e., Ig > 0
- **Electric cell**
  - It is a device which maintains a potential difference between its two terminals.
    - **EMF**
      - emf $= E = \frac{W}{q}$
      - It is equal to the potential difference between the terminals when the they are not connected externally.



    - **Internal Resistance**
      - $V_A - V_B = E - ir$
      - r = Internal resistance of the cell



- **Grouping of Cell**
  - **Parallel grouping**
    $$E_{eq} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2},\; i = \frac{E_{eq}}{R + \frac{r_1 r_2}{r_1 + r_2}}$$
  - **Series grouping**
    $$i = \frac{E_1 + E_2}{R_1 + (r_1 + r_2)} = \frac{E_0}{R_1 + R_2}$$
    $E_0 = E_1 + E_2,\;\; R_2 = r_1 + r_2$
- **Kirchhoff's Rules**
  - **Junction Rule**
    - $i_1 + i_2 + i_4 = i_3 + i_5$
    - At any junction, the sum of currents entering the junction is equal to the sum of currents leaving the junction.



  - **Loop Rule**
    - The algebraic sum of all the potential difference along a closed loop is zero.
      $\Sigma E = 0$

Trace the Mind Map
- First Level
- Second Level
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Moving Charges and Magnetism

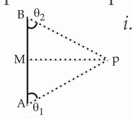
Magnetic Field ($\vec{B}$)

- It is a region around a magnet or current carrying conductor or a moving charge in which its magnetic effect can be felt
- SI unit is Tesla(T) = weber/m^2
- 1 Gauss = 10^{-4} Tesla where gauss is the CGS unit

Magnetic field due to straight current carrying wire

$B = \frac{\mu_0 i}{4\pi d}(\sin\theta_1 + \sin\theta_2)$

where θ_1 and θ_2 are the angles corresponding to the lower and upper ends respectively



i.e $\theta_1 = 0$

$\theta_2 = \pi$

$B = \frac{\mu_0 i}{2\pi d}$

Oersted's Law

In April 1820, Hans Christian Oersted discovered that flow of current in a wire can deflect a nearby magnetic compass needle.

Solenoid

- Magnetic field at a point inside due to a long solenoid, $B = \mu_0 ni$
- At a point on one end $B = \frac{\mu_0 ni}{2}$

where n = number of turns per unit length along the length of solenoid.

Magnetic Force on a moving charge

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

$= qvB\sin\theta$

- For $\theta = 0, \vec{F} = 0$ along the magnetic field
- For $\theta = 90°$, *i.e.* if charge's velocity is perpendicular to field direction, force is perpendicular to both field and velocity

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

$r = \frac{mv}{qB}$ = Radius of the circle in which charge rotates

Time period $(T) = \frac{2\pi m}{qB}$

Frequency $(\nu) = \frac{1}{T} = \frac{qB}{2\pi m}$

If $\theta \neq 0, 180°, 90°$

Then, $F = qvB\sin\theta$

Force between parallel current carrying wires

$F = \frac{\mu_0 i_1 i_2}{2\pi d}$

Torque experienced by a loop in uniform magnetic field

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

$\tau = NBiA$

Definition of Ampere

If two parallel wires carrying same current are kept 1 m apart, if experience a force $F = 2\times10^{-7}$ N, then current = 1A in each wire.

Sensitivity

Voltage sensitivity = NBA/CG

current sensitivity = NBA/C

Galvanometer

- Ammeter: $S = \frac{Ig}{I - Ig}G$
- Voltmeter: $R = \frac{V}{Ig} - G$

Field due to a current carrying circular ring

- Field at a point far away from the centre: i.e., for $d >> a$, $B = \frac{\mu_0 i a^2}{2d^3}$
- Field at an axial point: $B = \frac{\mu_0 i a^2}{2(a^2 + d^2)^{3/2}}$
- Field at the centre: $B = \frac{\mu_0 i}{2a}$ ⊗ ⊙

Force on a current carrying conductor

$d\vec{F} = i(d\vec{l}\times\vec{B})\ F = ilB$

Biot-Savart's Law

⊙ ⊗

$d\vec{B} = \frac{\mu_0}{4\pi}\frac{id\vec{l}\times\vec{r}}{r^3}$

$dB = \frac{\mu_0}{4\pi}\frac{idl\sin\theta}{r^2}$

[θ = angle between $d\vec{l}$ and $\vec{r}$]

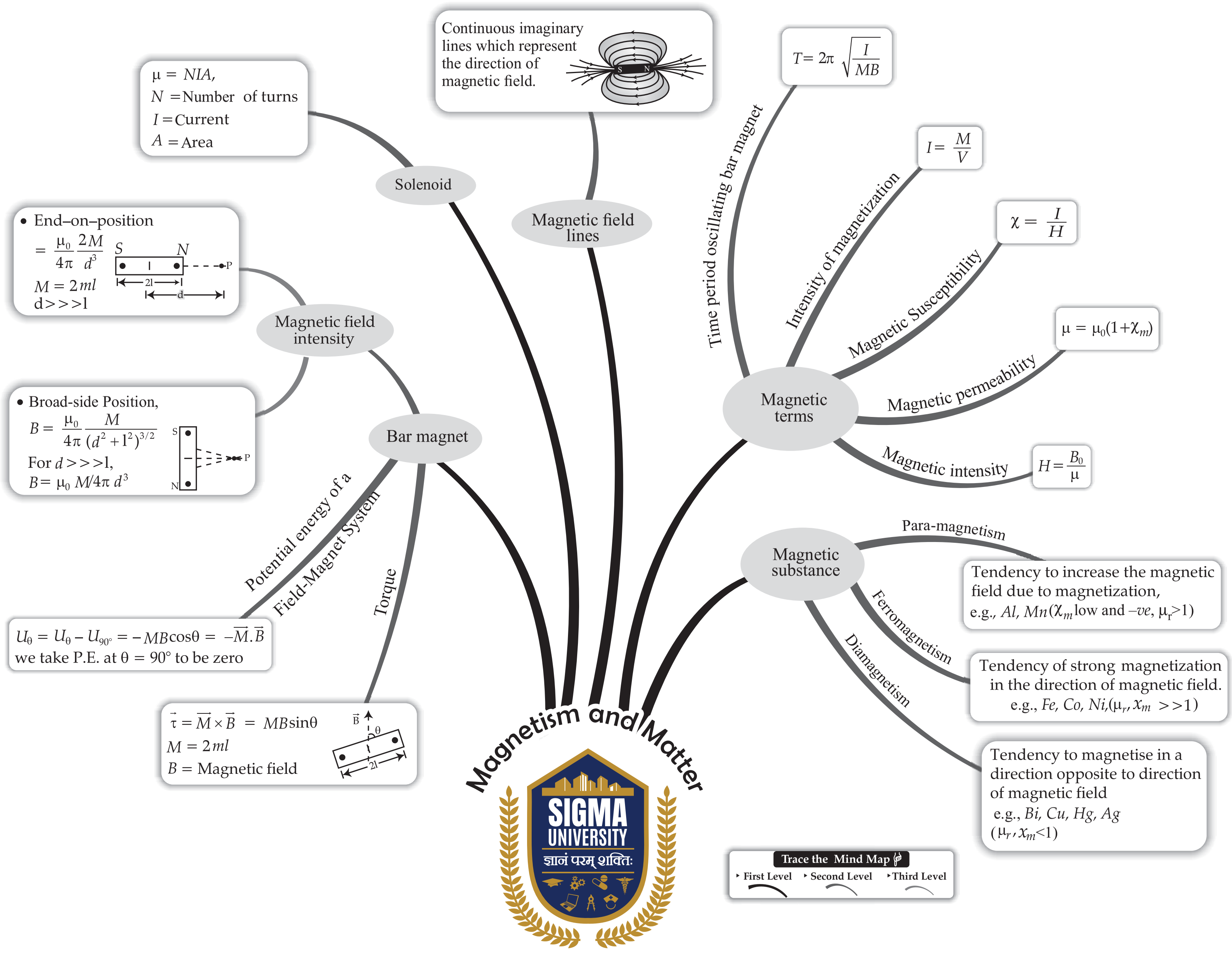
Direction of field will be perpendicular to the plane containing current element and the point of observation

Ampere's Law

$\oint \vec{B}.\vec{dl} = \mu_0 i$

where i = Total current crossing the area bounded by closed curve.

Trace the Mind Map
- First Level
- Second Level
- Third Level


Magnetism and Matter
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Solenoid
$\mu = NIA$,
N = Number of turns
I = Current
A = Area
Magnetic field lines
Continuous imaginary lines which represent the direction of magnetic field.
S
N
Bar magnet
Magnetic field intensity
• End–on–position
$= \frac{\mu_0}{4\pi}\frac{2M}{d^3}$
$M = 2ml$
d>>>l
S
N
P
2l
d
• Broad-side Position,
$B = \frac{\mu_0}{4\pi}\frac{M}{(d^2+l^2)^{3/2}}$
For $d >>> l$,
$B = \mu_0 M/4\pi d^3$
Potential energy of a Field-Magnet System
$U_\theta = U_\theta - U_{90^\circ} = -MB\cos\theta = -\vec{M}.\vec{B}$
we take P.E. at θ = 90° to be zero
Torque
$\vec{\tau} = \vec{M} \times \vec{B} = MB\sin\theta$
$M = 2ml$
B = Magnetic field
θ
Magnetic terms
Time period oscillating bar magnet
$T = 2\pi\sqrt{\frac{I}{MB}}$
Intensity of magnetization
$I = \frac{M}{V}$
Magnetic Susceptibility
$\chi = \frac{I}{H}$
Magnetic permeability
$\mu = \mu_0(1+\chi_m)$
Magnetic intensity
$H = \frac{B_0}{\mu}$
Magnetic substance
Para-magnetism
Tendency to increase the magnetic field due to magnetization, e.g., Al, Mn(χ_m low and –ve, μ_r>1)
Ferromagnetism
Tendency of strong magnetization in the direction of magnetic field. e.g., Fe, Co, Ni,(μ_r, χ_m >>1)
Diamagnetism
Tendency to magnetise in a direction opposite to direction of magnetic field e.g., Bi, Cu, Hg, Ag (μ_r, χ_m<1)
Trace the Mind Map
First Level
Second Level
Third Level

Electromagnetic Induction

Faraday's laws of electromagnetic induction

1. Whenever magnetic flux through an area bounded by a closed conducting loop changes, an emf is produced in the loop.
2. The emf is given by $\varepsilon = -d\phi/dt$ where, $\phi = \int \vec{B}.\vec{ds}$ is the magnetic flux through the area.

Lenz's law

The direction of the induced current is such that it opposes the change that has induced it.

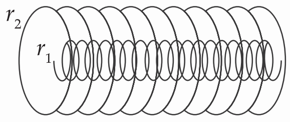
Mutual induction

$\phi = Mi$

$\frac{d\phi}{dt} = -M\frac{di}{dt}$

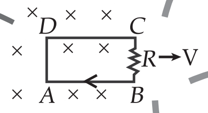
$M_{12} = \mu_0 N_1 N_2 \pi r_1^2 / l$

$M_{21} = \mu_0 N_1 N_2 \pi r_2^2 / l$



Emf induced in an a.c. generator, $\varepsilon = NBA\omega \sin \omega t$

Rectangular loop



Thermal power developed in the loop is

$P = \frac{v^2 B^2 l^2}{R}$

EMF induced

$E = vBl$

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

Magnetic force on the loop

$F = B^2 l^2 v/R$

= Force required to move the loop with constant velocity (v)

In 1831, Michael Faraday discovered electromagnetic induction and James Clerk Maxwell mathematically described it.

Self inductance of long solenoid

$L = \mu_0 n^2 \pi r^2 l$

n = Number of turns per unit length

ϕ = Flux = $(\mu_0 ni)\,\pi r^2$

r = Radius of each loop of solenoid

- **Growth of current in LR Circuit**

  $i = \frac{\varepsilon}{R}(1 - e^{tR/L}) = i_0(1 - e^{-t/\tau})$

- **Decay of current**

  $i = i_0 e^{-t/\tau}$

- **Energy stored in an Inductor**

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

Induced EMF

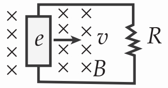
$\varepsilon = -\frac{d\phi}{dt}$

Motional EMF

$\varepsilon = \left|\frac{d\phi}{dt}\right| = \left|Bl\frac{dx}{dt}\right|$

$= Blv$

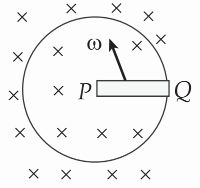
$i = Blv/(R+r)$



r = Resistance of rod moving with velocity v in uniform magnetic field $\vec{B}$

EMF induced in a rotating conductor

$\varepsilon = \frac{1}{2}B\omega l^2$



Where l = Length of rod

Induced current

$I = \frac{\varepsilon}{R} = -\frac{1}{R}\frac{d\phi}{dt}$

Self induction

If we consider a solenoid of N turns, the flux through each turn, $\phi = \int \vec{B}.\vec{ds}$.

EMF induced between the ends of coil, $\varepsilon = -N\frac{d}{dt}\int \vec{B}.\vec{ds}$

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Trace the Mind Map

First Level · Second Level · Third Level

Alternating Current

A C Circuits

R–C circuit
- $i = i_0 \sin(\omega t + \phi)$
- $Z = \sqrt{R^2 + X_c^2}$
- $X_c = 1/\omega C$
- $\tan\phi = 1/\omega CR$
- $i_0 = E_0/Z$
- Power factor $\cos\phi = \frac{R^2}{\sqrt{R^2 + X_c^2}}$
- current leading.

Inductive (L) circuit
- $i = i_0 \sin\left(\omega t - \frac{\pi}{2}\right)$
- Phase difference between $V\&I$, $\phi = \pi/2$
- Power factor $\cos(\phi) = 0$
- Voltage leads current by $\pi/2$
- $P = 0$

Capacitive (C) circuit
- $i = i_0 \sin\left(\omega t + \frac{\pi}{2}\right)$
- $\phi = \pi/2$ Power factor $\cos\phi = 0$
- Power $(P) = 0$
- Current leads the voltage by $\pi/2$

Resistive (R) circuit
- $i = i_0 \sin(\omega t)$
- $\phi = 0°$
- $\cos\phi = 1$
- $P = V_0 i_0 /2$
- Current & voltage both are in same phase

L–C–R circuit
- $i = i_0 \sin(\omega t \pm \phi)$
- $Z = \sqrt{R^2 + (X_c - X_L)^2}$
- $X = X_c - X_L$
- $= \left(\frac{1}{\omega c} - \omega L\right)$
- $\tan\phi = \left(\frac{1}{\omega c} - \omega L\right) / R$, $i_0 = \frac{E_0}{Z}$
- At resonance:
- $X_L = X_C$
- Voltage and current is in phase

L–R circuit
- $i = i_0 \sin(\omega t - \phi)$
- $Z = \sqrt{R^2 + X_L^2}$
- $X_L = \omega L$
- $\tan\phi = \omega L/R$
- $i_0 = E_0/Z$
- power factor $= R/Z$
- voltage is leading

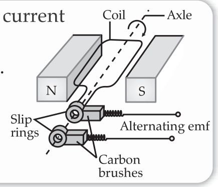
L–C circuit
- $i = i_0 \sin\left(\omega t \pm \frac{\pi}{2}\right)$
- $X = X_L - X_C$
- $\phi = \pi/2$
- Power factor = 0, Either voltage or current leading

Contribution
In 1883, Nikola Tesla invented AC motor, AC generator and AC transmission technology.

A C Generator
A device generating alternating current having elements magnet, armature and graphite brushes. emf induced through coil

$E = NBA\omega \sin \omega t$

$i = E/R = (NBA\omega \sin \omega t)/R$



Transformer
It is used to obtain a high AC voltage from a Low–voltage AC source or vice–versa

Efficiency of a transformer
η = output power/Input power

99% efficiency can easily achieved

Turns ratio
$\frac{E_s}{E_p} = \frac{I_p}{I_s} = \frac{N_s}{N_p} = K$

Power in AC Circuit
$P = E_{rms} i_{rms} \cos\phi = \frac{E_0}{\sqrt{2}} \times \frac{i_0}{\sqrt{2}} \cos\phi = \frac{1}{2} E_0 i_0 \cos\phi$

Impedance
The ratio of emf applied and the current produced in an AC circuit $Z = E_0/i_0$ Ohm

Reactance
The hindrance offered by inductor or capacitor or both to the flow of AC

AC Current
Direction of current changes alternatively

$i = i_0 \sin \omega t$

$V = V_0 \sin \omega t$

RMS value or root mean square value
$i_{rms} = i_0/\sqrt{2}$

$V_{rms} = V_0/\sqrt{2}$

Mean value or Average value
$i_{mean} = 2i_0/\pi$

$V_{mean} = 2V_0/\pi$

Peak value or Maxm value
$i_0 = \sqrt{2}\, i_{rms}$

$V_0 = \sqrt{2} V_{rms}$

Trace the Mind Map

- First Level
- Second Level
- Third Level

Electromagnetic Waves

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History

In 1886 Heinrich Hertz became the first person to transmit and receive controlled radio signal.

Conduction current

The current due to flow of charge is often called conduction current,

$I_c = \frac{dq}{dt}$

Displacement current

If there exists an electric current as well as a changing electric field, if results magnetic field and causes displacement current,

$I_d = \varepsilon_0 \frac{-d\phi_E}{dt}$

Electromagnetic spectrum

- **Radio waves :** $\lambda > 10^8$ nm
  Use : radio, TV signal
- **Micro waves :** $10^8 > \lambda > 10^5$ nm
  Use : micro wave oven, radar
- **Infrared :** $10^5 > \lambda > 700$ nm
  Use : night vision
- **Visible light :** $700 > \lambda > 400$ nm
  Use : to observe world
- **UV rays :** $400 > \lambda > 10$ nm
  Use : destroying bacteria
- **X-rays :** $10 > \lambda > 0.01$ nm
  Use : detect bone break
- **γ rays :** $0.01 \text{ nm} > \lambda$
  Use : to treat cancer

Maxwell's equations

Gauss's law (electricity)

$\oint \vec{E}.\vec{ds} = \frac{q_{in}}{\varepsilon_0}$

Gauss's law (magnetism)

$\oint \vec{B}.\vec{ds} = 0$

Faraday's law

$\oint \vec{E}.\vec{dl} = \frac{-d\phi_B}{dt}$

Ampere's law

$\oint \vec{B}.\vec{dl} = \mu_0 I + \mu_0\varepsilon_0 \frac{-d\phi_E}{dt}$

Characteristics of Electromagnetic waves

- Do not need any material medium for propagation
- Travel with speed of light (c) $= \frac{1}{\sqrt{\mu_0\varepsilon_0}}$
- Produced be accelerated charged particle
- Transverse in nature
- Oscillating electric & magnetic fields are in phase and their ratio is constant
  $(c) = \frac{aE_0}{B_0}$

Combination of mutually perpendicular electric and magnetic fields is referred to as an electromagnetic wave

Energy density

- $U = \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2}\frac{B^2}{\mu_0}$ = Total energy per unit volume
- U_{av} over a long time

  $U_{av} = \frac{1}{4}\varepsilon_0 E_0^2 + \frac{1}{4}\frac{B_0}{\mu_0}$

  $= \frac{1}{2}\varepsilon_0 E_0^2$ [as $c = \frac{E_0}{B_0}$ and $\mu_0\varepsilon_0 = \frac{1}{c^2}$]

  $= \frac{1}{2}\frac{B_0^2}{\mu_0}$

Trace the Mind Map

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Ray Optics & Optical Instruments

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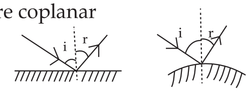
Sign Conventions

- Pole in case of mirror and optical centre in case of lenses are taken as origin
- Principle axis as the *X*-axis
- All distances are measured from origin
- All distances measured in the direction of incident ray are taken + ve.
- All distances measured in the direction opposite to the incident ray are taken - ve.

Reflection of Light

- $\angle i = \angle r$
- Incident ray reflected ray and normal to the reflecting surface are coplanar



Spherical Mirror

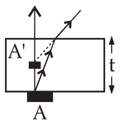
$$\frac{1}{u}+\frac{1}{v}=\frac{2}{R}=\frac{1}{f}$$

Lateral Magnification $=\frac{h_2}{h_1}=-\frac{v}{u}$

Refraction of light

$$\frac{\sin i}{\sin r}=\frac{v_1}{v_2}=\frac{\mu_2}{\mu_1}$$

$$\mu=\frac{\text{real depth}}{\text{apparent depth}}$$



$\Delta t=\left(1-\frac{1}{\mu}\right)t$ = image shift

Total Internal reflection

When ray passes from optically denser to rarer medium, if incident angle (i) greater than critical angle, entire light is then reflected back to the denser medium again, this process is called T.I.R. It is used in optical fibre.

Critical Angle

- Incident angle (θ_c) for which angle of refraction is 90°

i.e., $\sin\theta_c = 1/\mu$

$$\theta_c=\sin^{-1}\left(\frac{1}{\mu}\right)$$

When ray passes from optically denser to rarer medium.

Refraction on Spherical surface

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

Lateral Magnification

$$m=\frac{h_2}{h_1}=\frac{\mu_1 v}{\mu_2 u}=\frac{R-v}{R-u}$$

Prism

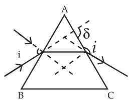
Dispersion

Splitting of polychromatic light into its constituent colours.

Angle of deviation $\delta = i+i'-A$

$\delta_{minimum}=2i-A \quad [i=i']$

$\delta_{minimum}=(\mu-1)A$, if A is small



Lens Marker's Formula

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

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

$$\frac{1}{f}=(\mu-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right) \quad [If\ \mu_2=\mu,\ \mu_1=1\ (air)]$$

$$\frac{1}{f}=\frac{1}{v}-\frac{1}{u} \quad \text{(lens formula)}$$

Lateral Magnification $=\frac{h_2}{h_1}=\frac{v}{u}$

Power of a lens

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

[For combination of lens when they are in contact]

$$P=\frac{1}{f_1}+\frac{1}{f_2}$$

for combination of lens when they are separated

$$P=\frac{1}{f_1}+\frac{1}{f_2}-\frac{d}{f_1 f_2}$$

Optical Instruments

Simple Microscope

$M=1+\frac{D}{f}$ [image at near point]

$M=D/f$ [image at infinity]

Compound Microscope

$M=\frac{v_0}{u_0}\left[\frac{D}{f_e}\right]$ [normal adjustment]

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

For final image at least distance

Telescope

$M=\frac{f_o}{f_e}\left(1+\frac{f_e}{D}\right)$ [image at near point]

$M=-\frac{fo}{fe}$ [image at infinity]

Trace the Mind Map

- First Level
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Wave Optics

- **Young's Double Slit Experiment**
  - Path difference
    - For bright fringe $\Delta\phi = n\lambda$
    - For dark fringe $\Delta\phi = \left(n + \frac{1}{2}\right)\lambda$
  - Based on interference of light
    - Distance between n[th] dark fringe and central fringe $x_n = \frac{(2n+1)\lambda D}{2d}$; d = distance between slits
    - Distance between n^{th} bright fringe and central fringe $x_n = \frac{n\lambda D}{d}$; D = distance between source and screen
  - Fringe-width
    - $\beta = \frac{D}{d}\lambda$. It is the distance between two consecutive, bright or dark fringes.
- **Interference of Light**
  - Two waves superimpose to form a resultant wave of greater or lower or same amplitude. $I = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2 = \beta(A_1 + A_2)^2$
    - For constructive Interference, $A = A_1 + A_2$
    - For destructive interference, $A = (A_1 \sim A_2)$
- **Coherent source**
  - Two sources of light are said to be coherent if the initial phase difference between the waves emitted by the sources remains constant with time, otherwise they are called incoherent source of light.
- **Diffraction of light by single slit**
  - $b\sin\theta = n\lambda$ (dark fringe)
  - Linear width of central maxima
  - Width of central maxima $= \frac{2\lambda}{b}$
  - Angular width $= \frac{2D\lambda}{b}$
  - $b\sin\theta = (2n+1)\frac{\lambda}{2}$ (for maxima bright fringe)
- **Huygens' Principle**
  - Each point on the primary wavefront is the source of a secondary wavelets
    - Wave front
      - Locus of all particles vibrating in some phase
        - For spherical wavefront $I \propto \frac{1}{r^2}$, $A \propto \frac{1}{r}$

Trace the Mind Map
- First Level
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Dual Nature of Radiation & Matter

Dual Nature of Radiation

- Light has both wave character as well as particle **nature**
- **Interference and diffraction can be explained by wave nature**
- When light isof sufficiently **small wavelength, it** behaves as particle.
- Light particles having definite energy and definite **linear momentum are called "photons"**
  Energy of each photon = $h\nu = hc/\lambda$
  Momentum of each photon = $h/\lambda = E/c$

Contribution

Einstein, after an average academic career put forward quantum theory of light in 1905 while working as a grade III technical officer in a patent office.

Matter waves

All matter can exhibit wave–like behaviour e.g., beam of electrons can be diffracted like **a** water wave

de-Broglie relation

$\lambda = h/p$

λ = wavelength associated with particle or de-Broglie wavelength

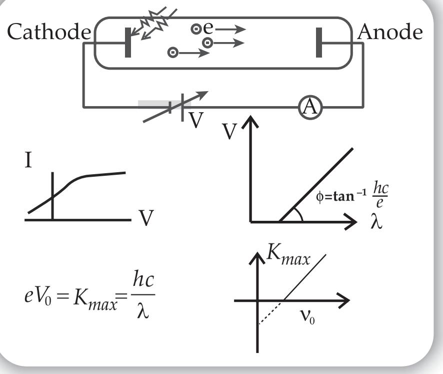
p = momentum

$$\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2\,m\,K_{max}}}$$

Photoelectric Effect

- When light of sufficient small wavelength is incident on metal surface, electrons are ejected from the metal, the phenomenon is called photoelectric effect.
- Ejected electrons are called photoelectrons
- Minimum energy equal to work function (ϕ) must be given to an electron so as to bring it out of the metal

Hertz and Lenard's Observation



$eV_0 = K_{max} = \frac{hc}{\lambda}$

Einstein's Photoelectric equation

- If $\lambda = \lambda_0 = hc/\phi$
  $K_{max} = 0$, i.e.,
  Electron may just come out **onto the surface**
- If $\lambda > \lambda_0$
  i.e., $E < \phi$
  no electron will come out
- If $\lambda > \lambda_0$.
  Electrons come out with definite KE.
- λ_0 = depends on metal used

- $K_{max} = E - \phi = eV_0$
  $= \frac{hc}{\lambda} - \phi$, V_0 = stopping potential
  K_{max} = maximum kinetic energy of **ejected**electrons

Here, $\lambda_0 = hc/\phi$

λ_0 = Threshold Wavelength

$\lambda_0 = c/\nu_0 = \phi/h$

ν_0 = Threshold frequency

$K_{max} = \lambda(\nu - \nu_0)$

Trace the Mind Map
- First Level
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Atoms

Contribution

In 1898, J.J Thomson proposed the first model of atom known as plum-pudding model.
In 1911, Rutherford prepared planetary model of atom.
In 1913, Niels Bohr prepared a model of Hydrogen atom based on quantum theory.

α – particle scattering experiment

- α- particle bombarded on thin gold foil
- Most of α– particles passed undeviated or with a small angle
- 1 out of 8000 α– particles were deflected by scattering angle

Impact parameter

$$b = \frac{Ze^2 \cot \theta / 2}{4\pi\varepsilon_0 \left(\frac{1}{2} mv^2\right)}$$

Rutherford's Model

Drawbacks

- Doesn't explain the stability of atom
- Doesn't explain the atomic spectra

Postulates

- Atoms have a central, massive, positively charged core called nucleus around which electrons revolve.
- Size of nucleus ≈ 1 fermi = 10^{-15}m

Energy Level

Energy of electron in each stationary orbits is

Given by $E_n = -13.6 \frac{Z^2}{n^2}$ eV

Where n = 1,2,3….

Z = atomic number of atom

- These stationary energy orbits are also called energy levels.
- When electron jumps from higher energy level to lower energy level, it releases energy.

$$\Delta E = E_f - E_i = 13.6\left[\frac{1}{n_i^2} - \frac{1}{n_f^2}\right] Z^2 \text{eV}$$

Hydrogen Spectrum

- Hydrogen gas heated in a sealed tube emits radiation when passed through prism components of different wavelength appear.
- Wavelength in each series given by

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

$n_f > n_i$

- Lyman series [U.V. region]
  $n_i = 1$, $n_f = 2,3,4….$
  $\lambda_{min} = 912$ Å , $\lambda_{max} = 1216$ Å
- Balmer series [visible region]
  $n_i = 2$ $n_f = 3, 4, 5…..$
  $\lambda_{min} = 3648$ Å , $\lambda_{max} = 6563$ Å
- Paschan series [IR region]
  $n_i = 3$ $n_f = 4, 5, 6…..$
  $\lambda_{min} = 8208$ Å , $\lambda_{max} = 18761$ Å
- Brackett series [IR region]
  $n_i = 4$ $n_f = 5, 6, 7…$
  $\lambda_{min} = 14592$ Å $\lambda_{max} = 40533$ Å
- P fund [IR region]
  $n_i = 5$ $n_f = 6, 7, 8……$
  $\lambda_{min} = 23850$ Å $\lambda_{max} = 74618$ Å

Bohr Model

Postulates

- Electron revolves around the nucleus in stationary orbits.
- Angular momentum of electron

  $mvr_n = n \times \frac{h}{2\pi}$ where, n is an integer

  It is also known as principal Quantum Number.
- It explains spectrums of hydrogen or hydrogen like [He^+, Li^{++}] atoms.

Limitations

- Fails to explain spectrum of complex atoms/ions of multi electron system.
- Doesn't explain Zeeman's and Stark's effect.

Radius of n^{th} Bohr's orbit

$$R_n = \frac{\varepsilon_0 h^2}{\pi me^2}\left(\frac{n^2}{Z}\right) = 0.53 \frac{n^2}{Z} \text{Å}$$

Velocity of electron in n^{th} Bohr's orbit

$$v_n = \frac{e^2}{2\varepsilon_0 h}\left(\frac{Z}{n}\right) = 2.2 \times 10^6 \frac{Z}{n} \text{ m/s}$$

Potential Energy

$$U_n = -\frac{KZe^2}{r_n} = \frac{-me^4}{4\varepsilon_0^2 h^2}\left(\frac{Z^2}{n^2}\right) = \frac{-27.2 Z^2}{n^2} \text{eV}$$

Kinetic Energy

$$E_k = \frac{KZe^2}{2r_n} = \frac{me^4}{8\varepsilon_0^2 h^2}\frac{Z^2}{n^2} = \frac{13.6}{n^2} Z^2 \text{ eV}$$

Total Energy

$$E = U_n + E_k = -\frac{KZe^2}{2r_n} = \frac{-13.6 Z^2}{n^2} \text{eV} = \frac{U_n}{2} = -E_K$$

Trace the Mind Map
- First Level
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Nuclei

Composition
- Nuclei consist of protons and neutrons.
- Common name of protons & neutrons in the nucleus is nucleons
- $_ZX^A$, $A = Z + N$ = Mass Number
  - Z = Atomic Number
  - N = No. of neutrons

Contribution
1n 1932, James Chadwick discovered neutrons – elementary particles devoid of any electrical charge.

Mass-Energy Relation
Einstein showed that mass is an another form of energy and gave a relation $E = mc^2$

Mass Defect
$\Delta M = [Z m_p + (A - Z)m_n] - M$

m_p = mass of proton,

m_n = mass of neutron

M = mass of nucleus

Binding Energy
- $B.E. = \Delta Mc^2 = [Z m_p + (A - Z)m_n - M] \times c^2$
- $B.E.$ per nucleon $= B.E/A$

Nuclear fission
- Splitting of a heavy nucleus into two or more lighter nuclei.

e.g., $_{92}U^{235} + _0n^1 \rightarrow _{56}Ba^{141} + _{36}Kr^{92} + 3_0n^1$ + 200 meV

Size of Nucleus

Nuclear Volume
$V = \frac{4}{3}\pi R^3$

$= \frac{4}{3}\pi R_0^3 A$

$V \propto A$ (mass no.)

Nuclear Radius
$R = R_0 A^{1/3}$

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

A = Mass No.

Nuclear Density
$\rho = \frac{\text{mass of nucleus}}{\text{volume of nucleus}}$

$= \frac{A \times 1.67 \times 10^{-27}}{\frac{4}{3}\pi \times (1.2 \times 10^{-15})^3 \times A}$

$\approx 2.9 \times 10^{17}$ kgm^{-3} (independent of A)

Types of Nuclei

Isotopes
- Same atomic No. (Z)
- Different mass No. (A)

e.g., $_6C^{12}$, $_6C^{14}$

Isobars
- Same mass No. (A)
- Different atomic No. (Z)

e.g., $_6C^{14}$, $_7N^{14}$

Isotones
Atoms whose nuclei having same number of neutrons (N)

e.g., $_{11}Na^{23}$, $_{12}Mg^{24}$

Nuclear fusion
- Combining two lighter nuclei to form a heavy nucleus

e.g., $_1^1H + _1^1H \rightarrow _1^2H + e^+ + \nu$ + 0.42 MeV (energy)

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Trace the Mind Map

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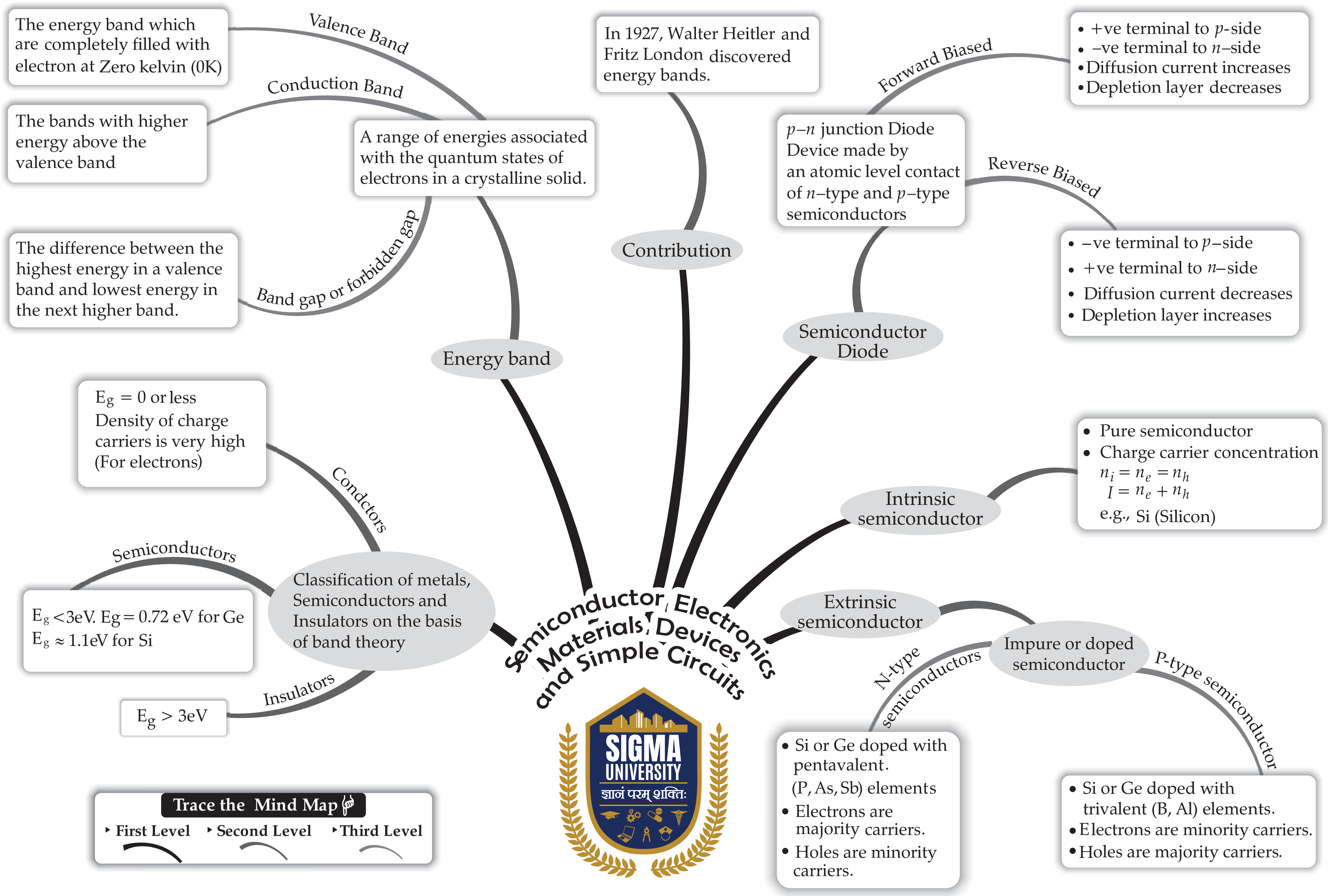
Semiconductor Electronics Materials, Devices and Simple Circuits
The energy band which are completely filled with electron at Zero kelvin (0K)
Valence Band
Conduction Band
The bands with higher energy above the valence band
A range of energies associated with the quantum states of electrons in a crystalline solid.
Band gap or forbidden gap
The difference between the highest energy in a valence band and lowest energy in the next higher band.
Energy band
In 1927, Walter Heitler and Fritz London discovered energy bands.
Contribution
p–n junction Diode Device made by an atomic level contact of n–type and p–type semiconductors
Semiconductor Diode
Forward Biased
• +ve terminal to p-side
• –ve terminal to n–side
• Diffusion current increases
• Depletion layer decreases
Reverse Biased
• –ve terminal to p–side
• +ve terminal to n–side
• Diffusion current decreases
• Depletion layer increases
Intrinsic semiconductor
• Pure semiconductor
• Charge carrier concentration
$n_i = n_e = n_h$
$I = n_e + n_h$
e.g., Si (Silicon)
Extrinsic semiconductor
Impure or doped semiconductor
N-type semiconductors
• Si or Ge doped with pentavalent. (P, As, Sb) elements
• Electrons are majority carriers.
• Holes are minority carriers.
P-type semiconductor
• Si or Ge doped with trivalent (B, Al) elements.
• Electrons are minority carriers.
• Holes are majority carriers.
Classification of metals, Semiconductors and Insulators on the basis of band theory
Condctors
$E_g = 0$ or less
Density of charge carriers is very high (For electrons)
Semiconductors
$E_g < 3eV$. Eg = 0.72 eV for Ge
$E_g \approx 1.1eV$ for Si
Insulators
$E_g > 3eV$
Trace the Mind Map
First Level
Second Level
Third Level