Electric Charge

Electric Dipole

Electric field by a dipole

On axial line

$$\vec{E} = \frac{2\vec{p}}{4\pi\varepsilon_0 r^3} \quad (\text{for } r >> a)$$

On equitorial plane

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

(for $r >> a$)

Torque on an electric dipole

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

Electric Field

Electric field due to a point charge

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

Electric field due to a system of charges

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{n}\frac{q_i}{r_{ip}^2}\hat{r_{ip}}$$

Electric field due to an infinitely long, uniformly charged straight wire

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

Electric field due to a thin infinite plane sheet of charge

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

Electric field due to a uniformly charged spherical shell

Outside:

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

Inside: $E = 0$

Laws

Gauss's Law

$$\Delta\phi = \vec{E}.\vec{A} = \frac{q_{en}}{\varepsilon_0}$$

Coulomb's Law

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

Superposition Principle

$$\vec{F}_q = \vec{F}_{q_1} + \vec{F}_{q_2} + \ldots + \vec{F}_{q_n}$$

Properties

Additivity of charges

$$q = q_1 + q_2 + q_3 \ldots\ldots q_n$$

Quantisation of charges

$$q = ne$$

Conservation of charges

Electrification

By Rubbing

By Conduction

By Induction

Electrostatics

Electrostatics of Conductor

(i) Electric field inside a conductor is zero.
(ii) Electric field at surface of charged conductor is perpendicular to surface at every point.
(iii) Any change inside the conductor resides on surface
(iv) Electric field inside a cavity is 0.
(v) Electric field at the surface of charged conductor is:

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

Electrostatic Potential

Electrostatic Potential due to Point Charge

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

Electrostatic Potential due to a System of Charges

$$V = \frac{q_1}{4\pi\varepsilon_0 r_1} + \frac{q_2}{4\pi\varepsilon_0 r_2} + \dots + \frac{q_n}{4\pi\varepsilon_0 r_n}$$

Electrostatic Potential due to a Dipole

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

(for $r >> a$)

Electrostatic Potential Energy

Due to Point Charge in an External Electric Field

$$U = qV(r)$$

Due to System of charges

$$U = \frac{q_1 q_2}{4\pi\varepsilon_0 r_{12}} + \frac{q_2 q_3}{4\pi\varepsilon_0 r_{23}} + \dots\dots\dots + \frac{q_n q_{n-1}}{4\pi\varepsilon_0 r_{n\,n-1}}$$

Due to Two Charge System in an External Electric Field

$$U = q_1 V(r_1) + q_2 V(r_2) + \frac{q_1 q_2}{4\pi\varepsilon_0 r_{12}}$$

Due to a Dipole in an External Electric Field

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

Capacitor

Capacitance

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

Energy Stored in a Capacitor

$$E = \frac{Q^2}{2C} = \frac{1}{2}QV$$

Effect of Dielectric on Capacitance

$$C = KC_o$$

Combination of Capacitors

Series:

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \dots\dots + \frac{1}{C_n}$$

Parallel:

$$C = C_1 + C_2 + \dots\dots + C_n$$

Current Electricity

Applications

Potentiometer

EMF of a battery : $\varepsilon = kl$

Internal Resistance : $r = \left(\frac{l_1}{l_2} - 1\right)R$

Meter Bridge

$$S = \frac{(100 - l)R}{l}$$

Wheat Stone Bridge

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

Kirchhoffs' Rules

Loop Rule

$$\sum V = 0$$

Junction Rule

$$\sum I = 0$$

Electric Cell

EMF: It is the voltage difference between the two terminals of a source in open circuit.

$$\varepsilon = V + Ir$$

Internal Resistance

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

Terminal Voltage

$$V = \varepsilon - Ir$$

Cells in Series

$$\varepsilon = \varepsilon_1 + \varepsilon_2$$

Cells in Parallel

$$\varepsilon = \frac{(\varepsilon_1 r_2 + \varepsilon_2 r_1)}{r_1 + r_2}$$

Ohm's Law

$$V = IR$$

Resistance

$$R = \frac{V}{I} = \rho\frac{l}{A}$$

Resistivity

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

$$\frac{eE}{m} = \rho\frac{ne^2}{m}v_d$$

Conductivity

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

Drift Velocity

$$v_d = \frac{I}{neA} = \frac{eE\tau}{m}$$

Mobility of electron

$$\mu = \frac{v_d}{E} = \frac{e\tau}{m}$$

Electromagnetic Induction

EMF induced in an A.C Generator

$$e = NBA\omega \sin \omega t$$

EMF Induced in a coil: Faraday's Law

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

Mutual Inductance of two coaxial solenoids

$$M = \mu_0 n_1 n_2 \pi r_1^2 l$$

Mutual Induction EMF Induced:

$$e = -M\frac{di}{dt}$$

EMF Induced in Solenoids

Self Induction EMF Induced:

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

Self Inductance of a Solenoid

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

Magnetic Energy Stored in a Coil

$$U = \frac{1}{2} L I^2$$

Energy Consideration in Motional EMF

Current: $I = \frac{e}{r} = \frac{Blv}{r}$

Force: $F = IlB = \frac{B^2 l^2 v}{r}$

Power : $P = Fv = \frac{B^2 l^2 v^2}{r}$

Straight Conductor moving in a Uniform Magnetic field

EMF Induced

$$e = Blv$$

Work done on a charge in moving it along the length of Conductor

$$w = qvBl$$

meritnation

Alternating Current

Resonance

$$f_R = \frac{1}{2\pi\sqrt{LC}}$$

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

Power Factor = $\cos\phi$

Where,

$$\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$$

L-C Oscillations

$$\omega = \frac{1}{\sqrt{LC}}$$

$$q = q_0\cos(\omega_0 t + \varphi)$$

RMS Values

Current: $I_{RMS} = \frac{I_0}{\sqrt{2}}$

Voltage: $V_{RMS} = \frac{V_0}{\sqrt{2}}$

Impedance

R-C Circuit : $Z = \sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2}$

R-L Circuit : $Z = \sqrt{R^2 + (\omega L)^2}$

R-L-C Circuit : $Z = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$

Average Values

Current: $I_{av} = \frac{2I_0}{\pi}$

Voltage: $V_{av} = \frac{2V_0}{\pi}$

Current and Voltage

$I = I_0 \sin\omega t$ or $I = I_0\cos\omega t$

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

Transformers

$$\frac{I_p}{I_s} = \frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$P_P = P_S = I_P V_P = I_S V_S$$

Step-Up Transformer: $N_S > N_P$

Step-Down Transformer: $N_S < N_P$

Summary of Simple AC Circuits

Purely Resistive Circuit:
* Voltage and Current are in Same phase

Purely Capacitive Circuit:
* Current leads the voltage by $\pi/2$.

Purely Inductive Circuit:
* Current lags the voltage by $\pi/2$.

Magnetism

Magnetic Dipoles

A Circular current loop
$M = IA$
$$B = \frac{\mu_0}{4\pi}\frac{2M}{x^3}$$

Revolving electron
$$\mu_l = \frac{neh}{4\pi m_e} = n(\mu_B)$$

Moving Coil Galvanometer
$$I = \frac{k}{NBA}\theta \; ; \; G = \frac{k}{NBA} \; ; \text{ Current Sensitivity} = \frac{\theta}{I} = \frac{NBA}{k} \; ; \text{ Voltage Sensitivity} = \frac{\theta}{V} = \frac{nBA}{kR}$$

Conversion to Ammeter
$$S = \frac{I_g}{I - I_g}G$$

Conversion to Voltmeter
$$R = \frac{V}{I_g} - G$$

Magnetism and Matter

Bar Magnet

In Uniform Magnetic Field

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

Potential Energy
$U = -\vec{M} \cdot \vec{B}$

Earth's Magnetism

$$\tan\delta = \frac{B_v}{B_H}$$

Gauss's Law: $\phi_B = \sum \vec{B} \cdot \Delta\vec{S} = 0$

Magnetic Material

A few important relations
$$I = \frac{M}{V}$$
$$B = \mu_0(H + I)$$
$$\chi_m = \frac{I}{H}$$
$$\mu = \mu_0(1 + \chi_m)$$
$$\mu_r = \frac{B}{B_0}$$

Diamagnetic
$-1 \leqslant \chi < 0$
$0 \leqslant \mu_r < 1$

Paramagnetic
$0 < \chi < \epsilon$
$1 < \mu_r < 1 + \epsilon$
$$\chi = C\frac{\mu_0}{T}$$

Ferromagnetic
$\chi \gg 1$
$\mu_r \gg 1$
$$\chi = \frac{C}{T - T_c}$$

Magnetism

Effects of Fields

Velocity Selector
$$v = \frac{E}{B}$$

Charged Particle in Combined Electric and Magnetic Field

Charged Particle in Magnetic Field

Velocity is at an angle to Magnetic field

$$r = \frac{mv\sin\theta}{qB} \qquad T = \frac{2\pi m}{qB}$$

$$\text{Pitch} = \frac{2\pi mv\cos\theta}{qB}$$

Velocity is perpendicular to Magnetic field

$$r = \frac{mv}{qB} \qquad T = \frac{2\pi m}{qB}$$

Cyclotron

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

$$v = \frac{qBR}{m} \qquad \text{K.E} = \frac{q^2B^2R^2}{2m}$$

Lorentz Force
$$F_L = |q[\vec{v}\times\vec{B} + \vec{E}]|$$

Forces on Current Carrying Conductor
$$F_L = |I(\vec{l}\times\vec{B})|$$

Force between Parallel Current Carrying Conductor
$$F = \frac{\mu_0}{4\pi}\frac{2I_1I_2}{r}$$

Torque on Rectangular Loop
$$\tau = IAB\sin\theta$$

Laws

Biot Savart Law
$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I\,d\vec{l}\times\vec{r}}{r^3}$$

Magnetic Field due to Current Carrying Circular Loop

At Axial Point:
$$B = \frac{\mu_0 I R^2}{2(x^2+R^2)^{3/2}}$$

At Centre:
$$B = \frac{\mu_0 I}{2R}$$

Ampere's Circuital Law
$$\oint \vec{B}\cdot d\vec{l} = \mu_0 I$$

Magnetic Field due to very long Current Carrying Circular Cylinder

Outside:
$$B_O = \frac{\mu_0 I}{2\pi r}$$

Inside:
$$B_I = \frac{\mu_0 I}{2\pi R^2}r$$

Magnetic Field inside a long Current Carrying Solenoid
$$B = \mu_0 n I$$

Magnetic Field due to Current in Ideal Toroid
$$B_O = \frac{\mu_0 N I}{2\pi r}$$

Ray Optics

Reflection

Mirror Formula

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

Refraction

Prism

$$\delta=(\mu-1)A$$

Total Internal Reflection

$$\mu_r=\frac{1}{\sin C}$$

Lens

Lens Formula

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

Lens Maker Formula

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

Power (in Diopters)

$$P=\frac{100}{f(\text{cm})}$$

Formula for calculation of focal length of two lenses in contact

$$\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}-\frac{d}{f_1f_2}$$

Snell's Law

$$\frac{\sin i}{\sin r}=\mu_r$$

Refractive Index

Absolute Refractive Index

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

Relative Refractive Index

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

Optical Instruments

Microscope

Simple Microscope

$$m=1+\frac{D}{f}$$

Compound Microscope

$$m=-\frac{L}{f_0}\times\frac{D}{f_e}$$

Telescope

Astronomical Telescope

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

Electromagnetic Waves

Displacement Current

$$I_D = \epsilon_0 \frac{d\phi}{dt}$$

Maxwell's Equations

$$\oint \vec{E}.d\vec{s} = \frac{Q}{\epsilon_0}$$

$$\oint \vec{B}.d\vec{s} = 0$$

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

$$\oint \vec{B}.d\vec{l} = \mu_0 I + \mu_0 \epsilon_0 \frac{d\phi_E}{dt}$$

Speed:

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = 3 \times 10^8 \text{ m/s}$$

Momentum:

$$p = \frac{U}{c}$$

Wave Optics

Polarisation

Brewster's Law

$\mu = \tan i_B$

Malus's Law

$I = I_0 \cos^2\theta$

Resolving Power

Limit of resolution of a compound microscope

$$d = \frac{\lambda}{2\mu\sin\theta}$$

Resolving power of compound microscope

$$\frac{1}{d} = \frac{2\mu\sin\theta}{\lambda}$$

Limit of resolution of an astronomical telescope

$$d\theta = \frac{1.22\lambda}{D}$$

Resolving power of an astronomical telescope

$$\frac{1}{d\theta} = \frac{D}{1.22\lambda}$$

Doppler Effect

$$\frac{\Delta f}{f} = \frac{\Delta\lambda}{\lambda} = -\frac{v_{\text{radial}}}{c}$$

Diffraction

Diffraction at single slit

Conditions for of n^{th} secondary minima

$$\sin\theta_n = \frac{n\lambda}{a},\ y_n = \frac{nD\lambda}{a}$$

Conditions for n^{th} secondary maxima

$$a\sin\theta_n = \frac{(2n+1)\lambda}{2}$$

Width of central maxima

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

Interference

Constructive Interference

$\phi = 2n\pi;\ x = n\lambda$

Destructive Interference

$$\phi = (2n+1)\pi;\ x = (2n+1)\frac{\lambda}{2}$$

Fringe Width

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

Resultant

$$I_R = I_1 + I_2 + 2\sqrt{I_1 I_2}\, cos\phi$$

Resultant for Coherent sources

$$I = 4I_0\cos^2\frac{\phi}{2}$$

Modern Physics-1

Radioactivity

Activity

$$R = \left|\frac{dN}{dt}\right| = \lambda N$$

$$R = R_0 e^{\lambda t}$$

1 Becquerel = 1 dps

1 Curie = 1 ci = 3.7×10^{10} dps

Decay Law

$$\frac{dN}{dt} = -\lambda N$$

$$N = N_0 e^{-\lambda t}$$

Half-Life and Decay Constant

$$\lambda = -\frac{dN/dt}{N}$$

$$\lambda T = \ln 2 \Rightarrow T = \frac{0.693}{\lambda}$$

Mean Life

$$\tau = \frac{1}{\lambda} = 1.44\,T$$

Nuclear Physics

Radius $R = R_0 A^{1/3}$ Where $R_0 = 1.2$ fermi

Mass defect $= \Delta M = Zm_p + (A - Z)m_n - M$

Binding energy $\Delta E = \text{BE} = (\Delta M)c^2$

Binding energy per nucleon $= \frac{\text{BE}}{A}$

Atomic Physics

Einstein's photoelectric equation

$$\frac{1}{2} m v_{\max}^2 = V_0 e = h\nu - \varphi_0 = h(\nu - \nu_0)$$

De – Broglie Wavelength

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

De – Broglie Wavelength for an electron

$$\lambda = \frac{h}{\sqrt{2meV}} = \frac{12.27}{\sqrt{V}}\ \text{Å}$$

Bohr's Model of Hydrogen Atom

Angular Momentum of electron, $mvr = \frac{nh}{2\pi}$

Radii of Bohr's Stationary Orbit, $r = \frac{n^2h^2}{4\pi^2 mKZe^2}$

Velocity of electron in Bohr's Stationary Orbit,

$$v = \frac{2\pi K e^2}{nh}$$

Frequency of electron in Bohr's Stationary Orbit,

$$f = \frac{KZe^2}{nhr}$$

Spectral Lines

$$\bar{\nu} = RZ^2\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

For Hydrogen Z = 1

For Lyman Series, $n_1 = 1$ and $n_2 = 2, 3, 4..$

For Balmer Series, $n_1 = 2$ and $n_2 = 3, 4, 5..$

For Paschen Series, $n_1 = 3$ and $n_2 = 4, 5, 6..$

For Brakett Series, $n_1 = 4$ and $n_2 = 5, 6,7..$

Total Energy in Bohr's Stationary Orbit

$$E = -\frac{2\pi^2 m K^2 e^4}{h^2}\frac{Z^2}{n^2} = -\frac{13.6}{n^2}\ \text{eV}$$

Semiconductors

- Intrinsic Semiconductor
- Extrensic Semiconductors
  - n-Type
  - p-Type
- p-n junction
- Semiconductor diode
- p-n junction reverse bias
- p-n junction forward bias
- Diode as Rectifier
  - Half-wave Rectifier
  - Full-wave Rectifier
- Zener Diode
- Voltage Regulation

Junction Transistor

- npn
- pnp

C-E Transistor Characteristics

Input Resistance

$$r_i = \left(\frac{\Delta V_{BE}}{\Delta I_B}\right)_{V_{CE}}$$

Output Resistance

$$r_o = \left(\frac{\Delta V_{CE}}{\Delta I_C}\right)_{I_B}$$

Current Gain

$$\beta_{ac} = \left(\frac{\Delta I_C}{\Delta I_B}\right)_{V_{CE}}$$

Switch

$$V_o = V_{CC} - I_C R_C$$

Amplifier

$$A_V = -\beta_{ac}\left(\frac{R_C}{R_B}\right)$$

$$A_V = -\beta_{ac}\left(\frac{R_L}{r}\right)$$

Logic Gates

AND

$$Y = A \cdot B$$

NOT

$$Y = \bar{A}$$

OR

$$Y = A + B$$

NAND

$$Y = \overline{A \cdot B}$$

NOR

$$Y = \overline{(A + B)}$$

Communication Systems

Elements of Communication Systems

- Transmitter
- Transmitted Signal
- Channel/Medium
- Noise
- Received Signal
- Reciever

Propagation of Em Waves

Ground Wave Propagation

$$h_{min} \sim \frac{\lambda}{4}$$

Sky Wave Propagation

Space Wave Propagation

Distance between two Antennas

$$d_M = \sqrt{2Rh_T} + \sqrt{2Rh_R}$$

Height of Antenna

$$d = \sqrt{2Rh}$$

Modulation

Frequency Modulation

Amplitude Modulation

Modulation Factor

$$m_a = \frac{\text{change in amplitude of carrier wave}}{\text{amplitude of original carrier wave}} = \frac{K_a E_m}{E_c}$$

Modulated Wave

$$e = E_c \sin\omega_c t + \frac{m_a E_c}{2}\cos(\omega_c - \omega_m)t - \frac{m_a E_c}{2}\cos(\omega_c + \omega_m)t$$