Important Formulas and Units

Chapter 1: Electric Charges and Fields

1. SI unit of electric charge is Coulomb (C).
2. If a system consists of n charges, namely, $q_1, q_2, q_3, \ldots q_n$ the total charge of the system will be $q_{\text{total}} = q_1 + q_2 + q_3 + \cdots + q_n$.
3. Quantization of charge states that
$$q = ne,$$
where $n = \pm 1, \pm 2, \pm 3, \ldots$ is an integer and e is equal to the charge on an electron.
4. The magnitude F of the electrostatic force exerted by one point charge q_1 on another point charge q_2 is
$$\vec{F} = k\frac{|q_1||q_2|}{r^2}\hat{r}.$$
5. If the charges are placed in a medium other than vacuum with absolute permittivity ε, then force between them is given by relation
$$\vec{F} = k\frac{|q_1||q_2|}{r^3}\vec{r}.$$
6. The numerical value of ε_0 = 8.854×10^{-12} C^2/Nm^2 and $1/4\pi\varepsilon_0 = 9 \times 10^9$ Nm^2/C^2.
7. The force exerted on charge q_2 due to charge q_1 is equal in magnitude but opposite in direction to the force exerted on charge q_1 on charge q_2:
$$\vec{F}_{12} = -\vec{F}_{21}.$$
8. Principle of superposition of force states that net force on a charge is
$$\vec{F}_{1,\text{net}} = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14} + \cdots + \vec{F}_{1n}.$$
9. Electric field $\vec{E}$ at point P due to the charged object is
$$\vec{E} = \frac{\vec{F}}{q_0}$$
10. Mathematically electric field is for a charge q is represented as
$$\vec{E}_1 = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1}{|\vec{r}|^2}\vec{r},$$
11. The total electric field due to system of charges is $\vec{E} = \vec{E}_1 + \vec{E}_2 + \cdots + \vec{E}_n$.
12. Electric flux is $\phi = \vec{E} \cdot \vec{A} = EA\cos\theta$.
13. Dipole moment is $\vec{p} = |q| \times 2\vec{a}$.
14. Electric field on axial line of electric dipole is
$$\vec{E}_{\text{p}} = \frac{2kpr}{(r^2 - a^2)^2}.$$
15. Electric field on equatorials line of electrical dipole is
$$E = \frac{kp}{(r^2 + a^2)^{3/2}}.$$
Torque on dipole placed in uniform electric field is $\vec{\tau} = \vec{p} \times \vec{E}$.
16. Linear charge density: $\lambda = \frac{q}{l}$.
17. Surface charge density: $\sigma = \frac{q}{S}$.
18. Volume charge density: $\rho = \frac{q}{V}$.
19. Gauss's law is expressed as following:
$$\Phi(\text{electric flux}) = \oint_S \vec{E} \cdot d\vec{s} = \frac{q}{\varepsilon_0}.$$
20. Electric field due to infinitely long straight uniformly charged wire:
$$\vec{E} = \frac{\lambda}{2\pi\varepsilon_0 r}.$$
21. Field due to a uniformly charged infinite plane sheet:
$$E = \frac{\sigma}{2\varepsilon_0}.$$
22. Electric field due to a uniformly charged thin spherical shell:
(i) For point outside the shell:
$$\vec{E} = \frac{1}{4\pi\varepsilon_0} \times \frac{q}{r^2}.$$
(ii) For a point on surface of shell:
$$\vec{E} = \frac{\sigma}{\varepsilon_0}.$$
(iii) For a point inside the shell: Zero.

Chapter 2 : Electrostatic Potential and Capacitance

1. SI unit of electric potential difference is volts (V) (i.e., joule/coulomb).
2. The small work done in displacing the charge by dr from point P toward the source charge against the force F is expressed as follows:

   $$\text{Work done} = \text{Force} \times \text{Displacement}$$

   or it is mathematically expressed as $dW = \vec{F} \cdot d\vec{r}$.
3. The net potential of n charges is

   $$V_{\text{Net}} = \sum_{i=1}^{n} V_i = \frac{1}{4\pi\varepsilon_0} \sum_{i=1}^{n} \frac{q_i}{r_i},$$

   where q_i is the value of the ith charge and r_i is the radial distance of the given point from the ith charge.
4. The relation between the electric field and electric potential is expressed as

   $$E_s = -\frac{\partial V}{\partial s},$$

   where s is perpendicular to the equipotential surfaces.
5. Potential energy of a system of two charges in an external field is

   $$U = q_1V(r_1) + q_2V(r_2) \frac{q_1q_2}{4\pi\varepsilon_0 r_{12}}.$$
6. The potential energy of dipole placed in external field is $U(\theta) = pE(\cos\theta_0 - \cos\theta_1)$.
7. Any conductor that has practically infinite supply of electrons to nullify any practical electric field, that is, $\vec{E}_{\text{net}} = \vec{E}_{\text{ext}} + \vec{E}_{\text{in}} = 0$.
8. Mathematical expression for polarization is $P = \chi_e E$, where χ_e is a constant known as electrical susceptibility of the dielectric medium.
9. When a dielectric is inserted between the plates fully occupying the region between the two plates, then the dielectric gets polarized and the electric field in the region between the plates reduces to

   $$E = \frac{\sigma - \sigma_p}{\varepsilon_0}$$

   and the mathematical expression for capacitance is

   $$C = \frac{K\varepsilon_0 A}{d}.$$
10. Formula for potential energy of a charged capacitor is

    $$U = \frac{1}{2}CV^2.$$
11. The equivalent capacitance, with the same total charge q and applied potential difference V as the combination, is given as $C_{\text{eq}} = C_1 + C_2 + C_3$.
12. The equivalent capacitance of n capacitors connected in series is equal to the sum of the reciprocals of the individual capacitances, which is expressed as

    $$\frac{1}{C_{\text{eq}}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots + \frac{1}{C_n}.$$

Chapter 3: Current Electricity

1. Current is expressed as

   $$I = \frac{dq}{dt}.$$
2. By integration, the charge that passes through the plane in a time interval extending from 0 to t is given by

   $$q = \int dq = \int_0^t I\, dt.$$
3. SI unit for current is coulomb per second (C/s) or ampere (A):

   $$1 \text{ ampere} = 1 \text{ A} = 1 \text{ coulomb per second} = 1 \text{ C/s}.$$
4. Ohm's law is mathematically expressed as

   $$V \propto I$$
   $$V = R.$$

   where $R = V/I$ is a constant of proportionality and is known as the *resistance* of the conductor.
5. SI unit of resistance is ohm (symbolically it is written as Ω.)
6. The resistance of a conductor is directly proportional to its length (l) and inversely proportional to its cross-sectional area (A). Mathematically this can be written as

   $$R \propto l \text{ and } R \propto \frac{1}{A}$$

   $$\text{Therefore, } R \propto \frac{l}{A} \text{ or } R = \rho\frac{l}{A},$$

   Where ρ is a constant of proportionality known as *resistivity* of the conductor.
7. The SI unit of resistivity is ohm-meter (symbolically it is written as Ω m.)
8. The reciprocal of resistivity of a conductor is known as *conductivity* and is represented by the symbol $\sigma = 1/\rho$ and it is measured per Ω / m.
9. If the velocity of ith electron at any instant of time is v_i, then

   $$\text{Average velocity of all electrons} = 0$$
   $$\frac{\vec{v}_1 + \vec{v}_2 + \vec{v}_3 + ... + \vec{v}_N}{N} = 0$$
   $$\frac{1}{N}\sum_{i=1}^{N} v_i = 0$$
10. The expression for the drift velocity is

    $$v_d = -\left(\frac{eE}{m}\right)\tau.$$

11. The expression for the mobility of conductor is

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

The SI unit of mobility is m^2/Vs and is always positive.

12. For conductors, the resistivity is expressed mathematically as

$$\rho - \rho_0 = \rho_0 \alpha (T - T_0),$$

where T_0 is a selected reference temperature and ρ_0 is the resistivity at that temperature. Usually, T_0 = 293 K (room temperature), for which $\rho_0 = 1.69 \times 10^{-8}\ \Omega$m for copper.

13. Power is the rate of doing work, which is expressed as

$$P = \frac{U}{t},$$

where P is the power delivered when an amount of energy U is transformed in a time interval t.

14. SI unit of power is the watt (W); 1 W = 1 joule per second = 1 J/s.

15. The power delivered to the charge passing through the power supply can be expressed as

$$P = \varepsilon I$$

16. When a number of resistors are placed in series, the resultant current is:

$$I = I_1 + I_2 + I_3 + \ldots.$$

17. Expression for the effective resistance, R_{eff}, of a parallel section of a circuit:

$$\frac{1}{R_{eff}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}.$$

18. The current in a circuit is equal to the emf divided by the total resistance of the circuit:

$$I = \frac{\varepsilon}{R + r}.$$

19. Internal resistance of a cell:

$$r_0 = \frac{r_1 r_2}{r_1 + r_2}.$$

20. In a Wheatstone bridge, four resistances P, Q, R, and X are connected to form a quadrilateral; Resistances P and Q are known resistances called ratio arms, R is a variable resistance, and X is unknown resistance. For a balanced bridge,

$$\frac{P}{Q} = \frac{R}{X}.$$

Chapter 4: Moving Charges and Magnetism

1. The magnetic force ($\vec{F}_m$) on a charge q moving with velocity $\vec{v}$ in a magnetic field $\vec{B}$ is given both in magnitude and direction by

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

2. SI unit of magnetic field is tesla (T).

3. A point charge q (moving with a velocity v and located at r at a given time t) in presence of both the electric field $\vec{E}(r)$ and the magnetic field $\vec{B}(r)$. The force on an electric charge q due to both of them can be written as

$$\vec{F} = q[\vec{E}(r) + \vec{v} \times \vec{B}(r)] = \vec{F}_{electric} + \vec{F}_{magnetic}.$$

4. The force on a conductor of length l carrying current I and placed inside a magnetic field of strength B is given by

$$|\vec{F}| = |I\vec{l} \times \vec{B}| = BIl \sin\theta.$$

5. According to **Biot–Savart law**, the strength of magnetic field dB due to a small current element Ids carrying a current I at a point distant r from the element is directly proportional to I, ds, sin θ and inversely proportional to the square of the distance (r^2) where θ is the angle between ds and r.

$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I d\vec{s} \times \hat{r}}{r^2}$$

6. Magnetic Field on the axis of a circular current loop at a distance z from the center of the loop of radius R carrying current I is given by

$$B_{loop} = \frac{\mu_0}{2} \frac{IR^2}{(z^2 + R^2)^{3/2}}$$

7. **Ampere's circuital law** mathematically expressed as

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

8. When two infinitely long parallel conductors carrying currents I_1 and I_2 are placed a distance r apart, then force on the unit length of a conductor due to the other conductor is given by

$$F = \frac{\mu_0}{4\pi} \cdot \frac{2I_1 I_2}{r}$$

9. When an electric current flows in a closed loop of wire, placed in a uniform magnetic field, the magnetic forces produce a torque which is given by

$$\tau = NIAB\cos\theta,$$

where N is the number of turns of the coil, A is the cross-sectional area, I is the current flowing in the coil, and θ is the angle between the coil and the direction of magnetic field.

10. **Magnetic dipole moment** is denoted by $\vec{M}$ and expressed as

$$\vec{M} = m(2\vec{l}),$$

where m is pole strength of the magnetic dipole.

11. SI unit of magnetic dipole moment is ampere-meter^2 (Am^2).

12. When an electric current flows in a closed loop of wire, placed in a uniform magnetic field, the magnetic forces produce a torque which tends to rotate the loop so that area of the loop is perpendicular to the direction of the magnetic field. A current loop of area A carrying current I behaves as a magnetic dipole having magnetic dipole moment.

$$M = IA.$$

13. An electron moving around the central nucleus has a magnetic moment, which is given by

$$\mu_l = \frac{e}{2m} l,$$

where l is the magnitude of the angular momentum of the circulating electron about the central nucleus.

Chapter 5: Magnetism and Matter

1. Magnetic field due to a bar magnet is

$$B = \frac{\mu_0}{4\pi}\frac{2m}{r^3}.$$

Potential energy of the bar magnet $= -\vec{m}\cdot\vec{B}$, where m is magnetic moment and B is the strength of the magnetic field.

2. If B is intensity of Earth's total magnetic field, then the horizontal component of Earth's magnetic field is given by $H = B_E \cos I$ Also, the vertical component of Earth's magnetic field is given by $V = B_E \sin I$. Therefore, $\tan I = \frac{V}{H}$.
3. If M is the strength of the magnetizing field, then magnetic induction is given by

$$B = \mu_0(H + M),$$

where H is the **magnetic intensity** and is equal to the degree to which a material can be magnetized by a magnetic field.

4. Magnetization M is a vector quantity and its SI unit is A/m, it is expressed as $M = m/V$.
5. SI unit of strength of magnetizing field is ampere/meter (A/m) and that of magnetic induction is tesla (T) or weber/meter^2 (Wb/m^2).
5. Magnetic susceptibility is given by

$$\chi = \frac{M}{H}.$$

Magnetic susceptibility has no units. It can be proved that $\mu = \mu_0(1+\chi)$ so that $\mu_r = 1+\chi$ is the analog of dielectric constant in electrostatics and is known as **relative magnetic permeability**. It is a dimensionless quantity.

6. SI unit of magnetic permeability is tesla meter/ampere (Tm/A).
7. If μ_0 is the absolute permeability of free space, then the relative permeability of a medium is given by

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

8. **Curie's law** mathematically expressed as

$$\chi \propto \frac{1}{T}$$

or

$$\chi T = \text{constant}.$$

Chapter 6 : Electromagnetic Induction

1. The **magnetic flux** is denoted by Φ, which is mathematically expressed as

$$\Phi = BA\cos\theta,$$

where B is the magnetic field, A is the surface area, and θ is the angle between magnetic field and normal to the surface area.

2. Unit of magnetic flux is weber (Wb).
3. **Faraday's second law** is mathematically expressed as

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

4. Motional emf, is expressed as $\varepsilon = -Blv$.
5. Rate of work done on a loop (also called thermal energy) as it is pulled from the magnetic field is given by

$$P = Fv = \frac{B^2L^2v^2}{R}.$$

6. Equation for resistive dissipation:

$$P = I^2R.$$

7. The coefficient of self-induction or simply self-inductance (L) of a coil is numerically equal to the magnetic flux linked with it when unit current flows through it:

$$\Phi = LI$$

8. The self-inductance of a coil is also numerically equal to the induced emf produced in the coil, when the rate of change of current in the coil is unity.

$$\varepsilon = -L\left(\frac{dI}{dt}\right)$$

9. SI unit of self-inductance is henry (H).
10. The inductance per unit length near the center of a long solenoid is

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

11. The coefficient of mutual induction or simply mutual inductance (M) of the two coils is numerically equal to the magnetic flux (Φ) linked with one coil, when a unit current flows through the neighboring coil:

$$\Phi = MI.$$

12. The mutual inductance of two coils is numerically equal to the induced emf produced in one coil, when rate of change of current is unity in the other coil:

$$\varepsilon = -M\left(\frac{dI}{dt}\right).$$

13. SI unit of mutual inductance is henry (H).
14. *Inductors in series:* Inductors, like resistors and capacitors, can be placed in series. Increasing levels of inductance can be obtained by placing inductors in series.

$$L_T = L_1 + L_2 + L_3 + \cdots + L_N.$$

15. *Inductors in parallel:* Decreasing levels of inductance can be obtained by placing inductors in parallel.

$$\frac{1}{L_T}=\frac{1}{L_1}+\frac{1}{L_2}+\frac{1}{L_3}+\cdots+\frac{1}{L_N}.$$

16. Energy stored in an inductor is

$$W=\frac{1}{2}LI^2.$$

17. When a current is passed through a solenoid of length l and cross-sectional area A, the energy stored inside it is given by

$$W=\frac{1}{2\mu_0}B^2Al.$$

Chapter 7 : Alternating Current

1. The common alternating current varying as sine function of the time is given by

$$I=I_0\sin\omega t=I_0\sin 2\pi vt=I_0\sin\frac{2\pi t}{T}$$

and

$$V=V_0\sin 2\pi vt=V_0\sin\frac{2\pi t}{T}.$$

Here, I_0 and V_0 are the maximum or peak values of current and voltage, ω the angular frequency, ν is the frequency, and T is the period of the given ac.

2. average or mean value of an ac means the average value of given ac over a half cycle:

$$I_{\text{ave}}=\frac{\int_0^{1/2} I\,dt}{\int_0^{1/2} dt}=\frac{2I_0}{\pi}=0.637I_0;$$

$$V_{\text{ave}}=0.637V_0.$$

3. The rms value of an ac is defined as

$$(I_{\text{rms}})^2=\frac{\int_0^{T} I^2\,dt}{\int_0^{T} dt}=\frac{(I_0)^2}{2}\Rightarrow I_{\text{rms}}=\frac{I_0}{\sqrt{2}};$$

$$V_{\text{rms}}=\frac{V_0}{\sqrt{2}}.$$

4. For a pure resistive circuit, the current and voltage are in same phase, and the current is given by $I=I_0\sin\omega t$. Also,

$$I=\frac{V}{R}\ \text{or}\ I_{\text{rms}}=\frac{V_{\text{rms}}}{R}.$$

For pure inductive circuit, the inductance offers some opposition toward the flow of ac. It is known as **inductive reactance**, which is expessed as $X_L=2\pi vL=L\omega$. Thus, a pure inductance does not oppose flow of dc ($\omega=0$) but oppose flow of ac. The current that flows is $I=V/X_L$. The current decreases with increase in frequency. The current lags behind the voltage by $\pi/2$ (or the voltage leads the current by $\pi/2$), which is given by

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

5. For a pure capacitive circuit, the capacitive reactance is given by

$$X_C=\frac{1}{C\omega}\,\Omega=\frac{1}{C2\pi v}\,\Omega.$$

The current that flows is $I=V/X_C$. The current increases with increase in frequency. The current leads the voltage by $\pi/2$ (or the voltage lags behind the current by $\pi/2$), which is given by

$$I=I_0\sin\left(\omega t+\frac{\pi}{2}\right).$$

$$I=I_0\sin\left(\omega t+\frac{\pi}{2}\right).$$

6. The opposition offered by a pure inductor or capacitance or both to the flow of ac through it is called reactance X whose unit is ohm (Ω) and the dimensional formula is $ML^2T^{-3}A^{-2}$. Reactance is of two types: (a) Inductive reactance $X_L=L\omega$ and (b) Capacitive reactance $X_C=1/C\omega$.

7. Reciprocal of reactance to known as **susceptance**:

$$S=\frac{1}{X}.$$

8. Total opposition offered by an ac circuit to flow through circuit is called its **impedance**, Z. Its SI unit is ohm and the dimensional formula is $ML^2T^{-3}A^{-2}$. For a circuit having a current of 1 A,

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

9. Reciprocal of impedance is known as **admittance**:

$$Y=\frac{1}{Z}.$$

The SI unit of admittance is siemen (S).

10. Let a voltage $V=V_0\sin\omega t$ be applied across an ac and consequently a current $I=I_0\sin(\omega t-\phi)$ flows through circuit. Then, the instantaneous power is $VI=V_0I_0\sin\omega t\sin(\omega t-\phi)$ and its value varies with time.

11. Average power over a full cycle of ac:

$$P_{\text{ave}}=V_{\text{rms}}I_{\text{rms}}\cos\phi=\frac{1}{2}V_0I_0\cos\phi,$$

where $V_{\text{rms}}I_{\text{rms}}$ is the apparent or virtual power and $V_{\text{rms}}I_{\text{rms}}\cos\phi$ is called the true power. The term $\cos\phi$ is known as power factor of the given circuit. Thus,

$$\cos\phi=\frac{R}{2}=\text{Power factor}=\frac{\text{True power}}{\text{Apparent power}}.$$

12. For a pure resistive circuit, V and I are in phase, that is, $\phi=0°$ and therefore, $\cos\phi=1$ and the average power is $V_{\text{rms}}I_{\text{rms}}$.

13. For a pure inductive or a pure capacitive circuit, the current and voltage differ in phase by $\pi/2$ (where $\pi/2$ is zero) and the average power is zero.

14. For a series *LCR* circuit,

$$E = E_0 \sin E_0 \sin wt \quad \text{and} \quad I = \frac{E_0}{z}\sin(\omega t - \phi),$$

where

$$Z = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2} \quad \text{and} \quad \tan\phi = \frac{X}{R} = \frac{X_L - X_C}{R}.$$

For $X_L > X_C$, the current lags voltage; For $X_L < X_C$, the current leads voltage; For $X_L = X_C$, the current and the voltage are in phase. If $X_L = X_C \Rightarrow \omega_0 = 1/\sqrt{LC}$, that is, the natural frequency of the circuit is equal to the applied frequency, then the circuit is said to be in resonance

15. $Q = \omega L / R$ or $1/\omega RC$ is termed as quality factor of a circuit. It determines the sharpness of resonance. Higher the value of *Q*, sharper is the resonance.

16. Average power is given by

$$P_{\text{ave}} = E_{\text{rms}} I_{\text{rms}} \cos\phi$$

The phase difference between E_{rms} and I_{rms} is ϕ. I_{rms} can be resolved into two components: $I_{\text{rms}}\cos\phi$ and $I_{\text{rms}}\sin\phi$

17. For an ideal transformer,

$$\frac{e_s}{e_p} = \frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s} = k,$$

where *k* is the transformation ratio. For a step-up transformer, $k > 1$, but for a step-down transformer, $k < 1$. In a transformer, input emf and output emf differ in phase by π radian. (Subscripts s and p refer to secondary and primary, respectively.)

18. The efficiency of a transformer is given by

$$\eta = \frac{\text{output power}}{\text{input power}} = \frac{V_s I_s}{V_p I_p}.$$

(Subscripts s and p refer to secondary and primary, respectivey.) For an ideal transformer, η = 100% or 1. However, for a practical transformer, $\eta \approx$ 85–90%.

Chapter 8 : Electromagnetic Waves

1. **Displacement current** is given by

$$I_d = \varepsilon_0 \frac{d\Phi_E}{dt},$$

where ε_0 is the absolute permittivity of free space.

2. Following four equations are called Maxwell's equation, which describe the laws of electromagnetism:

(a) $\oint \vec{E}\cdot d\vec{s} = \dfrac{q}{\varepsilon_0}$ (Gauss's law in electrostatics)

(b) $\oint \vec{B}\cdot d\vec{s} = 0$ (Gauss's law in magnetism)

(c) $\oint \vec{B}\cdot d\vec{l} = -\dfrac{d\Phi_B}{dt}$ (Faraday's law of electromagnetic induction)

(d) $\oint \vec{B}\cdot d\vec{l} = \mu_0\left(I_C + \varepsilon_0 \dfrac{d\Phi_B}{dt}\right)$ (Ampere – Maxwell circuital law)

4. The **speed of electromagnetic wave** is given by the relation

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} \quad \text{(wave speed).}$$

5. The amplitudes of the electric and magnetic fields in an electromagnetic wave have the relation

$$\frac{E}{B} = c \quad \text{(magnitude ratio).}$$

Chapter 9 : Ray Optics and Optical Instruments

1. A reflected ray deviates by an angle $\delta = \pi - 2\theta$.

2. Focal length of a spherical mirror of radius of curvature *R* is $f = R/2$.

3. If the height of the object is h_o and the height of the image is h_i, lateral magnification is given by

$$m = \frac{h_i}{h_o} = -\frac{v}{u},$$

where *v* and *u* are the image and object distances.

4. The mirror equation is

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

5. Refractive index *n* of a medium is given by

$$n = \frac{\text{Speed of light in vacuum}}{\text{Speed of light in the material}} = \frac{c}{v}.$$

6. Snell's law relates the angle of refraction θ_2 to the angle of incidence θ_1 by

$$n_1 \sin\theta_1 = n_2 \sin\theta_2.$$

7. Apparent depth h_i of an object is given by $\dfrac{h_i}{n_r} = \dfrac{h_o}{n_i}$.

8. The critical angle for total internal reflection is given by

$$\sin\theta_c = \frac{n_2}{n_1} \quad \text{where } n_1 > n_2.$$

9. The equation for a spherical refracting surface of radius of curvature R is

$$\frac{n_2}{v}-\frac{n_1}{u}=\frac{n_2-n_1}{R}.$$

10. Lateral magnification of a spherical refracting surface is given by

$$m=\frac{h_i}{h_o}=\frac{n_1\times v}{n_2\times u}.$$

11. The lens formula is

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

12. The lens maker's formula is

$$\frac{1}{f}=\left(\frac{n_2}{n_1}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right),$$

13. The power P of a lens of focal length f is given by

$$P=\frac{1}{f\ (\text{meter})}.$$

14. The total magnification m of the combination of lenses will be equal to the product of the magnification of individual lenses. That is,

$$m=m_1\times m_2\times m_2\times\cdots.$$

15. Angle of deviation of a prism is $\delta=i+e-A$.

16. Angle of minimum deviation of a prism is

$$n=\frac{\sin[(\delta_{\min}+A)/2]}{\sin(A/2)}.$$

17. For a thin prism, $\delta=(n-1)A$.

18. Cauchy's relation for chromatic dispersion by a prism is given by

$$n=A+\frac{B}{\lambda^2}.$$

19. The intensity of scattered light is related to the wavelength of the light as

$$I\propto\frac{1}{\lambda^4}.$$

20. Angular magnification of a magnifying glass is

$$M=\frac{\theta'}{\theta}\approx\left(\frac{1}{f}-\frac{1}{v}\right)N,$$

where N is the distance from the eye to the near point.

21. For a compound microscope, linear magnification is given by

$$M=\frac{-L}{f_o}\times\frac{D}{f_e}.$$

22. For a refracting telescope, $M=\frac{-l/f_e}{l/f_o}=\frac{-f_o}{f_e}$.

23. For a telescope, if the image forms at the least distance of distinct vision,

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

Chapter 10 : Wave Optics

1. The wavelengths of light in two media are proportional to the speeds of light in those media; that is

$$\frac{\lambda_1}{\lambda_2}=\frac{v_1}{v_2},$$

2. Snell's law of refraction: $n_1\sin\theta_1=n_2\sin\theta_2$.

3. The fractional change in frequency $\Delta\nu/\nu$ due to the Doppler's effect is given by

$$\frac{\Delta\nu}{\nu}=-\frac{-v_{\text{radial}}}{c},$$

where v_{radial} is the component of the source velocity (relative to the observer) along the line joining the observer to the source.

4. Doppler's effect formula in another form: When the direction of $\vec{v}$ is directly away from the source, then

$$\nu=\nu_0\sqrt{\frac{1-\beta}{1+\beta}},$$

where ν_0 represents the **proper frequency** of the source (frequency that is measured by an observer in the rest frame of the source), ν represents the frequency detected by an observer moving with velocity $\vec{v}$ relative to that rest frame, and $\beta=v/c$. When the direction of $\vec{v}$ is directly toward the source, we must change the signs in front of both β symbols.

5. For low-speed Doppler's effect: $\nu=\nu_0\left(1-\beta+\frac{1}{2}\beta^2\right)$ (where $\beta<<1$)

6. Astronomical Doppler's effect: $v=\frac{|\Delta\lambda|}{\lambda_0}c$

(radial speed of light source, $v<<c$), where the difference $\Delta\lambda$ is the *wavelength Doppler's shift* of the light source.

7. The relation between phase difference ϕ and path difference of x of two waves is

$$\phi=\frac{2\pi}{\lambda}x.$$

8. Constructive interference will result whenever the distances traveled by the waves are the same or differ by any integer number of wavelengths. If this difference is denoted by x,

$$x=n\lambda\text{, where } n=0, 1, 2, 3\ldots$$

9. Destructive interference will take place whenever the distances traveled by the waves differ by any odd integer number of half-wavelengths. That is,

$$x=\left(n+\frac{1}{2}\right)\lambda,\ \text{where } n=0, 1, 2, 3\ldots$$

10. In Young's double-slit experiment, the condition for bright fringes is given by

$$d\sin\theta = m\lambda, \quad \text{for } m = 0, 1, 2, \ldots$$

where d is the slit width. For dark fringes,

$$d\sin\theta = \left(m + \frac{1}{2}\right)\lambda, \quad \text{for } m = 0, 1, 2, \ldots$$

11. If D is the distance between the slits and the screen, the fringe width is given by

$$\Delta y = y_{m+1} - y_m = \frac{\lambda D}{d}.$$

12. Given the phase difference ϕ between the waves at the screen, the intensity of the interference pattern is given by

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

where I_0 is the uniform intensity on the screen when one of the slits is covered up.

13. The condition to obtain minima in a single-slit diffraction pattern is

$$a\sin\theta = m\lambda, \quad \text{for } m = 0,1,2,\ldots,$$

where a is the slit width and θ is the angle to the central axis.

14. By Rayleigh's criterion, two objects that are barely resolvable must have an angular separation θ_R given by

$$\theta_R = 1.22\frac{\lambda}{d},$$

where d is the least distance between the two objects so that their diffraction images are just resolved.

15. For a microscope,

$$\frac{1}{d} = \frac{2\mu\sin\theta}{1.22\lambda},$$

where θ is the semi-vertical angle of the cone in which rays of light from an object enter the objective lens of the microscope μ is the refractive index of the medium, and λ is the wavelength of the light used to observe the objects.

16. For a telescope,

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

17. If the transmission axis of an analyzer is oriented at an angle θ relative to the transmission axis of the polarizer, Malus' Law is given by

$$I = I_0\cos^2\theta,$$

Where I_0 is the average intensity of the light entering the analyzer.

18. Brewster's angle θ_B is given by

$$\theta_B = \tan^{-1}\frac{n_2}{n_1},$$

where n_1 is the refractive index of the medium through which the incident and reflected rays travel and n_2 is the refractive index of the medium from which the light reflects.

Chapter 11 : Dual Nature of Radiation and Matter

1. Energy of a photon of light of frequency ν is given by

$$E = h\nu,$$

where h is the Planck's constant.

2. In photoelectric emission, the kinetic energy of the most energetic electrons is given by

$$K_{\max} = eV_0,$$

where V_0 is the stopping potential.

3. Einstein's photoelectric equation is

$$h\nu = K_{\max} + \phi_0$$

Where ϕ_0 is the work function of the metal surface.

4. It can also be written as

$$\frac{1}{2}mv_{\max}^2 = h\nu - h\nu_0.$$

where ν_0 is the threshold frequency.

5. Momentum of a photon is

$$p = \frac{E}{c} = \frac{h\nu}{c} = \frac{h}{\lambda}.$$

6. Momentum of a particle of rest mass m_0 traveling at velocity v is

$$p = \frac{m_0 v}{\sqrt{1 - v^2/c^2}}.$$

7. The relativistic formula for total energy of a particle is

$$E^2 = p^2c^2 + m_0^2c^4.$$

8. The be Broglie wavelength of the matter wave associated with a particle of momentum p is

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

9. The de Broglie wavelength associated with an electron accelerated through a potential difference of V volts is

$$\lambda = \left(\frac{1.225}{\sqrt{V}}\right)\text{nm}.$$

10. Heisenberg's uncertainty principle states that the uncertainty in the position of a particle, Δx is related to the uncertainty in its momentum Δp by

$$\Delta x\,\Delta p \ge \hbar, \quad \text{where } \hbar = \frac{h}{2\pi}.$$

Chapter 12 : Atoms

1. The Rydberg's formula is given by the relation

$$\frac{1}{\lambda} = R_H\left(\frac{1}{2^2} - \frac{1}{n^2}\right).$$

2. Orbital radius of the electron in a hydrogen atom is

$$r = \frac{e^2}{4\pi\varepsilon_0 mv^2}.$$

3. Potential energy of electron in orbit around the nucleus is

$$U = \frac{-e^2}{4\pi\varepsilon_0 r}.$$

4. The wavelength of the spectra emitted by hydrogen is given by

$$\frac{1}{\lambda} = R_H\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right).$$

5. Angular momentum of an electron in a stationary orbit is given by

$$L = mvr = \frac{nh}{2\pi}.$$

6. Frequency of radiation absorbed or emitted by an electron is given by

$$h\nu = E_{\text{initial}} - E_{\text{final}}.$$

7. Radius of the *n*th orbit in an atomic number Z is

$$r_n = (5.29 \times 10^{-11}\ \text{m})\frac{n^2}{Z}, \qquad n = 1, 2, 3, \ldots.$$

8. Energy of an electron in the *n*th orbit of an atom having atomic number Z is

$$E_n = -(13.6\ \text{eV})\frac{Z^2}{n^2}, \qquad n = 1, 2, 3, \ldots.$$

Chapter 13 : Nuclei

1. Nuclei are made up of protons and neutrons. The number of protons in a nucleus (called the **atomic number** or **proton number** of the nucleus) is represented by the symbol *Z*; the number of neutrons (the **neutron number**) is represented by the symbol *N*. The total number of neutrons and protons in a nucleus is called its **mass number** *A*; thus

$$A = Z + N.$$

2. Effective radius of Nuclide is given by

$$r = r_0 A^{1/3},$$

in which *A* is the mass number and $r_0 \approx 1.2$ fm.

3. Atomic masses are often reported in *atomic mass units,* a system in which the atomic mass of neutral ^{12}C is defined to be exactly 12 u, where 1 u = $1.660\,538\,86 \times 10^{-27}$ kg.

4. If the total mass of the participants in a nuclear reaction changes by an amount Δm, there is an energy release or absorption given by the equation $Q = -\Delta mc^2$. As we shall now see, nuclear energies are often reported in multiples of 1 MeV. Thus, a convenient conversion between mass units and energy units is provided by the following equation:

$$c^2 = 931.494013\ \text{MeV/u}.$$

5. Albert Einstein was able to show that when mass converts to energy, the change in energy, Δ*E*, is related to the change in rest mass, Δ*m*, by the following equation, now called the Einstein equation.

$$\Delta E = \Delta mc^2$$

where *c* is the velocity of light, 3.00×10^8 m s^{-1}.

6. The mass *M* of a nucleus is *less* than the total mass Σ *m* of its individual protons and neutrons. That means that the mass energy Mc^2 of a nucleus is *less* than the total mass energy $\sum(mc^2)$ of its individual protons and neutrons. The difference between these two energies is called the **binding energy** of the nucleus:

$$\Delta E_{be} = \sum(mc^2) - Mc^2 \qquad \text{(binding energy)}.$$

7. A better measure is the **binding energy per nucleon** ΔE_{ben}, which is the ratio of the binding energy ΔE_{ben} of a nucleus to the number *A* of nucleons in that nucleus:

$$\Delta E_{ben} = \frac{\Delta E_{be}}{A} \qquad \text{(binding energy per nucleon)}.$$

8. Radioactive decay is given by

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

in which N_0 is the number of radioactive nuclei in the sample at $t = 0$ and *N* is the number remaining at any subsequent time *t*.

9. An alternative form of the law of radioactive decay:

$$R = \lambda N,$$

where *R* and the number of radioactive nuclei *N* that have not yet undergone decay must be evaluated at the same instant. The total decay rate *R* of a sample of one or more radionuclides is called the **activity** of that sample. The SI unit for activity is the **becquerel**, named for Henri Becquerel, the discoverer of radioactivity:

$$1\ \text{becquerel} = 1\ \text{Bq} = 1\ \text{decay per second}.$$

10. An older unit, the **curie**, is still in common use:

$$1\text{curie} = 1\text{Ci} = 3.7 \times 10^{10}\,\text{Bq}.$$

11. The half life $T_{1/2}$ of a radionucleide is expressed as

$$T_{1/2} = \frac{\ln 2}{\lambda} = \tau \ln 2.$$

12. the probability of decay of a given nucleus is

$$\frac{N_0 - N}{N_0} = 1 - e^{-\lambda t}.$$

Chapter 14 : Semiconductor Electronics :Materials, Devices and Simple Circuits

1. Mathematically, electrical conductivity is defined as the reciprocal of the resistivity of the material. That is, $\sigma = 1/\sigma$.

2. *The number of free electrons (in the conduction band) and holes (in the valence band) are equal in case of intrinsic semiconductors*. Mathematically, this is expressed as $n_e = n_h = n_i$, where *ne*, *n*h are the number densities of electrons and holes and *ni* is the intrinsic carrier concentration (i.e. electrons or holes).

3. The movement of holes constitutes the hole current (*I*h) and the movement of electrons constitutes the electron current (*I*e). The total current *I* which flows through the semiconductor when an electric field is applied, is $I = I_e + I_h$

4. In *p*-type semiconductors, holes are the majority carriers and electrons are the minority carriers. For *p*-type semiconductors, we have $n_h >> n_e$.

5. In some semiconductors, such as gallium arsenide or indium phosphide, the energy can be emitted as a photon of energy at wavelength *hν*

$$\lambda = \frac{c}{v} = \frac{c}{E_g/h} = \frac{hc}{E_g}.$$

7. The emitter current (*I*E) is equal to the sum of the base current (*I*B) and the collector current (*I*C), and is mathematically written as $I_E = I_B + I_C$

8. To obtain the input characteristics when the transistor is in active state, the collector– emitter voltage *V*CE is kept large enough so that the base–collector junction is reverse-biased. The relation between the input and output voltage is $V_{CE} = V_{CB} + V_{BE}$.

9. The ratio of change in the base–emitter voltage (Δ*V*BE) to the resulting change in the base current (Δ*I*B) at constant collector–emitter voltage (*V*CE) is known as **input resistance**. The mathematical expression for the input resistance is

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

10. The ratio of the change in collector–emitter voltage (Δ*V*CE) to the resulting change in the collector current (Δ*I*C) at constant base current (*I*B) is known as **output resistance**. The mathematical expression for the output resistance is ΔC*I*Δ

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

11. The mathematical expression for the current amplification factor is

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

12. Mathematically, the dc current gain is expressed by

$$\beta_{dc} = \frac{I_C}{I_B}$$

13. Mathematically, the small signal voltage gain is written as

$$A_v = \frac{\Delta V_o}{\Delta V_i}$$

14. The power gain (A_p) of an amplifier is defined as the product of the voltage and current gains. Mathematically, it is expressed as

$$A_p = A_v \times \beta_{ac}$$

Chapter 15 : Communication Systems

1. If the signals are digital, they are rectangular in shape. They can be expressed as a superposition of sinusoidal waves of frequencies $n\nu_0$, where $n = 1, 2, 3, \ldots$ and ν_0 is the frequency of the rectangular waves.

2. If *N* is the electron density (per cubic meter) of an ionospheric layer, its critical frequency is given by

$$\nu_c = 9\sqrt{N}.$$

3. Let the transmitting antenna be at a height h_T and the distance to the horizon, *d* – also known as the radio horizon of the transmitting antenna – then becomes

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

where *R* is the radius of the Earth.

4. The maximum line-of-sight distance d_M between the transmitting and receiving antennas is given by

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

Where h_R is the height of the receiving antenna.

5. The power radiated from a linear antenna of length l obeys the relation

$$P \propto \left(\frac{l}{\lambda}\right)^2.$$

Therefore, for a given antenna length, the power radiated increases with decrease in λ, which corresponds to increase in frequency.

6. The high-frequency carrier wave used to transmit information can be represented as

$$c(t) = A_c \sin(\omega_c t + \phi),$$

where $c(t)$ is the strength of the signal, which can be a voltage or a current, A_c is its amplitude, ω_c is the angular frequency, and ϕ is the initial phase.

7. In amplitude modulation (AM), the amplitude of the carrier wave, A_c, is modulated by the information signal. Let this **modulating signal** be represented by

$$m(t) = A_m \sin \omega_m t$$

with A_m being the signal's amplitude and ω_m its angular frequency.

8. The sideband frequency is represented as

$$\omega_{SB} = \omega_c \pm \omega_m.$$

9. The modulation index is represented as

$$\mu = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}.$$