PHYSICS

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INDEX

1^{st} Chapter: Heat and Thermodynamics

1.1. Principle of Temperature Measurements:

1.1.1. Define temperature and heat.

Ans:

Temperature: Temperature is a measure of the average kinetic energy of the particles in a substance. In simpler terms, it tells us how hot or cold an object or substance is.

Temperature is typically measured in degrees Celsius (°C) or Fahrenheit (°F) in everyday use, and in Kelvin (K) in scientific contexts.

Heat: Heat is the transfer of thermal energy between systems with different temperatures. It is the energy in transit from a warmer object to a cooler one.

Heat is measured in units such as joules (J) or calories.

1.1.2. Write the difference between temperature and heat.

Ans: The temperature and heat have distinct meanings:

Characteristic	**Temperature**	**Heat**
Definition	Measure of average kinetic energy of particles	Transfer of thermal energy between systems
Units	Celsius (°C), Fahrenheit (°F), Kelvin (K)	Joules (J), calories
Role	Reflects how hot or cold an object is	Represents the energy transfer from hot to cold regions
Measurement	Represents intensity of thermal energy	Represents the quantity of energy transferred

1.2. Platinum Resistance Thermometer:

Ans: Definition:

A Platinum Resistance Thermometer (PRT) is a temperature sensor that relies on platinum's resistance changes to measure temperature.

Characteristics:

1. Precision: PRTs are highly accurate.
2. Temperature Range: They work in a wide range of temperatures.
3. Calibration Dependence: Accurate readings require calibration.
4. Design Variety: Available in different designs.
5. Applications: Used in various industries for precise temperature control.
6. Relationship: Follows a clear link between resistance and temperature.

1.3. Thermo-electric Thermometer:

1.3.1. Describe thermo-electric thermometer.

A thermo-electric thermometer is a temperature-measuring device that works by using the Seebeck effect. It generates an electric voltage when there's a temperature difference between its two ends. This voltage is directly related to the temperature, allowing the thermometer to provide a simple and direct temperature measurement.

1.3.2. Write short notes on i) Seebeck effect, and ii) Peltier effect.

Seebeck Effect:

The Seebeck effect is a phenomenon where a temperature difference between two different metals or semiconductors creates an electric voltage. This voltage is proportional to the temperature difference, allowing for the generation of electric power or the measurement of temperature. It forms the basis of thermo-electric devices like thermocouples and explains the principles behind thermoelectric thermometers.

Peltier Effect:

The Peltier effect is the reverse of the Seebeck effect. When an electric current passes through the junction of two different metals or semiconductors, it either absorbs or releases heat, depending on the direction of the current. This effect is used in Peltier coolers, where the absorption of heat is exploited for cooling purposes.

1.4. Pyrometer:

Ans: A pyrometer is a tool that measures really hot temperatures without touching the object by detecting the heat radiation it gives off, commonly used in industries.

A pyrometer is a device used to measure high temperatures without direct contact. It works by detecting the infrared radiation emitted by a hot object, converting it into an electrical signal, and providing a non-contact temperature reading. Pyrometers are commonly used in industries like metal processing, glass manufacturing, and aerospace for accurate temperature monitoring in extreme conditions.

1.5. Kinetic Theory of Gases:

1.5.1. Write down the postulates of kinetic theory of gases/ State the fundamental postulates of the kinetic theory of gases/ State the fundamental assumptions of the kinetic theory of gases.

Ans: The postulates of the kinetic theory of gases are as follows:

1. Particles in Constant Motion: Gas is composed of small particles (atoms or molecules) that are in constant, random motion.
2. Negligible Volume: The volume occupied by the gas particles themselves is negligible compared to the overall volume of the gas.
3. Negligible Forces Between Particles: The particles exert no forces on each other except during collisions. These collisions are assumed to be perfectly elastic.

4. Constant, Random Collisions: Collisions between gas particles and with the walls of the container are perfectly elastic, meaning there is no loss of kinetic energy. The collisions happen randomly and result in changes in speed and direction.

5. Average Kinetic Energy Proportional to Temperature: The temperature of a gas is proportional to the average kinetic energy of its particles. The higher the temperature, the greater the average kinetic energy.

1.5.2. Show from the kinetic theory that the mean kinetic energy of translation of one molecule of perfect gas is $\frac{3}{2}kT$. Where k is Boltzmann's constant and T is the absolute temperature of the gas.

Ans: According to the kinetic theory, the kinetic energy (KE) of a molecule is given by:

$$KE = \frac{1}{2}mv^2$$

Where:

- m is the mass of the gas molecule,
- v is the velocity of the gas molecule.

Now, the average kinetic energy per molecule (KE) can be found by taking the average over all possible directions of motion. Since the molecule can move in three perpendicular directions in three-dimensional space, we have three components of velocity: v_x, v_y, v_z.

The mean kinetic energy per molecule is the average of the kinetic energy in each direction:

$$KE = \frac{1}{2}mv_x^2 + \frac{1}{2}mv_y^2 + \frac{1}{2}mv_z^2$$

Now, by the equipartition theorem, each degree of freedom contributes $\frac{1}{2}kT$ to the average energy, where k is the Boltzmann constant and T is the temperature.

In three dimensions, a molecule has three translational degrees of freedom. Therefore, we can write:

$$KE = \frac{1}{2}kT + \frac{1}{2}kT + \frac{1}{2}kT = \frac{3}{2}kT$$

So, the mean kinetic energy of translation of one molecule in a perfect gas is $\frac{3}{2}kT$.

1.5.3. Derive an expression for the pressure of a gas. / Prove that $P = \frac{1}{3}\rho c^2$.

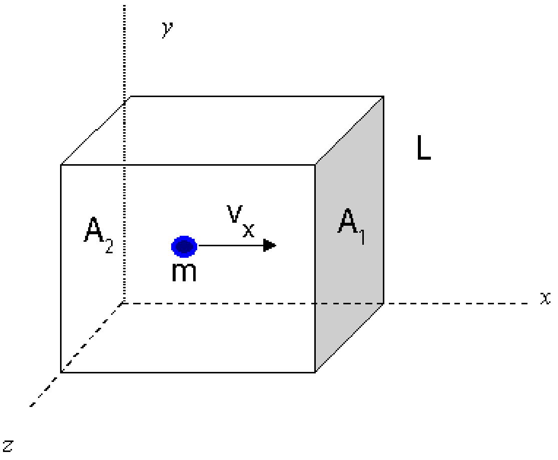
Ans: When an individual molecule collides with a wall, as shown in Fig, its momentum doubles.

Considering the motion in the x-direction with a velocity U_x, where the length of the cube, mass of the molecule, and velocity are denoted by l, m, and v respectively, the analysis proceeds as follows:

- Momentum in the x-direction: mU_x
- Momentum in the -x-direction: $-mU_x$
- Change in momentum: $2mU_x$

- Total time taken (from one end to the other and back): $\frac{2l}{U_x}$

- Rate of change in momentum: $\frac{2mU_x}{\frac{2l}{U_x}} = \frac{mU_x^2}{l}$



According to Newton's Second Law, the rate of change of momentum is the force exerted by the molecule on the wall. Therefore, Force $F = \frac{mU_x}{l}$.

Since pressure (P) is defined as force per unit area, $P = \frac{\frac{mU_x^2}{l}}{l^2} = \frac{mU_x^2}{l^3} = \frac{mU_x^2}{V}$, where V is the volume of the container (the cube).

If there are N molecules in the container, $P = \frac{m(U_1^2+U_2^2+U_3^2+\cdots+U_N^2)}{V}$.

If the velocities are equal, $P = \frac{NmU_x^2}{V}$.

Since the velocity components are equal, $U_x^2 = \frac{U^2}{3}$, where U^2 is the mean square velocity denoted as $\bar{c}^2$. Therefore, $P = \frac{Nm\bar{c}^2}{3V}$.

Combining pressure and volume, $PV = \frac{1}{3}mN\bar{c}^2$. Recognizing that mN/V is the density (ρ), we can express this as $P = \frac{1}{3}\frac{mN}{V}\bar{c}^2 = \frac{1}{3}\rho\bar{c}^2$.

1.5.4. Using the kinetic molecular theory, explain how an increase in the number of moles of gas at constant volume and temperature affects the pressure.

Ans: Kinetic Molecular Theory Foundation:

The kinetic molecular theory forms the foundation for understanding gas behavior at the molecular level. It explains how macroscopic properties, such as pressure, result from the interactions of gas molecules. The key principles include the constant, random motion of gas molecules, the correlation between temperature and average kinetic energy, and elastic collisions that preserve kinetic energy.

Influence of Increased Moles on Pressure at Constant Volume and Temperature:

When the number of moles of gas increases at a constant volume and temperature, the system experiences a rise in pressure. This is because the additional gas molecules lead to more frequent collisions with the container walls. According to the kinetic molecular theory, pressure is directly influenced by the frequency and force of these molecular collisions. As the number of moles increases, both the collision frequency and force amplify, resulting in an overall increase in pressure within the system.

1.5.5. The kinetic energy of a molecule of Hydrogen at 0℃ is 5.64×10^{14} *ergs* and the molecular gas constant R equals to 8.32×10^{7} *ergs.gm*$^{-1}$*.mol*$^{-1}$*. K*$^{-1}$. Calculate Avogadro's number N.

Ans: Convert the temperature from Celsius to Kelvin:

$$T(K) = 0^{\circ}C + 273.15$$

Use the formula for kinetic energy:

$$K.E. = \frac{3}{2}kT$$

Where, (k) is the Boltzmann constant.

Rearrange the kinetic energy formula to solve for (N):

$$N = \frac{K.E.}{\frac{3}{2}kT}$$

Given:

- Kinetic energy (K.E.) $= (5.64 \times 10^{14})$ ergs
- Gas constant (R) = $(8.32 \times 10^{7}) ergs.gm^{-1}.mol^{-1}.K^{-1}$
- Temperature (T) $=0^{\circ}C = 273.15)K$ (converted to Kelvin)

Now, calculate (N). Ok?

1.6. Maxwell's Distribution of Molecular Speeds:

1.6.1. Define root mean square (RMS) velocity of a gas molecule.

Ans: The root mean square (RMS) velocity of a gas molecule is a measure of the average speed of molecules in a gas. It is calculated as the square root of the average of the squared velocities of all the gas molecules in a sample.

The formula for calculating the RMS velocity (c) is given by:

$$c = \sqrt{\frac{3RT}{M}}$$

where:

- (c) is the RMS velocity,
- (R) is the gas constant,
- (T) is the temperature in Kelvin,
- (M) is the molar mass of the gas molecule in kilograms,
- (N_A)is Avogadro's number.

1.6.2. The density of Hydrogen at NTP is 0.000089 g/cc. Find the RMS velocity of Oxygen.

Ans:

1.6.3. Calculate the root mean square velocity of a molecule of mercury (molecular weight 221) vapor at 300K.

Ans: Given:

- Molecular weight of mercury (M) is 221 g/mol,
- Temperature (T) is 300 K.

Convert molecular weight to molar mass (M):

$$M = \frac{\text{Molecular weight}}{N_A}$$

Calculate the RMS velocity (c):

$$c = \sqrt{\frac{3RT}{M}}$$

Now, we'll substitute the known values and calculate c.

1.6.4. Calculate the RMS velocity of H_2 molecules at 1.01×10^5 Pa pressure and 0.004 m^3. Under these conditions, H_2 has a density of 8.99×10^{-2} kg/m^3.

Ans: Here's the formula:

$$c = \sqrt{\frac{3P}{\rho}}$$

Now, substitute the given values:

- Pressure (P) = $(1.01 \times 10^5 \text{ Pa})$
- Density $(\rho) = (8.99 \times 10^{-2}\, \text{kg/m}^3)$

$$c = \sqrt{\frac{3 \times 1.01 \times 10^5}{8.99 \times 10^{-2}}}$$

Perform this calculation to find the RMS velocity (c).

1.7. Mean Free Path:

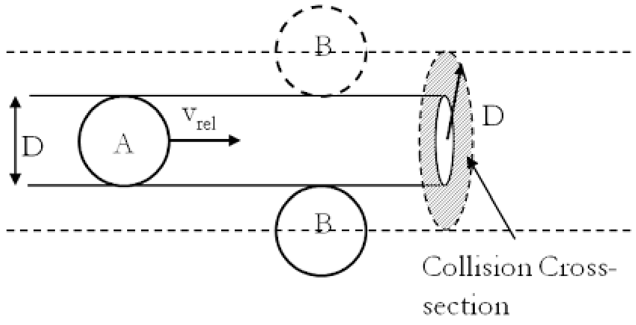
1.7.1. Define mean free path.

Ans: The mean free path describes the average distance traveled by a gas molecule between successive collisions. It provides an indication of the distance over which a particle moves freely before interacting with another particle.

1.7.2. Derive the expression of mean free path of ideal gas.

Ans: Derivation of Mean Free Path for an Ideal Gas:

Consider a gas consisting of spherical particles moving randomly in three dimensions.



The mean free path (λ) can be derived as follows:

1. Number Density (n):

Define the number density (n) as the number of particles per unit volume.

$$n = \frac{N}{V}$$

Where, (N) is the total number of particles, and (V) is the volume.

2. Cross-Sectional Area (A):

Assume that each particle has a cross-sectional area (A) in which collisions can occur.

3. Effective Volume (V_{eff}):

The effective volume that a particle sweeps out during a time interval (Δt) is

$$V_{\text{eff}} = A v_{\text{rms}}\, \Delta t$$

Where, (v_{rms}) is the root mean square velocity.

4. Number of Collisions (N_{coll}):

The number of collisions experienced by a particle in the time interval (Δt) is $(N_{\text{coll}} = n \cdot V_{\text{eff}})$.

5. Mean Free Path (λ):

The mean free path is then the average distance traveled by a particle between collisions. It is given by:

$$\lambda = \frac{V_{\text{eff}}}{N_{\text{coll}}}$$

6. Substitute (V_{eff}) and (N_{coll}):

$$\lambda = \frac{A v_{\text{rms}} \Delta t}{n \cdot V_{\text{eff}}}$$

$$\lambda = \frac{v_{\text{rms}} \Delta t}{nA}$$

7. Substitute ($n = \frac{N}{V}$) and rearrange:

$$\lambda = \frac{1}{n\sigma}$$

Where, (σ) is the collision cross-section, and (λ) is the mean free path.

The mean free path is inversely proportional to the number density (n) and the collision cross-section (σ).

1.8. Equipartition of Energy:

Ans: Equipartition of energy is a principle that describes how energy is shared among different motions (like movement or rotation) in a system at a certain temperature.

It also states each way a system can store energy (degree of freedom) contributes $\frac{1}{2}kT$ to the total energy. Where, (k) is a constant (Boltzmann constant) and (T) is the temperature.

1.9. Brownian Motion:

Ans: Brownian motion is the random and jumpy movement of tiny particles, like dust or pollen, when they are suspended in a fluid (like water or air). This erratic motion happens because these particles are constantly bumped and nudged by the surrounding molecules in the fluid.

Brownian motion helped scientists confirm the existence of atoms and molecules and the dynamic behavior of small particles in various fields of science.

1.10. Van der Waal's Equation of State:

Derive Vander Waals equation and write some limitations of Vander Waals equation.

Derive and discuss the Vander Waals equation of state of a gas.

1.11. Review of the First Law of Thermodynamics and its Application:

Write and explain the first law of thermodynamics.

Write short notes on i) adiabatic process, ii) isothermal process.

State first law of thermodynamics. From it derive Mayer's law.

A certain mass of gas at NTP is expanded to three times its volume under adiabatic conditions. Calculate the resulting temperature and pressure. γ for the gas is 1.40.

What will happen to the pressure of a system i) where the volume is decreased at constant temperature, and ii) where the temperature is increased and the volume remains constant?

1.12. Reversible and Irreversible Processes:

Distinguish between reversible and irreversible process.

Write the differences between reversible and irreversible processes.

1.13. Second Law of Thermodynamics:

State and explain second law of thermodynamics?

State second law of thermodynamics.

1.14. Carnot's Cycle:

Describe the four states of Carnot cycle.

1.15. Efficiency of Heat Engines:

1.15.1. How does a Carnot heat engine work?

1.15.2. Find the efficiency of a Carnot's engine working between 227℃ and 27℃. // If the temperature of a sink is 27℃ and that if the source 227℃, calculate the efficiency of the Carnot engine.

Ans: The efficiency (η) of a Carnot engine is given by the formula:

$$\eta = 1 - \frac{T_c}{T_h}$$

where:

-T_c is the absolute temperature of the cold reservoir (in Kelvin),

-T_h is the absolute temperature of the hot reservoir (in Kelvin).

$$T_c = 27 + 273.15 = 300.15\,\mathrm{K}$$

$$T_h = 227 + 273.15 = 500.15\,\mathrm{K}$$

$$\eta = 1 - \frac{300.15}{500.15} = 1 - 0.6 = 0.4$$

So, the efficiency of the Carnot engine operating between a source at 227°C and a sink at 27°C is approximately 0.4, or 40%.

1.16. Carnot's Theorem:

1.17. Entropy and Disorder:

1.1.1. Define entropy // What do you mean by entropy?

Ans: Entropy is a measure of how things can get mixed up or disorganized in a system. It tells us how spread out or random the particles are within a substance.

The mathematical expression for entropy change ΔS is given by the equation:

$$\Delta S = \int \frac{dQ}{T}$$

Where, ΔS is the change in entropy, dQ is the heat added to or removed from the system, and T is the temperature in Kelvin.

1.1.2. Show that entropy remains constant in reversible process but increases in irreversible process.

Ans: Reversible Process:

For a reversible process, the change in entropy (ΔS) is given by:

$$\Delta S = \int \frac{dQ}{T}$$

In a reversible process, we assume that the heat (dQ) is transferred at each step in such a way that the system remains in thermal equilibrium, and the temperature (T) is constant. This simplifies the integral to:

$$\Delta S = \frac{1}{T}\int dQ$$

The integral of dQ represents the total heat added or removed during the reversible process. As T is constant, the change in entropy is simply proportional to the total heat transfer.

Irreversible Process:

For an irreversible process, the expression for entropy change is the same:

$$\Delta S = \int \frac{dQ}{T}$$

However, in an irreversible process, the temperature (T) may vary, and the heat transfer might not be happening in a way that the system stays in thermal equilibrium at each step. Therefore, the integral becomes more complex, and the change in entropy (ΔS) is positive, indicating an increase in disorder:

$$\Delta S = \int \frac{dQ}{T} > 0$$

The inequality (> 0) emphasizes that the entropy change is positive for an irreversible process, reflecting the overall increase in disorder.

1.1.3. Calculate the change in entropy when 10 g of water at 60℃ is mixed with 30 g of water at 20℃.

1.1.4. Write short notes on i) Entropy is a measure of disorder, ii) Temperature-Entropy diagram, iii) Phase changes of the second order.

1.18. Thermodynamic Functions:

1.19. Maxwell Relations:

1.19.1. Derive Maxwell's thermodynamic relations / Derive Maxwell's four thermodynamics relations.

Ans: Maxwell's thermodynamic relations are four equations that relate various thermodynamic properties. These relations are derived from the fundamental equations of thermodynamics.

Derivation:

The four thermodynamic potentials:

1. Internal Energy (U):
   $dU = TdS - PdV$
2. Enthalpy (H):
   $dH = TdS + VdP$
3. Helmholtz Free Energy (A):
   $dA = -SdT - PdV$
4. Gibbs Free Energy (G):
   $dG = -SdT + VdP$

Now, let's derive the Maxwell relations.

Maxwell Relation 1:

$$\left(\frac{\partial T}{\partial V}\right)_S = -\left(\frac{\partial P}{\partial S}\right)_V$$

Starting with the enthalpy (H) equation:

$$dH = TdS + VdP$$

Taking partial derivatives at constant entropy (S):

$$\left(\frac{\partial T}{\partial V}\right)_S = \left(\frac{\partial P}{\partial S}\right)_V$$

Maxwell Relation 2:

$$\left(\frac{\partial S}{\partial P}\right)_T = \left(\frac{\partial V}{\partial T}\right)_P$$

Starting with the Gibbs free energy (G) equation:

$$dG = -SdT + VdP$$

Taking partial derivatives at constant temperature (T):

$$\left(\frac{\partial S}{\partial P}\right)_T = \left(\frac{\partial V}{\partial T}\right)_P$$

Maxwell Relation 3:

$$\left(\frac{\partial T}{\partial P}\right)_S = \left(\frac{\partial V}{\partial S}\right)_P$$

Starting with the Helmholtz free energy (A) equation:

$$dA = -SdT - PdV$$

Taking partial derivatives at constant entropy (S):

$$\left(\frac{\partial T}{\partial P}\right)_S = \left(\frac{\partial V}{\partial S}\right)_P$$

Maxwell Relation 4:

$$\left(\frac{\partial S}{\partial V}\right)_T = \left(\frac{\partial P}{\partial T}\right)_V$$

Starting with the internal energy (U) equation:

$$dU = TdS - PdV$$

Taking partial derivatives at constant temperature (T):

$$\left(\frac{\partial S}{\partial V}\right)_T = -\left(\frac{\partial P}{\partial T}\right)_V$$

1.20. Clausius-Clapeyron Equation:

1.20.1. Use one of the Maxwell’s four thermodynamics relations to obtain Clausius-Clapeyron’s latent heat equation.

Ans: The Clausius-Clapeyron equation relates the latent heat (heat of transformation) of vaporization or condensation to the rate of change of vapour pressure with temperature.

Let us imagine a vapour in equilibrium with its liquid held in a cylinder by a piston at the boiling point for that pressure. While a mass dm of the liquid vaporizes, so that the Gibbs free energy for the liquid decreases by $G_1 dm$ and the Gibbs free energy for the vapour increases by $G_2 dm$.

Where, G_1 is the specific Gibbs free energy for the liquid and G_2 is the specific Gibbs free energy for the vapour.

But the Gibbs free energy for the system is constant. That is:

$$H_1 - TS_1 = H_2 - TS_2, (14.1)$$

or

$$T(S_2 - S_1) = H_2 - H_1, (14.2)$$

in which the enthalpy and entropy are specific. The left-hand side is the specific latent heat of vaporization

The equality of the specific Gibbs free energies of liquid and vapour can also be written

$$U_1 - TS_1 + PV_1 = U_2 - TS_2 + PV_2, (14.3)$$

or

$$T(S_2 - S_1) = (U_2 - U_1) + P(V_2 - V_1), (14.4)$$

This shows that the latent heat of vaporization goes into two things: To increase the internal energy upon vaporization and the PdV work done against the external pressure as the volume increases. Thus, we could divide the latent heat into an internal latent heat and an external latent heat. Thus

$$-S_1 dT + V_1 dP = -S_2 dT + V_2 dP, (14.5)$$

or

$$\frac{dP}{dT} = \frac{S_2 - S_1}{V_2 - V_1}, (14.6)$$

While $S_2 - S_1 = L/T$, where L is the specific latent heat of vaporization.

Thus, we arrive at the Clausius-Clapeyron equation:

$$\frac{dP}{dT} = \frac{L}{T(V_2 - V_1)}, (14.7)$$

1.20.2. Calculate the depression of melting point of ice produced by one atmosphere increase of pressure. Given that latent heat of ice 80 *cal/g* and specific volume of ice and water at 0°C are 1.091 cm^3 and 1.0 cm^3 respectively.

Ans:

1.21. Gibbs Phase Rule:

Ans: The Gibbs Phase Rule is a fundamental principle in thermodynamics that describes the relationships between the number of components, phases, and degrees of freedom in a system at equilibrium.

The Gibbs Phase Rule is expressed mathematically as:

$$F = C - P + 2$$

where:

- F is the degrees of freedom,
- C is the number of components,
- P is the number of phases.

The term +2 accounts for temperature and pressure, which are often the variables that can be adjusted in a system.

1.22. Third Law of Thermodynamics:

State and explain the third law of thermodynamics?

2^{nd} Chapter: Structure of Matter

2.1. Crystalline and Non-crystalline Solids:

2.1.1. Distinguish between crystal and amorphous solid.

Ans:

Characteristic	Crystals	Amorphous Solids
Atomic/Molecular Arrangement	Highly ordered and repeating pattern, forming a three-dimensional lattice structure.	Lacks long-range order, particles are more randomly packed with no specific repeating pattern.
Melting Point	Sharp and well-defined melting point.	Softening occurs over a range of temperatures.
Examples	Table salt (NaCl), quartz, diamonds.	Glass, rubber, some plastics.
Transparency	Some crystals can be transparent or translucent.	They can also be transparent but transparency is not necessarily tied to a specific crystal lattice.
Mechanical Properties	Often have well-defined mechanical properties, including anisotropy.	Typically exhibit isotropic properties due to a more random arrangement of particles.

2.2. Single Crystal and Polycrystal Solids:

2.2.1. Define single crystal and polycrystalline solids.

Ans: Single Crystal:

A single crystal is a solid material in which the arrangement of atoms or molecules is highly ordered and consistent throughout the entire structure.

In a single crystal, the lattice structure extends without interruption, and there are no grain boundaries or defects in the atomic arrangement. The atoms or molecules in a single crystal align in a specific, repeating pattern, resulting in a homogeneous and uniform structure.

Examples of single crystals include diamonds, quartz, and some metals under certain conditions.

Polycrystalline Solids:

Polycrystalline solids consist of multiple crystal domains or grains. Each grain is a small, well-ordered crystalline structure, but the orientation of the crystals in adjacent grains may differ. The boundaries between these grains are called grain boundaries, where the atomic arrangement may be less ordered.

Polycrystalline materials are more common than single crystals and exhibit a combination of properties associated with their individual grains.

2.2.2. Explain the terms crystal lattice, basis, unit cell, lattice parameter and Bravais lattice.

2.2.3. Describe the detail three-dimensional lattice types.

2.2.4. Discuss different types of stress, strain and elastic constants.

2.3. Unit Cell:

2.3.1. Define unit cell.

Ans: A unit cell is the smallest repeating structural unit in a crystal lattice that, when stacked together in three-dimensional space and it builds up the entire crystal structure.

The unit cell represents the arrangement of atoms, ions, or molecules in a crystal and provides the basis for describing the overall symmetry and properties of the crystal lattice.

2.4. Crystal Systems:

What are the three-dimension crystal system?

2.5. Co-ordination Number:

2.5.1. Explain co-ordination number and packing fraction.

Ans:

1. Coordination Number:

- The coordination number is the number of nearest neighbors surrounding a particular atom or ion in a crystal lattice or solid structure. In simple terms, it represents the number of atoms or ions that are in direct contact with a central atom.

- For example, in a face-centered cubic (FCC) structure, each atom has 12 nearest neighbors, so the coordination number is 12.

2. Packing Fraction:

- Packing fraction, also known as packing efficiency, is a measure of how efficiently the atoms or particles in a crystal structure occupy the available space. It is the ratio of the volume occupied by the atoms or particles to the total volume of the unit cell (the basic repeating unit of the crystal lattice).

- The packing fraction can range from 0 to 1, where 0 indicates an empty space or voids between particles, and 1 indicates a perfect, tightly packed structure.

- Different crystal structures have different packing fractions. For example, the FCC structure has a packing fraction of about 0.74, while the body-centered cubic (BCC) structure has a slightly lower packing fraction of about 0.68.

2.6. Crystal Planes and Directions:

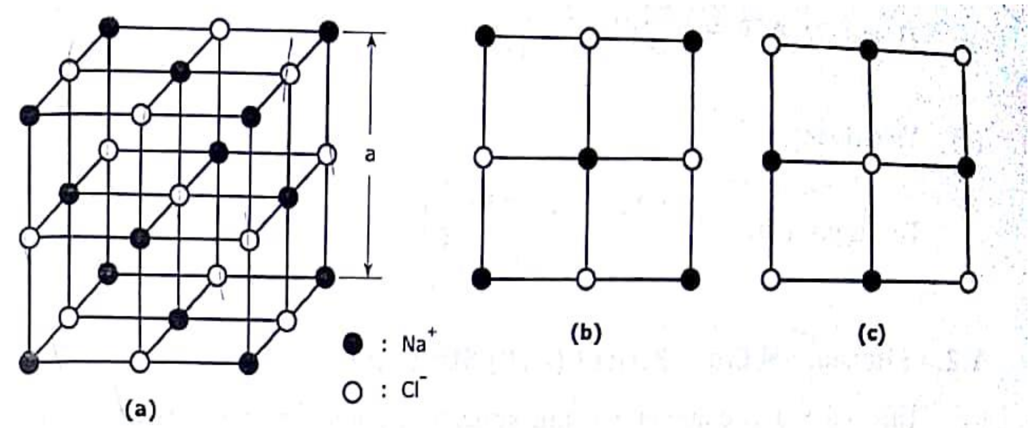
2.7. Sodium Chloride (NaCl) and CsCl Structure:

2.7.1. Draw and explain the NaCl crystal structure and find the total number of Na ions and Cl ions per unit cell.

Ans: The total number of sodium ions (Na^+) and chloride ions (Cl^-) per unit cell in the NaCl crystal structure:

In a face-centered cubic (FCC) unit cell:

- There is 1/8th of each corner ion within the unit cell.
- There is 1/2 of each face-centered ion within the unit cell.



Sodium Ions (Na^+):

1. From corners:
   - Each corner contributes 1/8th of an ion to the unit cell.
   - Total contribution from corners = 8 corners × (1/8) Na^+ ion/corner = 1 Na^+ ion.
2. From face centers:
   - Each face center contributes 1/2 of an ion to the unit cell.
   - Total contribution from face centers = 6 faces × (1/2) Na^+ ion/face = 3 Na^+ ions.

Total Na^+ ions per unit cell = Na^+ ions from corners + Na^+ ions from face centers = 1 + 3 = 4 Na^+ ions.

Chloride Ions (Cl^-):

1. From corners:
   - Each corner contributes 1/8th of an ion to the unit cell.
   - Total contribution from corners = 8 corners × (1/8) Cl^- ion/corner = 1 Cl^- ion.
2. From face centers:
   - Each face center contributes 1/2 of an ion to the unit cell.
   - Total contribution from face centers = 6 faces × (1/2) Cl^- ion/face = 3 Cl^- ions.

Total Cl^- ions per unit cell = Cl^- ions from corners + Cl^- ions from face centers = 1 + 3 = 4 Cl^- ions.

Therefore, there are 4 Na^+ ions and 4 Cl^- ions per unit cell in the NaCl crystal structure.

2.8. Packing Factor:

2.8.1. Define packing factor.

Ans: Packing factor is the fraction of the volume of a unit cell that is occupied by "hard sphere" atoms or ions. It is the sum of the sphere volumes of all atoms within a unit cell divided by the unit cell volume.

It is dimensionless and always less than unity. The packing factor is expressed as a percentage.

The formula for calculating the packing factor is given by:

$$\text{Packing Factor} = \frac{\text{Volume of atoms, ions, or molecules}}{\text{Volume of the unit cell}} \times 100\%$$

2.8.2. Calculate the packing factor of a NaCl crystal.

2.8.3. Prove that the packing fraction for body centered cubic (bcc) structure is 0.68 and for face centered cubic (fcc) structure is 0.74.

Ans: The packing fraction is a measure of how efficiently spheres (atoms in a crystal) pack together in a crystal structure. It is defined as the ratio of the total volume occupied by the atoms to the volume of the unit cell.

1. Body Centered Cubic (bcc) Structure:

In a bcc structure, each corner atom is shared by eight-unit cells, and there is one additional atom at the center of the unit cell.

The volume of the unit cell (V_{uc}) in a bcc structure is given by:

$$V_{\text{uc, bcc}} = a^3$$

Where, a is the length of the edge of the cube.

The volume occupied by the atoms in one unit cell is given by:

$$V_{\text{atoms, bcc}} = 1 \times \frac{4}{3}\pi\left(\frac{a}{2}\right)^3$$

Now, the packing fraction (PF_{bcc}) is calculated as:

$$\text{PF}_{\text{bcc}} = \frac{V_{\text{atoms, bcc}}}{V_{\text{uc, bcc}}}$$

$$\text{PF}_{\text{bcc}} = \frac{\frac{4}{3}\pi\left(\frac{a}{2}\right)^3}{a^3} = \frac{\pi}{6\sqrt{2}}$$

So, the simplified packing fraction for bcc is approximately 0.68.

2. Face Centered Cubic (fcc) Structure:

In an fcc structure, each corner atom is shared by eight-unit cells, and there are six additional atoms (at the centers of the faces).

The volume of the unit cell (V_{uc}) in an fcc structure is still given by:

$$V_{\text{uc, fcc}} = a^3$$

The volume occupied by the atoms in one unit cell is given by:

$$V_{\text{atoms, fcc}} = 4 \times \frac{1}{8} \times \frac{4}{3} \pi \left(\frac{a}{2}\right)^3 + 6 \times \frac{1}{2} \times \frac{4}{3} \pi \left(\frac{a}{2}\right)^3$$

Now, the packing fraction (PF_{fcc}) is calculated as:

$$\text{PF}_{\text{fcc}} = \frac{V_{\text{atoms, fcc}}}{V_{\text{uc, fcc}}}$$

$$\text{PF}_{\text{fcc}} = \frac{\frac{4}{3}\pi \left(\frac{a}{2}\right)^3 + 3\pi \left(\frac{a}{2}\right)^3}{a^3} = \text{PF}_{\text{fcc}} = \frac{\pi}{6}$$

So, the simplified packing fraction for fcc is approximately 0.74.

2.9. Miller Indices:

2.9.1. What are Miller indices?

Ans: Miller indices are a symbolic notation used in crystallography to represent the orientation of crystal planes and directions within a crystal lattice.

Miller indices are used to describe specific crystallographic planes and directions in a crystal structure. They involve three integers (h, k, l) that represent the intercepts of the plane or direction with the three axes of the crystal lattice.

2.9.2. How can Miller indices be determined?

Ans:

1. Miller Indices for Crystal Planes (h, k, l):

- Identify the intercepts of the plane with the three crystallographic axes (usually labeled as a, b, and c).
- Take the reciprocals of these intercepts.
- Multiply the reciprocals by a common factor to obtain the smallest set of integers.
- Enclose the resulting integers in parentheses as (h, k, l).
- If any of the intercepts is infinite, its reciprocal is considered as zero.

For example, if a plane intersects the x-axis at 1, the y-axis at 2, and the z-axis at 3, the Miller indices for that plane would be (1, 2, 3).

2. Miller Indices for Crystal Directions [h, k, l]:

- Determine the direction vector of the line in terms of crystallographic axes.
- Take the reciprocals of the direction cosines (ratios of the lengths of the direction vector to the lengths of the crystallographic axes).
- Multiply the reciprocals by a common factor to obtain the smallest set of integers.
- Enclose the resulting integers in square brackets as [h, k, l].

For example, if a direction has direction cosines of 1/2, 1/3, and 1/4 along the x, y, and z axes respectively, the Miller indices for that direction would be [2, 3, 4].

2.9.3. Explain Miller indices of a planar of a crystal.

2.9.4. Prove that the direction [h, k, l] is normal to the plane [h, k, l] for a cubic lattice.

2.10. Relation between Interplanar Spacing and Miller Indices:

1.1.1. Show that the spacing d of plane (h, k, l) in a simple cubic lattice of side a is-

$$d = \frac{a}{\sqrt{h^2+k^2+l^2}}.$$

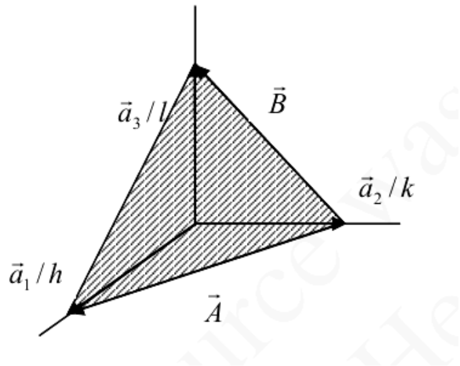
Ans: In a simple cubic lattice, the lattice vectors can be expressed as:

$$a_1 = a\hat{\imath},$$

$$a_2 = a\hat{\jmath},$$

$$a_3 = a\hat{k},$$

where a is the lattice constant, and $\hat{\imath}$, $\hat{\jmath}$, and $\hat{k}$ are unit vectors along the x, y, and z directions, respectively.



The position vector of a general point (h, k, l) in the reciprocal lattice is given by:

$$G = hb_1 + kb_2 + lb_3,$$

where b_1, b_2, and b_3 are the reciprocal lattice vectors. For a simple cubic lattice:

$$b_1 = \frac{2\pi}{a}\hat{\imath},$$

$$b_2 = \frac{2\pi}{a}\hat{\jmath},$$

$$b_3 = \frac{2\pi}{a}\hat{k}.$$

The magnitude of the reciprocal lattice vector is given by:

$$|G| = \frac{2\pi}{a}\sqrt{h^2 + k^2 + l^2}.$$

Now, the spacing between crystal planes is related to the reciprocal lattice vector magnitude by:

$$d = \frac{1}{|G|}.$$

Substitute the expression for $|G|$:

$$d = \frac{a}{\sqrt{h^2 + k^2 + l^2}}.$$

Therefore, we've derived the formula for the spacing d of a plane (h, k, l) in a simple cubic lattice of side a.

1.1.2. Find the d-spacing of d_{110} of a cubic crystal of lattice constant 4.12 Å.

2.11. Bragg's Law:

2.11.1. What is Bragg's law? Deduce Bragg's equation// State and derive Bragg's law.

Ans: Bragg's Law:

When the X-ray is incident onto a crystal surface, its angle of incidence, θ, will reflect with the same angle of scattering, θ. And, when the path difference, d is equal to a whole number, n, of wavelength, λ, constructive interference will occur.

Bragg's Law is used to explain the phenomenon of X-ray diffraction by crystals.

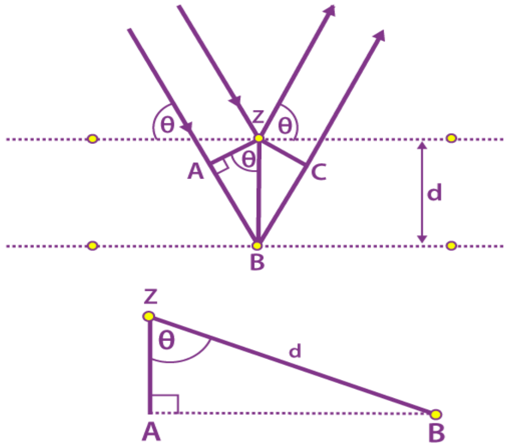
The equation for Bragg's Law is given by:

$$n\lambda = 2d \sin(\theta)$$

Where:

- n is an integer (known as the order of reflection).
- λ is the wavelength of the incident X-rays.
- d is the spacing between crystal planes.
- θ is the angle of incidence.

Derivation:



Let's consider the condition for constructive interference of X-rays scattered by different crystal planes.

1. Consider two parallel crystal planes separated by a distance d.

2. An incident X-ray beam with wavelength λ strikes the crystal planes.

3. X-rays are diffracted by the crystal lattice, and if the path difference between the X-rays scattered by adjacent planes is a multiple of the wavelength, constructive interference occurs.

The condition for constructive interference is given by:

$$n\lambda = 2d\sin(\theta)$$

For constructive interference, the angle of incidence is such that the path difference between the rays scattered by adjacent planes is a multiple of the wavelength.

2.12. Methods of Determination of Interplanar Spacing from Diffraction Patterns:

2.13. Defects in Solids:

2.13.1. How many types of point defects are there? Explain one of them.

2.13.2. Describe various defects in a crystal.

2.13.3. Write and describe the two defects in solids.

2.14. Point Defects:

2.14.1. What are the point defects?

Ans: Point defects are imperfections in the regular arrangement of atoms within a crystalline structure, occurring at specific points in the lattice.

There are several types of point defects:

1. Vacancy Defects:
   - Vacancies occur when an atom is missing from its regular lattice position. This creates an empty space or "hole" in the crystal structure.
2. Interstitial Defects:
   - Interstitial defects happen when atoms occupy positions in the crystal structure that are not part of the regular lattice sites.
3. Substitutional Defects:
   - Substitutional defects occur when an atom is replaced by a different type of atom in the crystal lattice.
4. Interstitialcy:
   - Interstitialcy involves an atom moving from its regular lattice position to an interstitial site and back.
5. Frenkel Defects:
   - Frenkel defects consist of a cation vacancy and a displaced cation that occupies an interstitial position.

2.15. Line Defects:

2.15.1. What are the line defects?

Ans: Line defects, also known as dislocations, are imperfections that occur in the arrangement of atoms along a line or a plane within a crystalline structure.

There are two main types of line defects: edge dislocations and screw dislocations.

1. Edge Dislocations:
   - An edge dislocation occurs when an extra plane of atoms, often called a "burger's vector," is introduced into the crystal lattice. This extra plane creates a mismatch between the upper and lower sections of the crystal, leading to a line defect.
2. Screw Dislocations:
   - A screw dislocation results from the shear or rotational movement of one part of a crystal lattice with respect to the other. This movement creates a spiral or helical pattern along the dislocation line.

2.16. Bonds in Solids:

Explain the formation of different energy bonds in a solid.

2.17. Inter-atomic Distances:

2.18. Calculation of Cohesive and Bonding Energy:

Calculate the cohesive energy of an ionic crystal.

2.19. Introduction to Band Theory:

Give the energy band description of conductor, semiconductor and insulators.

2.20. <u>Distinction between Metal, Semiconductor and Insulator:</u>

2.20.1. Explain the formation of different energy bands in a solid.

2.20.2. <u>Distinguish among an insulator, a semiconductor and a conductor.</u>

Ans: Insulator, semiconductor, and conductor are classifications of materials based on their electrical conductivity. The distinction among these three types is primarily determined by the behavior of electrons in their atomic or molecular structures.

1. Conductor:
   - Characteristics:
     - High electrical conductivity.
     - Electrons in the outermost energy level (valence band) are loosely bound.
     - Allows the easy flow of electric current.
   - Example: Metals like copper, aluminum, silver.
2. Semiconductor:
   - Characteristics:
     - Moderate electrical conductivity, between conductors and insulators.
     - The energy gap between the valence band and the conduction band is relatively small.

    - Conductivity can be altered by introducing impurities (doping) or changing temperature.
  - Example: Silicon (Si), germanium (Ge).

3. Insulator:
  - Characteristics:
    - Very low electrical conductivity.
    - Electrons in the valence band are tightly bound to atoms.
    - Insulates against the flow of electric current.
  - Example: Rubber, glass, wood, ceramics.

A table that distinguishes among an insulator, a semiconductor, and a conductor:

Property	**Insulator**	**Semiconductor**	**Conductor**
Electrical Conductivity	Very low	Moderate	High
Band Gap	Wide (typically > 3 eV)	Moderate (typically 1-3 eV)	Very small or none (0 eV)
Temperature Dependence	Generally low	Moderate	High
Examples	Rubber, glass, wood	Silicon, germanium	Copper, aluminum, silver
Application	Electrical insulation	Electronic devices, diodes	Wires, electrical conductors
Mobility of Charge Carriers	Very low	Moderate	High

3rd Chapter: Waves and Oscillations

3.1. Differential Equation of a Simple Harmonic Oscillator:

3.1.1. A simple harmonic motion is represented by the equation $y = 10\sin\left(10\mathrm{t} - \frac{\pi}{6}\right)$. Where y is measured in meters, t in seconds and the phase in radians. Calculate i) the frequency, ii) the time period, iii) the maximum acceleration, iv) the maximum displacement, v) the maximum velocity, and vi) displacement, velocity and acceleration at time $t = 0$ and $t = 1$ second.

3.1.2. A simple harmonic motion is represented by the equation $\mathrm{y} = 10\sin\left(10\mathrm{t} + \frac{\pi}{6}\right)$ in SI units. Calculate the i) frequency and time period, ii) maximum acceleration and velocity, iii) velocity after 2 seconds, and iv) acceleration after 3 seconds.

Ans: Given that simple harmonic motion equation $y = 10\sin\left(10t + \frac{\pi}{6}\right)$.

i) Frequency and Time Period:

The equation for simple harmonic motion is given by $y = A\sin(\omega t + \phi)$, where:

- A is the amplitude,
- ω is the angular frequency,
- ϕ is the phase angle.

In the given equation:

- Amplitude (A) = 10,
- Angular frequency (ω) is the coefficient of t, so ω = 10.

The frequency (f) is $f = \frac{\omega}{2\pi}$, and the time period (T) is ($T = \frac{1}{f}$).

$$f = \frac{10}{2\pi} \approx 1.5915 \text{ Hz}$$

$$T = \frac{1}{f} \approx \frac{1}{1.5915} \approx 0.6283 \text{ s}$$

ii) Maximum Acceleration and Velocity:

The maximum acceleration ($a_{\max}$) and maximum velocity ($v_{\max}$) are -

$$a_{\max} = A\omega^2$$

$$v_{\max} = \omega A$$

$$a_{\max} = 10 \times (10)^2 = 1000\,\mathrm{m/s^2}$$

$$v_{\max} = 10 \times 10 = 100\,\mathrm{m/s}$$

iii) Velocity after 2 seconds:

The velocity (v) at any time t is given by -

$v(t) = A\omega\cos(\omega t + \phi)$

Substitute t = 2 seconds into this equation.

$$v(2) = 10 \times 10 \times \cos\left(10 \times 2 + \frac{\pi}{6}\right)$$

$$v(2) \approx -92.74\,\mathrm{m/s}$$

iv) Acceleration after 3 seconds:

The acceleration (a) at any time t is given by-

$$a(t) = -A\omega^2 \sin(\omega t + \phi)$$

Substitute t = 3 seconds into this equation.

$$a(3) = -10 \times (10)^2 \times \sin\left(10 \times 3 + \frac{\pi}{6}\right)$$

$$a(3) \approx -500\,\mathrm{m/s^2}$$

In summary:

i) Frequency = 1.5915 Hz, Time Period = 0.6283 s

ii) Maximum Acceleration = 1000 m/s², Maximum Velocity = 100 m/s

iii) Velocity after 2 seconds ≈ -92.74 m/s

iv) Acceleration after 3 seconds ≈ 500 m/s²

3.1.3. The path difference between two points in a wave is $\frac{\lambda}{4}$. What is the phase difference between these two points?

3.1.4. Show that for a body vibrating simple harmonically the time period is given by

$$T = 2\pi\sqrt{\text{displacement}/\text{acceleration}}.$$

3.1.5. Derive the different equation of linear and angular simple harmonic motion.

3.1.6. How can we explain uniform circular motion as a SHM?

3.2. Total Energy and Average Energy:

3.2.1. Calculate the total energy of a body executing simple harmonic motion // Show that the total energy of the particle in SHM is constant and it is independent of the instantaneous displacement.

Ans: The total energy (E) in simple harmonic motion (SHM) can be expressed as the sum of kinetic energy (KE) and potential energy (PE).

In the case of a mass-spring system undergoing SHM, where a mass (m) is attached to a spring with a force constant (k), the expression for total energy is as follows:

$$E = KE + PE$$

1. Kinetic Energy (KE):

- In SHM, the velocity (v) of the mass is given by $v = \omega\sqrt{A^2 - x^2}$, where ω is the angular frequency and x is the displacement from the equilibrium position.

- The kinetic energy is expressed as $KE = \frac{1}{2}mv^2$.

2. Potential Energy (PE):

- In SHM, the potential energy is stored in the spring and is given by $PE = \frac{1}{2}kx^2$, where k is the spring constant.

Putting it all together:

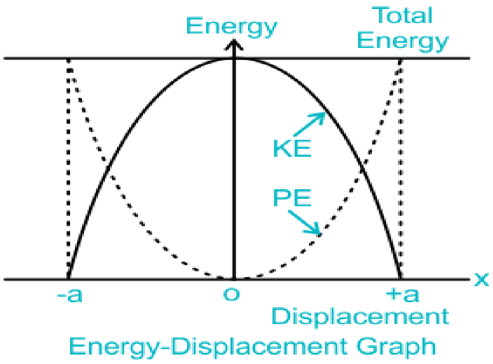
$$E = \frac{1}{2}m\left(\omega\sqrt{A^2 - x^2}\right)^2 + \frac{1}{2}kx^2$$

Simplifying further, you can express the angular frequency ω in terms of the spring constant k and mass m using the relation $\omega = \sqrt{\frac{k}{m}}$:

$$E = \frac{1}{2}m\left(\sqrt{\frac{k}{m}}\sqrt{A^2 - x^2}\right)^2 + \frac{1}{2}kx^2$$

$$E = \frac{1}{2}kA^2$$

So, in the case of simple harmonic motion, the total energy E is- $E = \frac{1}{2}kA^2$.



Energy-Displacement Graph

Since both A and k are constants and do not depend on the instantaneous displacement x, the total energy E remains constant throughout the motion. This means that E is independent of the instantaneous displacement of the mass at any given time.

3.3. Combination of Simple Harmonic Oscillations:

3.4. Lissajous' Figures:

3.4.1. What are the Lissajous' Figures?

Ans: Lissajous figures/ Lissajous curves are graphical representations of complex harmonic motion resulting from the interaction of two oscillating perpendicular variables. Commonly these figures are created by plotting the displacement of one variable against the displacement of another.

The general parametric equations for Lissajous figures are:

$$x(t) = A\sin(at + \delta_x)$$
$$y(t) = B\sin\left(bt + \delta_y\right)$$

Here,

- A and B are the amplitudes of the oscillations,
- a and b are the angular frequencies of the oscillations,
- δ_x and δ_y are phase offsets.

The resulting patterns can take various shapes, including ellipses, circles, and more complex patterns depending on the ratios of the frequencies and phase differences. Lissajous figures are often characterized by the frequency ratio between the two oscillations.

3.4.2. Explain how Lissajous' figures are useful in the laboratory.

Ans: In the laboratory, Lissajous figures are useful for:

1. Frequency and Phase Measurement:
   - Comparing frequencies and phases of oscillating signals.
2. Instrument Calibration:
   - Verifying the accuracy of instruments like oscilloscopes.
3. Resonance and Harmonic Analysis:
   - Identifying resonance frequencies and harmonic components in systems.
4. PLL Tuning:
   - Optimizing and tuning phase-locked loops for synchronization.
5. FM and AM Analysis:
   - Analyzing frequency and amplitude modulation.
6. Education and Demonstration:
   - Visualizing complex oscillatory concepts for educational purposes.
7. Nonlinear Dynamics and Chaos:
   - Revealing intricate patterns in experiments related to chaotic behavior.

3.5. Spring-mass System:

3.5.1. After landing on an unfamiliar planer, a space explorer constructs a simple pendulum of length 50 cm. She finds that the pendulum makes 100 complete swings in 136 s. What is the value of g on this planet?

Ans: The period (T) of a simple pendulum is -

$$\mathrm{T} = 2\pi\sqrt{\frac{L}{g}}$$

where:

- T is the period of the pendulum,
- L is the length of the pendulum,
- g is the acceleration due to gravity.

The period T for one swing:

$$T = \frac{\text{Total time}}{n} = \frac{136\ \text{s}}{100} = 1.36\ \text{s}$$

So, the acceleration due to gravity:

$$g = \frac{4\pi^2 L}{T^2} = \frac{4\pi^2 \times 0.5}{(1.36)^2} = 9.8\ ms^{-2}.$$

3.6. Calculation of Time Period of Torsional Pendulum:

3.6.1. Write short note on Torsional Pendulum.

Ans: Torsional Pendulum:

A torsional pendulum (a torsion pendulum or torsional oscillator) is a type of mechanical system used to study the oscillatory motion of an object about an axis of rotation. Unlike a simple pendulum, which swings back and forth in a linear fashion, a torsional pendulum undergoes rotational oscillations.

The basic setup of a torsional pendulum involves suspending a rigid body (often a disc or a rod) from a thin wire or a torsion fiber. The wire or fiber provides a restoring torque proportional to the angle of rotation.

Torsional pendulums are used in various scientific experiments and educational demonstrations to study the properties of rotational motion, investigate the effects of damping, and determine physical constants.

3.6.2. Calculate the Time Period of Torsional Pendulum.

Ans:

The equation of motion for a torsional pendulum is given by Hooke's law for rotation:

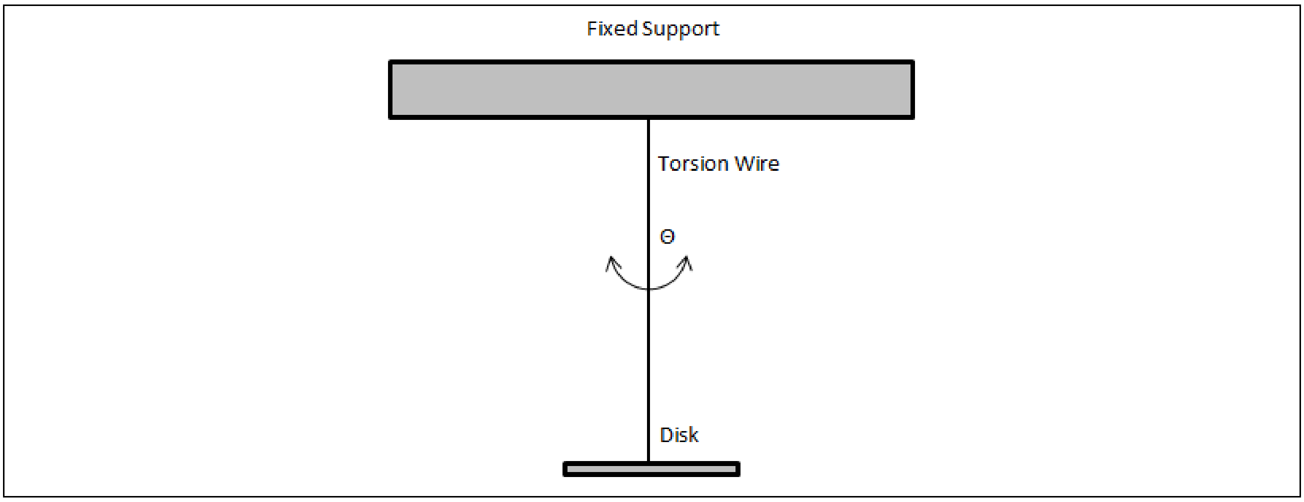
$$\tau = -\kappa\,\theta$$

Where:

- τ is the torque applied,
- κ is the torsional constant,
- θ is the angular displacement.

The torque (τ) is also related to the moment of inertia (I) and angular acceleration (α) by the equation:

$$\tau = I\,\alpha$$



For simple harmonic motion,

$$\alpha = -\frac{\kappa}{I}$$

Now, the angular frequency (ω):

$$\alpha = -\omega^2$$

Comparing this with the previous equation relating α and θ, we get:

$$\omega^2 = \frac{\kappa}{I}.$$

Now, the time period (T) is related to the angular frequency (ω) by the equation:

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

Substituting the expression for ω^2, we get:

$$T = 2\pi\sqrt{\frac{I}{\kappa}}$$

And this is the time period (T) of a torsional pendulum.

3.7. Damped Oscillation:

3.7.1. What are the free, damped and forced vibrations?

Ans:

Free Vibrations:

- Free vibrations occur when a system is allowed to oscillate without any external influence or driving force.
- In the absence of damping and external forces, a vibrating system will continue oscillating indefinitely with constant amplitude.

- The natural frequency of the system determines the rate at which these free vibrations occur.

Damped Vibrations:

- Damped vibrations occur when an external force opposes the motion and reduces the amplitude of oscillation over time.
- Damping can be caused by various factors, such as friction, air resistance, or other dissipative forces.
- The damping effect is characterized by a damping ratio. Overdamped systems decay more slowly, critically damped systems decay optimally fast, and underdamped systems exhibit oscillatory behavior before decaying.

Forced Vibrations:

- Forced vibrations occur when an external force is applied to a system, driving it to oscillate at a frequency different from its natural frequency.
- The external force is typically periodic and has a frequency known as the forcing frequency.
- Resonance can occur when the forcing frequency matches the natural frequency of the system, leading to large amplitude vibrations.

3.7.2. Derive the differential equation of damped harmonic oscillator // Derive the differential equation of a damped harmonic oscillation and solve it.

3.7.3. What is physical significance of damped harmonic motion?

Ans:

Damped harmonic motion is characterized by oscillations that gradually decrease in amplitude over time due to the presence of a damping force.

The physical significance of this phenomenon includes:

1. Energy Dissipation:
   - Damping leads to the gradual loss of energy to the environment, usually in the form of heat.
2. Realistic Modeling:
   - Damped harmonic motion provides a realistic representation for systems subject to damping forces, commonly found in mechanical and electrical systems.
3. Shock Absorption:
   - Damping is utilized in engineering to control vibrations, such as in shock absorbers for vehicles.
4. Resonance Control:

- Damping helps prevent excessive energy buildup at a system's natural frequency, controlling resonance effects.

5. Electrical Circuits:

- Damping in electrical circuits helps stabilize systems and prevent unwanted oscillations.

6. Biological Systems:

- Biological motions, such as walking, involve damping for energy dissipation and motion control.

7. Musical Instruments:

- Damping contributes to the gradual decay of sound in musical instruments, influencing the instrument's timbre.

3.7.4. Distinguish between simple harmonic oscillation and damped harmonic oscillation.

Ans: Simple harmonic oscillation and damped harmonic oscillation are two types of oscillatory motion, and they differ primarily in the presence of damping forces.

- Nature of Motion:

Simple harmonic oscillation is a type of periodic motion where an object oscillates back and forth about a central point (equilibrium position) under the influence of a restoring force that is directly proportional to the displacement from the equilibrium.

Damped harmonic oscillation occurs when there is an additional damping force acting on the oscillating object. This force is proportional to the velocity of the object and acts opposite to the direction of motion.

- Equation of Motion:

The displacement (x) of the object in simple harmonic motion is described by a sinusoidal function, typically expressed as $x(t) = A\cos(\omega t + \phi)$, where A is the amplitude, ω is the angular frequency, t is time, and ϕ is the phase angle.

The equation of motion for damped harmonic oscillation is more complex and includes a damping term. A commonly used equation is $m\ddot{x} + c\dot{x} + kx = 0$ where m is the mass, $\dot{x}$ is the velocity, c is the damping coefficient, and k is the spring constant.

- Energy Conservation:

In simple harmonic motion, energy is conserved, and the amplitude remains constant over time. In damped harmonic oscillation, energy is not conserved due to the presence of damping forces. The amplitude of oscillation decreases over time, and the system eventually comes to rest.

The differences between simple harmonic oscillation and damped harmonic oscillation:

Characteristic	Simple Harmonic Oscillation	Damped Harmonic Oscillation
Nature of Motion	Periodic motion without damping forces.	Oscillation with damping forces.
Equation of Motion	$x(t) = A \cdot \cos(\omega t + \phi)$	$m\ddot{x} + c\dot{x} + kx = 0$
Energy Conservation	Energy is conserved.	Energy is not conserved.
Amplitude	Remains constant over time.	Decreases over time due to damping.
System Behavior	Sustained oscillation.	Gradual decay and eventual rest.

3.7.5. Explain the conditions under which the oscillation become aperiodic, critically damped and oscillatory.

3.8. Determination of Damping Co-efficient:

3.9. Forced Oscillation:

Explain the term-forced oscillation.

3.10. Resonance:

3.11. Two-body Oscillations:

3.12. Reduced Mass:

3.13. Differential Equation of a Progressive Wave:

3.13.1. Derive the equation of wave motion in the form $y = A\sin\frac{2\pi}{\lambda}(\mathrm{vt} - \mathrm{x})$.

3.13.2. The amplitude of a wave is 0.5 cm. Find the displacement of the point at a distance $x = \frac{\lambda}{6}$ from the source at time $t = \frac{T}{3}$.

3.14. Power and Intensity of Wave Motion:

3.15. Stationary Wave:

3.15.1. Explain the principal of superposition of two waves.

Ans: Principle of Superposition:

The principle of superposition says that when two waves meet, their effects add up. If you have two waves traveling through the same medium, at any point, the total displacement is the sum of the displacements caused by each wave individually.

3.15.2. Derive an expression of stationary waves and also discuss the conditions for nodes and antinodes.

Ans: Consider two waves traveling in opposite directions:

$$y_1 = A\sin(kx - \omega t)$$

$$y_2 = A\sin(kx + \omega t)$$

Now, the total displacement y is the sum of these two waves:

$$y = y_1 + y_2$$

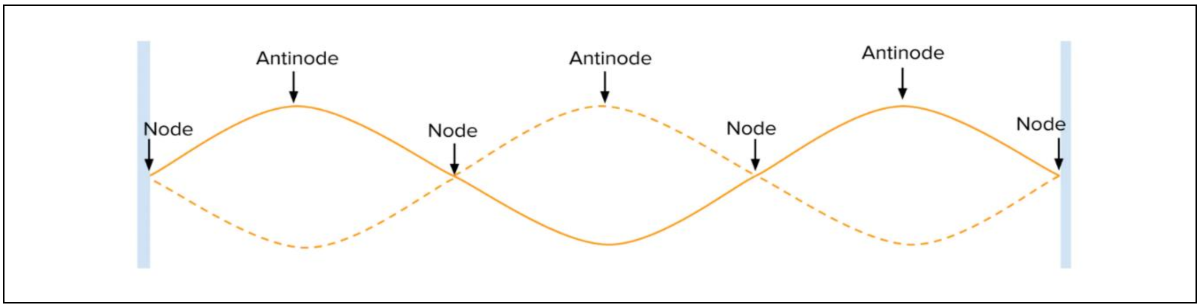
$$y = A\sin(kx - \omega t) + A\sin(kx + \omega t)$$

$$y = 2A\sin\left(\frac{kx - \omega t + kx + \omega t}{2}\right)\cos\left(\frac{(kx - \omega t) - (kx + \omega t)}{2}\right)$$

$$y = 2A\sin\left(\frac{2kx}{2}\right)\cos\left(\frac{-2\omega t}{2}\right)$$

$$y = 2A\sin(kx)\cos(\omega t)$$

So, the expression for a stationary wave is: $y = 2A\sin(kx)\cos(\omega t)$.



Conditions for Nodes and Antinodes:

Nodes:

- For nodes, $\cos(kx) = 0$. Where $k = \frac{2\pi}{\lambda}$.
- This happens when $kx = (2n + 1)\frac{\pi}{2}$, where n is an integer.
- Solving for x:

$$x = \frac{(2n + 1)\pi}{2 \times \frac{2\pi}{\lambda}} = (2n + 1)\frac{\lambda}{4}.$$

This equation represents the positions along the wave where the displacement is always zero (nodes).

Antinodes:

- For antinodes, $\cos(kx) = \pm 1$.
- This happens when $kx = n\pi$, where n is an integer.
- Solving for x:

$$x = \frac{n\pi}{k} = \frac{n\pi}{\frac{2\pi}{\lambda}} = n\frac{\lambda}{2}.$$

This equation represents the positions along the wave where the displacement is maximum (antinodes).

The superposition of two waves traveling in opposite directions creates a stationary wave with nodes and antinodes at specific positions.

3.16. Group Velocity and Phase Velocity:

Write short notes on group velocity.

3.17. Architectural Acoustics:

3.18. Reverberation and Sabine’s Formula:

Write short notes on i) reverberation.

4th Chapter: Physical Optics

4.1. Theories of Light:

4.2. Interference of Light:

4.2.1. What is coherent source? // When two sources are said to be coherent?

Ans:

Coherent sources are two or more wave sources that maintain a constant phase relationship between their waves. This coherence is essential for phenomena like interference, where waves combine either constructively or destructively.

Lasers are an example of coherent light sources.

Two sources are said to be coherent when they meet the following conditions:

1. Constant Frequency: The two sources must emit waves of the same frequency.
2. Constant Phase Difference: The phase relationship between the waves from the two sources should be constant.
3. Stability Over Time: Coherence requires the maintenance of a constant phase difference over time.

4.2.2. What are the conditions of interference?

4.2.3. What is meant by interference of light?

4.2.4. Prove that, $\text{phase difference } (\delta) = \frac{2\pi}{\lambda} \times \text{path difference } (x)$.

4.2.5. Explain the interference of light.

4.2.6. What is the condition of constructive and destructive interfaces?

4.2.7. Write the relation between path difference and phase difference.

4.2.8. Write down the conditions for sustained interference pattern. Show that for interference the intensity varies in accordance with the law of cosine square.

4.3. Young's Double Slit Experiment:

4.3.1. Describe the Young's double slit experiment //Describe about Young's double slit experiment.

Ans: Young's double-slit experiment demonstrates the wave nature of light and the phenomenon of interference and contributed to the broader understanding of the duality of light as both a particle and a wave. The setup involves shining light through two closely spaced slits and observing the resulting pattern on a screen.

Experimental Setup:

1. Light Source:

A coherent light source, such as a laser or a monochromatic light, is used to ensure that the light waves have a constant frequency and phase relationship.

2. Barrier with Two Slits:

A barrier with two small, closely spaced slits is placed in the path of the light. The distance between the slits is denoted as d.

3. Screen:

A screen is placed some distance away (D) from the barrier, in a position where the light passing through the slits can form an observable pattern.

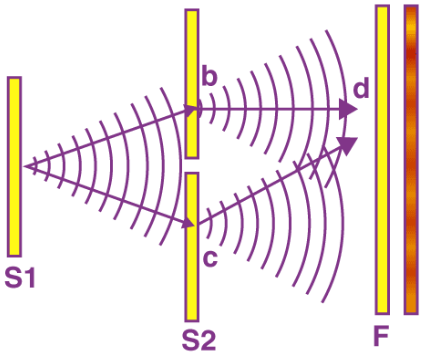
Observation:

1. Interference Pattern:

As light passes through the two slits, it behaves as a wave. The waves emanating from the two slits overlap on the screen. This overlapping of waves results in an interference pattern of alternating bright and dark fringes.

2. Bright and Dark Fringes:

The interference pattern consists of bright fringes (maxima) where constructive interference occurs, and dark fringes (minima) where destructive interference occurs. The bright fringes are locations where the waves from the two slits reinforce each other, while the dark fringes are locations where the waves cancel each other out.



Young's Double Slits Experiment

Mathematical Description:

The conditions for bright and dark fringes are given by the equations:

- Bright Fringes: $d\sin\theta = m$
- Dark Fringes: $d\sin\theta = \left(m + \frac{1}{2}\right)$

where d is the slit separation, θ is the angle of observation, m is an integer, and λ is the wavelength of light.

4.3.2. Discuss the conditions for bright and dark bands // For Young's double slit experiment, establish the condition for bright fringes // Briefly describe the condition of bright and dark fringe from Young's double slit experiment.

Ans: The condition for bright (constructive interference) and dark (destructive interference) fringes in Young's double-slit experiment can be expressed mathematically as follows:

1. Bright Fringes (Maxima):

The condition for a bright fringe is that the path difference (Δx) between the waves from the two slits is an integer multiple (m) of the wavelength (λ) of the light.

Mathematically, this is expressed as:

$$\Delta x = m\lambda$$

2. Dark Fringes (Minima):

The condition for a dark fringe is that the path difference (Δx) between the waves from the two slits is a half-integer multiple ($m+\frac{1}{2}$) of the wavelength (λ) of the light.

Mathematically, this is expressed as:

$$\Delta x = \left(m+\frac{1}{2}\right)\lambda$$

Here, Δx is the path difference between the waves arriving at a point on the screen from the two slits, m is an integer, and λ is the wavelength of the light.

These conditions ensure that the waves either reinforce (bright fringe) or cancel each other out (dark fringe) due to their phase relationship.

4.3.3. For interference in plane parallel film, establish the condition for the bright and dark fringes.

4.3.4. An interference spectrum is formed in the screen at a distance of 1.0 m from two slits having separation of 0.4 mm. If the wavelength of light is 5000 Å. Find the distance between two successive bright bands.

4.3.5. Green light of wavelength 5100Å from a narrow slit is incident on a double slit. If the overall separation of 10 fringes on a screen 200 cm away is 2 cm, find the slit separation.

4.3.6. <u>In Young's double slit experiment, the distance between the two slits 0.8 mm and the distance of the screen from the slits is 1 m. Calculate the width of the bright band when the slits are illuminated by a monochromatic light of wavelength of 5890 Å.</u>

Ans: The width of a single bright fringe (W):

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

Given that:

- Wavelength (λ) $= 5890\ \text{Å} = 5890 \times 10^{-10}\ m$.
- Distance from slits to screen (D) = 1 m,
- Separation between the slits $(d) = 0.8\ mm = 0.8 \times 10^{-3}\ m$.

$$W = \frac{1 \times 5890 \times 10^{-10}}{2 \times 0.8 \times 10^{-3}} = 3.67625 \times 10^{-4}\ m$$

So, the width of a single bright fringe is approximately $3.68 \times 10^{-4}\ m$ or $0.368\ mm$.

4.3.7. Green light of wavelength 5100 Å from a narrow slit is incident on a double slit. If the overall separation of 10 fringes on a screen 200 cm away is 2 cm, find the slit separation.

4.4. Displacements of Fringes and its Uses:

4.5. Fresnel Bi-prism:

4.6. Interference at Wedge Shaped Films:

4.7. <u>Newton's Rings:</u>

4.7.1. What is wave front?

4.7.2. <u>Why the fringes are circular in Newton's ring experiment?</u>

Ans: In Newton's ring experiment, circular fringes are observed due to the interference of light waves reflecting between a spherical lens and a flat surface.

When light strikes the thin air film formed between the lens and the surface, some waves reflect from both the upper and lower interfaces. Circular symmetry arises because of the spherical lens shape, causing variations in the path length difference and resulting in concentric circles of constructive and destructive interference. The circular fringes are a manifestation of the interference patterns, forming a distinct and recognizable pattern in the experiment.

4.7.3. How does interference occur in Newton's ring experiment?

4.7.4. How will you determine the wavelength of light by Newton's rings? Explain elaborately with necessary figure.

4.8. Interferometers:

4.9. <u>Diffraction of Light:</u>

4.9.1. Explain Huygen's principle.

4.9.2. <u>What do you mean by diffraction? // What is the diffraction of light? // Define diffraction of light with example.</u>

Ans: Diffraction of light refers to the bending or spreading of light waves as they encounter an obstacle or pass through an aperture. This phenomenon is a result of the wave nature of light, and it leads to the distribution of light in different directions beyond the geometric shadow of an obstacle or aperture.

Diffraction of light is characterized by:

1. Wave Nature:

- Occurs when light encounters obstacles or apertures comparable in size to its wavelength, exhibiting wave properties.

2. Interference:
   - Involves interference patterns as light waves spread out, resulting in bright and dark regions.
3. Patterns:
   - Diffraction patterns feature a central bright region surrounded by alternating bright and dark fringes, determined by aperture size and light wavelength.
4. Apertures and Obstacles:
   - Can occur with various geometries, such as slits or edges, influencing the specific diffraction pattern.
5. Quantum Aspect:
   - Demonstrates wave-particle duality, observed not only with light waves but also with particles like electrons and neutrons.

4.9.3. Write down the condition of diffraction.

4.9.4. <u>Distinguish between interference and diffraction.</u>

Ans: The differences between interference and diffraction in a table:

Characteristic	**Interference**	**Diffraction**
Definition	Overlapping of waves leading to reinforcement or cancellation of amplitudes.	Bending or spreading of waves as they encounter an obstacle or pass through an aperture.
Wave Interaction	Involves the interaction of multiple coherent waves.	Often occurs when waves encounter an obstruction or a slit. Can involve a single wave source.
Pattern Formation	Results in alternating bright and dark fringes.	Results in characteristic patterns, including central maxima and fringes.
Conditions	Coherence between sources is essential.	Coherence is not strictly required; depends on the size of the diffracting element.
Examples	Double-slit interference, Michelson interferometer.	Single-slit diffraction, double-slit diffraction, diffraction grating.

4.9.5. State Huygens principle for the propagation of light.

4.9.6. What are X-rays and how can they be produced?

4.9.7. A beam of X-rays of wavelength 0.071 nm is diffracted by (110) plane of rock salt with lattice constant of 0.28 nm. Find the glancing angle for the second order diffraction.

4.10. <u>Fresnel and Fraunhoffer Diffraction:</u>

4.10.1. Distinguish between Fresnel and Fraunhofer types of diffraction.

4.10.2. Distinguish between Fresnel and Fraunhoff diffraction.

4.11. Diffraction by Single Slit:

4.11.1. A grating containing 400 slits per centimeter is illuminated with a monochrome light and produces the second order bright line at a 30º angle. What is the wavelength of the light used?

4.11.2. Explain the method for determination of wavelength of monochromatic light by a plane transmission grating?

4.11.3. A grating containing 400 slits per centimeter is illuminated with a monochrome light and produces the second-order bright line at a 30° angle. What is the wavelength of the light used?

4.12. Diffraction from a Circular Aperture:

4.13. Resolving Power of Optical Instruments:

4.14. Diffraction at Double Slit & N-slits-diffraction Grating:

4.15. Polarization:

4.15.1. Define polarization. What are the methods of obtaining polarized light? Explain one of this.

4.15.2. Distinguish between polarized and unpolarized light.

4.15.3. Mention some applications of polarized light.

4.15.4. What is meant by the polarization of light?

4.16. Production and Analysis of Polarized Light:

4.16.1. How will you have to orient the polarizer and analyzer so that a beam of natural light is reduced to 0.25, 0.50 and 0.75 of its initial intensity?

4.17. Brewster's Law:

4.17.1. State the followings: Brewster's law.

Ans:

Brewster's Law: If the tangent of the angle of incidence of incident light is numerically equal to the refractive index of the medium, the light wave experiences maximum plane polarization. In other terms, when the angle between the reflected angle and the refracted angle is 90°, maximum polarization is achieved. The polarization angle is known as Brewster's angle.

The law is expressed mathematically as:

$$\tan \theta_B = \frac{n_2}{n_1}$$

where:

- θ_B is the Brewster angle,
- n_1 is the refractive index of the first medium (from which light is coming),
- n_2 is the refractive index of the second medium (through which light is transmitted).

The Brewster angle is the angle of incidence at which the reflected light is completely polarized perpendicular to the plane of incidence.

4.17.2. According to Brewster law, prove that the reflected light and the refracted light are remained at right angle to each other.

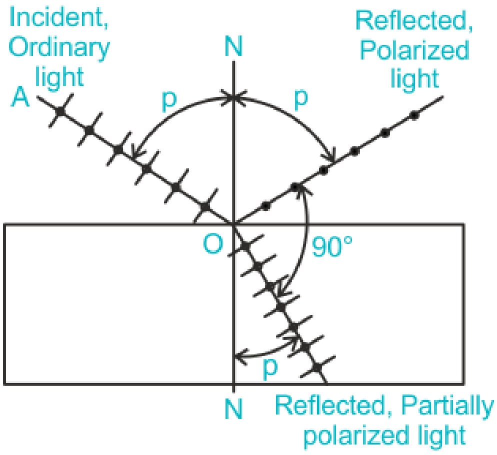
Ans: Mathematically, Brewster's law is stated as:

$$\mu = tan i_p$$

Where-

μ = Refractive index of the medium

i_p = Brewster's angle



The Brewster's law can be proved mathematically in the following method:

From Snell's law,

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

From Brewster's law,

$$\mu = tan i$$

$$= \frac{sin i}{cos i}$$

Combining both equations we get,

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

$$cos i = sin r = cos\left(\frac{\pi}{2} - r\right)$$

$$\text{Thus, } i = \frac{\pi}{2} - r \text{ or } i + r = \frac{\pi}{2}$$

Thus, the incident ray is perpendicular to the refracted ray.

4.17.3. Derive Brewster's law and according to Brewster's law, find out a relation between Brewster's angle and critical angle.

4.18. Malus Law:

4.18.1. State and explain Malus law of polarization. // State the Malus law and explain the law with the help of a diagram. // State the followings: Malu’s law.

Ans: The intensity of the transmitted light varies as the square of the cosine of the angle between the two planes of transmission.

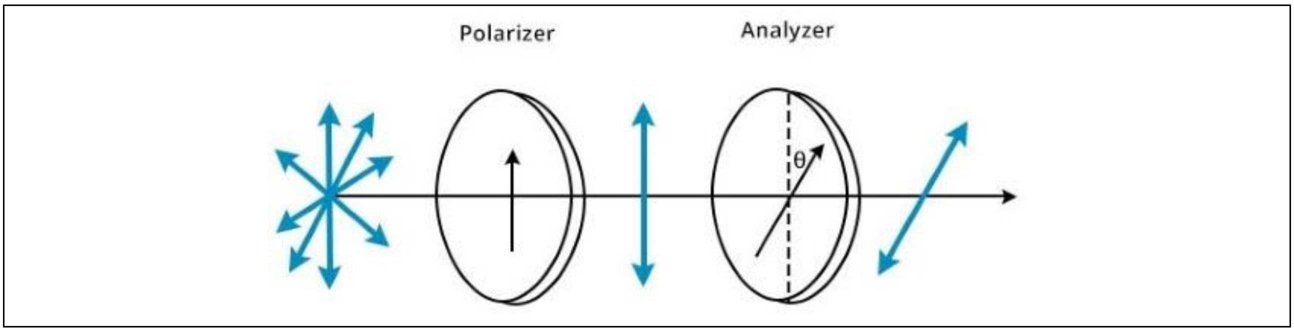
Malus's Law quantifies the relationship between the initial intensity of unpolarized light and the intensity of light after passing through a polarizer.

Malus's Law is expressed mathematically as:

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

where:

- I is the intensity of the light transmitted through the polarizer,
- I_0 is the initial intensity of unpolarized light incident on the polarizer,
- θ is the angle between the transmission axis of the polarizer and the plane of polarization of the incident light.



The equation indicates that the transmitted intensity is proportional to the square of the cosine of the angle between the transmission axis and the plane of polarization.

When $\theta = 0°$ (parallel alignment), $\cos^2(0°) = 1$, and the transmitted intensity is maximum.

When $\theta = 90°$ (perpendicular alignment), $\cos^2(90°) = 0$, and the transmitted intensity is zero.

4.19. Polarization by Double Refraction:

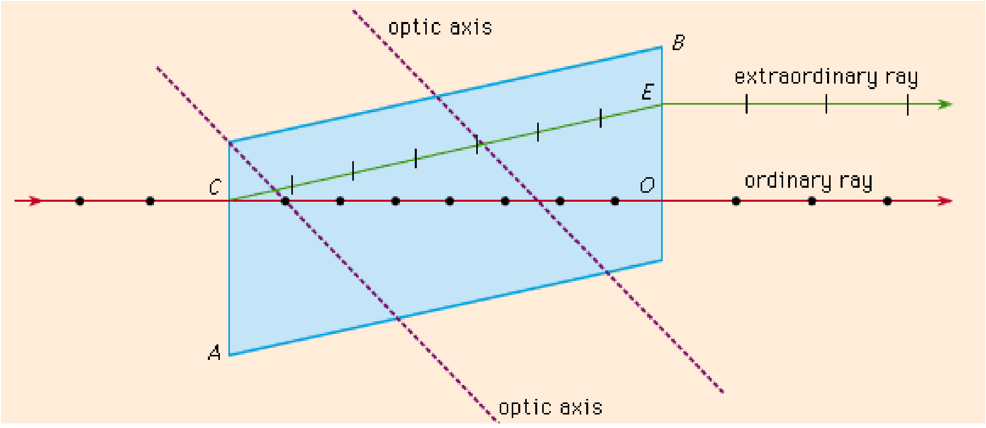
4.19.1. Discuss about the polarization by double refraction method.

Ans: Double refraction is an optical property in which a single ray of unpolarized light entering an anisotropic medium is split into two rays, each traveling in a different direction.

One ray (called the extraordinary ray) is bent, or refracted, at an angle as it travels through the medium; the other ray (called the ordinary ray) passes through the medium unchanged.

The Figure shows the phenomenon of double refraction through a calcite crystal. An incident ray is seen to split into the ordinary ray CO and the extraordinary ray CE upon entering the crystal face at

C. If the incident ray enters the crystal along the direction of its optic axis, however, the light ray will not become divided.



All transparent crystals except those of the cubic system, which are normally optically isotropic, exhibit the phenomenon of double refraction: in addition to calcite, some well-known examples are ice, mica, quartz, sugar, and tourmaline.

4.19.2. Explain Huygen's theory of double refraction.

4.19.3. The refractive index for plastic is 1.25. Calculate the angle of refraction for a ray of light incident at a polarizing angle.

4.20. Retardation Plates:

4.21. Nicol Prism:

4.22. <u>Optical Activity:</u>

4.22.1. <u>What is the physical significance of optical activity?</u>

Ans: Optical activity is a property exhibited by certain substances, particularly chiral molecules, causing them to rotate the plane of polarized light. The physical significance of optical activity is diverse:

1. Chirality Identification:

Optical activity helps identify the chirality of molecules, offering insights into molecular structures.

2. Pharmaceutical Quality Control:

Crucial in the pharmaceutical industry for determining drug purity and ensuring the correct enantiomeric form.

3. Food and Beverage Analysis:

Used in assessing the quality and purity of substances like sugars in the food and beverage industry.

4. Chemical Analysis Tool:

Applied in laboratories for chemical analysis, substance identification, and monitoring reactions.

5. Molecular Structure Insights:

Provides information about the three-dimensional arrangement of atoms in a molecule.

6. Biological Applications:

Relevant in studying the structures and functions of chiral biomolecules in biological systems.

7. Materials Science:

Applied in materials science for designing materials with unique optical properties, especially in optics and photonics.

Overall, optical activity plays a crucial role in various scientific, industrial, and biological contexts, contributing to our understanding of molecular properties and enabling diverse applications.

Characteristic	**Fresnel Diffraction**	**Fraunhofer Diffraction**
Source and Diffracting Element Proximity	Close proximity of light source, diffracting element, and observation screen.	Infinite separation between light source, diffracting element, and observation screen.
Wavefront Curvature	Curved wavefronts taken into account in calculations.	Wavefronts treated as planar; curvature is negligible.
Mathematical Description	Described by the Fresnel diffraction integral.	Described by the Fraunhofer diffraction integral.
Observation Point Location	Near the diffracting element (near-field diffraction).	Far from the diffracting element (far-field diffraction).
Wavefront Assumption	Wavefront curvature is considered in calculations.	Wavefronts are essentially planar.

4.23. Polarimeters:

4.24. Polaroid:
