# VIJAYAM INSTITUTE OF TECHNOLOGY

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## UNIT- I (WAVE OPTICS)

| | | | | | |
|---|---|---|---|---|---|
| | a | Define Interference. | [CO1] | [2M] | [L1] |
| | b | Define Diffraction. | [CO1] | [2M] | [L1] |
| | c | Define Polarisation. | [CO1] | [2M] | [L1] |
| | d | Define Diffraction Grating. | [CO1] | [2M] | [L1] |
| | e | Define Resolving Power of Grating. | [CO1] | [2M] | [L1] |
| 2 | a | State and explain principle of superposition. | [CO1] | [4M] | [L2] |
| | b | Discuss the theory of interference of light due to thin films by reflection with suitable ray diagram. | [CO1] | [6M] | [L2] |
| 3 | a | Describe the formation of Newton's ring with necessary theory with relevant diagrams. | [CO1] | [6M] | [L3] |
| | b | Explain how the wavelength of light sources is determined using Newton's rings. | [CO1] | [4M] | [L2] |
| 4 | a | Distinguish between Fraunhofer and Fresnel's diffraction. | [CO1] | [5M] | [L3] |
| | b | Compare Interference and Diffraction. | [CO1] | [5M] | [L2] |
| 5 | | In the study of Fraunhofer diffraction due to single slit how the diffraction fringes formed. Derive the conditions for bright and dark fringes. | [CO1] | [10M] | [L4] |
| 6 | a | Describe Fraunhofer diffraction due to double slit and derive the conditions for principal maxima, secondary maxima and minima. | [CO1] | [8M] | [L3] |
| | b | A plane transmission grating having 4250 lines per cm is illuminated with sodium light normally. In the second order spectrum, the spectral lines are deviated by $30^0$. What is the wavelength of the spectral line? | [CO1] | [2M] | [L3] |
| 7 | a | Describe the Fraunhofer Diffraction Due to N-Slits. | [CO1] | [6M] | [L2] |
| | b | Define Dispersive power and resolving power of Grating and write their expressions. | [CO1] | [4M] | [L3] |
| 8 | a | Mention the representation of the Plane polarized light and unpolarized light | [CO1] | [4M] | [L1] |
| | b | Explain the various types of polarizations. | [CO1] | [6M] | [L2] |
| 9 | a | Explain the Polarization by reflection with neat sketch. | [CO1] | [5M] | [L2] |
| | b | Illustrate the Double refraction in crystal. | [CO1] | [5M] | [L4] |
| 10 | a | Explain the production of plane polarized light using Nicol Prism. | [CO1] | [6M] | [L2] |
| | b | Describe the propagation of polarized light in Quarter –Wave plate. | [CO1] | [4M] | [L3] |
| 11 | a | Describe the propagation of polarized light in Half –Wave plate. | [CO1] | [6M] | [L3] |
| | b | Calculate the thickness of Half-Wave plate, given that $\mu_e = 1.533$, | [CO1] | [4M] | [L4] |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
|  |  | $\mu_e = 1.544$ and $\lambda = 5000\ A^0$. |  |  |  |

## UNIT – II CRYSTALLOGRAPHY & X-RAY DIFFRACTION

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 1 | a | Define lattice parameter? | [CO2] | 2M | [L1] |
|  | b | Draw the planes for given Miller indices i). (111) ii). (202) in cubic system. | [CO2] | 2M | [L3] |
|  | c | Define unit cell . | [CO2] | 2M | [L1] |
|  | d | Define Bragg’s condition for X-Ray diffraction. | [CO2] | 2M | [L1] |
|  | e | What are applications of Powder X-Ray diffraction method? | [CO2] | 2M | [L1] |
| 2 | a | What is (i) Unit cell (ii) Basis (iii) Bravais Lattice. | [CO2] | [3M] | [L1] |
|  | b | Explain the various types of crystal systems with a neat sketch and examples | [CO2] | [7M] | [L2] |
| 3 | a | Explain the various types of Bravais lattices with a neat sketch | [CO2] | [4M] | [L2] |
|  | b | Define atomic packing fraction and derive it for simple cubic crystal structure. | [CO2] | [6M] | [L3] |
| 4 |  | Define atomic packing fraction and derive it for body centered cubic crystal structure. | [CO2] | [10M] | [L3] |
| 5 |  | Show that Face centered cubic crystal structure has more closely packed structure than SC and BCC. | [CO2] | [10M] | [L3] |
| 6 | a | What are Miller indices? Mention the procedure to find Miller Indices | [CO2] | [6M] | [L1] |
|  | b | Write the important features of Miller indices | [CO2] | [4M] | [L1] |
| 7 | a | Deduce the expression for the inter planar distances in terms of miller indices for a cubic system | [CO2] | [7M] | [L4] |
|  | b | Draw miller indices of planes (1 0 0), (1 0 1) and ( 0 11 ) in a cubic system. | [CO2] | [3M] | [L4] |
| 8 | a | Define the Bragg’s law of X-ray diffraction and derive<br>**$2d \sin\theta = n\lambda$** | [CO2] | [6M] | [L3] |
|  | b | Calculate $d_{100} : d_{110} : d_{111}$ for a cubic crystal system. | [CO2] | [4M] | [L3] |
| 9 | a | Derive the Bragg’s condition for X-ray diffraction. | [CO2] | [6M] | [L3] |
|  | b | A beam of X rays of wavelength 0.71 nm is diffracted by (110) plane of rock salt with lattice constant of 0.28nm. Find the glancing angle for the second order diffraction. | [CO2] | [4M] | [L3] |
| 10 | a | Explain how crystal structure determined by Laue X-Ray diffraction method. | [CO2] | [7M] | [L2] |
|  | b | What are the advantages of Laue X-Ray diffraction method? | [CO2] | [3M] | [L1] |
| 11 | a | Explain how crystal structure determined by Powder X-Ray diffraction method. | [CO2] | [7M] | [L2] |
|  | b | What are the advantages of Powder X-Ray diffraction method? | [CO2] | [3M] | [L1] |

## UNIT – III (DIELECTRICS AND MAGNETIC MATERIALS)

| | | | | | |
|---|---|---|---|---|---|
| 1. | a | Define dielectric polarization | [CO3] | [2M] | [L1] |
| | b | Define dielectric polarisability | [CO3] | [2M] | [L1] |
| | c | Define magnetic susceptibility and magnetization. | [CO4] | [2M] | [L1] |
| | d | What is Bohr magnetron? | [CO4] | [2M] | [L1] |
| | e | What is hysteresis? | [CO4] | [2M] | [L1] |
| 2. | a | With usual notations, show that $P= \varepsilon_o (\varepsilon_r -1)E$ | [CO4] | [6M] | [L3] |
| | b | Write the differences between polar and non -polar molecules | [CO3] | [4M] | [L2] |
| 3. | a | Explain the different types of polarizations. | [CO3] | [4M] | [L2] |
| | b | Derive the expression for electronic polarizabilty, $\boldsymbol{\alpha_e}$ in dielectrics. | [CO3] | [6M] | [L3] |
| 4. | a | Deduce an expression for Lorentz field relating to Dielecric material. | [CO3] | [7M] | [L4] |
| | b | The relative permittivity of argon at $0^0$ C and at 1 atmospheric pressure is 1.000435.Calculate the polarizability of the atom if the gas contains $2.7\text{x}10^{25}$ atoms/m$^3$.Given $\varepsilon_0$= 8.85 x $10^{-12}$ F/m. | [CO3] | [3M] | [L2] |
| 5. | a | Obtain Clausius-Mosotti equation and explain how it can be used to determine the dipole moment of a polar molecule. | [CO3] | [7M] | [L4] |
| | b | A solid elemental dielectric with $3\text{x}10^{28}$ atoms/ m$^3$ shows an electronic polarisability of $10^{-40}$ F-m$^2$ assuming the internal electric field to be a Lorenz field. Calculate a dielectric constant of the material. | [CO3] | [3M] | [L1] |
| 6. | a | Discuss the frequency dependence of various polarization processes in dielectric materials. | [CO3] | [7M] | [L2] |
| | b | Write the causes for Dielectric loss. | [CO3] | [3M] | [L4] |
| 7 | a | Describe the origin of magnetic moment in an atom. | [CO4] | [6M] | [L1] |
| | b | A circular loop of copper having a diameter of 10 cm carries a current of 500mA.Calculate the magnetic moment associated with the loop. | [CO4] | [4M] | [L3] |
| 8 | | Describe the classification of magnetic materials based magnetic moments. | [CO4] | [10M] | [L1] |
| 9 | a | Explain hysteresis of ferromagnetic material. | [CO4] | [8M] | [L2] |
| | b | A magnetic material has magnetization 3300A/m and flux density of 0.0044 Wb/m$^2$. Calculate the magnetizing force and relative permeability of the material. | [CO4] | [2M] | [L3] |
| 10 | a | Explain the domain concept of ferromagnetism. | [CO4] | [7M] | [L2] |
| | b | A paramagnetic material has a magnetic field intensity of $10^4$ A/m. If the susceptibility of the material at room temperature is 3.7 x $10^{-3}$. Calculate the magnetization and flux density in the material. | [CO4] | [3M] | [L3] |
| 11 | a | Distinguish between Soft and Hard magnetic material. | [CO4] | [8M] | [L2] |
| | b | A paramagnetic material has $10^{28}$ atoms per m$^3$. Its susceptibility at 350 K is 2.8 x $10^{-4}$. Calculate the susceptibility at 300 K. | [CO4] | [2M] | [L3] |

## UNIT – IV (QUANTUM MECHANICS & FREE ELECTRON THEORY)

| | | | | | |
|---|---|---|---|---|---|
| 1 | a | What are matter waves | [CO5] | [2M] | [L1] |
| | b | Mention any two properties of matter waves. | [CO5] | [2M] | [L1] |
| | c | What is drift velocity? | [CO5] | [2M] | [L1] |
| | d | Define mean free path. | [CO5] | [2M] | [L1] |
| | e | What is Fermi energy level? | [CO5] | [2M] | [L1] |
| 2 | a | Derive the expression for de Broglie wavelength | [CO5] | [6M] | [L3] |
| | b | Explain the properties of matter waves | [CO5] | [4M] | [L2] |
| 3 | a | Derive Schrödinger's time independent wave equation | [CO5] | [7M] | [L3] |
| | b | Explain the physical significance of wave function | [CO5] | [3M] | [L2] |
| 4 | a | Derive Schrödinger's time dependent wave equation. | [CO5] | [7M] | [L3] |
| | b | An electron is moving under a potential field of 15 kV. Calculate the wavelength of the electron wave. | [CO5] | [3M] | [L3] |
| 5 | a | Explain Heisenberg uncertainty principle | [CO5] | [7M] | [L2] |
| | b | The position of an electron in an atom is located within a distance of 0.1 $A^0$ using a microscope. What is the uncertainty in the momentum of the electron located in this way? | [CO5] | [3M] | [L3] |
| 6 | a | Describe the behavior of particle in a one dimensional infinite potential well in terms of Eigen values and function. | [CO5] | [8M] | [L2] |
| | b | An electron in bounded in a one dimensional infinite well having a width of $1 \times 10^{-10}$ m. Find the energy values in the ground state and the first two excited states. | [CO5] | [2M] | [L3] |
| 7 | a | What are the postulates of classical free electron theory? | [CO5] | [4M] | [L1] |
| | b | Derive an expression for electrical conductivity in a metal by using classical free electron theory. | [CO5] | [6M] | [L3] |
| 8 | b | Derive an expression for electrical conductivity in a metal by using Drude & Lorentz theory. | [CO5] | [7M] | [L3] |
| | c | Find relaxation time of conduction electron in metal if its resistivity is $1.54 \times 10^{-8}\Omega$-m and it has $5.8 \times 10^{28}$ conduction electron/$m^3$.Given m= $9.1 \times 10^{-31}$ kg, e= $1.6 \times 10^{-19}$ C. | [CO5] | [3M] | [L3] |
| 9 | a | What are the advantages of quantum free electron theory over classical free electron theory? | [CO5] | [4M] | [L1] |
| | b | Derive an expression for electrical conductivity in a metal by quantum free electron theory. | [CO5] | [6M] | [L3] |
| 10 | a | Write brief note on Fermi Dirac distribution. What is the effect of temperature on Fermi Dirac distribution function? | [CO5] | [7M] | [L1] |
| | b | Find the probability at which there is 1% probability that a state with energy 0.5 eV is above Fermi energy. | [CO5] | [3M] | [L3] |
| 11 | a | Define density of states in metals. | [CO5] | [2M] | [L1] |
| | b | Derive an expression for the number of allowed states per unit volume of a solid. | [CO5] | [8M] | [L3] |

## UNIT – V (SEMICONDUCTORS)

| | | | | | |
|---|---|---|---|---|---|
| 1 | a | Write any two difference between Intrinsic and Extrinsic semiconductors. | [CO6] | [2M] | [L2] |
| | b | What is extrinsic semiconductor? | [CO6] | [2M] | [L1] |
| | c | Define Hall effect. | [CO6] | [2M] | [L1] |
| | d | What is Drift and Diffusion in semiconductors. | [CO6] | [2M] | [L1] |
| | e | What are the applications of Hall effect | [CO6] | [2M] | [L1] |
| 2 | a | What is Fermi level? Prove that the Fermi level is lies exactly in between conduction band and valance band of intrinsic semiconductor. | [CO6] | [6M] | [L4] |
| | b | If $R_H$ of a specimen is $3.66 \times 10^{-4}$ $m^3$ $c^{-1}$. Its resistivity is $8.93 \times 10^{-3}$ Ω- m. Find mobility and electron concentration. | [CO6] | [4M] | [L3] |
| 3 | a | Derive the expression for the conductivity of intrinsic semiconductor with relevant energy band diagrams. | [CO6] | [7M] | [L3] |
| | b | The following data are given for an intrinsic Ge at 300K. Calculate the conductivity of the sample? ($n_i$= 2.4 x10 $^{19}$$m^{-3}$, $\mu_e$ = 0.39 $m^2$-$V^{-1}$$S^{-1}$, $\mu_p$ = 0.19 $m^2$-$V^{-1}$$S^{-1}$). | [CO6] | [3M] | [L3] |
| 4 | a | Explain the formation of n-type semiconductors with banddiagram | [CO6] | [7M] | [L2] |
| | b | In an Intrinsic semiconductor, the energy gap is 1.2 eV. Calculate the ratio between conductivity at 600K and at 300K. | [CO6] | [3M] | [L3] |
| 5 | a | Explain the formation of p-type semiconductors with banddiagram. | [CO6] | [7M] | [L2] |
| | b | The following data are given for an intrinsic Ge at 300K. Calculate the resistivity of the sample? ($n_i$= 2.4 x10 $^{19}$$m^{-3}$, $\mu_e$ = 0.39 $m^2$-$V^{-1}$$S^{-1}$, $\mu_p$ = 0.19 $m^2$-$V^{-1}$$S^{-1}$). | [CO6] | [3M] | [L3] |
| 6 | a | Enumerate the expression for current generated due to drifting of charge carriers in semiconductors in the presence of electric field. | [CO6] | [5M] | [L1] |
| | b | Enumerate the expression for current generated due to diffusion of charge carriers in semiconductors in the absence of electric field. | [CO6] | [5M] | [L1] |
| 7 | a | Derive Einstein's relation for charge carriers in semiconductor | [CO6] | [7M] | [L3] |
| | b | Find the diffusion co-efficient of electron in Si at 300 K if $\mu_e$ =0.19 $m^2$-$V^{-1}$$S^{-1}$. | [CO6] | [3M] | [L3] |
| 8 | a | Describe the Hall Effect in semiconductors. | [CO6] | [8M] | [L1] |
| | b | What are the applications of Hall Effect? | [CO6] | [2M] | [L1] |
| 9 | a | Explain the formation of energy bands in solids. | [CO6] | [4M] | [L2] |
| | b | Classify the solids into conductor, semiconductor & insulators based on band theory of solids. | [CO6] | [6M] | [L2] |
| 10 | a | Prove that Fermi Level $E_F = \frac{E_C+E_V}{2}$ in the case of an intrinsic semiconductor. | [CO6] | [7M] | [L4] |

| | | | | | |
|---|---|---|---|---|---|
| | b | Mobilities of electrons and holes in an intrinsic germanium at 300K are 0.36 $m^2$/V-s and 0.17 $m^2$/V-s respectively. If the resistivity is 2.12 Ω- m. Calculate the intrinsic concentration. | [CO6] | [3M] | [L3] |
| 11 | a | Distinguish between Intrinsic and Extrinsic semiconductors. | [CO6] | [5M] | [L2] |
| | b | Explain the temperature dependence of Fermi Energy Level ($E_F$) in an Extrinsic semiconductor. | [CO6] | [5M] | [L2] |

**Prepared by: Dept. of Physics**

# UNIT – I

## WAVE OPTICS

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1. | Two sources are said to be coherent if their emitted waves have | | | | | | | | [ D ] |
| | A | Same wavelength | B | Same amplitude | C | Constant phase difference | D | All | |
| 2. | In the presence of a plane parallel film, the path difference is equal to | | | | | | | | [ B ] |
| | A | $2\mu \sin i$ | B | $2\mu t \cos r$ | C | $2\mu t \cot r$ | D | $2\mu t \cos i$ | |
| 3. | In Newton's rings experiment, what is the condition for dark fringes in case of reflected light. | | | | | | | | [ C ] |
| | A | D α $2n+1$ | B | D α n | C | D α $n$ | D | D α $2n-1$ | |
| 4. | If a light wave is refracted from air to denser medium then the phase and path difference is | | | | | | | | [ B ] |
| | A | π and λ | B | π and λ/2 | C | π/2 and λ | D | π/2 and λ/2 | |
| 5. | When the light wave is reflected from the glass-air interface, the change of the reflected wave will be | | | | | | | | [ A ] |
| | A | 0 | B | π/2 | C | π/4 | D | Π | |
| 6. | Which of the following phenomenon can only be seen in transfers wave. | | | | | | | | [ C ] |
| | A | Diffraction | B | Interference | | | | | |
| | C | Polarization | D | Dispersion | | | | | |
| 7. | When the light wave is reflected from the air-glass interface, the change of phase of the reflected wave will be | | | | | | | | [ D ] |
| | A | 0 | B | π/2 | C | π/4 | D | Π | |
| 8. | In Newton's rings experiment, what is the condition for bright fringes in case of reflected light | | | | | | | | [ D ] |
| | A | D α $\sqrt{2n+1}$ | B | D α n | C | D α $\sqrt{n}$ | D | D α $\sqrt{2n-1}$ | |
| 9. | In a diffraction grating, the condition for principal maxima is | | | | | | | | [ B ] |
| | A | $e \sin\theta = n\lambda$ | B | $(e+d)\sin\theta = n\lambda$ | C | $d \sin\theta = n\lambda$ | D | $\sin\theta = n\lambda$ | |
| 10. | Diffraction phenomenon are usually divided into | | | | | | | | [ B ] |
| | A | One | B | Two | C | Three | D | Four | |
| 11. | On increasing width of the slit, the width of the diffraction pattern | | | | | | | | [ B ] |
| | A | Increases | B | Decreases | C | Remains same | D | None | |
| 12. | Diffraction grating has a | | | | | | | | [ A ] |
| | A | Large number of equidistant slits | B | Large number of randam distant slits | C | More than two slits | D | Circular slits | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 13. | In a grating, the combined width of a ruling and a slit is called ________ | | | | | | | | [ C ] |
| | A | Diffraction | B | Corresponding points | C | Grating element | D | None | |
| 14. | The spreading of waves when they pass through an aperture the edge of barrier is called as | | | | | | | | [ B ] |
| | A | Interference | B | Diffraction | C | Polarization | D | Scattering | |
| 15. | Approximately how many lines can be found on a diffraction grating | | | | | | | | [ C ] |
| | A | 5,000 | B | 15,000 | C | 30,000 | D | 50,000 | |
| 16. | Number of types of polarization | | | | | | | | [ C ] |
| | A | 1 | B | 2 | C | 3 | D | 4 | |
| 17. | Which phenomenon Causes the polarization of Light. | | | | | | | | [ C ] |
| | A | Diffraction | B | Reflection | C | Double Refraction | D | None | |
| 18. | Nicol Prism is based on the phenomenon of----- | | | | | | | | [ A ] |
| | A | Double Refraction | B | Reflection | C | Refraction | D | Scattering | |
| 19. | In which experiment the screen and sources are at finite distance | | | | | | | | [ B ] |
| | A | Fraunhofer Diffraction | B | Fresnel's diffraction | C | Young's diffraction | D | Newton's diffraction | |
| 20. | Maximum number of orders possible with a grating is | | | | | | | | [ C ] |
| | A | Independent of grating element | B | Inversely proportional to grating element | C | Directly proportional to grating element | D | Directly proportional to wavelength | |
| 21. | In Positive crystal the relation between refractive indices of e-ray and o-ray is | | | | | | | | [ B ] |
| | A | $\mu_0 > \mu_e$ | B | $\mu_0 < \mu_e$ | C | $\mu_0 = \mu_e$ | D | None | |
| 22. | Phase difference between coherent waves is | | | | | | | | [ C ] |
| | A | Constant | B | Zero | C | Both A and B | D | None | |
| 23. | If amplitude is doubled then the intensity raises by------times | | | | | | | | [ C ] |
| | A | 2 | B | 16 | C | 4 | D | 8 | |
| 24. | Soap bubbles produces colours due to the phenomenon of | | | | | | | | [ B ] |
| | A | Reflection | B | Interference | C | Diffraction | D | Polarization | |
| 25. | If different frequencies of waves superposition to each other, then the result is | | | | | | | | [ B ] |
| | A | Clear | B | More complicated | C | Both A and B | D | None | |
| 26. | When the film is observed by white light, colours are observed due to | | | | | | | | [ A ] |
| | A | Interference | B | Diffraction | C | Polarization | D | Coherence | |
| 27. | In Negative crystal the relation between refractive indices of e-ray and o-ray is | | | | | | | | [ A ] |
| | A | $\mu_0 > \mu_e$ | B | $\mu_0 < \mu_e$ | C | $\mu_0 = \mu_e$ | D | None | |
| 28. | If the thickness of the parallel film increases, the path difference | | | | | | | | [ B ] |
| | A | Decreases | B | Increases | C | Remains same | D | None | |
| 29. | The vibrations of the light rays are restricted to only one direction is--- | | | | | | | | [ A ] |
| | A | Polarized light | B | Unpolarized light | C | Both A& B | D | None | |
| 30. | Resultant amplitude of the waves of equal phase and frequency | | | | | | | | [ B ] |
| | A | $A = A_1 - A_2 + - - -$ | B | $A = A_1 + A_2 + - - -$ | C | $A = A_1^2 - A_2^2 + - - -$ | D | $A = A_1^2 + A_2^2 + - - -$ | |
| 31. | Wave nature of light is evidenced by | | | | | | | | [ B ] |
| | A | Photoelectric effect | B | Interference | C | Black body radiation | D | All | |
| 32. | Along the optic axis the velocities of e-ray and o-ray….. | | | | | | | | [ C ] |
| | A | $V_e > V_0$ | B | $V_e < V_0$ | C | $V_e = V_0$ | D | None | |
| 33. | In Fraunhofer diffraction the wave front undergoing diffraction has to be | | | | | | | | [ D ] |
| | A | Spherical | B | Cylindrical | C | Elliptical | D | Plane | |
| 34. | In interference pattern fringes have-------width | | | | | | | | [ A ] |
| | A | Equal | B | Unequal | C | Both A and B | D | None | |
| 35. | In diffraction pattern fringes have ------ width | | | | | | | | [ B ] |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | A | Equal | B | Unequal | C | Both A and B | D | None | |
| 36. | When a thin film of oil or soap bubble is illuminated with white light, multiple colours appears. This is due to | | | | | | | | [ B ] |
| | A | Diffraction | B | Interference | C | Polarization | D | Total internal reflection | |
| 37. | In single slit diffraction, the first diffraction minima is observed at an angle of 30$^o$, when the light of wavelength 500 nm is used. The width of the slit is | | | | | | | | [ B ] |
| | A | 5 x 10$^{-5}$ cm | B | 2.5 x 10$^{-15}$ cm | C | 10 x 10$^{-5}$ cm | D | 1.25 x 10$^{-5}$ cm | |
| 38. | Calacite crystal is a----- | | | | | | | | [ B ] |
| | A | Uni-axial Positive Crystal | B | Uni-Axial Negitive | C | Bi-axial positieve crystal | D | None | |
| 39. | The light rays that are vibrating in all directions is called | | | | | | | | [ **B** ] |
| | A | Polarization | B | Unploarization | C | Both A and B | D | None | |
| 40. | The light rays that are vibrating in only one direction is called | | | | | | | | [ A ] |
| | A | Polarization | B | Unploarization | C | Both A and B | D | None | |

## UNIT – II

## CRYSTALLOGRAPHY& X – RAY DIFFRACTION

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1. | Lattice + Basis = | | | | | | | | [ B ] |
| | A | Unit cell | B | Crystal | C | Amorphous solid | D | None of these | |
| 2. | A smallest block whose repetition in space indefinitely generates a crystal is called | | | | | | | | [ C ] |
| | A | Primitive cell | B | Space lattice | C | Unit cell | D | Basis | |
| 3. | The number of atoms present in a unit cell of simple cubic structure | | | | | | | | [ B ] |
| | A | 8 | B | 1 | C | 4 | D | 6 | |
| 4. | The number of atoms per unit cell in a BCC lattice is | | | | | | | | [ B ] |
| | A | 1 | B | 2 | C | 4 | D | 8 | |
| 5. | The number of atoms per unit cell in an FCC lattice is | | | | | | | | [ C ] |
| | A | 1 | B | 2 | C | 4 | D | 8 | |
| 6. | Atomic packing factor of FCC crystal system is | | | | | | | | [ B ] |
| | A | 0.68 | B | 0.74 | C | 0.52 | D | | |
| 7. | Atomic packing factor of simple cubic crystal system in | | | | | | | | [ A ] |
| | A | 0.68 | B | 0.7 | C | 1.0 | D | 0.52 | |
| 8. | Atomic packing factor of BCC crystal system is | | | | | | | | |
| | A | 0.68 | B | 0.72 | C | 1.0 | D | 0.52 | |
| 9. | Atomic packing factor of FCC crystal system is | | | | | | | | [ A ] |
| | A | 0.68 | B | 0.74 | C | 0.52 | D | 1.00 | |
| 10 | Which of the following has the greatest packing fraction | | | | | | | | [ C ] |
| | A | SC | B | BCC | C | FCC | D | None | |
| 11 | The relation between atomic radius ‘r’ and lattice constant ‘a’ for the case of simple cubic structure is | | | | | | | | [ A ] |
| | A | a=2r | B | $a = \frac{r}{2}$ | C | $a = 2\sqrt{2}\,r$ | D | $a = \frac{\sqrt{3}}{4}\,r$ | |
| 12 | The relation between atomic radius ‘r’ and lattice constant ‘a’ for the case of BCC system is | | | | | | | | [ B ] |
| | A | a=2r | B | $a = \frac{4}{\sqrt{3}}\,r$ | C | $a = 2\sqrt{2}\,r$ | D | $a = \frac{\sqrt{3}}{4}\,r$ | |
| 13 | The relation between atomic radius ‘r’ and lattice constant ‘a’ for the case of FCC system is | | | | | | | | [ C ] |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | A | a=2r | B | $a = \frac{4}{\sqrt{3}} r$ | C | $a = 2\sqrt{2}\, r$ | D | $a = \frac{\sqrt{3}}{4} r$ |
| 14. | The crystal system of primitives a=bG $c$ and interfacial angles a= $\beta = 90^\circ, \gamma = 120^\circ$ is known as | | | | | | | [ D ] |
| | A | Cubic | B | Tetragonal | C | Monoclinic | D | Hexagonal |
| 15. | The crystal system of primitives a=bG $c$ and interfacial angles $\alpha = \beta = \gamma = 90^\circ$ known as | | | | | | | [B ] |
| | A | Cubic | B | Tetragonal | C | Trigonal | D | Hexagonal |
| 16. | Triclinic system possesses lattice parameters is | | | | | | | [A ] |
| | A | $a$ G $b$ G $c$;<br>$\alpha$ G $\beta$ G $\gamma$ | B | $a$ G $b$ G $c$;<br>$\alpha = \beta$ G $\gamma$ | C | $a$ G $b$ G $c$;<br>$\alpha = \beta = \gamma$ | D | $a = b$ G $c$;<br>$\alpha = \beta = \gamma$ |
| 17. | The three axes of a crystal are mutually perpendicular but all lattice parameters are unequal. The crystal system is | | | | | | | [ C] |
| | A | Cubic | B | Tetragonal | C | Orthorhombic | D | Hexagonal |
| 18. | The number of crystal system is | | | | | | | [ D ] |
| | A | 4 | B | 5 | C | 6 | D | 7 |
| 19. | The coordination number of a simple cubic is | | | | | | | [ C ] |
| | A | 6 | B | 8 | | 12 | D | 13 |
| 20. | If miller indices are (101) then it represents | | | | | | | [ B ] |
| | A | Plane parallel to X-axis | B | Plane parallel to Y-axis | C | Plane parallel to Z-axis | D | Plane parallel to X-axis and Z-axis |
| 21. | The planes (112) and (224) are | | | | | | | [ B ] |
| | A | Perpendicular to each other | B | Parallel to each other | C | Intersecting at an angle other than $90^\circ$ | D | None of these |
| 22. | The miller indices of the plane parallel to z-axis are | | | | | | | [ C ] |
| | A | (0 0 1) | B | (1 0 1) | C | (11 0) | D | (100) |
| 23. | For a cubic system if 1A$^\circ$ is the lattice constant then the interplanar separation for (212) plane is | | | | | | | |
| | A | 5 Å | B | 0.33 Å | C | 9 Å | D | 0.11 Å |
| 24. | Interplanar distance for (111) plane is | | | | | | | [ B ] |
| | A | $a\sqrt{3}$ | B | $\frac{a}{\sqrt{3}}$ | C | $3a$ | D | $\frac{a}{3}$ |
| 25. | The Miller indices (hkl) represents | | | | | | | [ B ] |
| | A | The direction | B | A plane | C | System of planes | D | A set of parallel plane |
| 26. | A family of directions is represented by | | | | | | | [ C ] |
| | A | (hkl) | B | {uvw} | C | {hkl} | D | [uvw] |
| 27. | The angle between [112] and [224] directions in a cubic crystal is (in degrees) | | | | | | | [ A ] |
| | A | 0 | B | 45 | C | 90 | D | 180 |
| 28. | ----------- is a system of notation of planes within a crystal of space lattice | | | | | | | [ C ] |
| | A | Space lattice | B | Crystalline | C | Miller indices | D | Identical |
| 29. | Bragg's condition for X-ray diffraction | | | | | | | [ A ] |
| | A | $2d \sin\theta = n\lambda$ | B | $d \sin\theta = n\lambda$ | C | $\sin\theta = n\lambda$ | D | $2d = n\lambda$ |
| 30. | Minimum interplanar spacing required for Bragg's diffraction is | | | | | | | [ B ] |
| | A | $\frac{\lambda}{4}$ | B | $\frac{\lambda}{2}$ | C | $\lambda$ | D | 2 |
| 31. | Bragg's reflection can occur only for wavelengths | | | | | | | [ A ] |
| | A | $\lambda \le 2d$ | B | $\lambda \le d$ | C | $\lambda \le 2a$ | D | All of the above |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 32. | Which radiation produces diffraction as they pass through the crystals? | | | | | | | | [ A ] |
| | A | X-rays | B | IR-rays | C | γ -rays | D | UV-rays | |
| 33. | X-rays are used to study the crystal structure by means of diffraction because | | | | | | | | [ B ] |
| | A | The X-rays are electromagnetic waves | B | The wavelength of X-rays is of the same order of interatomic spacing | | | | | |
| | C | The wavelength of X-rays is larger than the interplanar distance | D | The X-rays can be scattered by ions in the lattice. | | | | | |
| 34. | In the powder method ,incident X-rays reflected back when the incident angle is | | | | | | | | [ B ] |
| | A | $\frac{\pi}{4}$ | B | $\frac{\pi}{2}$ | C | $\frac{3\pi}{2}$ | D | $\pi$ | |
| 35. | In X-ray powder camera technique, the detector used is | | | | | | | | [ B ] |
| | A | PMT | B | Photographic film | C | Bolometer | D | Thermister | |
| 36. | The X-ray diffraction is based upon | | | | | | | | [ C ] |
| | A | Illkovic equation | B | Boltzmann equation | C | Bragg’s equation | I | Van deemter equation | |
| 37. | Laue’s model pictures XRD as reflection from parallel crystalline planes. Refection is different from refraction as | | | | | | | | [ D ] |
| | A | Diffraction occurs throught the bulk | B | Intensity of diffracted beam is less | C | Diffraction in crystals occurs only at Bragg’s angles | D | All of the mentioned | |
| 38. | Bragg’s law was proposed in ___________ | | | | | | | | [ A ] |
| | A | 1903 | B | 1913 | C | 1893 | D | 1853 | |
| 39. | Bragg’s law is used in which process | | | | | | | | [ C ] |
| | A | X-ray production | B | Gamma-ray production | C | X-ray crystallography | D | X-ray scan | |
| 40. | If X-ray of wavelength 100 Å is incident on an atom at an angle of 90°, then what should be the value of d for first-order sepctrum? | | | | | | | | [ C ] |
| | A | 30 Å | B | 40 Å | C | 50 Å | D | 60 Å | |

## UNIT – III

## DIELECTRICS AND MAGNETIC MATERIALS

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1. | What is the process of producing electric dipoles inside the dielectric by an external electric field? | | | | | | | | [ A ] |
| | A | Polarisation | B | Dipole moment | C | Susceptibility | D | Magnetization | |
| 2. | Dielectrics are_____ | | | | | | | | [ C ] |
| | A | Metals | B | Semiconductors | C | Insulating material | D | None | |
| 3. | How does ionic polarisation occur? | | | | | | | | [ C ] |
| | A | Splitting of ions | B | Passing magnetic field | C | Displacement of cations and anions | D | Never occurs | |
| 4. | Which of the following is the slowest polarisation method? | | | | | | | | [ D ] |
| | A | ionic polarization | B | electronic polarization | C | Orientation polarization | D | Space charge polarization | |
| 5. | When does a dielectric become a conductor? | | | | | | | | [ C ] |
| | A | At avalanche breakdown | B | At high temperature | C | At dielectric breakdown | D | In the presence of magnetic field | |
| 6. | Dielectric material's atoms and molecules are microscopically | | | | | | | | [ C ] |
| | A | Positive | B | Negative | C | neutral | D | None | |
| 7. | Which of the following easily adapt itself to store electrical energy | | | | | | | | [ B ] |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | A | Superconductors | B | Passive dielectrics | C | Polar molecules | D | Active dielectric | |
| 8. | Local electric field is calculated by using the method suggested by | | | | | | | | [ A ] |
| | A | Lorentz | B | Weiss | C | Curie | D | Coulomb | |
| 9. | Find the capacitance of layer of $A1_3$ $O_3$ that is 0.5μm thick and 2000mm$^2$ of square area $\varepsilon_r = 8$. | | | | | | | | [ B ] |
| | A | 1000Mf | B | 0.283μF | C | 16μF | D | 2.83μF | |
| 10. | A Dielectric material can be polarized by applying_________field on it | | | | | | | | [ C ] |
| | A | Magnetic | B | Gravitational | C | Electric | D | Meason | |
| 11. | Polorization per unit applied electric field is called | | | | | | | | [ C ] |
| | A | Electric susceptability | B | Magnetic susceptability | C | Electric polorization | D | Dielectric constant | |
| 12. | Dipolar polarization is actually applicable to | | | | | | | | [ D ] |
| | A | Gases | B | Liquids | C | Solids | D | Both A&B | |
| 13. | Dipole moment is defined as the__________of one of the charge and separation between the charges | | | | | | | | [ A ] |
| | A | Product | B | Sum | C | Ratio | D | None | |
| 14. | Dipole moment per unit volume of material is called | | | | | | | | [ A ] |
| | A | Polorization | B | Plorizability | C | Both A&B | D | None | |
| 15. | In the aqbsence of an applied electric field on a dipolar substance ,the polarization is | | | | | | | | [ B ] |
| | A | Finite | B | Zero | C | High | D | All the above | |
| 16. | By applying electric field on a dipolar substance ,it results in________polarization | | | | | | | | [ D ] |
| | A | Eletical | B | Ionic | C | Orientatinal | D | All the above | |
| 17. | The total polorizability of a substance,it is the sum of____________polorizabilities | | | | | | | | [ D ] |
| | A | Dipolar | B | Ionic | C | Electric | D | All the above | |
| 18. | Orientation polarization is due to the________of polar molecules in dielectric substance. | | | | | | | | [ A ] |
| | A | Rotation | B | Change in separation | C | Both | D | None | |
| 19. | Clausius-Mosotti relation makes relation between microscopic and macroscopic quantities of | | | | | | | | [ C ] |
| | A | Electric field | B | Capacitance | C | Polorization | D | None | |
| 20. | The electronic polarization exists up to a frequency of__________. | | | | | | | | [ A ] |
| | A | $10^{15}$Hz | B | $10^{18}$Hz | C | $10^{20}$Hz | D | $10^{22}$Hz | |
| 21. | Copper is ________magnetic material. | | | | | | | | [ A ] |
| | A | Dia | B | Para | C | Ferro | D | Anti -ferro | |
| 22. | The SI unit of magnetic moment is _________ | | | | | | | | [ D ] |
| | A | Wb/m$^2$ | B | Wb | C | A/m$^2$ | D | A m$^2$ | |
| 23. | Relation between B, H and M is | | | | | | | | [ A ] |
| | A | $B = \mu_o(H+M)$ | B | $M = \mu_o(H+B)$ | C | $H = \mu_o(B+M)$ | D | $B = \mu(H+M)$ | |
| 24. | Magnetic susceptibility is | | | | | | | | [ C ] |
| | A | torque per unit area | B | dipole moment per unit volume | C | magnetization per unit magnetic field intensity | D | none of these | |
| 25. | One Bohr magneton $\mu_B$ is equal to | | | | | | | | [ D ] |
| | A | $\frac{4\pi m}{eh}$ | B | 4πmhe | C | $\frac{me}{4\pi h}$ | D | $\frac{eh}{4\pi m}$ | |
| 26. | Relative permeability $\mu_r$ is related to magnetic susceptibility $\chi$ by | | | | | | | | [ B ] |
| | A | $\mu_r = 1 - \chi$ | B | $\mu_r = 1 + \chi$ | C | $\mu_r = \chi - 1$ | D | $\mu_r = 1/\chi$ | |
| 27. | A field of strength 100 A/m produces a magnetization 2000 A/m in a ferromagnetic | | | | | | | | [ C ] |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | material. The relative permeability of the material is | | | | | | | | |
| | A | 19 | B | 3 | C | 21 | D | 1.05 | |
| 28. | The area enclosed by hysteresis loop is a measure of | | | | | | | | [ D ] |
| | A | Retentivity | B | susceptibility | C | permeability | D | energy loss per cycle | |
| 29. | Material which lack permanent dipoles are called_________ magnetic material. | | | | | | | | [ A ] |
| | A | Dia | B | Para | C | Ferro | D | Anti -ferro | |
| 30. | The permeability of free space is | | | | | | | | [ B ] |
| | A | $4\pi$ x $10^{7}$ H/m | B | $4\pi$ x $10^{-7}$ H/m | C | $2\pi$ x $10^{-7}$ H/m | D | $2\pi$ x $10^{-8}$ H/m | |
| 31. | The magnetisation retained by the specimen when the magnetizing field is reduced from saturation value to zero is known as | | | | | | | | [ B ] |
| | A | Coercivity | B | retintivity | C | hysteresis | D | Spontaneous magnetisation | |
| 32. | When a material is used in a magnetic field B, a magnetic moment proportional to B but in opposite direction is induced. Then the material is magnetic. | | | | | | | | [ A ] |
| | A | Dia | B | Para | C | Ferro | D | Ferri | |
| 33. | Magnetic materials which can be readily magnetized in either direction are called______ materials. | | | | | | | | [ B ] |
| | A | Hard magnetic | B | Soft magnetic | C | Low hysteresis loss | D | Low hysteresis loss | |
| 34. | Soft magnetic materials possess | | | | | | | | [ D ] |
| | A | Low coercivity and hysteresis loss | B | Low remanent magnetisation | C | High remanent permeblility and susceptibility | D | All of the above | |
| 35. | Hard magnetic materials possess | | | | | | | | [ D ] |
| | A | Low permeblility | B | High hysteresis loss | C | High remanent magnetisation and coercivity | D | All of the above | |
| 36. | Paramagnetic susceptibility varies as | | | | | | | | [ B ] |
| | A | $T^2$ | B | $\frac{1}{T}$ | C | $\frac{1}{T^2}$ | D | T | |
| 37. | The magnetic dipole moments of neighboring atoms are antiparallel and equal for magnetic material. | | | | | | | | [ D ] |
| | A | Dia | B | Para | C | Ferri | D | Anti -ferro | |
| 38. | Diamagnetic materials possesses | | | | | | | | [ B ] |
| | A | Permanent magnetic dipoles | B | No permanent magnetic dipoles | C | Induced dipoles along field direction | D | No induces dipoles even when external field is applied. | |
| 39. | One nuclear magneton equals | | | | | | | | [ B ] |
| | A | 9.27 x $10^{-24}$ A-$m^2$ | B | 5.05 x $10^{-27}$ A-$m^2$ | C | 5.05 x $10^{27}$ A-$m^2$ | D | 9.27 x $10^{24}$ A-$m^2$ | |
| 40. | The magnetic dipole moments of neighboring atoms are antiparallel and unequal for magnetic material. | | | | | | | | [ C ] |
| | A | Dia | B | Para | C | Ferri | D | Anti -ferro | |

## UNIT – IV
## QUANTUM MECHANICS AND FREE ELECTRON THEORY

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1. | When an electron is accelerated by a potential of V volts. Then the de Broglie wavelength is given by | | | | | | | | [ D ] |
| | A | A) $\frac{12.26}{\sqrt{V}}\ nm$ | B | $\frac{26.12}{\sqrt{V}}\ A^0$ | B | $\frac{12.26}{\sqrt{V}}\ \mu m$ | D | $\frac{12.26}{\sqrt{V}}\ A^0$ | |
| 2. | An electron, neutron and proton have the same wavelength. Which particle has greater velocity? | | | | | | | | [ C ] |
| | A | Neutron | B | Proton | C | Electron | D | All | |
| 3. | Probability density of wave function is | | | | | | | | [ B ] |
| | A | **T** | B | $\|T\|^2$ | C | $\mathbf{TT^*T}$ | D | none | |
| 4. | When an electron is accelerated through a potential field of 100 V then it is associated with a wave of wavelength equal to | | | | | | | | [ C ] |
| | A | ) 0.1226 nm | B | 1.226 nm | C | 12.26 nm | D | 122.6 nm | |
| 5. | The wavelength of de Broglie wave associated with a moving particle is independent of it's | | | | | | | | [ B ] |
| | A | Mass | B | Charge | C | Velocity | D | Momentum | |
| 6. | If E is the kinetic energy of the material particle of mass m then the de Broglie wavelength is | | | | | | | | [ A ] |
| | A | $\frac{h}{\sqrt{2mE}}$ | B | $\frac{\sqrt{2mE}}{h}$ | C | ) $h\sqrt{2mE}$ | D | $\frac{h}{2mE}$ | |
| 7. | The characteristic of particles are | | | | | | | | [ D ] |
| | A | A) Wavelength | B | Frequency | C | Amplitude | D | Momentum | |
| 8. | Dual nature of matter wave proposed by | | | | | | | | [ A ] |
| | A | de Broglie | B | B) Planck | C | Einstein | D | Newton | |
| 9. | The dual nature is exhibited by | | | | | | | | [ D ] |
| | A | Particle only | B | Wave only | C | Photon only | D | By both A and B | |
| 10. | The wave function Ψ associated with a moving particle | | | | | | | | [ D ] |
| | A | Is not an observable quantity | B | does not have direct physical meaning | C | is a complex quantity | D | all of the above | |
| 11. | The most probable position of a particle in a one dimensional potential well of width a in the first quantum state is | | | | | | | | [ B ] |
| | A | a/4 | B | a/3 | C | a/2 | D | 2a/3 | |
| 12. | Einstein mass –energy relation is | | | | | | | | [ A ] |
| | A | $\nu = \frac{mc^2}{h}$ | B | $\nu = \frac{mc}{h}$ | C | $\nu = \frac{hc}{\lambda}$ | D | $\lambda = \frac{mc}{h}$ | |
| 13. | The uncertainty principle is applicable to | | | | | | | | [ C ] |
| | A | Only small particles | B | Microscopic particles | C | All material particles | D | None | |
| 14. | The wavelength of electron moving with a velocity of 500 m/s is | | | | | | | | [ A ] |
| | A | 1.45 nm | B | 0.50 nm | C | 2.90 nm | D | 3.00 nm | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 15. | If an electron is moving under a potential field of 15 kV. Calculate the wavelength of electron waves | | | | | | | | [ B ] |
| | A | 1 Å | B | 0.1 Å | C | 10 Å | D | 0.01Å | |
| 16. | Which of the following equation is the normalized wave equation | | | | | | | | [ B ] |
| | A | $|T|^2 dx\,dy\,dz = 0$ | B | $|T|^2 dx\,dy\,dz = 1$ | C | $|T|\,dx\,dy\,dz = 0$ | D | $|T|\,dx\,dy\,dz = 1$ | |
| 17. | In a one dimensional infinite potential box, particle energy is given as | | | | | | | | [ D ] |
| | A | $\frac{n^2h}{2ma^2}$ | **B** | $\frac{\pi^2h^2}{2ma^2}$ | C | $\frac{nh^2}{2ma^2}$ | **D** | $\frac{n^2h^2}{8ma^2}$ | |
| 18. | The characteristic of particles are | | | | | | | | [ D ] |
| | A | Mass | B | Velocity | C | Energy | D | All the above | |
| 19. | For n=1, the most probable position of the particle is at | | | | | | | | [ A ] |
| | A | a/2 | B | a/4 | C | a/3 | D | a | |
| 20. | The wavelength 'λ' of de Broglie wave associated with a moving particle is | | | | | | | | [ C ] |
| | A | $\lambda = \frac{mv}{h}$ | B | $\lambda = \frac{m}{vh}$ | C | $\lambda = \frac{h}{mv}$ | D | $\lambda = \frac{1}{mvh}$ | |
| 21. | Classical free electron theory was developed by | | | | | | | | [ B ] |
| | A | Sommerfeld | B | Drude and Lorentz | C | Bloch | D | Einstein | |
| 22. | Quantum free electron theory was developed by | | | | | | | | [ A ] |
| | A | Sommerfeld | B | Drude and Lorentz | C | Bloch | D | Einstein | |
| 23. | According to quantum free electron theory the expression for electrical conductivity is | | | | | | | | [ C ] |
| | A | $\frac{ne^2\tau}{m}$ | B | $\frac{ne^2\tau_F}{m}$ | C | $\frac{ne^2\tau_F}{m^*}$ | D | $\frac{e^2\tau_F}{nm}$ | |
| 24. | The Classical free electron theory is based on the principle of | | | | | | | | [ A ] |
| | A | Classical mechanics | B | Quantum mechanics | C | Statistical mechanics | D | None | |
| 25. | The Quantum free electron theory is based on the principle of | | | | | | | | [ B ] |
| | A | Classical mechanics | B | Quantum mechanics | C | Statistical mechanics | D | None | |
| 26. | The time taken by electron to reach original position from the disturbed position is called as | | | | | | | | [ C ] |
| | A | Mean free path | B | Drift velocity | C | Relaxation time | D | Average velocity | |
| 27 | SI unit of electrical resistivity is | | | | | | | | [ B ] |
| | A | ohm | B | ohm-m | C | mho | D | mho – m | |
| 28. | SI unit of electrical conductivity is | | | | | | | | [ D ] |
| | A | ohm | B | ohm-m | C | mho | D | mho/m | |
| 29. | Random motion of electron produces | | | | | | | | [ A ] |
| | A | No current | B | Current | C | Volatge | D | None | |
| 30. | The average distance travelled by an electron between two successive collisions in the presence of applied field is known as | | | | | | | | [ A ] |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | A | Mean free path | B | Drift velocity | C | Relaxation time | D | Average velocity |
| 31. | The highest filled energy level occupied by electrons is called as | | | | | | | [ A ] |
| | A | Fermi energy level | B | Conduction band | C | valence band | D | Ionic band |
| 32. | The SI unit of mobility is | | | | | | | [ C ] |
| | A | $\frac{m}{V-s^2}$ | B | $\frac{m}{V^2-s}$ | C | $\frac{m^2}{V-s}$ | D | $\frac{m}{V-s}$ |
| 33. | The expression for Fermi-Dirac distribution function is given as | | | | | | | [ B ] |
| | A | $F(E) = \frac{1}{1+e^{\left(\frac{E_F-E}{K_BT}\right)}}$ | B | $F(E) = \frac{1}{1+e^{\left(\frac{E-E_F}{K_BT}\right)}}$ | C | $F(E) = \frac{1}{1-e^{\left(\frac{E-E_F}{K_BT}\right)}}$ | D | $F(E) = \frac{1}{e^{\left(\frac{E_F-E}{K_BT}\right)}}$ |
| 34. | The drift velocity $v_d$ of electron in a metal is related to the electric field E and collision time as | | | | | | | [ B ] |
| | A | $\frac{e}{mE}$ | B | $\frac{eE}{m}$ | C | $\frac{E}{me}$ | D | $\frac{m}{eE}$ |
| 35. | Classical free electron theory failed to explain | | | | | | | [ D ] |
| | A | Specific heat of metals | B | Magnetic susceptibility of metals | C | Thermionic emission | D | All the above |
| 36. | According to quantum free electron theory, the expression for electrical resistivity ‘ρ’ Is | | | | | | | [ C ] |
| | A | $\frac{ne^2}{m}$ | B | $\frac{m}{ne^2}$ | C | $\frac{m}{ne^2}$ | D | $\frac{e^2}{nm}$ |
| 37. | The value of Fermi function in the Fermi level at T= 0K is | | | | | | | [ B ] |
| | A | 0.5 | B | 1 | C | 0 | D | 1.5 |
| 38. | At any temperature other than 0K , the probability of finding an electron at Fermi level Is | | | | | | | [ C ] |
| | A | 1 | B | 0 | C | 0.5 | D | -1 |
| 39. | The expression for electrical conductivity ‘σ’ ( in terms of mobility of electron and density of electron | | | | | | | [ A ] |
| | A | Neμ | B | n/eμ | C | μ/ne | D | 1/neμ |
| 40 | The value of Fermi function for an Energy $K_BT$ above Fermi energy is | | | | | | | [ B ] |
| | A | 2.7 | B | 0.27 | C | 0.72 | D | 7.2 |

## UNIT - V
## SEMICONDUCTOR

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1. | The number of valence electrons in Si atom is | | | | | | | [ D ] |
| | A | 1 | B | 2 | C | 3 | D | 4 |
| 2. | Under forward bias, the width of depletion region_____________ | | | | | | | [ A ] |
| | A | Decreases | B | Increases | C | Constant | D | None |
| 3. | If the charge carriers are electrons, the Hall coefficient is | | | | | | | [ B] |
| | A | Positive | B | Negative | C | Zero | D | None |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 4. | Electric conduction in a semiconductor occurs due to the motion of | | | | | | | | [C ] |
| | A | Free electrons only | B | Holes only | C | Both electrons and holes | D | N ne | |
| 5. | Holes are majority charge carriers in | | | | | | | | [ D ] |
| | A | Intrinsic Semiconductor | B | Extrinsic Semiconductor | | | | | |
| | C | N-type Semiconductor | D | P-type Semiconductor | | | | | |
| 7 | Even when no light is applied, minimum reverse leakage current is called | | | | | | | | [ A ] |
| | A | Dark current | B | Forward | C | Reverse | D | None | |
| 8 | Phosphorous, arsenic and antimony are___________elements | | | | | | | | [A ] |
| | A | Pentavalent | B | trivalent | C | Mono | D | Divalent | |
| 9 | In intrinsic semiconductors the carrier concentration varies as | | | | | | | | [ B ] |
| | A | T | B | $T^{3/2}$ | C | $T^2$ | D | 1 $T^{1/2}$ | |
| 10 | The excess concentration of carrier injected into a semiconductor --- with time | | | | | | | | [ B ] |
| | A | Increases linearly | B | decreases exponentially | C | Increases exponentially | D | d creases linearly | |
| 11. | The product np varies by changing | | | | | | | | [ A ] |
| | A | Temperature | B | Pressure | C | doping trivalent impurities | D | doping Pentavalent impurities | |
| 12. | Under reverse bias, the width of the depletion region | | | | | | | | [ B ] |
| | A | Decreases | B | Increases | C | Constant | D | None | |
| 13. | Silicon is a_________band gap semiconductor. | | | | | | | | [ B ] |
| | A | Direct | B | Indirect | C | Both A & B | D | None | |
| 14. | The ratio of diffusion coefficient to mobility of charge carriers is proportional to | | | | | | | | [A ] |
| | A | T | B | $T^2$ | C | 1/T | D | $1/T^2$ | |
| 15. | At 0K, a pure semiconductor is | | | | | | | | [ C ] |
| | A | Conductor | B | Semiconductor | C | Insulator | D | None | |
| 16. | The majority charge carriers of a P-type semiconductors are | | | | | | | | [B ] |
| | A | Electrons | B | Holes | C | Ions | D | None | |
| 17. | The majority charge carriers of a N-type semiconductors are | | | | | | | | [ A ] |
| | A | Electrons | B | H les | C | Ions | D | N ne | |
| 18. | The Fermi level in an n-type semiconductor lies | | | | | | | | [ B ] |
| | A | Near the valence band | B | Near the conduction band | C | Exactly at the middle of the energy gap | D | None of these | |
| 19. | The Hall coefficient, $R_H$ = | | | | | | | | [ A ] |
| | A | 1/ne | B | n/e | C | e/n | D | en | |
| 20. | If the Hall coefficient is negative then the semiconductor is | | | | | | | | [ B ] |
| | A | P-type | B | N-type | C | Intrinsic | D | N ne | |
| 21. | At 0 K, pure silicon is | | | | | | | | [ C ] |
| | A | Conductor | B | Semiconductor | C | Insulator | D | None | |
| 22. | The Fermi level in an p – type semiconductor lies | | | | | | | | [ A ] |
| | A | Near the valence band | B | Near the conduction band | C | Exactly at the middle of the energy gap | D | None of these | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 23. | The diffusion current is proportional to__________of charge carriers. | | | | | | | [ A ] |
| | A | Concentration gradient | B | drift velocity | C | Mobility | D | none of these |
| 24. | If the Hall coefficient is positive then the semiconductor is | | | | | | | [ A ] |
| | A | P-type | B | N-type | C | Intrinsic | D | None |
| 25. | An n – type germanium (Ge) is obtained by doping pure Ge with | | | | | | | [ A ] |
| | A | Pentavalent | B | trivalent | C | Mono | D | Divalent |
| 26. | In case of intrinsic semiconductor | | | | | | | [ A ] |
| | A | $E_F = \frac{E_C + E_V}{2}$ | B | $E_F > \frac{E_C + E_V}{2}$ | C | $E_F < \frac{E_C + E_V}{2}$ | D | $E_F = \frac{E_C - E_V}{2}$ |
| 27. | The carrier concentration in an intrinsic semiconductor ----- with increase of temperature | | | | | | | [ A ] |
| | A | Increases | B | Decreases | C | constant | D | None |
| 28. | The electrical conductivity of a semiconductor at absolute zero of temperature is | | | | | | | [ D ] |
| | A | Very small | B | Very large | C | Finite | D | Zero |
| 29. | The drift velocity acquired by a carrier per unit electric field strength is called | | | | | | | [ C ] |
| | A | Conductivity | B | Resistivity | C | Mobility | D | None |
| 30. | With increase of temperature the Fermi energy level moves -------in P-type semiconductor. | | | | | | | [ B ] |
| | A | Downwards | B | Upwards | C | Left | D | Right |
| 31. | With increase of temperature the Fermi energy level moves -------in N-type semiconductor. | | | | | | | [ A ] |
| | A | Downwards | B | Upwards | C | Left | D | Right |
| 32. | Einstein's relation between the diffusion constant D and mobility $\mu$ of a carrier is given | | | | | | | [ B ] |
| | A | $\frac{2K_BT}{e}$ | B | $\frac{K_BT}{e}$ | C | $\frac{e}{2K_BT}$ | D | $\frac{e}{K_BT}$ |
| 33. | In intrinsic semiconductor the electron concentration is equal to | | | | | | | [ B ] |
| | A | Ion concentration | B | Hole concentration | C | Proton concentration | D | Neutron concentration |
| 34. | The energy gap of a conductor is | | | | | | | [ A ] |
| | A | Constant | B | varies with temperature | C | Varies with voltage | D | Varies with doping concentration |
| 35. | The ratio of diffusion coefficient to mobility of charge carriers is proportional to | | | | | | | [ A ] |
| | A | T | B | $T^2$ | C | 1/T | D | $1/T^3$ |
| 36. | Electrical conductivity of a semiconductor at absolute zero of temperature is | | | | | | | [ D ] |
| | A | Very small | B | Very large | C | Finite | D | Zero |
| 37. | The excess concentration of carrier injected into a semiconductor______with time. | | | | | | | [ B ] |
| | A | Increases linearly | B | Decreases | C | Increases | D | Decreases |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | exponentially | | exponentially | | linearly | |
| 38. | As compared to an intrinsic conductor , the resistivity of an extrinsic (doped) semiconductor is | | | | | | | | [ B ] |
| | A | Higher | B | Lower | C | Same | D | None | |
| 39. | When a pure semiconductor is heated, its resistance ______________ | | | | | | | | [ B ] |
| | A | Increases | B | Decrease | C | Same | D | Can not say | |
| 40. | An n-type semiconductor is ___________________ | | | | | | | | [ C ] |
| | A | Positively charged | B | Negatively charged | C | Electrically neutral | D | None | |

**Prepared by: Dept. of Physics**

# SHORT QUESTIONS- ANSWERS

## UNIT- I (WAVEOPTICS)

### 1. Define Interference.

When two light waves of nearly same amplitude ,same frequency,and travelling in the same direction of medium ,superimpose over each other then there occurs variation of intensity of light with distance(maximum and minimum) .This phenomenon is defined as interference of light.

### 2.Define Diffraction.

When light falls on an obstacle whose size is comparable with the wavelength of light then light bends around the edges or corners of an obstacle and enters into the geometrical shadow.This bending of light is known as diffraction.

### 3.Define polarization

Polarisation of light is a property shown by transverse waves. The light waves which travel only in a single plane are known as polarized light waves. The process of transforming unpolarized light waves to polarized light waves is called the polarisation of light.

### 4.Define Diffraction Grating.

An arrangement which consists of a large number of parallel slits of the same width and separated by equal opaque spaces is known as diffraction grating.

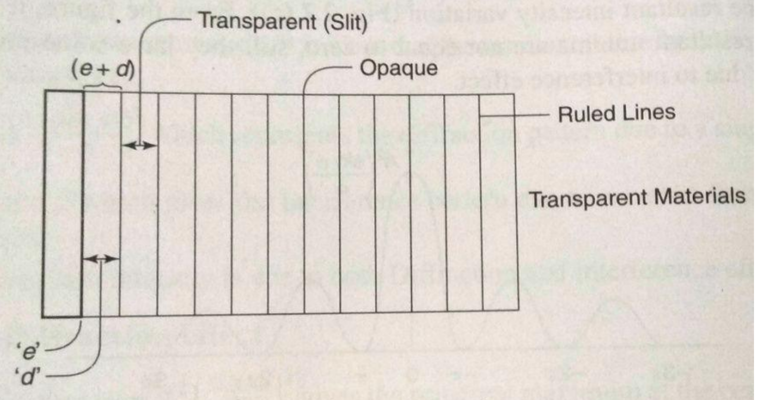


Figure 2.8 Diffraction grating

### 5. Define Resolving Power of Grating.

The ability to separate spectral lines which have nearly the same wave length is called resolving power.

$$\frac{\lambda}{d\lambda} = \frac{N(e+d)\sin\theta}{\lambda}$$

## UNIT – II CRYSTALLOGRAPHY & X-RAY DIFFRACTION

### 1) **Define lattice parameters**?

The lattice parameters are the quantities specifying a unit cell or the unit of the periodicity of the atomic arrangement. The lattice parameters (constants) are composed of "a, b, c," lengths of the unit cell in three dimensions, and "α, β, γ," their mutual angles.

### 3) Define unit cell?

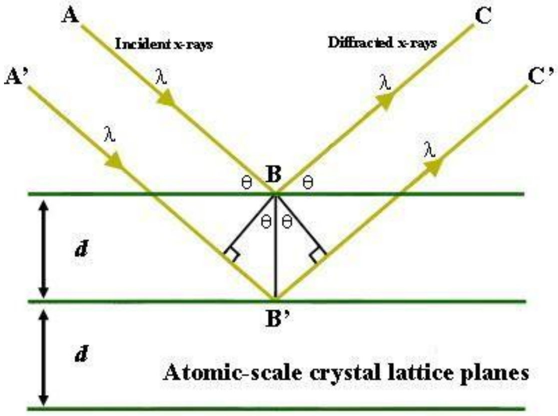
A unit cell is the smallest portion of a crystal lattice that shows the three-dimensional pattern of the entire crystal. A crystal can be thought of as the same unit cell repeated over and over in three dimensions.

### 4) Define Bragg's condition for X-ray diffraction.

The conditions for a sharp peak in the intensity of the scattered radiations are as follows: The x-rays should be reflected by the ions in any one of the planes. The reflected rays that come out from the crystal's successive planes should interfere constructively.

To interfere constructively, the difference in path length between the beams reflecting off two atomic planes must be a whole number (n) of wavelengths (λ), or nλ.

This leads to the Bragg law $2d \sin\theta = n\lambda$

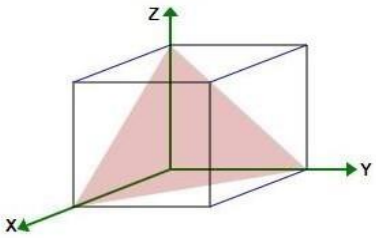


### 5) What are the applications of powder X-ray diffraction method.

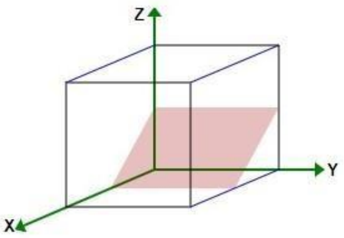
X-ray powder diffraction is most widely used for the identification of unknown crystalline materials (e.g. minerals, inorganic compounds). Determination of unknown solids is critical to studies in geology, environmental science,
material science,
engineering and biology.

### 2) Draw the planes for given millerindices i) (111), ii) (202) in cubic system.

(111) plane



(2 0 2) plane



## UNIT–III DILECTRICS AND MAGNETIC MATERIALS

### 1. Define dielectric polarization?

When an electric field is applied to a capacitor, the dielectric material (or electric insulator) becomes polarized, such that the negative charges in the material orient themselves toward the positive electrode and the positive charges shift toward the negative electrode

### 2. Define dielectric polarizability?

When an external electric field is applied to a dielectric material this material becomes polarized, which means that acquires a dipole moment. This property of dielectrics is known as polarizability. (or)

Dielectric polarizability defined as the ratio of average dipole moment to the electric field applied.

$$\alpha = \frac{\overline{\mu}}{E}$$

### 3. Define magnetic susceptibility and magnetization?

**Magnetic susceptibility ($\chi$) :-**

The magnetic susceptibility is defined as the ratio of the magnetization(M) produced in a sample to the magnetic field strength (H).

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

**Magnetization:-** Magnetization is defined as the magnetic moment per unit volume of a material.

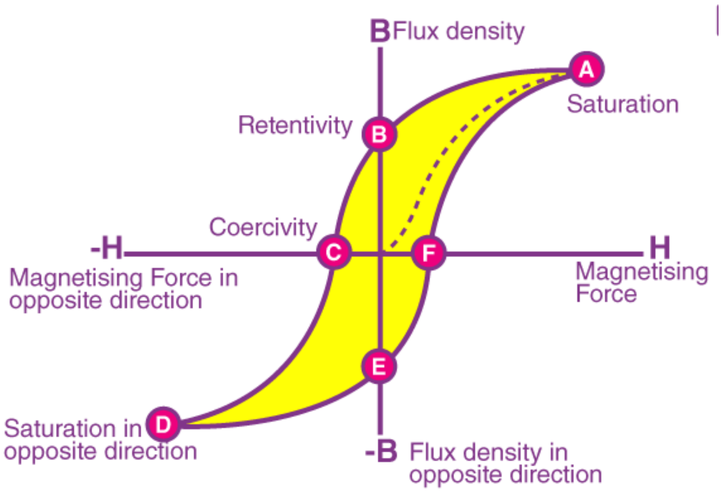
### 4. What is Bohr magnetron?

Bohr magneton ($\mu_B$) is *a physical constant value* and it is *the magnitude of the magnetic dipole moment of an electron orbiting an atom with this angular* momentum.

$$\text{Bohr magneton}(\mu_B) = \frac{\text{eh}}{4\pi m} = 9.27\ X\ 10^{-24}\ Am^2$$

### 5. What is hysteresis or B-H curve?

The meaning of hysteresis is “lagging”. Hysteresis is characterized as a lag of magnetic flux density (B) behind the magnetic field strength (H). All ferromagnetic materials exhibit the phenomena of hysteresis.



# UNIT–IV QUANTUM MECHANICS & FREE ELECTRON THEORY

## 1. What are matter waves?

All moving particles have dual nature ( particle and wave) and moves through space as a wave. The matter wave is also called as de Broglie wave. The matter-wave describes the relationship between momentum and wavelength. The wavelength is inversely proportional to the momentum (mass and velocity) of the particle and it is given by

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

Where h is Plank's constant and P is momentum of the particle

## 2. Mention any two properties of matter waves?

**Since** $\lambda = \frac{h}{mv} = \frac{h}{p}$

- The lighter the particle, the greater the wavelength associated with it.
- Lesser the velocity of the particle , longer the wavelength.
- When v = 0, $\lambda = \infty$, if $v = \infty$, $\lambda = 0$ this shows that matter waves are generated by the motion of particles.
- Matter waves are independent of charge of the particle.
- Matter waves are not electromagnetic waves.
- Matter waves are pilot waves guiding the particles.
- While the position of the particle is confined to a location at any time, the matter wave associated with it has some spread as it is a wave.

## 3. What is drift velocity?

The average velocity attained by the charged particles (eg. Electrons) in a material due to the application of an eternal electric field.

$$V_d = \frac{eE}{m}$$

Where r = mean collision time

e =charge of an electron

E= electric field

$V_d$= drift velocity The S.I unit of drift velocity is - **m/s**

## 4. Define mean free path.

The average distance over which a moving particle (such as an atom) travels before collosion is known as mean free path (λ) and is given by

$$= (\,rms\ velocity\ X\ mean\ collision\ time) = \bar{c}\tau$$

$\bar{c}$= rms velocity

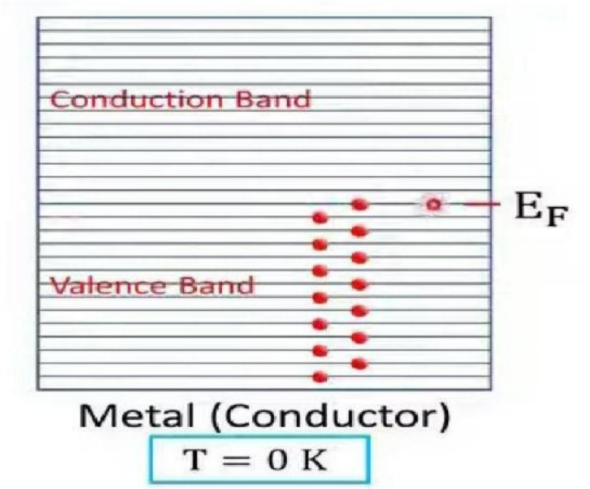
= mean collision time

**5. What is Fermi energy level?**

The highest energy level that an electron can occupy at the absolute zero temperature is known as the Fermi energy level ($E_F$).

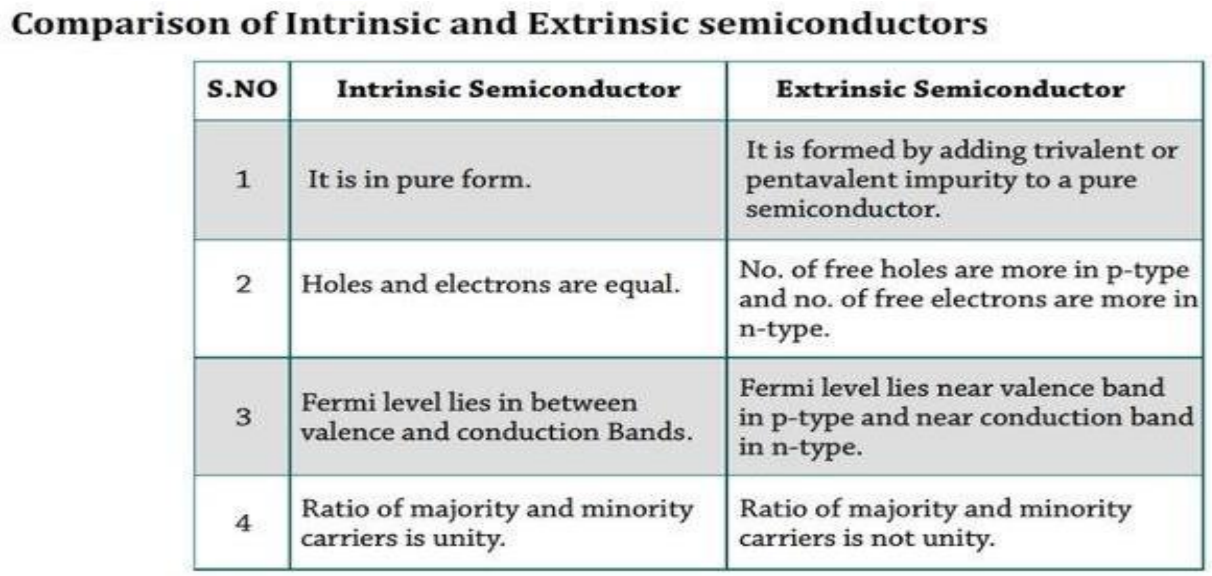
(or)

The energy level which separates the both filled and unfilled energy levels at T=0 K is called Fermi energy level ($E_F$).



# UNIT – V SEMICONDUCTORS

## 1. Distinguish between Intrinsic and Extrinsic semiconductor.



**Comparison of Intrinsic and Extrinsic semiconductors**

| S.NO | Intrinsic Semiconductor | Extrinsic Semiconductor |
|---|---|---|
| 1 | It is in pure form. | It is formed by adding trivalent or pentavalent impurity to a pure semiconductor. |
| 2 | Holes and electrons are equal. | No. of free holes are more in p-type and no. of free electrons are more in n-type. |
| 3 | Fermi level lies in between valence and conduction Bands. | Fermi level lies near valence band in p-type and near conduction band in n-type. |
| 4 | Ratio of majority and minority carriers is unity. | Ratio of majority and minority carriers is not unity. |

## 2. What is the effect the temperature on Fermi energy level in Extrinsic semiconductor.

With increase in temperature of extrinsic semiconductor, minority charge carriers increase because of bond breakage and minority charge carriers may become almost equal with majority charge carriers. Thus, extrinsic semiconductor behaves almost as an intrinsic semiconductor with increase in temperature.

## 3. Define Hall effect.

The Hall effect is the production of a potential difference (the Hall voltage) across an electrical conductor that is transverse to an electric current in the conductor and to an applied magnetic field perpendicular to the current.

$$\text{Hall Coefficient } R_H = \frac{1}{ne}$$

## 4. What is Drift and Diffusion in Semiconductors.

- Diffusion current = the movement caused by variation in the carrier concentration. Direction of the diffusion current depends on the slope of the carrier concentration.
- Drift current = the movement caused by electric fields. Direction of the drift current is always in the direction of the electric field.

## 5. What are the applications of Hall effect.

Applications of Hall Effect

- By knowing the sign of $R_H$ , we can know the type of charge carrier as well as semiconductor. If the sign is negative then the charge carriers are electron and it is a n-type semiconductor and vice versa.
- Magnetic field sensing equipment
- For the measurement of direct current, Hall effect Tong Tester is used.
- It is used in phase angle measurement
- Hall effect Sensors and Probes
- Linear or Angular displacement transducers
- For detecting wheel speed and accordingly assist the anti-lock braking system.

# ENGINEERING PHYSICS
# DESCRIPTIVE ANSWERS
## UNIT-I :: WAVE OPTICS
## INTERFERENCE AND DIFFRACTION

### 2(a) State and explain principle of superposition.

**Principle of superposition:**

When two or more waves meet, they interfere and produce a resultant wave whose properties can be calculated by using the principle of superposition

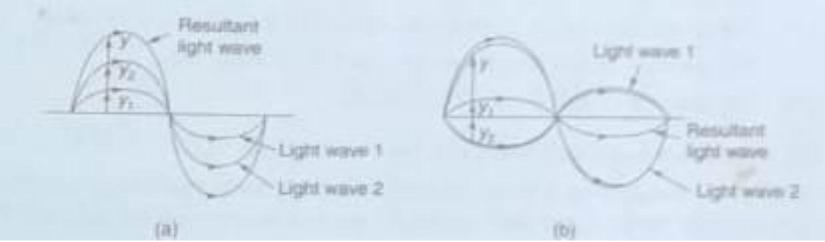


Fig: Superposition of two waves

The principle of superposition states that whenever two or more waves travelling in the same region superpose, the total displacement(y) at any point is equal to the vector sum of their individual displacements($y_2$,$y_3$…..) at that point .i.e,

$$\mathbf{y = y_1 \pm y_2 \pm y_3 + \ldots\ldots}$$

If there only two waves, then the resultant displacement is given by;

$$\mathbf{y = y_1 \pm y_2}$$

**Case1:**

- If the two waves are in phase with each other, they undergo constructive interference producing maximum intensity of light called bright band or fringe.

$$y = y_1 + y_2$$

$$A_{max} = a_1 + a_2 \qquad \text{(since } I \alpha A^2\text{)}$$

$$I_{max} = (a_1^2 + a_2^2)$$

- The condition for constructive interference to occur is

Path difference = $n\lambda$ (or) phase difference $= 2n\pi$

**Case: 2**

- If the two waves are out of phase, then they undergo destructive interference producing zero intensity of light called dark band or fringe.

$$y = y_1 - y_2$$

$$A_{min} = a_1 - a_2$$

$$I_{min} = (a_1^2 - a_2^2)$$

- The condition for destructive interference to occur is

Path difference = $(2n - 1)\frac{h}{2}$ (or) phase difference $=(2n - 1)\pi$

## 2(b) Discuss the theory of interference of light due to thin films by reflection with suitable ray diagram.

## Interference in uniform thin films by reflection of light:

**Plane parallel thin film:**

A transparent thin film of uniform thickness which is bounded by two plane parallel surfaces is known as plane parallel thin film.

**Principle:**

When light is incident on plane parallel thin film, some portion of light gets reflected from the top surface and the reaming portion is transmitted into the film. Again, some portion of the transmitted light is reflected back into the film by the bottom surface and emerges through the top surface. These reflected light waves superimpose with each other, producing interference and forming interference patterns. This is the principle of interference in thin films by reflection.

**Theory:**

- Let us consider a transparent film of uniform thickness’t’ bounded by two parallel surfaces, as shown in fig.
- Let the refractive index of the material be $\mu$.The film is surrounded by a common medium say, air on both sides.
- Let a monochromatic light ray AB is incident on the top surface at an angle ***‘i’***.

- The ray AB is partly reflected along BC and is partly transmitted into the film along CD makes an angle ***r*** with the normal CH and meets the lower surface.
- At C, it is again partly reflected back into the film along CD
- The reflected ray CD refracts at the outer surface and emerges out along DF which is parallel to the ray BE.
- The waves travelling along directions BE and BCDF are obtained from the incident wave AB.

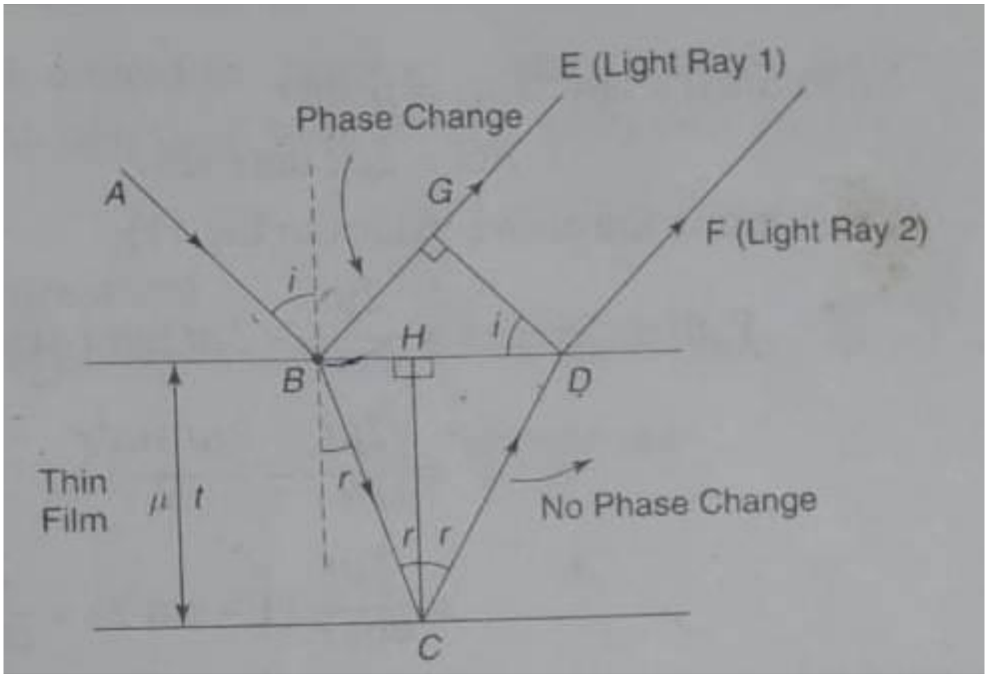


Fig: Interference in uniform thin films by reflection of light

- Therefore, these two light rays superimpose and produce interference patterns. Condition of interference depends on the optical path difference between the rays 1 and 2.
- Let us now calculate the optical path difference between the reflected ray BE (ray1) and the refracted ray BCDF (ray 2).
- A normal DG is drawn on line BE. From points G and D onwards the rays GE and DF equal distances.
- The reflected ray BE travels in air while the refracted ray (BC+CD) travels in the film of refractive index ***μ*.**
- The Optical path difference (OPD**)** between the rays (1) and (2) is

Total path difference (T.P.D) = μ (BCD) in film - μ BG in air

$$= \mu\,(BC+CD) - \mu_{air}\,(BG) \qquad [\text{Since } \mu_{air} = 1]$$

$$= \mu\,(BC+CD) - BG \qquad ---\rightarrow(1)$$

**b) Derive the condition for bright and dark rings interference in the case of reflected system.**

**Step 1: Calculation of geometrical path BFD in film**

Let us calculate path BC+ CD in film,

From fig; ΔBCH, $\text{Cos r} = \frac{HC}{BC}$

$$BC = \frac{t}{\text{Cos r}} \quad --------\rightarrow (2)$$

Similarly;

From ΔDCH, $\text{Cos r} = \frac{HC}{CD}$

$$CD = \frac{t}{\text{Cos r}} \quad -----\rightarrow (3)$$

$$\therefore BC+CD = \frac{t}{\text{Cos r}} + \frac{t}{\text{Cos r}}$$

$$\therefore \quad BCD = BC+CD = \frac{2t}{\text{Cos r}} \quad ------\rightarrow (4)$$

**Step 2: Calculation of geometrical path BH in air**

To calculate BG air, first BD which is equal to (BH+HD) has to be obtained.

From ΔBHC; $\tan r = \frac{BH}{CH} = \frac{BH}{t}$

$$BH = t.\tan r \quad -----\rightarrow (5)$$

Similarly;

FromΔHCD; $\tan r = \frac{HD}{HC} = \frac{HD}{t}$

$$HD = t.\tan r \quad ------\rightarrow (6)$$

$$\therefore BD = BH+HD = t.\tan r + t.\tan r$$

$$= 2t \tan r \quad ------\rightarrow (7)$$

From ΔBGD; $\text{Sin i} = \frac{BG}{BD}$

$$BG = BD \text{ Sin i}$$

$$= 2t \tan r \text{ Sini} \quad ----\rightarrow (8)$$

From Snell's law $\mu = \frac{\text{Sini}}{\text{Sinr}}$

$$\text{Sin i} = \mu \text{ Sin r}$$

From equation (8)

$$BG = 2t \tan r\ \mu \text{ Sin r}$$

$$= 2\mu t \tan r.\ \text{Sin r}$$

$$= 2\mu t\ \frac{\text{Sin r}}{\text{Cos r}}.\ \text{Sin r}$$

$$\text{Total path difference} = 2\mu t\, \frac{\mathrm{Sin}^2 \mathrm{r}}{\mathrm{Cos\,r}} \quad - - - - - - - \rightarrow (9)$$

Substituting equation (4) and equation (9) in equation (1); we have,

$$= \frac{2\mu t}{\mathrm{Cos\,r}} - 2\mu t\, \frac{\mathrm{Sin}^2 \mathrm{r}}{\mathrm{Cos\,r}} - - - - - - \rightarrow (10)$$

$$= \frac{2\mu t}{\mathrm{Cos\,r}} (1 - \mathrm{Sin}^2 \mathrm{r})$$

$$= \frac{2\mu t}{\mathrm{Cos\,r}}\ \mathrm{Cos}^2 \mathrm{r}$$

$$\text{Total path difference} = 2\mu t\ \mathrm{Cos\ r} - - - - \rightarrow (11)$$

At the point B, reflection occurs from the upper surface of the thin film (denser medium) Light ray 1 under goes an additional phase change of $\pi$ or an additional path difference of $\frac{h}{2}$

$$\boxed{\text{Total path difference} = 2\mu t\ \mathrm{Cos\ r} + \frac{h}{2}}$$

**Case 1: Condition for bright band (or) maximum (or) constructive interference:**

When the path difference is equal to integral multiples of $\lambda$ then the ray (1) and (2) meet in phase and undergo constructive interference.

The condition for bright fringe is

$$2\mu t\ \mathrm{Cos\ r} + \frac{h}{2} = \mathrm{n}\lambda$$

$$2\mu t\ \mathrm{Cos\ r} = \mathrm{n}\lambda - \frac{h}{2}$$

$$2\mu t\ \mathrm{Cos\ r} = (2\mathrm{n}-1)\,\frac{h}{2} \quad \text{where n= 0, 1, 2, 3…}$$

This is the condition for maxima. The film appears bright under this condition.

**Case2: Condition for dark band (or) minimum (or) Destructive interference:**

When the path difference is equal to half integral multiples of $\lambda$ then the ray (1) and (2) meet out phase and undergo destructive interference.

The condition for dark fringe is

$$2\mu t\ \mathrm{Cos\ r} + \frac{h}{2} = (2\mathrm{n} + 1)\,\frac{h}{2}$$

$$2\mu t\ \mathrm{Cos\ r} = 2\mathrm{n}\frac{h}{2} + \frac{h}{2} - \frac{h}{2}$$

$$2\mu t\ \mathrm{Cos\ r} = \mathrm{n}\lambda \quad \text{where n=0, 1, 2, 3…}$$

This is the condition for minima. The film appears dark under this condition.

## 3a) Describe the formation of Newton's ring with necessary theory with relevant diagram and derive the expressions for dark and bright fringes.

## Newton's rings:

Newton's rings are one of the best examples for the interference in a no uniform thin film.

**Definition:**

If a Plano-convex lens with its convex surface is placed on a plane glass plate, then air film is formed between the lower surface of the Plano-convex lens and the upper surface of the glass plate. The thickness of the air film is zero at point of contact and gradually increases from the point of contact outer wards.

If a monochromatic light is allowed to fall normally on this air film, a system of alternate bright and dark circular rings is formed in the air film. These rings were discovered by Newton and are called Newton's rings.

**Principle:**

Newton's rings are formed due to interference between the light rays reflected from the top and bottom surfaces of air film between the glass plate and the Plano-convex lens.

**Experimental Arrangement:**

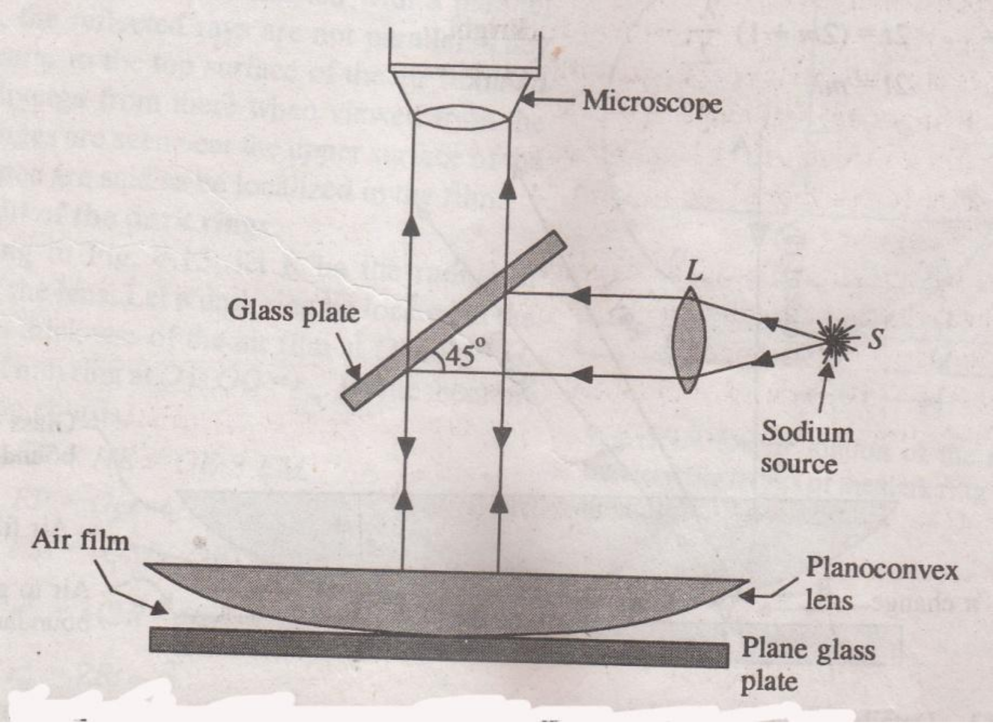


Figure: Experimental arrangement of Newton's rings.

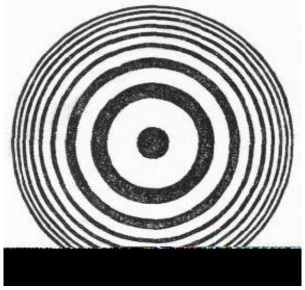


Fig: The experimental arrangement for producing Newton rings.

1. The experimental arrangement for producing Newton rings is as shown in fig (1).
2. Keep the convex surface of the Plano-convex lens over the plane glass plate and arrange glass plate G at an angle of $45^0$ over the base set.
3. Switch on the monochromatic light source ‘S’ (Sodium vapor lamp) and it is focus on the Double convex lens (L). This sends parallel beam of light. This beam of light falls on the glass plate B at $45^0$.
4. The glass plate ‘G’ reflects a part of light towards the air film enclosed by the Plano-convex lens and the plane glass plate.
5. A part of the light is reflected by the curved surface of the Plano-convex lens and a part is transmitted which is reflected back from the plane surface of the plane glass plate.
6. These reflected light rays superimpose with each other producing interference and forming interference and forming interference patterns in the form of bright dark circular rings.
7. These rings are seen with a microscope (M) focused on the air film.

**Theory of Newton’s rings:**

To find the diameters of dark and bight rings, let ‘L’ be a Plano convex lens placed on a glass plate P.

The convex surface of the lens is the part of spherical surface with centre at C as shown in fig. Let R be the radius of curvature and r be the radius of Newton’s ring corresponding to the thin film thickness‘t’

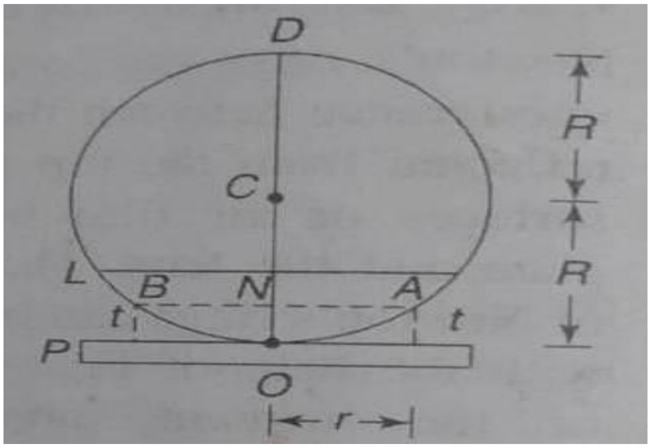


Fig: Theory of Newton’s rings

From the property of circle,

$$NA \times NB = NO \times ND$$

Substituting the values,

$$r \times r = t \times (2r - t)$$

$$r^2 = 2Rt - t^2$$

As t is small, $t^2$ will be negligible

$$r^2 = 2Rt$$

$$t = \frac{r^2}{2R}$$

**(1) <u>Calculation of Diameters of the bright rings:</u>**

Let us now suppose that a bright ring be located at the point Q.

Therefore, the radius of the nth bright ring will be given by

$$r_n^2 = 2Rt$$

We know that, the condition of the bright band is $2t = (2n-1)\frac{h}{2}$

From above equations we have,

$$r_n^2 = (2n-1)\frac{h}{2} R = (n - \frac{1}{2})\lambda R$$

$$r_n = \sqrt{(n - \frac{1}{2})\lambda R} \quad \rightarrow (7)$$

This is the condition for radii of the bright rings.

The diameter of the bright ring is therefore given by

$$\frac{D_n^2}{4} = (n - \frac{1}{2})\lambda R \qquad [\text{Since, } r_n = \frac{D_n}{2}]$$

$$\frac{D_n^2}{4} = (\frac{2n-1}{2})\lambda R$$

$$D_n = \sqrt{(2n-1)2\lambda R} \quad \rightarrow (8)$$

∴ The diameters of the bright rings is directly proportional to (i) $\sqrt{2n-1}$

(ii) $\sqrt{\lambda}$

(iii) $\sqrt{R}$

**(2) <u>Calculation of diameter of the dark rings:</u>**

Thus, the radius of the nth dark ring will be given by,

$$r_n^2 = 2Rt$$

We know that, the condition of the dark ring is $2t = n\lambda$

From the above equations we have,

$$r_n^2 = n\lambda R$$
$$r_n = \sqrt{n\lambda R}$$

This is the condition for radii of the dark rings.

The diameter of the dark ring is therefore given by

$$\frac{D_n^2}{4} = n\lambda R \qquad \left[\text{Since, } r_n = \frac{D_n}{2}\right]$$

$$D_n = \sqrt{4n\lambda R}$$
$$D_n = 2\sqrt{n\lambda R} \rightarrow (9)$$

∴ The radii (diameters) of the dark rings is directly proportional to (i) $\sqrt{n(\text{ natural nuber})}$
(ii) $\sqrt{\lambda}$

## 3 b) Explain how the wavelength of light sources is determined by forming Newton's ring.

### Determination of wavelength of monochromatic light source.

Let 'R' be the radius of curvature of a Plano-convex lens, $\lambda$ be the wavelength of monochromatic light source.

Let $D_m$ and $D_n$ are the diameters of mth and nth dark rings respectively.

Then,
$$D_m^2 = 4m\lambda R,$$
$$D_n^2 = 4n\lambda R\,,$$

And
$$D_n^2 - D_m^2 = 4n\lambda R - 4m\lambda R$$
$$D_n^2 - D_m^2 = 4(n-m)\lambda R$$
$$\lambda = \frac{D_n^2 - D_m^2}{4(n-m)R}$$

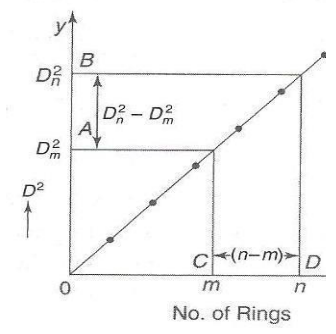


Fig: A graph between ($D^2$) and number of rings.

Experiment

Experimental arrangements after forming the Newton's rings, the microscope is adjusted so that the center of the cross wire is adjusted at the central dark spot of the ring pattern. By counting the number of the rings, the microscope is moved the extreme left of the pattern and the cross wire is adjusted tangentially in the middle of the $n^{th}$ ($21^{st}$) dark ring. The reading of the microscope is noted. Now the microscope is moved to the right and its reading are noted successively at $(n-3)^{th}$ $is(18^{th})$,$(n-6)^{th}$ $is(15^{th})$ ….rings, etc., with a difference of three rings up to the central dark spot. Again crossing the central dark spot in the same direction, the readings corresponding to

$(n-6)^{th} is (15^{th}), (n-3)^{th} is (18^{th})$ and nth $(21^{st})$ rings are noted. The difference between the left and right reading gives the diameter of the particular ring.

A graph is drawn with the number of rings on the x-axis and the square of the diameter of the ring ($D^2$) on the y-axis. The graph is straight line passing through the origin. Form the graph the values of $D_m^2$ and $D_n^2$ corresponding to $n^{th}$ and $m^{th}$ rings are found. From the graph, the slope is calculated.

From graph,

$$\frac{D_n^2 - D_m^2}{(n-m)} = \frac{AB}{CD}$$

The radius of curvature 'R' of the Plano-convex lens can be obtained with the help of a spherometer. Substituting these values in the formula, the wavelength of the light source can be known.

## 4(a) Distinguish between Fraunhofer and Fresnel's diffraction.

**Difference between Fresnel's diffraction and Fraunhoffer diffraction:**

| Fresnel's Diffraction | Fraunhoffer diffraction |
|---|---|
| 1.For diffraction to occur,the light source and screen are at finite distance from the obstacle. | 1.For diffraction to occur,the light source and screen are at infinite distance from the obstacle. |
| 2.No lenses are necessary to study the diffractiondiffraction. | 2. Lenses are necessary to study the diffractiondiffraction. |
| 3.Study of diffraction is complicated. | 3.Study of diffraction is easy. |
| 4.Either a point source or an illuminated narrow slit is used. | 4.Extended source at infinite distance is used.. |
| 5.Diffraction can be studied only in the direction of propagation of light. | 5. Diffraction can be studied in any direction of propagation of light. |
| 6.In this case the incident wavefronts are either spherical (or) spherical. | 6.In this case, incident wavefronts are plane. |

## 4b) Compare Interference and Diffraction

| Interference | Diffraction |
|---|---|
| 1.Superposition is due to two separate wavefronts originating from two cohenent sources. | 1.Superposition is due to secondary wavelets originating from different parts of the same wavefront. |

| | |
|---|---|
| 2.Interfernce bands are of equal widths. | 2.Diffractionbands decrease in their width as the order increases. |
| 3.All the bright fringes have same intensity. | 3.The intensity of bright fringes usually decreases with increase of order. |
| 4.All the dark fringes have zero intensity. | 4.The intensity of dark fringes is not zero. |

## 5 In the study of Fraunhofer diffraction due to single slit how the diffraction fringes formed. Derive the condition for bright and dark fringes .

### Fraunhoffer diffraction at Single Slit:

- Consider a slit AB of width ‘e’ perpendicular to the plane of the paper. Let a plane wave front of monochromatic light of wavelength ‘λ’ incident at this slit.
- At slit, each and every point is able to generate secondary wavelets. These wavelets are focused through the lens ‘L’.
- The wavelets travelling normal to the lens are brought to focus at at $P_0$ and the wavelets travel with an angle θ are focused at $P_1$ .Now the intensity at $P_O$ is central maximum with bright fringe ,and intensity at $P_1$ is either maxima or minima depends upon the angle ‘θ’.

- To find the intensity at $P_1$, first we should calculate the phase difference at point $P_1$. For this, AC is perpendicular to BC.

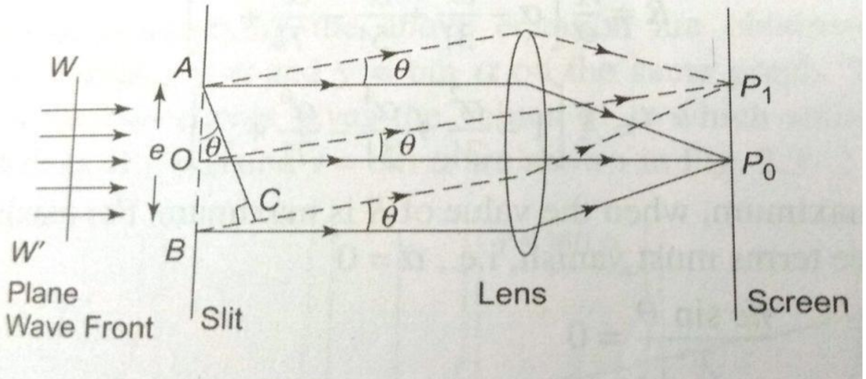


Figure 2.2 Fraunhofer diffraction—single slit

Path difference between the wavelets along $P_o$ & $P_1$ is given by,

$$\delta = BC$$

From ΔACB, $\sin\theta = \frac{BC}{AB}$

$$BC = AB \sin\theta$$

$$BC = e \sin\theta$$

$$\therefore\ \delta = BC = e\sin\theta$$

But the phase difference $\phi = \frac{2\pi}{\lambda}$ (Path difference $\delta$ )

$$\therefore\ \phi = \frac{2\pi}{\lambda}\ (e\sin\theta) \text{ ---------------- > (1)}$$

Let the slit ‘s’ is decided into ‘n’ number of small slits of each with amplitude ‘a’, then,

Phase difference at each slit (d) $= \frac{Total\ phase\ difference}{number\ of\ slits}$

$$d = \frac{\phi}{n} = \frac{2\pi}{n\lambda}\ (e\sin\theta) \text{ ------------- > (2)}$$

After diffraction, the resulting amplitude R can be obtained by using vector addition method with each of amplitude ‘a’.

$$R = \frac{a\,Sin\,(\frac{nd}{2})}{Sin\,d/2} \qquad \text{---------------- > (3)}$$

Substitute eq(2) in eq(3) we get,

$$R= \frac{a\,Sin\,(n\{\frac{2\pi eSin\theta}{n\lambda}\})/2 \quad {}_{2\pi}}{Sin\,\{\frac{eSin\theta}{n\lambda}/2\}}$$

$$R= \frac{a\,Sin\,(\frac{\pi eSin\theta}{\lambda}) \quad {}_{\pi}}{Sin\,(\frac{eSin\theta}{\lambda})/n}$$

Put $\frac{\pi}{\lambda}$ esin$\theta$ =$\alpha$ , then

$$R=\frac{aSin\alpha}{Sin\,(\frac{\alpha}{n})}$$

Since $\frac{\alpha}{n}$ is small, Sin($\alpha$/n) ≈ $\alpha$/n

$$R= a\,\frac{Sin\alpha}{(\alpha/n)}$$

$$R= n\,a\,\frac{Sin\alpha}{\alpha}$$

$$R= A\,\frac{Sin\alpha}{\alpha} \qquad \text{---------------- > (4)}$$

Intensity at $P_1$ is given by,

$$I = R^2 = (A\,\frac{Sin\alpha}{\alpha})^2 = A^2\,\frac{Sin^2\alpha}{\alpha^2} \qquad \text{---------------- > (5)}$$

**Condition for dark and bright fringes**

**(1) Principal maximum :**

From eq(4) The resultant amplitude R can be written in ascending power of $\alpha$ as,

$$R = \frac{A}{\alpha}[\alpha-\frac{\alpha3}{3!}+\frac{\alpha5}{5!}-\frac{\alpha7}{7!}\text{---------} ]$$

$$= \frac{A\alpha}{\alpha}[\alpha-\frac{\alpha2}{3!}+\frac{\alpha4}{5!}-\frac{\alpha6}{7!}\text{---------} ]$$

In above equation for 'R' maximum, the negative terms and higher order terms vanishes i.e, $\alpha=0$.

But $\frac{\pi}{\lambda}e\sin\theta=\alpha=0$
$\therefore \sin\theta=0 \Rightarrow \theta=0°$
Then $R = A \Rightarrow I^2 = A^2=R^2$
At $\theta=0°$, the maximum intensity is formed at $P_o$ known as principal maximum.

**2.Minimum intensity position :**
From eq(5) for '$I_{\text{minimum}}$, $\sin\alpha=0$

$\therefore \alpha = \pm m\pi$ , m= 0,1,2,3,---------

For m=0, $\alpha=0$ which gives principal maxima and for $\alpha = \pm\pi, \pm2\pi, \pm3\pi$,------------ minimum intensity is observed at $P_1$,

$\therefore \alpha = \pm m\pi$

$\frac{\pi}{\lambda}e\sin\theta = \pm m\pi$

$e\sin\theta = \pm m\lambda$

The above condition is for minimum intensity position.

**3. Secondary Maxima:**
Between two secondary minima, the secondary maxima can be obtained by differentiating eq(4) w.r.to $\alpha$ and equating to zero , we get

$\frac{dI}{d\alpha}=0 \Rightarrow \frac{dI}{d\alpha}=\frac{d}{d\alpha}\left[A^2\left(\frac{Sin\alpha}{\alpha}\right)^2\right]=0$

$A^2\left(\frac{2Sin\alpha}{\alpha}\right)\left[\frac{\alpha Cos\alpha - Sin\alpha}{\alpha^2}\right]=0$

$A^2\left(\frac{2Sin\alpha}{\alpha}\right) \neq 0$, then $\frac{\alpha Cos\alpha - Sin\alpha}{\alpha^2}=0$

$\alpha \cos\alpha - \sin\alpha = 0$

$\alpha \cos\alpha = \sin\alpha$

$\alpha = \tan\alpha$

which is interms $y=\alpha$ and $y=\tan\alpha$

Now draw graphs $y=\alpha$ and $y=\tan\alpha$

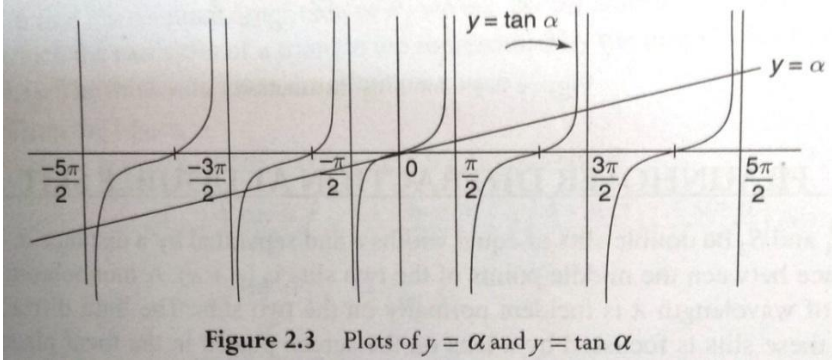


**Figure 2.3** Plots of $y = \alpha$ and $y = \tan \alpha$

From graph, it is clear that y=α line touches the y=Tanα curves at $\alpha = 0, \pm\frac{3\pi}{2}, \pm\frac{5\pi}{2}, \pm\frac{7\pi}{2}$ ---- --.

So, at these α values, secondary maxima can be obtained.We already know that α = 0 is principal maxima. So,

1. $\alpha = \pm\frac{3\pi}{2}$, $I = A^2\left[\frac{Sin(\frac{3\pi}{2})}{(\frac{3\pi}{2})}\right]^2 = \frac{A^2}{\frac{9\pi^2}{4}} = \frac{4A^2}{9\pi^2}$ ---→ first secondary maxima

2 . $\alpha = \pm\frac{5\pi}{2}$, $I = A^2\left[\frac{Sin(\frac{25\pi}{2})}{(\frac{5\pi}{2})}\right]^2 = \frac{A^2}{\frac{25\pi^2}{4}} = \frac{4A^2}{25}$ ---→ second secondary maxima

**4. Intensity distribution :**

The intensity distribution of diffraction intensity depends on α values, i.e, α = 0, principal maxima.

$\alpha = 0, \pm\frac{3\pi}{2}, \pm\frac{5\pi}{2}, \pm\frac{7\pi}{2}$ ------- secondary maxima.

For α = ±π,±2π,±3π ,----------- minimum distribution of intensity.

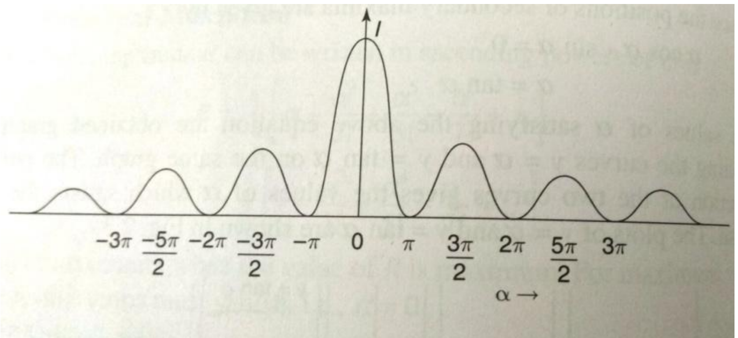


**Figure 2.4** Intensity distribution

**6(a) Describe Fraunhofer diffraction due to double slit and derive the conditions for principal maxima, secondary maxima and minima.**

**b) A plane transmission grating having 4250 lines per cm is illuminated with sodium light normally. In the second order spectrum, the spectral lines are deviated by 30$^0$. What**

**is the wavelength of the spectral line?**

## Fraunhoffer diffraction at double slit:

- Let S1 and S2 be double slits of equal widths ‘e’ and separated by a distance‘d’. The distance between the middle points of the two slits is (e+d).
- A monochromatic light of wavelength of $\lambda$ is incident normally on the two slits .The light diffracted from these slits is focused by a lens on the screen placed in the focal plane of the lens.

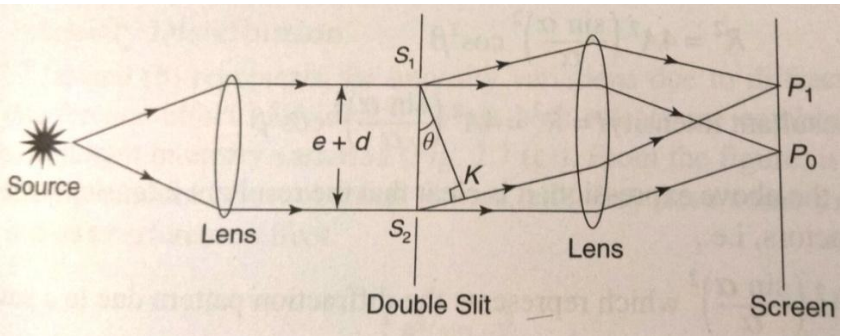


**Figure 2.5** Fraunhofer diffraction—double slit

- The diffraction at two slits is the combination of diffraction as well as interference.i.e, the pattern on the screen is the diffraction pattern due to a single slit on which a system of interference fringes is superimposed.
- When a plane wave front is incident normally on two slits, the secondary wavelets from the slits travels uniformly in all directions. The wavelets travelling in the direction of incident light comes to a focus at $P_o$ while the wavelets travelling in a direction making an angle θ, come to focus at $P_1$ (see figure 2.5).

From the study of diffraction due to single slit, the resultant amplitude = $\frac{ASin\alpha}{\alpha}$ where $\alpha = \frac{\pi e Sin\theta}{}$.

Since we use double slit,from each slit we get a wavelet of amplitude $\frac{ASin\alpha}{\alpha}$ in a direction θ.These two wavelets interfere and meet at a point $P_1$ on the screen .To calculate the path difference between the wavelets,let us draw a normal $S_1K$ to the wavelet through $S_2$ .

Path difference = $S_2$ K

= (e+d)Sinθ

Phase difference $\delta = \frac{2\pi}{}(e+d)Sin\theta$

To find the resultant amplitude at $P_1$ we use vector addition method (see fig.2.6) in which the two sides of a triangle are represented by the amplitudes through $S_1$ and $S_2$.The third side gives the resultant amplitude.

From figure,

$$(OH)^2 = (OG)^2+(GH)^2+2(OG)(GH)\ Cos\delta$$

$$R^2 = \left(\frac{ASin\alpha}{\alpha}\right)^2 + \left(\frac{ASin\alpha}{\alpha}\right)^2 + 2\left(\frac{ASin\alpha}{\alpha}\right)\left(\frac{ASin\alpha}{\alpha}\right) Cos\delta$$

$$= A^2\, \frac{Sin^2\alpha}{\alpha^2}[2+2\cos\delta]$$

$$= 2\left(\frac{ASin\alpha}{\alpha}\right)^2 (1+ Cos\delta)$$

$$= 2\left(\frac{ASin\alpha}{\alpha}\right)^2 (1+2\, Cos^2 (\delta/2) -1)$$

$$R^2 = 4A^2 \left(\frac{Sin\alpha}{\alpha}\right)^2 Cos^2\left[\frac{\pi(e+d)Sin\theta}{}\right]$$

$$\text{Let } \beta = \frac{\pi(e+d)Sin\theta}{}$$

$$R^2 = 4A^2 \left(\frac{Sin\alpha}{\alpha}\right)^2 Cos^2\beta$$

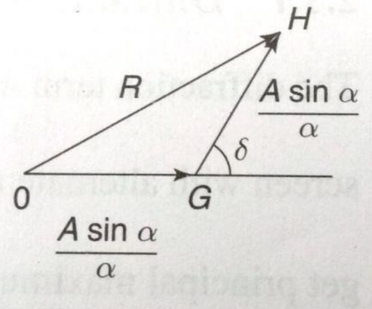


**Figure 2.6** Vector addition method

The resultant intensity I = $R^2 = 4A^2 \left(\frac{Sin\alpha}{\alpha}\right)^2 Cos^2\beta$

From the above expression it is clear that the resultant intensity is the product of two factors i.e,

1. $4A^2 \left(\frac{Sin\alpha}{\alpha}\right)^2$ which represents the diffraction pattern due to a single slit.
2. $Cos^2\beta$ which gives the interference pattern due to wavelets from double slits.

The resultant intensity is due to both diffraction and interference effects.

## 1. Diifraction effect :

The diffraction term $4A^2 \left(\frac{Sin\alpha}{\alpha}\right)^2$ gives the principal maximum at the centre of the screen with alternate minima and secondary maxima of decreasing intensity.

We get principal maximum for θ=0.We get minima for Sinα=0.

$\alpha = \pm m\pi$ ,    where m=1,2,3,4---

$$\frac{\pi e Sin\theta}{} = \pm m\pi$$

$$eSin\theta = \pm m\lambda$$

The positions of secondary maxima occurs for $\alpha = \frac{\pm 3\pi}{2}, \frac{5\pi}{2}, \frac{\pm 7\pi}{2}, ------$

## 2. Interference effect :

The interference term $Cos^2\beta$ gives the equidistant bright and dark fringes.

The maxima will occur for $Cos^2\beta=1$.

$\beta = \pm n\lambda$    where n=0, 1,2,3-------

$$\beta = 0, \pm\pi\ , \pm 2\pi\ , \pm\ \pi\ \text{---------}$$

$$\frac{\pi(e+d)Sin}{} = \pm n\pi$$

$$(e+d)Sin\theta = \pm n\lambda$$

The minima will occur for $Cos^2\beta=0$.

$$\beta = \pm(2n+1)\frac{\pi}{2} \qquad \text{where } n=0,1,2,3,\text{-----}$$

$$(e+d)Sin\theta = \pm(2n+1)\frac{}{2}$$

**Intensity Distribution:**

The figures shown here represents the intensity variations due to diffractions as well as interference effect individually (fig.(2.7 a) and fig.(2.7 b )) . When both effects are combined, then we get the resultant intensity variations(fig.2.7(c). From the figure, it is clear that the resultant minima are not equal to zero still they have some minimum intensity due to interference effect.

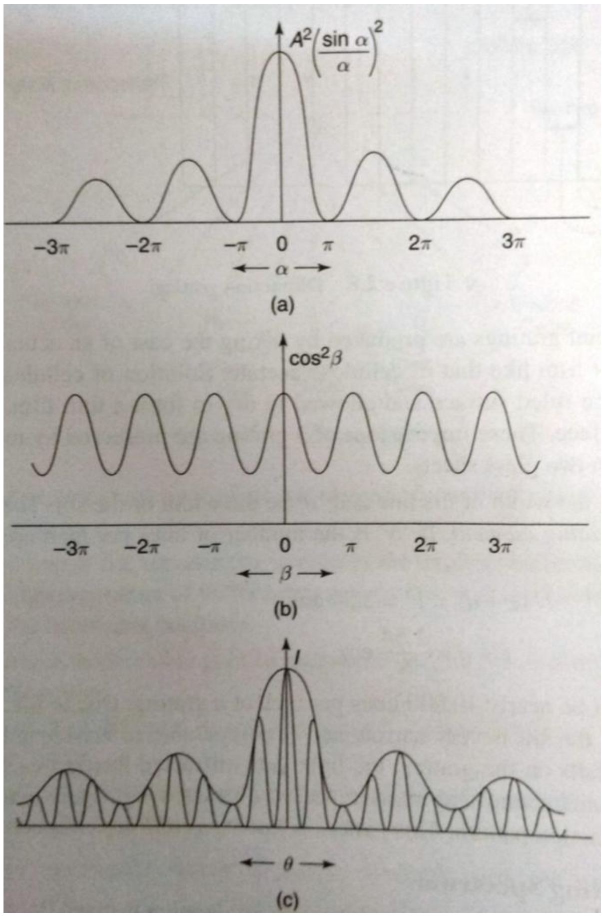


Figure 2.7: (a) Diffraction effect (b) Interference effect (c) Resultant Intensity

**b) A plane transmission grating having 4250 lines per cm is illuminated with sodium light normally. In the second order spectrum, the spectral lines are deviated by $30^0$. What is the wavelength of the spectral line?**

Given data Number of lines in the grating N=4250 lines/cm

Angle of diffraction $\theta = 30^0$
Order of spectrum n=2

Solution: $(e+d)\sin\theta = n\lambda$

Each slit width (e+d)= $\frac{1}{N} = \frac{1}{4250} = 2.353\times10^{-4}\,cm$

$$2.353\times10^{-4}\times\sin 30^{0} = 2\lambda$$

$$2.353\times10^{-4}\times 0.5 = 2\lambda$$

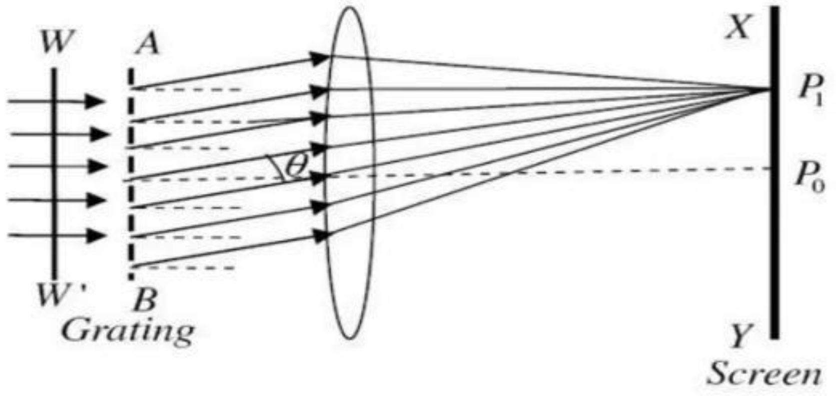
$$1.1765\times10^{-4} = 2\lambda$$

$$\lambda = 0.5882\times10^{-4}\,cm$$

$$\lambda = 5882\,A^{0}$$

## 7(a) Describe the Fraunhofer diffraction Due to N-slits.

An arrangement which consists of a large number of parallel slits of the same width and separated by equal opaque space is knowns as diffraction grating (N-slits)



The intensity at point $p_1$ on the screen due to a Fraunhofer diffraction due to N-sits is given as

$$I = R^2 = 4A^2 \left(\frac{Sin\alpha}{\alpha}\right)^2 \left(\frac{SinN\beta}{Sin\,\beta}\right)^2$$

$$\text{Where} \quad \alpha = \underline{\pi e Sin\theta}$$

$$\beta = \underline{\pi(e+d)Sin\theta}$$

- The factor $\left(a\,\frac{Sin\alpha}{\alpha}\right)$ gives the diffraction effect due to single slit.
- $\left(\frac{SinN\beta}{Sin\,\beta}\right)^2$ represents combined effects of interference and diffraction due to all slits of gration.

**7(b) Define Dispersive power and resolving power of Grating and write their expressions.**

**<u>Dispersive power</u>**

➢ The dispersive power of a diffraction grating is defined as the rate of change of the angle of diffraction with the wavelength of light.

➢It is expressed as dθ/dλ.

➢The angle of diffraction θ for the principal maximum is related to the corresponding wavelength by

➢ (e+d) Sinθ = n λ

Differentiate with respect to λ

$$(e + d)cos\theta \left(\frac{d\theta}{d\lambda}\right) = n$$

$$\frac{d\theta}{d} = \frac{n}{(a+b)cos\theta}$$ dispersive power of grating.

From the above equations the following conclusions can be

- ❖ Dispersive power is directly proportional to the order n .
- ❖ Dispersive power is inversely proportional to the grating element or directly proportional to the number of rulings.
- ❖ Dispersive power is inversely proportional to cos θ, i.e. larger the value of θ higher is the dispersive power.

**Resolving power**

It is defined as the capacity to forms separate diffraction maxima of two wavelengths which are very close to each other

The ability to separate spectral lines which are nearly the same wavelength is called resolving power.

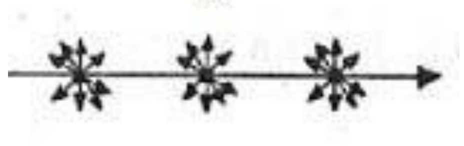
Resolving power= $\frac{\lambda}{d\lambda}$

$$\frac{\lambda}{d\lambda} = N$$

$$\frac{\lambda}{d\lambda} = \frac{(e+d)\ Sin\theta}{\lambda}$$

## 8(a)Mention the representation of the plane polarized light and un polarised light.

**Unpolarized light** : The ordinary light also called as unpolarized light, consists of a very large number of vibrations in all planes with equal probability at right angles to the direction of propagation. Hence the un polarized is represented by a star as shown in fig .

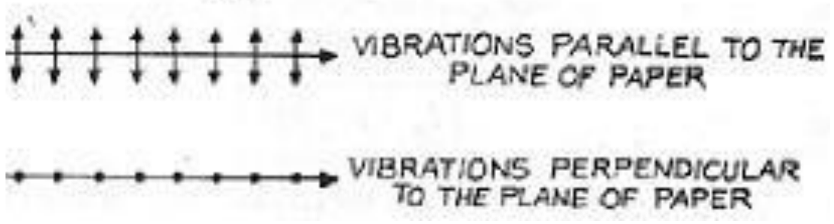


(a)

**Plane polarized light:**

We know that in plane polarized light the vibrations are along a straight line. If the direction of vibration is parallel to the plane of paper, it is represented by a straight line arrow as shown in Fig. 2.

If the direction of vibration is perpendicular to the plane ofthe paper, it is represented by a dot as shown in Fig. 3.

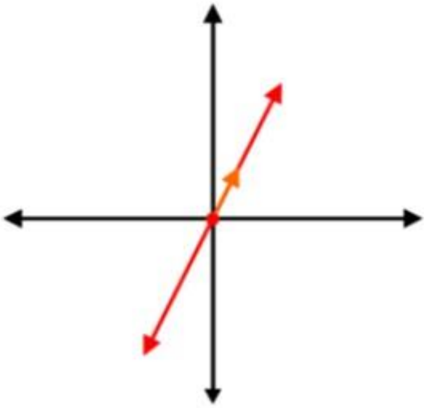


(b)

## 8(b) Explain the various types of polarisation.

### Linear Polarization

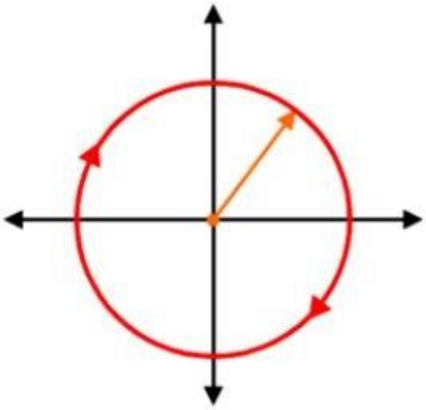
In linear polarization, the electric field of light is confined to a single plane along the direction of the propagation .of light.



Linear Polarization

### Circular Polarization

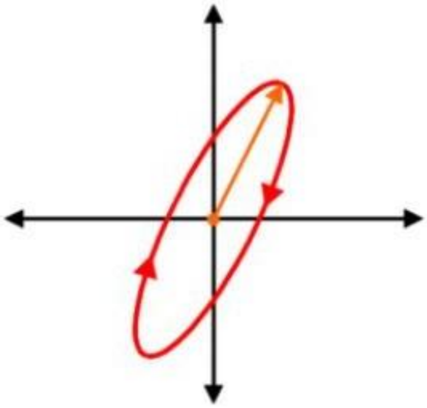
In circular polarization the electrical field of light has two linear components that are perpendicular to each other and have identical amplitudes such that their amplitudes , but the phase difference is π/2. The electric field that occurs will propagate in a circular motion.



Circular Polarization

### Elliptical Polarization

In elliptical polarization the electric field of light propagates along an elliptical path. The two linear component do not have the same amplitude and phase difference in elliptical polarization.

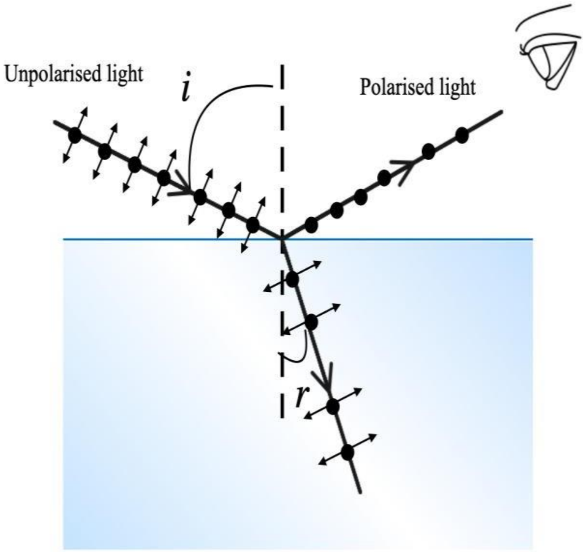


Eleptical Polarization

## 9(a)Explain the polarisation by reflection with neat sketch.

If light incidents on a refractive surface so that the refracted light and the reflected light are at 90° angle, then the reflected light will be linearly polarized, and the plane of polarization will be parallel to the plane of the interface.

The following diagram shows the polarization by reflection.



The angle of incidence that produces 90° angle between the refracted and reflected light wave is called Brewster angle.

When the light falls on the medium at Brewster angle, the reflected wave has no electric field vectors that are parallel to the refracted ray.

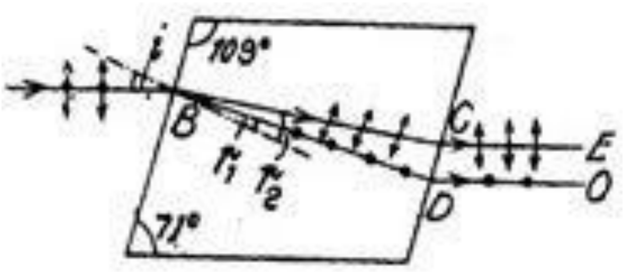
The only direction possible for the light wave is perpendicular to the plane of the image. So, the reflected wave is completely polarized. Whereas, the refracted wave is partially polarized.
Brewster’s law formula is given by, $\mu=\tan i$

Where,
$\mu$= is the refractive index of the material
$i$= is the polarization angle.

We can write from Snell’s law,
$\mu=\sin i/\sin r$....................... (1)
The reflected light and refracted light should be perpendicular to each other.
Hence, we can write,
$i+r+90=180$
$\Rightarrow r=90-i$
Hence,quation (1) such that,
$\mu=\sin i/\sin(90-i)$
$\Rightarrow \mu=\sin i/\cos i$
$\Rightarrow \mu=\tan i$
This is the formula of Brewster’s law.

## 9b) Illustrate the double reflection in crystal.

When unpolarised light passes through anisotropic crystals such as calicite (or )quartz,it spilt into two refracted beams and this phenomenon is called Double refraction (or)Bifringes.



Consider a beam AB of unpolarised light incident on the A calcites crystal at an angle of incidence 'i' as 9shown in Fig. Inside the crystal the ray breaks up into ordinary and extra-ordinary ' rays. The ordinary ray along BD makes an angle of refraction $r_1$ while the extraordinary traveling along BC makes an angle of refraction $r_2$• Since the two opposite faces of the crystal are always ,both the rays emerge parallel to the incident rays.

- The ordinary ray(O-Ray) travels with the same velocity in all directons .The corresponding refractive index is called ordinary Refractive index $\mu_0$.
- The exordinary ray(E-Ray) travels the velocity decreases gradually . The corresponding refractive index is called extra-ordinary Refractive index $\mu_{e.}$
- The refractive index of ordinary Ray, $\mu_0$ is same for all angles of incidence while refractive index of exordinary ray varies with angle of incidence.
- Hence O-ray travels with same velocity and it is represented by a spherical wave front.
- E-ray trvels with different velocities in different direction and is given by ellipsoidal wave front.

Both the rays travel with same velocities along optic axis

## 10 (a)Explain the production of plane polarized light using Nicol prism.

A Nicol prism is an optical device made from a calcite crystal for producing and analysing plane polarised light .

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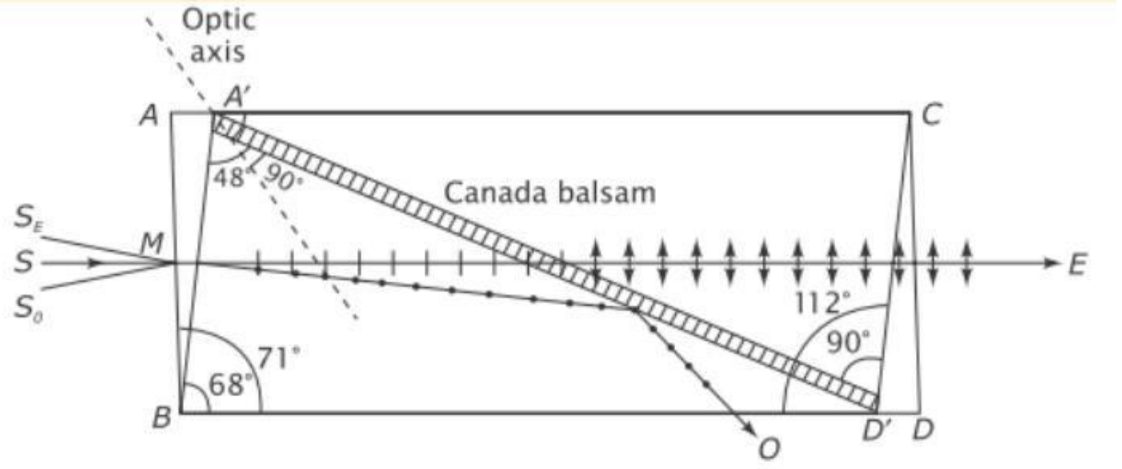


## Working

When a ray SM of unpolarised light nearly parallel to BD' is incident on the face A'B, it splits up into two refracted rays, O and E-rays, both being plane polarised.

➢ The O-ray has vibrations perpendicular to the principal section of the crystal, while E-ray has vibration in the principal section.

➢ The refraction indices of Canada balsam, O-ray, and E-ray for calcite crystal are in order as $\mu CB$ =1.55, $\mu o$= 1.658, and $\mu E$ = 1.486.

➢Now the refractive index of Canada balsam is less than the refractive index of calcite for the O-ray(1.658).But greater than the refractive index of calcite for the E-ray(1.486).Therefore, when the O-ray reaches the layer of the Canada balsam.

➢It is passing from an optically denser to rarer medium Since the length of the crystal is large,the angle of incidence of the O-ray at the calcite balsam surface becomes greater than the crystal angle ($69^0$)for the O-ray. Hence ,the O-ray is totally reflected at the calcite balsam surface & is absorbed by the tube containing the crystal.

➢The E-ray however,on reaching the calcite balsam surface passes from a rarer to a denser medium and is transmitted.

➢Since, the E-ray is plane polarised,the light emerging from the Nicol is plane polarised with vibrations

Parallel to the principal section

➢These vibrations are parallel to the shorter diagonol of the end face of the crystal.

## 10(b)Describe the propagation of polarized light in Quarter wave plate.

Quarter wave plate is the thickness of the crystal plate at which the path difference between o-ray and e-ray inside the crystal is equal to $\lambda/4$ .

Consider a light of wavelength 'λ' falls normally on a crystal surface; the refracted light splits up into o-ray and e-rays.

Let 't' is the thickness of crystal at which path difference of o-ray and e-ray is $\lambda\, 4$ , then

Path difference of o-ray and e-ray = $\lambda/4$ --------- (1)

optical path of o-ray = $\mu_0$ t,

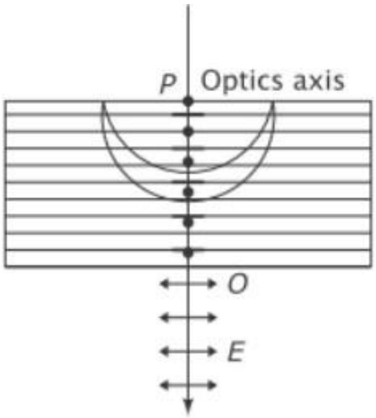
optical path of e-ray = = $\mu_e$t

optical path difference between o-ray and e-ray = $(\mu o-\mu e)$ t-------- (2)

from eqns (1) & (2),

$$(\mu_0-\mu_e)\, t = \lambda/4$$

$$t = \lambda/4\, (\mu_0-\mu_e)$$



<u>Applications</u>

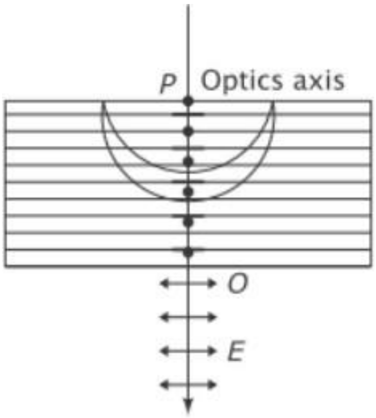
- QWP is used  to produce circularly polarized light, if the optic axis of the crystal makes an angle of $45^0$ with the incident beam of light .
- QWP is used to produce epllitically polarized light if the incident beam makes  an angle other than $45^0$ with the ptic axis of the crystal.

## 11(a) Describe the propagation of polarized light in Half wave plate

A half wave plate(HWP) is a doubly refracting uniaxial negative or positive crystal cut in such a way it can produce a path difference between o-ray and e-ray inside the crystal is equal to $\lambda/2$ .

Consider a light of wavelength 'λ' falls normally on a crystal surface; the refracted light splits up into o-ray and e-rays.

Let 't' is the thickness of crystal at which path difference of o-ray and e-ray is $\lambda 2$ , then
Path difference of o-ray and e-ray = $\lambda/2$ --------- (1)
optical path of o-ray = $\mu_0$ t,
optical path of e-ray = $\mu_e t$
optical path difference between o-ray & e-ray = $(\mu o \sim \mu e)\, t$ --------(2)
from eqns (1) & (2),
$(\mu_0-\mu_e)\, t = \lambda/2$
$t = \lambda/2\, (\mu_0-\mu_e)$



Applications

- HWP produces a phase difference of π between the ordinary and exordinary rays.
- The emergent beam from a HWP is a plane polarized light .
- It rotates the azimuth of a beam plane polarized light by $90^0$ ,provided the incident light makes an angle of $45^0$ with the optic axis of the half wave plate.

## 11(b)Calculate the thickness of Half Wave plate,given that $\mu_e$=1.533, $\mu$o=1.5444 and $\lambda$=5000A°

FOR HALF WAVE $t = \lambda/2\ (\mu_0 - \mu_e)$

$t = 5000\mathrm{x}10^{-8}/2\ (1.544-1.533)$

$t = 5000\mathrm{x}10^{-8}/2\ (0.011)$

$t = 5000\mathrm{x}10^{-8}/0.022$
t=2.7272mm

# UNIT – II

# CRYSTALLOGRAPHY & X-RAY DIFFRACTION

## 2 a) What is (i) Unit cell (ii) Space Lattice (iii) Bravais Lattice

**Unit Cell**: The unit cell is the smallest portion of crystal lattice which have repeated in different directions we generate the entire lattice. It is formed by application of translational group.

**Space lattice** : A space lattice is an array of points showing how particles (atoms, ions or molecules) are arranged at different sites in three dimensional spaces.

**Bravais lattice**: If all atoms are identical at lattice point then that lattice known bravais lattice. We have fourteen kinds of bravais lattices that all belongs to seven crystal system.

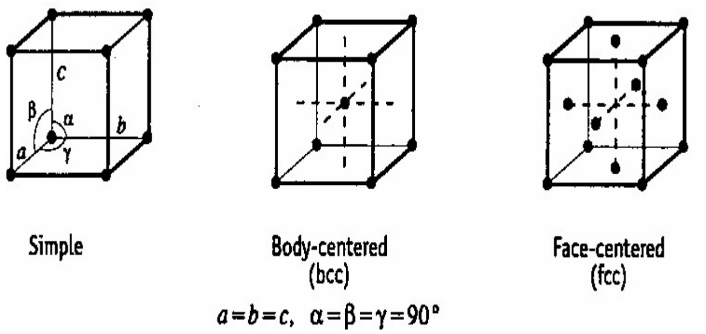
## 2 b) Explain the various types of crystal systems with a neat sketch and examples.

There are 7 basic crystal systems which are distinguished based on three vectors or the intercepts and the3 interfacial angles between the 3 axes of the crystal. They are

1. Cubic
2. Tetragonal
3. Orthorhombic
4. Monoclinic
5. Triclinic
6. Trigonal (Rhombohedral)
7. Hexagonal

### 1) Cubic crystal system

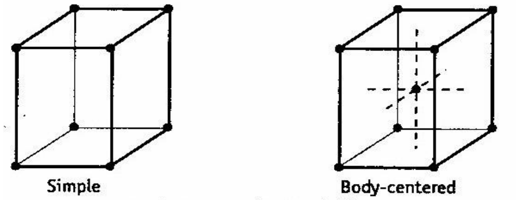
a = b = c, $\alpha = \beta = \gamma = 90^0$



The crystal axes are perpendicular to one another, and the repetitive interval in the same along all the three axes. Cubic lattices may be simple, body centered or face-centered.

**2) Tetragonal crystal system**

a = b G c, $\alpha = \beta = \gamma = 90^0$



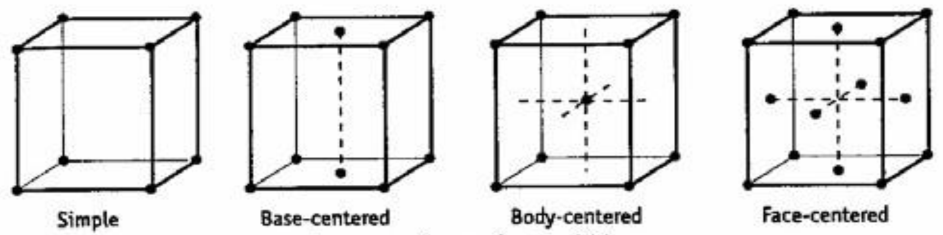
$a=b\neq c, \ \alpha=\beta=\gamma=90°$

TETRAGONAL SYSTEM

The crystal axes are perpendicular to one another. The repetitive intervals along the two axes are the same, but the interval along the third axes is different. Tetragonal lattices may be simple or body-centered.

**3) Orthorhombic crystal system**

a G b G c, $\alpha = \beta = \gamma = 90^0$



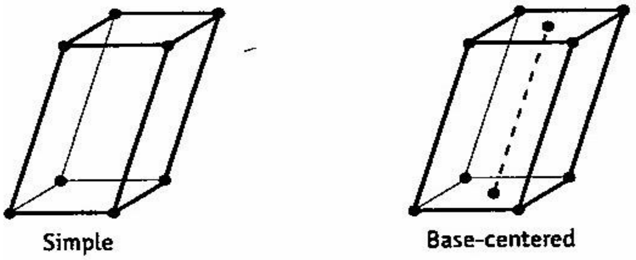
$a\neq b\neq c$ ; and $\alpha=\beta=\gamma=90°$

ORTHORHOMBIC SYSTEM

The crystal axes are perpendicular to one another but the repetitive intervals are different along the three axes. Orthorhombic lattices may be simple, base centered, body centered or face centered.

**4) Monoclinic crystal system**

a G b G c, $\alpha = \beta = 90^0$ G $\gamma$



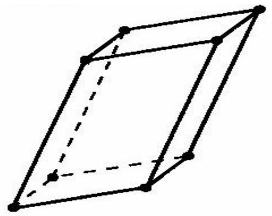
$a\neq b\neq c, \ \alpha=\gamma=90°\neq\beta$

MONOCLINIC SYSTEM

Two of the crystal axes are perpendicular to each other, but the third is obliquely inclined. The repetitive intervals are different along all the three axes. Monoclinic lattices may be simple or base centered.

### 5) Triclinic crystal system

a G b G c, $\alpha$ G $\beta$ G $\gamma$ G $90^0$

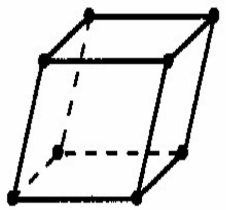


$a \neq b \neq c$
$\alpha \neq \beta \neq \gamma \neq 90°$
TRICLINIC SYSTEM

None of the crystal axes is perpendicular to any of the others, and the repetitive intervals are different along the three axes.

### 6) Trigonal (Rhombohedral) crystal system

a = b = c, $\alpha = \beta = \gamma$ G $90^0$



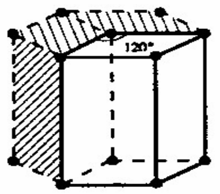
$a = b = c$
$\alpha = \beta = \gamma \neq 90°$
IOMBOHEDRAL (TRIGONAL) SYSTEM

The three axes are equal in length and are equally inclined to each other at an angle other than $90^0$.

### 7) Hexagonal crystal system

a = b G c, $\alpha = \beta = 90^0$ and $\gamma = 120^0$

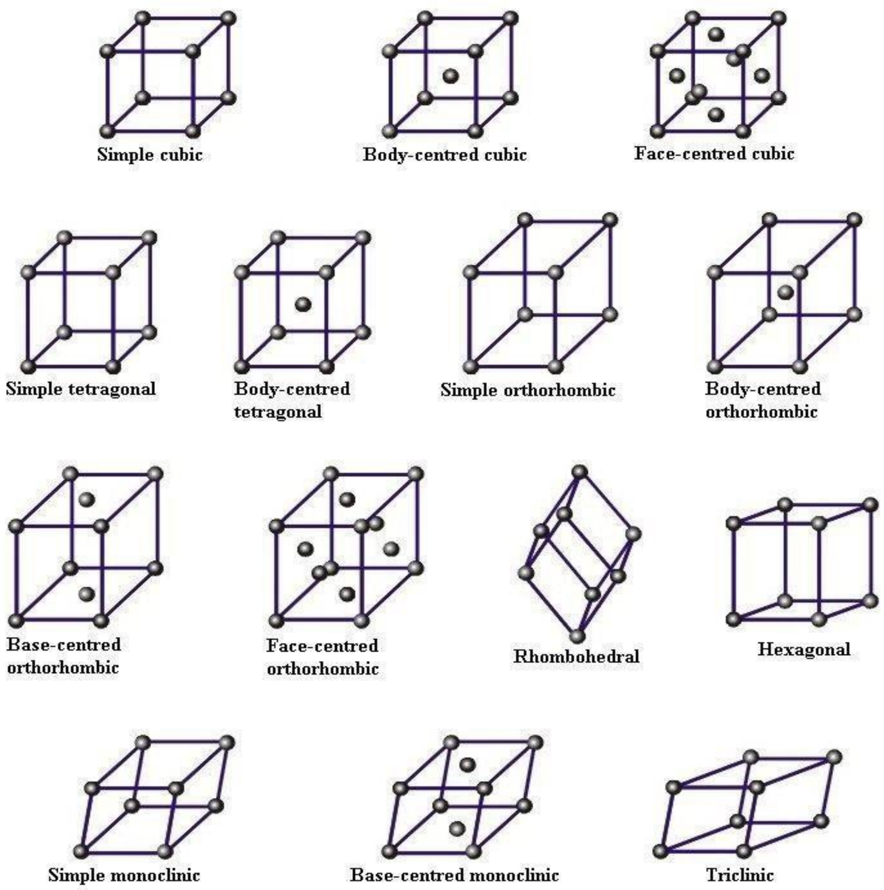
Two of the crystal axes are $60^0$ apart while the third is perpendicular to both of them. The repetitive intervals are the same along the axes that are $60^0$ apart, but the interval along the third axis is different.



$a = b \neq c$
$\alpha = \beta = 90°, \ \gamma = 120°$
HEXAGONAL SYSTEM

## 3 a) Explain the various types of Bravais lattices with a neat sketch.

**Bravais lattice**: If all atoms are identical at lattice point then that lattice known bravais lattice. We have fourteen kinds of bravais lattices that all belongs to seven crystal system.



| S.No. | Name of the crystal system | Lattice parameters | Types of Bravais lattices |
|---|---|---|---|
| 1 | Cubic | $a = b = c : \quad \alpha = \beta = \gamma = 90^\circ$ | P, I, F |
| 2 | Tetragonal | $a = b \neq c : \quad \alpha = \beta = \gamma = 90^\circ$ | P, I, |
| 3 | Orthorhombic | $a \neq b \neq c : \alpha = \beta = \gamma = 90^\circ$ | P, I, F, B |
| 4 | Monoclinic | $a \neq b \neq c : \alpha = \beta = 90^\circ \neq \gamma$ | P, B |
| 5 | Triclinic | $a \neq b \neq c : \alpha \neq \beta \neq \gamma \neq 90^\circ$ | P |
| 6 | Trigonal | $a = b = c : \alpha = \beta = \gamma \neq 90^\circ$ | P |
| 7 | Hexagonal | $a = b \neq c : \alpha = \beta = 90^\circ ; \gamma = 120$ | P |

## 3 b) Define atomic packing fraction and derive it for simple cubic crystal structure.

**Atomic packing factor or fraction:**

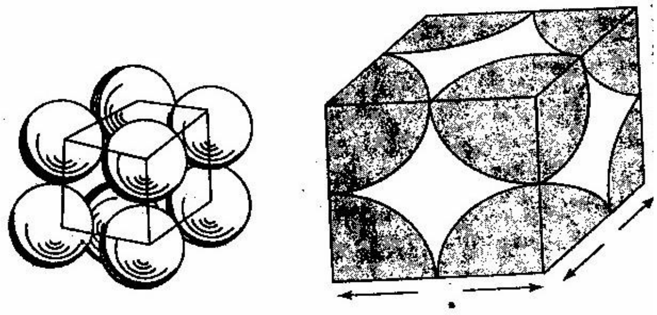
It is the ratio of the volume occupied by the atoms in unit cell(v) to the total volume of the unit cell (V).

$$\text{P.F.} = v / V$$

$$\text{P.F} = \frac{\text{Number of atoms present in a unit cell x Volume of the one atom}}{\text{Volume of the unit cell}}$$

**Simple cubic (SC) structure**

In the simple cubic lattice, there is one lattice point at each of the 8 corners of the unit cell. The atoms touch along cubic edges.



Nearest neighbouring distance $2r = a$

Atomic radius $r = a / 2$

Lattice constant $a = 2r$

Coordination number = 6 (since each corner atom is surrounded by 6 equidistant nearest neighbours )

Effective number of atoms belonging to the unit cell or no.of atoms per unit cell = $(\frac{1}{8}) \times 8 = 1$ atom per unit cell.

$$\text{Atomic packing factor} = \frac{\text{volume of the all atoms in the unit cell}}{\text{volume of the unit cell}}$$

$$= 1 \text{ x } (4 / 3)\, \pi r^3 / a^3 = 4\pi r3 / 3(2r)^3$$

$$= \pi / 6 = 0.52 = 52\%$$

This structure is loosely packed. Polonium is the only element which exhibits the simple cubic structure.

## 4) Define atomic packing fraction and derive it for body centered cubic crystal structure.

**Atomic packing factor or fraction:**

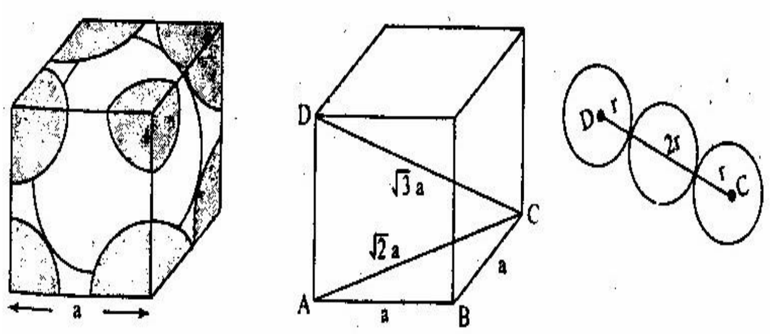
It is the ratio of the volume occupied by the atoms in unit cell(v) to the total volume of the unit cell (V).

$$\text{P.F.} = v / V$$

$$\text{P.F} = \frac{\text{Number of atoms present in a unit cell x Volume of the one atom}}{\text{Volume of the unit cell}}$$

**Body centered cube structure (BCC)**

BCC structure has one atom at the centre of the cube and one atom at each corner. The centre atom touches all the 8 corner atoms.



Diagonal length = 4r

Body diagonal = $(\sqrt{3})a$

i.e. $4r = (\sqrt{3})a$

Nearest neighbouring distance = $2r = (\sqrt{3})a / 2$

Atomic radius = $r = (\sqrt{3})a / 4$

Lattice constant = $a = 4r / \sqrt{3}$

Coordination number = 8 (since the central atom touches all the corner 8 atoms )

Effective number of atoms belonging to the unit cell or no. of atoms per unit cell = $(1/8) \times 8 + 1 =$ 2 atom per unit cell.

i.e. each corner atom contributes $(1/8)^{th}$ to the unit cell. In addition to it, there is a centre atom.

Atomic packing factor = $v / V = \frac{\text{volume of the all atoms in the unit cell}}{\text{volume of the unit cell}}$

$= 2 \times (4/3)\pi r^3 / a^3 = 8\pi r^3 / 3(4r/\sqrt{3})^3$

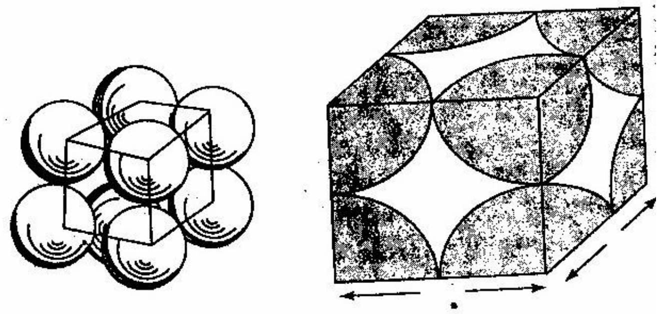
$= \sqrt{3}\pi / 8 = 0.68 = 68\%$

Tungsten, Na, Fe and Cr exhibits this type of structure.

**5) Show that Face centered cubic crystal structure has more closely packed structure than SC and BCC.**

**Simple cubic (SC) structure**

In the simple cubic lattice, there is one lattice point at each of the 8 corners of the unit cell. The atoms touch along cubic edges.



Nearest neighbouring distance = $2r = a$

Atomic radius = $r = a / 2$

Lattice constant = $a = 2r$

Coordination number = 6 (since each corner atom is surrounded by 6 equidistant nearest neighbours )

Effective number of atoms belonging to the unit cell or no.of atoms per unit cell = $(\frac{1}{8})x8 = 1$ atom per unit cell.

Atomic packing factor = v / V = $\frac{\text{volume of the all atoms in the unit cell}}{\text{volume of the unit cell}}$

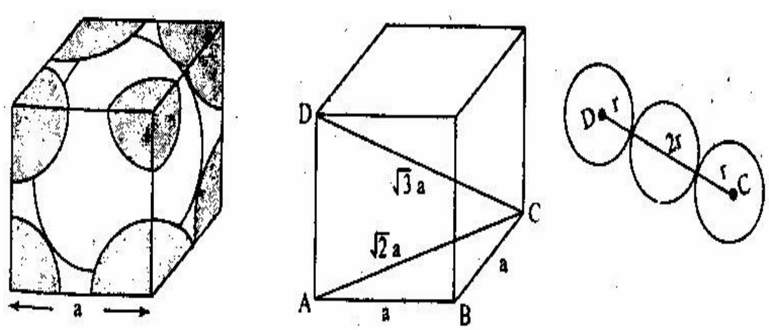
$$= 1 \text{ x } (4 / 3)\ \pi r^3 / a^3 = 4\pi r3 / 3(2r)^3$$

$$= \pi / 6 = 0.52 = 52\%$$

This structure is loosely packed. Polonium is the only element which exhibits the simple cubic structure.

**Body centered cube structure (BCC)**

BCC structure has one atom at the centre of the cube and one atom at each corner. The centre atom touches all the 8 corner atoms.



Diagonal length = 4r

Body diagonal = $(\sqrt{3})a$

i.e. $4r = (\sqrt{3})a$

Nearest neighbouring distance = $2r = (\sqrt{3})a / 2$

Atomic radius = $r = (\sqrt{3})a / 4$

Lattice constant = $a = 4r / \sqrt{3}$

Coordination number = 8 (since the central atom touches all the corner 8 atoms )

Effective number of atoms belonging to the unit cell or no. of atoms per unit cell = $(\frac{1}{8})x8 + 1 =$ 2 atom per unit cell.

i.e. each corner atom contributes $(\frac{1}{8})^{th}$ to the unit cell. In addition to it, there is a centre atom.

Atomic packing factor = v / V = $\frac{\text{volume of the all atoms in the unit cell}}{\text{volume of the unit cell}}$

$$= 2 \text{ x } (4 / 3)\ \pi r^3 / a^3 = 8\pi r^3 / 3(4r / \sqrt{3}\ )^3$$

$$= \sqrt{3}\pi / 8 = 0.68 = 68\%$$

Tungsten, Na, Fe and Cr exhibits this type of structure.

**Face centered cubic (FCC) structure**

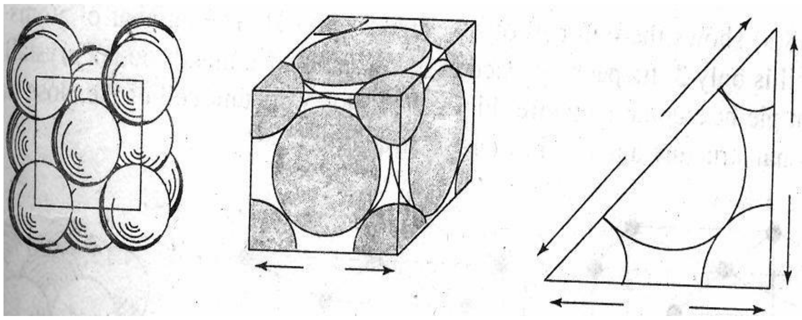
In FCC structure, there is one lattice point at each of the 8 corners of the unit cell and 1 centre atom on each of the 6 faces of the cube.

Face diagonal length = $4r = (\sqrt{2})\ a$

Nearest neighbouring distance = $2r = (\sqrt{2})a / 2 = a / \sqrt{2}$

Atomic radius = $r = a / 2\sqrt{2}$

Lattice constant = $a = 2\sqrt{2}\ r$



Coordination number = 12 (the centre of each face has one atom. This centre atom touches 4 corner atoms in its plane, 4 face centered atoms in each of the 2 planes on either side of its plane)

Effective number of atoms belonging to the unit cell or no. of atoms per unit cell = (⅛)x8 + (1/2)x 6 = 1 + 3 = 4 atom per unit cell.

i.e. each corner atom contributes (⅛)th to the unit cell. In addition to it, there is a centre atom on each face of the cube.

$$\text{Atomic packing factor} = v/\ V = \frac{\text{volume of the all atoms in the unit cell}}{\text{Volume of the unit cell}}$$

$$= 4 \times (4/3)\ \pi r^3 / a^3 = 16\pi r^3 / 3(2\sqrt{2}r)^3$$

$$= \pi / 3\sqrt{2} = 0.74 = 74\%$$

Cu, Al, Pb and Ag have this structure.

So FCC has highest packing factor.

## 6 a) What are Miller indices? Mention the procedure to find Miller indices

### Planes in Crystals (Miller Indices)

It is possible for defining a system of parallel and equidistant planes which can be imagined to pass through the atoms in a space lattice, such that they include all the atoms in the crystal. Such a system of planes is called crystal planes. Many different systems of planes could be identified for a given space lattice.

The position of a crystal plane can be specified in terms of three integers called Miller indices.

Consider a crystal plane intersecting the crystal axes.

Procedure for finding Miller indices

1. Find the intercepts of the desired plane on the three coordinate axes.
   Let these be (pa, qb, rc).
2. Express the intercepts as multiples of unit cell dimensions or lattice parameters i.e. (p, q, r)
3. Take the reciprocals of these numbers i.e. 1/p: 1/q: 1/r
4. Convert these reciprocals into whole numbers by multiplying each with their LCM to get the smallest whole number.

This gives the Miller indices (h k l) of the plane.

Ex: $(3a, 4b, \alpha c)$
$(3, 4, \alpha)$
$1/3\ 1/4\ 1/\alpha$
$(4\ 3\ 0) = (h\ k\ l)$

Def: Miller indices is a set of 3 lowest possible integers whose ratio taken in order is the same as that of the reciprocals of the intercepts of the planes on the corresponding axes in the same order.

## 6 b) Write the important features of Miller indices

## Important features of Miller indices

1. A plane that is parallel to in the least one of the coordinate axes comes with an intercept of infinity (∞) and consequently, the Miller index for the said axis becomes zero.
2. All of the similarly spaced parallel planes having a specific alignment come with the same index number (h k I).
3. Miller indices don't only give the definition of the specific plane but a combination of many parallel planes.
4. Only the ratio of indices is considered important over everything else. The planes do not matter.
5. A plane fleeting over the origin is defined in comparison to a parallel plane that has nonzero intercepts.
6. Altogether the parallel equally far planes consist of the same Miller indices. Therefore, the Miller indices are used in relation to a set of parallel planes.
7. A plane that is parallel to anyone out of the many coordinate axes comes with an intercept of infinity.
8. If the Miller indices relating to two planes comes with the same ratio, for example, (8 4 4) and (4 2 2) or (2 1 1) then the planes can be proved as parallel to each other.
9. If h k I am the Miller indices relating to a plane, then the plane will divide or cut the axes into a/h, b/k, and c/l equivalent sections individually.

## 7 a) Deduce the expression for the interplanar distances in terms of miller indices for a cubic system

### Separation Between successive (h k l) Planes

Let (h k l) be the Miller indices of the plane ABC.

Let OP=$d_{(h\,k\,l)}$ be the normal to the plane ABC passing through the origin O.

Let OP make angles α, β, γ with X, Y & Z axes respectively.

Then $\cos\alpha = d / OA = d / x = d / (a/h)$

$\cos\beta = d / OB = d / y = d / (b/k)$

$\cos\gamma = d / OC = d / z = d / (c/l)$

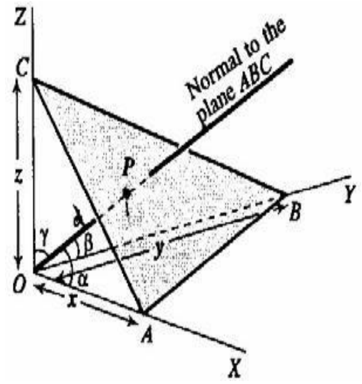
(Since convention in designing Miller indices x=a/h, y=b/k, z=c/l)

Now $\cos^2\alpha + \cos^2\beta + \cos^2\gamma = 1$

Hence $d^2 / (a/h)^2 + d^2 / (b/k)^2 + d^2 / (c/l)^2 = 1$

$(dh / a)^2 + (dk / b)^2 + (dl / c)^2 = 1$

$d_{(h\,k\,l)} = OP = 1 / \sqrt{(h^2/a^2 + k^2/b^2 + l^2/c^2)}$.



Therefore for cubic structure, a = b = c,

$d_{(h\,k\,l)} = a / \sqrt{( h^2 + k^2 + l^2 )}$

Let the next plane be parallel to ABC be at a distance OQ from the origin.

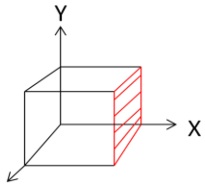
Then its intercepts are 2a / h, 2a / k, 2a / l.

Therefore $OQ = 2d = 2a / \sqrt{(h^2 + k^2 + l^2)}$

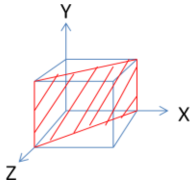
Hence the spacing between adjacent planes = OQ - OP = PQ.

i.e. $d = a / \sqrt{( h^2 + k^2 + l^2)}$

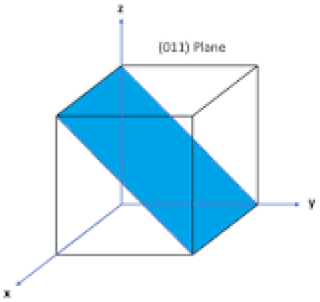
7 b) Draw miller indices of planes (1 0 0), (1 0 1) and (011) in a cubic system.



(1 0 0)



(1 0 1)



(0 1 1)

## 8 a) Define the Bragg’s law of X-ray diffraction and derive 2d sinθ = nλ

### Bragg’s Law

It states that the X-rays reflected from different parallel planes of a crystal interfere constructively when the path difference is integral multiple of wavelength of X-rays.

Consider a crystal made up of equidistant parallel planes of atoms with the interplanar spacing d.

Let wave front of a monochromatic X-ray beam of wavelength $\lambda$ fall at an angle $\theta$ on these atomic planes. Each atom scatters the X-rays in all directions.

In certain directions these scattered radiations are in phase i.e., they interfere constructively while in all other directions, there is destructive interference.

Consider the X-rays PE and P’A are inclined at an angle $\theta$ with the top of the crystal plane XY. They are scattered along AQ and EQ’ at an angle $\theta$ w.r.t plane XY. Consider another incoming beam P’C is scattered along CQ”

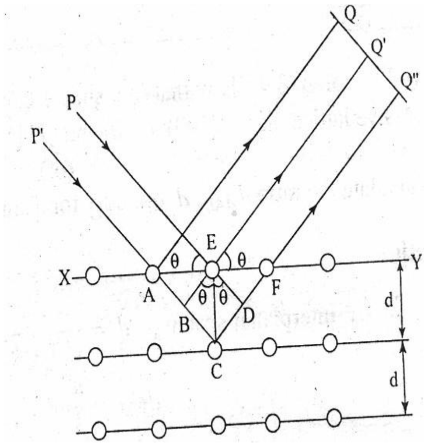
Let normal EB & ED be drawn to AC &CF. If EB & ED are parallel incident and reflected wave fronts then the path difference between the incident and reflected waves is given by $\Delta = BC + CD$ ---------------------- (1)

In $\Delta ABC$ , $\sin\theta = BC / EC = BC / d$

i.e., $BC = d \sin\theta$

Similarly, in $\Delta DEC$, $CD = d \sin\theta$

Hence path difference $\Delta = 2d \sin\theta$



If the 2 consecutive planes scatter waves in phase with each other, then the path difference must be an integral multiple of wavelength.

i.e., $\Delta = n\lambda$ where n = 0, 1, 2, 3, ........is the order of reflection

Thus the condition for in phase scattering by the planes in a crystal is given by

$$\mathbf{2d \sin\theta = n\lambda} \text{ .....................} (2)$$

This condition is known as Bragg’s Law.

The maximum possible value for $\theta$ is 1.

$$n\lambda / 2d \leq 1$$

The wavelength $\lambda$ should not exceed twice the interplanar spacing for diffraction to occur.

## 8 b) Calculate $d_{100}$ : $d_{110}$: $d_{111}$ for a cubic crystal system.

$$d_{100} = \frac{a}{\sqrt{1^2+0^2+0^2}} = a,$$

$$d_{110} = \frac{a}{\sqrt{1^2+1^2+0^2}} = \frac{a}{\sqrt{2}},$$

$$d_{111} = \frac{a}{\sqrt{1^2+1^2+1^2}} = \frac{a}{\sqrt{3}}$$

## 9 a) Derive the Bragg's condition for X-ray diffraction.

**Bragg's Law**

It states that the X-rays reflected from different parallel planes of a crystal interfere constructively when the path difference is integral multiple of wavelength of X-rays.

Consider a crystal made up of equidistant parallel planes of atoms with the interplanar spacing d.

Let wave front of a monochromatic X-ray beam of wavelength $\lambda$ fall at an angle $\theta$ on these atomic planes. Each atom scatters the X-rays in all directions.

In certain directions these scattered radiations are in phase i.e., they interfere constructively while in all other directions, there is destructive interference.

Consider the X-rays PE and P'A are inclined at an angle $\theta$ with the top of the crystal plane XY. They are scattered along AQ and EQ' at an angle $\theta$ w.r.t plane XY. Consider another incoming beam P'C is scattered along CQ"

Let normal EB & ED be drawn to AC &CF. If EB & ED are parallel incident and reflected wave fronts then the path difference between the incident and reflected waves is given by $\Delta = BC + CD$ ---------------------- (1)

In $\Delta ABC$ , $\sin\theta = BC / EC = BC / d$

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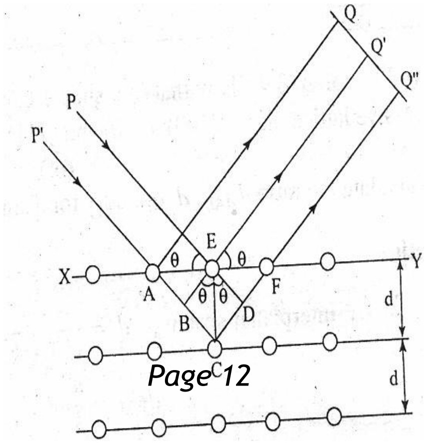
Similarly, in $\Delta DEC$, $CD = d \sin\theta$

Hence path difference $\Delta = 2d \sin\theta$



If the 2 consecutive planes scatter waves in phase with each other, then the path difference must be an integral multiple of wavelength.

i.e., $\Delta = n\lambda$ where n = 0, 1, 2, 3,…….is the order of reflection

Thus the condition for in phase scattering by the planes in a crystal is given by

$$\mathbf{2d \sin\theta = n\lambda} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

This condition is known as Bragg's Law.

The maximum possible value for θ is 1.

$$n\lambda / 2d \leq 1$$

The wavelength λ should not exceed twice the interplanar spacing for diffraction to occur.

**9 b) A beam of X rays of wavelength 0.71 nm is diffracted by (110) plane of rock salt with lattice constant of 0.28nm. Find the glancing angle for the second order diffraction.**

Given data are:

Wavelength (λ) of X-rays = 0.071 nm

Lattice constant ($a$) = 0.28 nm

Plane ($hkl$) = (110)

Order of diffraction = 2

Glancing angle $\theta$ = ?

Bragg's law is $2d \sin\theta = n\lambda$

$$d = \frac{a}{\sqrt{h^2 + k^2 + l^2}}, \text{ because rock salt is FCC}$$

$$= \frac{0.28 \times 10^{-9}}{\sqrt{1^2 + 1^2 + 0^2}}\,\mathrm{m} = \frac{0.28 \times 10^{-9}}{\sqrt{2}}\,\mathrm{m}$$

Substitute in Bragg's equation

$$2 \times \frac{0.28 \times 10^{-9}}{\sqrt{2}} \sin\theta = 2 \times 0.071 \times 10^{-9}$$

$$\sin\theta = \sqrt{2} \times \frac{0.071}{0.28} = 0.3586$$

$$\theta = \sin^{-1}(0.3586) = 21.01^\circ \approx 21^\circ$$

## 10 a) Explain how crystal structure determined by Laue X-Ray diffraction method.

The Laue method is mainly used to determine the orientation of large single crystals. White radiation is reflected from, or transmitted through, a fixed crystal. The experimental arrangement is shown in fig.

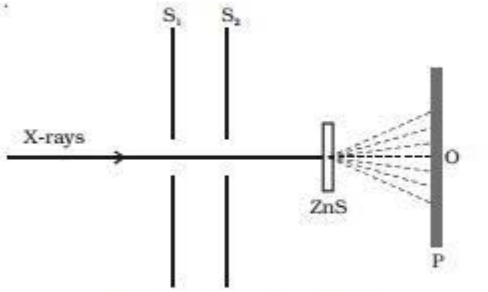


*Fig (a) Laue experimental set up*

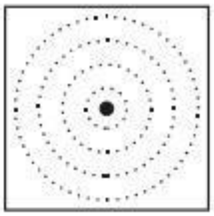


*Fig (b) Laue spot*

The crystal whose structure has to be studied ,is held stationary in a continuous X-ray beam. After passing through the pin hole of lead diaphragms, we obtain a fine beam of X-rays.These X-rays are allowed to fall on the crystal. The crystal planes in the crystal diffract the X-rays satisfying Bragg’s law.

The diffracted X-rays are allowed to fall on a photographic plate.The diffraction pattern consists of a series of bright spots corresponding to interference maximum for a set of crystal planes satisfying the Bragg’s equation 2dsinɵ =nλ for a particular wavelength of the incident beam.

The distribution of spots depends on the symmetry of the crystal and its orientation with respect to X-ray beam. For a simple cubic crystal the Laue photograph is shown in fig.

## 10 b) What are the advantages of Laue X-Ray diffraction method?

1 This method is used for determination of crystal orientation and symmetry.

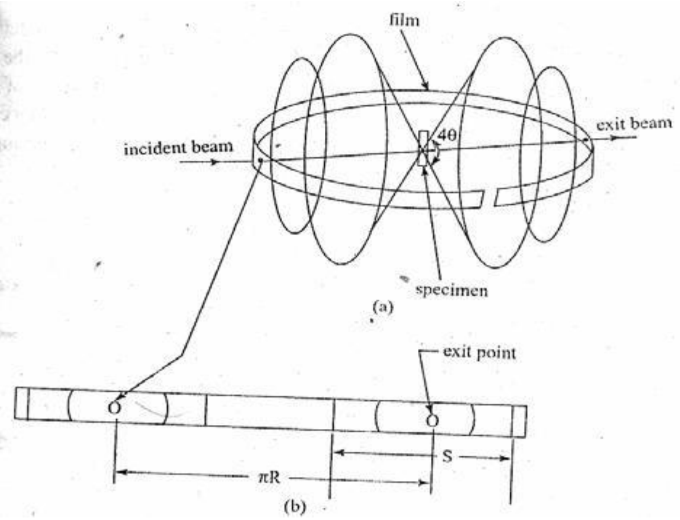
2. This method is used to study crystalline imperfections(defects).

3. It is used for checking the orientation of crystals and their quality. It can be used for analyzing specimens that are thick and large.

## 11) a) Explain how crystal structure determined by Powder X-ray diffraction method.

### Powder method (Debye – Scherrer Method)

This method is widely used for experimental determination of crystal structures. A monochromatic X- ray beam is incident on randomly oriented crystals in powder form. In this we used a camera called Debye – Scherrer camera. It consists of a cylindrical cassette, with a strip of photographic film positioned around the circular periphery of cassette. The powder specimen is placed at the centre, either pasted on a thin fibre of glass or filled in a capillary glass tube. The X- ray beam enters through a small hole in the camera and falls on the powder specimen. Some part of the beam is diffracted by the powder while the remaining passes out through the exit port.



Since large no. of crystals is randomly oriented in the powder, set of planes which make an angle θ with the incident beam can have a no. of possible orientations. Hence reflected radiation lies on the surface of a cone whose apex is at the point of contact of the radiation with the specimen. If all the crystal planes of interplanar spacing d reflect at the same bragg angle θ, all reflections from a family lie on the same cone.

After taking n=1 in the Bragg's law

$$2d\sin\theta = \lambda$$

There are still a no of combinations of d and θ, which satisfies Bragg's law. Hence many cones of reflection are emitted by the powder specimen. In the powder camera a part of each cone is recorded by the film strip.

The full opening angle of the diffracted cone 4θ is determined by measuring the distance S between two corresponding arcs on the photographic film about the exit point direction beam. The distance S on the film between two diffraction lines corresponding to a particular plane is related to Bragg's angle by the equation

$$4\theta = (S / R) \text{ radians (or)}$$

$$4\theta = (S / R) \times (180 / \Pi) \text{ degrees where R- radius of the camera}$$

A list of θ values can be thus be obtained from measured values of S. Since the wavelength 'λ' is known, substitution of λ gives a list of spacing'd'. Each spacing is the distance between neighbouring plane (h k l). From the ratio of interplanar spacing, the type of lattice can be identified.

**11 b) What are the advantages of Powder X-ray diffraction method.**

1) The powder method is used to determine the value of the lattice parameters accurately.
2) It is mostly used to characterize and identify phases, and to refine details of an already known structure.
3) Using filter ,we get monochromatic X-rays.
4) Knowing all parameters ,crystal structure can be studied completely.

# UNIT -3

# DIELECTRIC AND MAGNETIC MATERIAL

### 2 a ) With usual notations, show that P= ε₀ (εᵣ -1)E

Consider a polarized dielectric in a result electric field 'E'. The field is characterized by electric lines of forces.

These lines of forces while passing through the dielectric make it polarized.

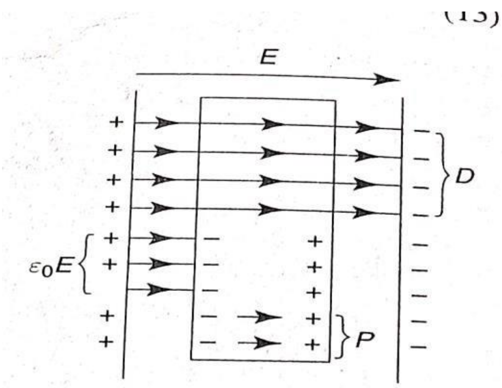


**Figure 8.3** Electric lines of forces in a polarised dielectric

The total number of electric lines of force passing through the dielectric is known as electric flux density 'D'.

$$D = \varepsilon_0 E + P -----> 1$$

$$but, D = \varepsilon E -----> 2$$

$$\varepsilon E = \varepsilon_0 E + P (\therefore \varepsilon = \varepsilon_0 \varepsilon_r)$$

$$\varepsilon_0 \varepsilon_r E = \varepsilon_0 E + P$$

$$\varepsilon_0 \varepsilon_r E - \varepsilon_0 E = P$$

$$\varepsilon_0 E(\varepsilon_r - 1) = P$$

$$\varepsilon_r - 1 = \frac{P}{\varepsilon_0 E} -------> 3$$

$$\varepsilon_r - 1 = \chi \left( \therefore \chi = \frac{P}{\varepsilon_0 E} \right)$$

## b ) Write the differences between polar and non -polar molecules

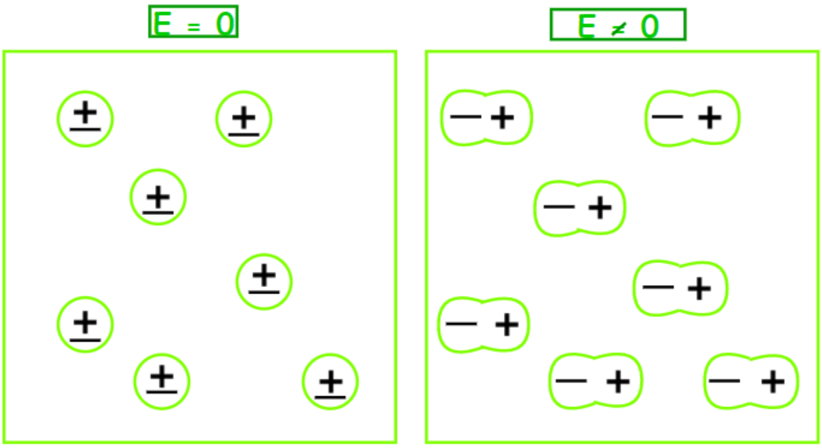
| Polar dielectrics | Nonpolar dielectrics |
|---|---|
| These are material which have inherent dipole moment | These materials do not have dipole moment. |
| In presence of electric field, positive and negative charges are separated by small distance. | In presence of electric field, positive and negative charges are not separated by small distance |
| These materials show the property of polarity. | These materials do not show the property of polarity. |
| Polar dielectrics are the polar compounds that do not conduct electricity. | Non polar dielectrics are the non-polar compounds that do not conduct electricity. |
| Shape of these dielectrics are asymmetric. | Shape of the dielectrics are symmetric. |
| Polar dielectrics are polar. | Non polar dielectrics are non-polar. |
| Example: ammonia,HCl and water | Example: benzene and methane |

## 3 a) Explain the different types of polarizations.

Depending upon the type of displaced charges causing polarization of dielectric in the presence of an electric field, we have three type of polarization

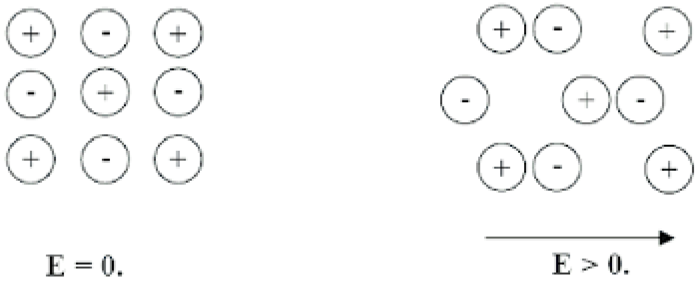
1. Electronic polarization, 2. Ionic polarization, 3. Orientation or dipolar polarization

**1. Electronic polarization:-** When electric field is applied on a dielectric material then all the positive nuclei of atoms move in the field direction and all the negative electron clouds of atoms move in opposite direction, hence dipoles will be formed. This phenomenon is known as electronic polarization. Electronic polarization takes place in all dielectrics as they are made up of atoms.



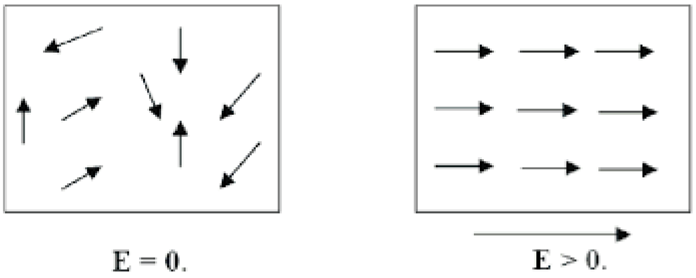
Electric Polarization

**2. Ionic polarization:-** When electric field is applied on an ionic dielectric material then positive ions move in the field direction where as negative ions move in the opposite direction, hence dipoles will be formed. This phenomenon is known as electronic polarization. Ionic polarization takes place only in ionic dielectrics due to displacement of positive and negative ions by the influence of external electric field.



**3. Orientation or dipolar polarization:-** When electric field is applied on a polar dielectric then all the dipoles tends to rote in the field direction, hence dipole moment increases enormously.

This phenomenon is known as dipolar polarization or orientation polarization. This polarization takes place only in polar dielectrics.



### b) Derive the expression for electronic polarizabilty, $\alpha_e$ in dielectrics.

Consider an atom consisting of nucleus at the centre and electronics revolving in their orbits. These electrons from an electron cloud surrounding the nucleus. In the absence of an electric field, the centers of net positive and negative charges coincide and the atom is not polarized. When an electric field E is applied to the atom as shown in fig, displacement of an electron cloud takes place w.r.t nucleus in a direction opposite to the applied field taking place due to action of electrical force. Now the centre of net positive and negative charges do not coincide and it act as a dipole having dipole moment. As a result, the atom gets polarized. Such type of polarization due to displacement of electron cloud in atom in the presence of an electric field is known as electronic polarization

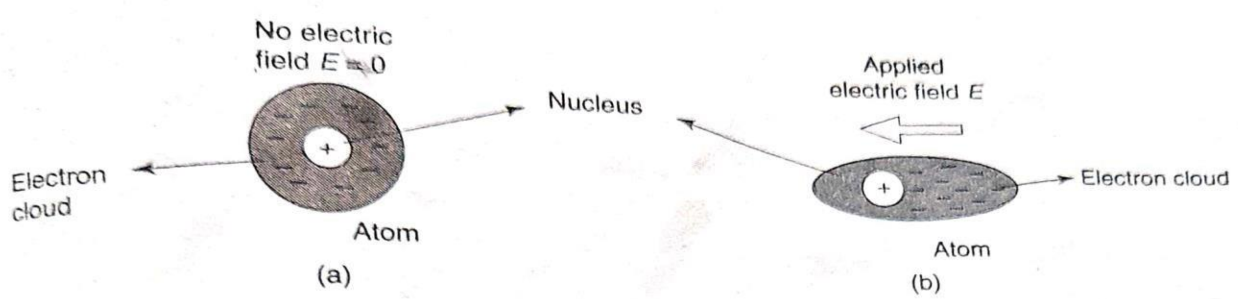


**Figure 8.4** (a) Unpolarised atom in the absence of field, (b) Electronic polarisation due to distortion of electron cloud by the field $E$

The induced electronic dipole moment is given by

$$\mu_e = \alpha_e E \text{ ---------------} \rightarrow (1)$$

Where $\alpha_e$ is the electronic polarizability. If the atom is spherical with radius 'R' then

$$\alpha_e = 4\pi\varepsilon_0 R^3 \text{------------} \rightarrow (2)$$

Where $\varepsilon_0$ is the permittivity of free space. From the above relation, it is clear that $\alpha_e$ depends on the size of the atom.

The induced electronic dipole moment per unit volume is the electronic polarization $P_e$ . If 'N' is the number of atoms per unit volume then

$$P_e = N\mu_e$$

$$P_e = N\alpha_e E \text{ -----------} \rightarrow (3)$$

But $$P_e = \varepsilon_0 E(\varepsilon_r - 1) \text{ -------} \rightarrow (4)$$

Comparing the equation 3 and 4, we have

$$\varepsilon_0 E(\varepsilon_r - 1) = N\alpha_e E$$

$$\varepsilon_0 (\varepsilon_r - 1) = N\alpha_e$$

$$\alpha_e = \frac{\varepsilon_0 (\varepsilon_r - 1)}{N}$$

From the above relation, it is clear that electronic polarization is independent of temperature. It takes place in a time period of $10^{-14}$ *and* $10^{-15}$ second.

## 4 a) Deduce an expression for Lorentz field relating to Dielecric material.

"The total resultant electric field acting on an atom inside the polarized dielectric is known as Local Field or Internal Field or Lorentz field."

- To find the expression for local on an atom at point 'A' inside the dielectric, this is placed inside the charged parallel plate capacitor.
- Now the dielectric is placed in the electric field across the charged plates.
- According to Lorentz method, let us imagine a spherical region with the atom at 'A' as the center so that the spherical region can cover the maximum surface of polarized dielectric as shown in fig.

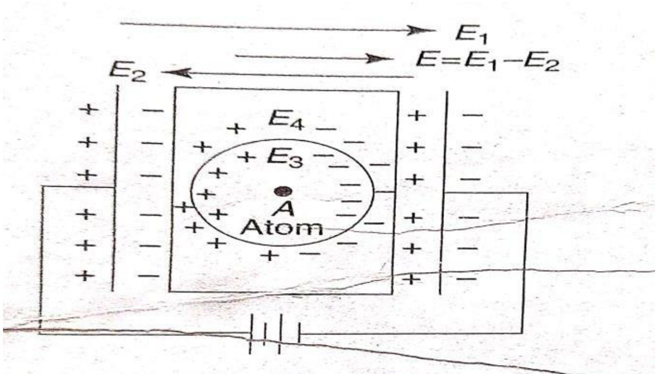


Figure 8.7 Polarised dielectric in electric field

Let $E_1$ be the electric field due to charged capacitor

$E_2$ is the electric field due to induced charges on the dielectric

$E_3$ is the field due the dipoles present within the spherical region

$E_4$ is the field due to the surface charges on the spherical region.

Then the total electric field on an atom at point ‘A’ inside the dielectric is given by

Local field $E_i = E_1+E_2+E_3+E_4$ --------------→(1)

As shown in the fig, let E be the resultant field due to $E_1$ and $E_2$

For a cubic structure, due to symmetrical distributions of charges within the spherical region $E_3=0$

$E_2=E+E_4$ --------------→(2)

Calculation of field $E_4$

The enlarged view of the spherical region is shown in fig. If dA is the surface area of the sphere of radius r lying between $\theta$ and $\theta + d\theta$ , where $\theta$ is the direction with reference to the direction of the applied field, then

$$dA = 2\pi (SQ)(QR)$$

$$\begin{aligned} \sin\theta &= SQ/r \\ SQ &= r\sin\theta \end{aligned} \quad , \quad \begin{aligned} d\theta &= QR/r \\ QR &= rd\theta \end{aligned} \quad \text{---------}\rightarrow(3)$$

$$dA = 2\pi (r\sin\theta)(rd\theta)$$

$$dA = 2\pi r^2 \sin\theta d\theta \text{ ---------------- }\rightarrow(4)$$

The charge dq on the surface dA is equal to the normal component of the polarization multiplied by the surface area. Therefore,

$$dq = P\cos\theta dA$$

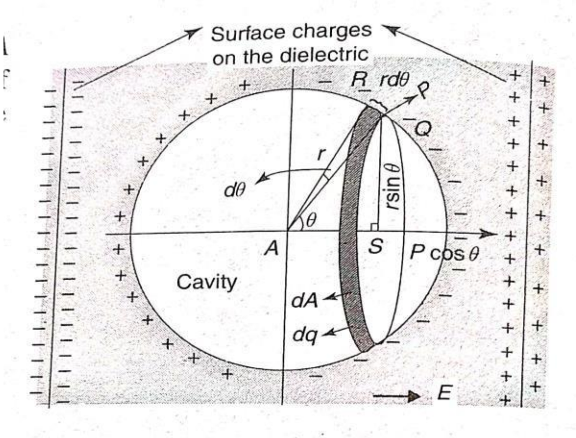


Figure 8.8 Enlarged view of spherical region

$$dq = P(2\pi r^2 \sin\theta \cos\theta d\theta) \text{------} \rightarrow (5)$$

The field due to the charge dq is denoted by $dE_4$ it is in the direction is $\theta = 0$

$$dE_4 = \frac{dq\cos\theta}{4\pi\varepsilon_o r^2} \text{-----------------} \rightarrow (6)$$

$$= \frac{P(2\pi r^2 \sin\theta \cos\theta) d\theta \cos\theta}{4\pi\varepsilon_o r^2} \text{-------} \rightarrow (7)$$

$$dE_4 = \frac{P\cos^2\theta \sin\theta d\theta}{2\varepsilon_o} \text{-------------} \rightarrow (8)$$

integrating the above equation within the limit $0, \pi$

$$\int dE_4 = \frac{p}{2\varepsilon_0}\int_0^{\pi} \cos^2\theta \sin\theta d\theta$$

$\cos\theta = x$ $\theta = 0$ => x=1

$-\sin\theta d\theta = dx$ $\theta = \pi$ => x=-1

$$E_4 = \frac{-P}{2\varepsilon_0}\int_1^{-1} x^2 dx$$

$$E_4 = \frac{-P}{2\varepsilon_0}\left|\frac{x^3}{3}\right|_1^{-1}$$

$$E_4 = \frac{-P}{2\varepsilon_0}\left[\frac{-1}{3} - \frac{1}{3}\right]$$

$$E_4 = \frac{P}{3\varepsilon_0} \text{----------} \rightarrow (9)$$

Total field $E_i = E_1 + E_2 + E_3 + E_4$

$$E_i = E + 0 + \frac{P}{3\varepsilon_0}$$

$$E_i = E + \frac{p}{3\varepsilon_O}$$

This equation is known as Lorentz equation or local field or internal field.

Local field is greater than the electric field applied

**b ) The relative permittivity of argon at $0^0$ C and at 1 atmospheric pressure is 1.000435.Calculate the polarizability of the atom if the gas contains $2.7\text{x}10^{25}$ atoms/$m^3$.Given $\varepsilon_0 = 8.85 \text{ x } 10^{-12}$ F/m.**

Dielectric constant $\varepsilon_r = 1.000435$

Number of atoms/$m^3$, $N = 2.7\text{X}10^{25}$ atom/$m^3$

` $\varepsilon_0 = 8.85 \text{ x } 10^{-12}$ F/m.

Electronic polarisability $\alpha_e = ?$

Electronic polarisability $\alpha_e = \frac{\varepsilon_0(\varepsilon_r - 1)}{N}$

$$\alpha_e = \frac{8.85 \times 10^{-12}\,(1.000435 - 1)}{2.7 \times 10^{25}}$$

$$\alpha_e = 1.42 \times 10^{-40}\, Fm^2$$

**5 a) Obtain Clausius-Mosotti equation and explain how it can be used to determine the dipole moment of a polar molecule.**

The relation between the dielectric constant and the polarizability of polarized dielectric is known as Clausius – Mosotti equation.

To derive the relation, let its consider a polarized dielectric in which $E_i$ is the local field.

Then the induced dipole moment is proportional to $E_i$

$$\mu \; \alpha \; E_i$$

$$\mu = \alpha \; E_i \text{-------------} \rightarrow (1)$$

where $\alpha$ is the polarisability of dielectric.

N is the number of atoms per unit volume of a dielectric

Then the polarization is given by

$$P = N\mu$$

$$P = N\alpha E_i \text{-----------}\rightarrow(2)$$

Displacement vector $D = \varepsilon_0 E + P$

but, $D = \varepsilon E = \varepsilon_0 \varepsilon_r E$

$$\varepsilon_0 \varepsilon_r E = \varepsilon_0 E + P$$

$$P = \varepsilon_0 E(\varepsilon_r - 1) \text{ --------}\rightarrow(3)$$

But local field, $E_I = E + \frac{P}{3\varepsilon_O}$ ------→(4)

From equation (2), $P = N\alpha E_i$

$$P = N\alpha\left[E + \frac{P}{3E_O}\right]$$

$$P = N\alpha E + N\alpha \frac{p}{3\varepsilon_0}$$

$$P = N\alpha E + N\alpha \frac{p}{3\varepsilon_0}$$

$$P\left[1 - \frac{N\alpha}{3\varepsilon_O}\right] = N\alpha E$$

$$P = \frac{N\alpha E}{\left[1 - \frac{N\alpha}{3\varepsilon_O}\right]} \text{ ------------}\rightarrow(5)$$

From (3) and (5) equations

$$\varepsilon_O E((\varepsilon_r - 1) = \frac{N\varepsilon E}{1 - \frac{N\alpha}{3\varepsilon_o}}$$

$$1 - \frac{N\alpha}{3\varepsilon_O} = \frac{N\alpha E}{\varepsilon_O E(\varepsilon_r - 1)}$$

$$1 - \frac{N\alpha E}{\varepsilon_O(\varepsilon_r - 1)} = \frac{N\alpha}{3\varepsilon_O}$$

$$1 = \frac{N\alpha}{3\varepsilon_O} + \frac{N\alpha E}{\varepsilon_O(\varepsilon_r - 1)}$$

$$1=\frac{N\alpha}{3\varepsilon_O}\left[\frac{3}{(\varepsilon_r-1)}+1\right]$$

$$1=\frac{N\alpha}{3\varepsilon_O}\left[\frac{3+\varepsilon_r-1}{\varepsilon_r-1}\right]$$

$$1=\frac{N\alpha}{3\varepsilon_O}\left[\frac{\varepsilon_r+2}{\varepsilon_r-1}\right]$$

$$\frac{N\alpha}{3\varepsilon_O}=\frac{\varepsilon_r-1}{\varepsilon_r+2}$$

The above reaction relating $\alpha$ and $\varepsilon_r$ known as the Clausius – mosotti relation (or) equation.

**b) A solid elemental dielectric with 3x$10^{28}$ atoms/ $m^3$ shows an electronic polarisability of $10^{-40}$ F-$m^2$ assuming the internal electric field to be a Lorenz field. Calculate a dielectric constant of the material.**

Density of electric atoms, $N=3X10^{28}$ atom/$m^3$

Electronic polarisability, $\alpha_e=10^{-40}\,Fm^2$

Dielectric constant $\varepsilon_r=?$

$$\varepsilon_r-1=\frac{N\alpha_e}{\varepsilon_0}$$

$$\varepsilon_r=\frac{N\alpha_e}{\varepsilon_0}+1$$

$$\varepsilon_r=\frac{3\times10^{28}\times10^{-40}}{8.854\times10^{-12}}+1$$

$$\varepsilon_r=\frac{3}{8.854}+1$$

$$\varepsilon_r=1.339$$

**6 a) Discuss the frequency dependence of various polarization processes in dielectric materials.**

When dielectric is subjected to an electric field, the polarization process occurs as a function of time. The total polarization, P as functions of time can be expressed as

$$P=P_0\left[1-e^{\frac{-t}{T_r}}\right]$$

Where $P_0$ is the maximum polarization gained on continuous application of electric field and

$T_r$ is the relaxation time for the particular polarization process

$T_r$ is defined as the time taken for a polarization process to reach 0.63 of its maximum value. This $T_r$ will be different for different polarization process.

1. **Electronic polarization:-**
   Electronic polarization is due to displacement of positive nuclei and negative electron cloud the frequency of the applied voltage is very high in the optical range (near $10^{15}$Hz)
   Electronic polarization takes place during every cycle of applied voltage.
   Electronic polarization is rapid process.
2. **Ionic polarization :-**
   Ionic polarization is due to displacement of ions over a small distance.
   Since ions are heavier then electron cloud, the time taken for displacement is larger.
   When the frequency of the applied voltage is in the same order of the frequency of lattice vibration (near $10^{13}$Hz)

The ionic polarization takes place during every cycle of applied voltage. It clearly says that for optical frequency the ions will not respond.

Because the time required for lattice vibrations is nearly 100 time larger than the period of applied voltage at optical frequency.

3. **Orientation polarization:-**
   Orientation polarization is even slower process than ionic polarization.
   When the frequency of applied voltage is in the audio range (near $10^6$Hz), orientation polarization takes place.
   This means in the frequency range $10^6$Hz to $10^{10}$ Hz

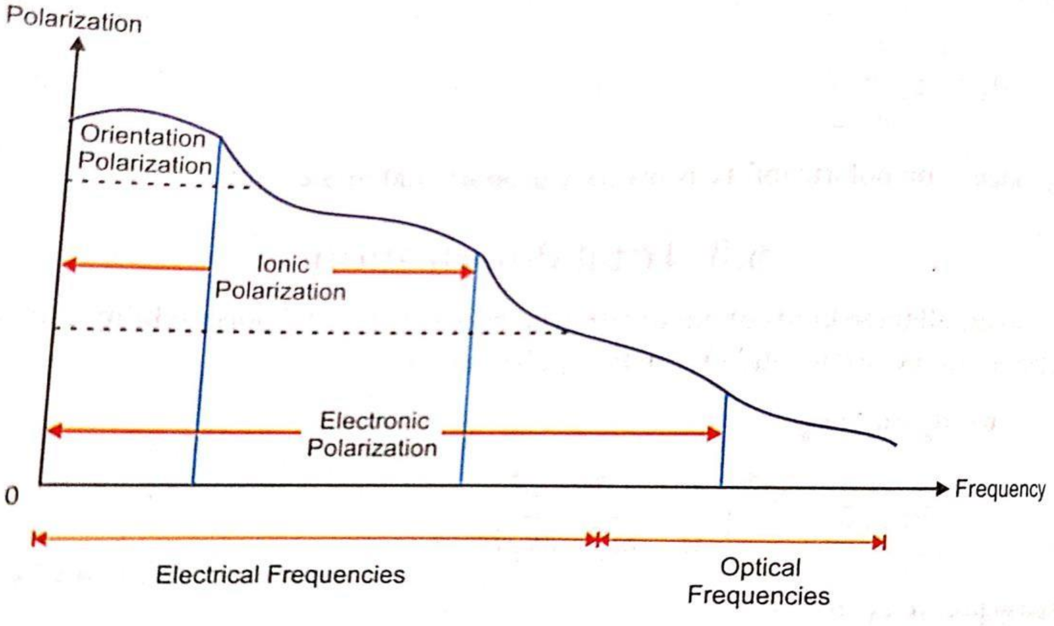


*Fig. 6.9: Frequency dependence of polarization processes*

## b) Write the causes for Dielectric loss.

The causes for Dielectric loss are

i) high frequency of the applied electric field

ii) high temperature

iii) presence of humidity

iv) high applied voltage

## 7 a) Describe the origin of magnetic moment in an atom.

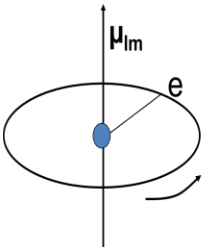
Origin of Magnetic Moment: Magnetism arises from the Magnetic Moment or Magnetic dipole of Magnetic Materials. When the electrons revolves around the nucleus Orbital magnetic moment arises, similarly when the electron spins, spin Magnetic moment arises. The Magnetic moment in a material originates from the orbital motion and spinning motion of electrons in an atom

The permanent Magnetic Moments can arise due to the

1.The magnetic moment due to orbital motion of the electrons

2.The magnetic moment dur to spin of the electrons, and

3.The magnetic moment due to spin of the nucleus.



Consider an atom & each electron in that, orbiting around the nucleus produces a loop current

$$i = q / t$$

$$i = q f$$

Where f is a frequency of electron..

If L is the angular momentum of electron, the Magnetic moment of the electron

$$\mu_{lm} = (\text{Area of loop}) \times (\text{Current})$$

$$\mu_{lm} = (\pi r^2)(\frac{q}{t})$$

$$\mu_{lm} = (\pi r^2)(qf)$$

$$\mu_{lm} = (\pi r^2)(\frac{q}{2\pi} \times 2\pi f)$$

$$\mu_{lm} = (\pi r^2)(\frac{q}{2\pi} \times \omega)$$

$$\mu_{lm} = (\pi r^2)(\frac{q}{2\pi} \times \frac{v}{r})$$

$$\mu_{lm} = \frac{qvr}{2}$$

$$\mu_{lm} = \frac{q}{2m}.mvr$$

$$\mu_{lm} = \frac{q}{2m}.L$$

Where L is a Angular Momentum of electron

$$L = mvr = \frac{lh}{2\pi}$$

$$L = mvr = \sqrt{l(l+1)}\frac{h}{2\pi}$$

$$\mu_{lm} = \frac{q}{2m}.L$$

$$\mu_{lm} = \frac{q}{2m}.\sqrt{l(l+1)}\frac{h}{2\pi}$$

$$\mu_{lm} = \frac{qh}{4\pi m}.\sqrt{l(l+1)}$$

$$\mu_{lm} = \mu_B.\sqrt{l(l+1)}$$

$$where.,\mu_B(Bhor,.magnaton) = \frac{qh}{4\pi m} \rightarrow 9.27408 \times 10^{-24} A - m^2$$

**Electron Spin :**

The value of spin angular momentum is given by

$$\mu_s = \frac{1}{2}\left(\frac{eh}{4\pi\pi}\right)$$

Thus the spin magnetic moment is half of a Bohr Magneton

**Nuclear Spin: -**

The atomic nucleus possesses nuclear spin. As the electron magnetic moment is expressed in the unit of Bohr Magneton, the nuclear magnetic moment is expressed in the unit of nuclear magneton µn.

$$\mu_n = \frac{eh}{4\pi Mp} = 5.05 * 10^{-27} Am^2$$

Where Mp is the mass of the proton

b) A circular loop of copper having a diameter of 10 cm carries a current of 500mA.Calculate the magnetic moment associated with the loop.

Diameter of the circular loop d = 10cm

d = 2r =10 cm =0.1m

`Radius of the circular loop r=5cm=0.05m

Current in the circular loop I=500mA=0.5A

Magnetic moment

$$\mu = AI = \pi r^2 l$$
$$\mu = 3.14 \times 0.05^2 \times 0.5$$
$$\mu = 3.93 \times 10^{-3}\ Am^2$$

**8 Describe the classification of magnetic materials based magnetic moments.**

| Diamagnetic materials | Paramagnetic materials | Ferromagnetic materials | Antiferromagnetic materials | Ferrimagnetic materials |
|---|---|---|---|---|
| 1 Net magnetic moment exists in the presence of magnetic field in opposite direction. . | 1 Net magnetic moment exists in the direction of applied magnetic field | 1 Large net magnetic moment exists in the direction of applied magnetic field. | 1 Net magnetic moment exists in the direction of applied magnetic field. . . | 1 Net large magnetic moment exists in the direction of applied magnetic field. |
| 2 There is an induced magnetism opposite to applied magnetic field. | 2 There is an induced magnetism direction of the field. | 2 There is strong induced magnetism in the direction of field. | 2 There is an induced magnetism in the direction of the field. | .2 There is a large induced magnetism in the direction of field. |
| 3 It repels the magnetic lines of force due to the external magnetic field. | 3 It allows the magnetic lines of force pass through it. | 3 It allows a large number of magnetic lines of force pass through it. | 3 It allows the magnetic lines of force pass through it. | 3 It allows a large number of magnetic lines of force to pass through it |
| 4 Relative permeability $\mu_r < 1$ | 4 Relative permeability $\mu_r > 1$ | 4 Relative permeability $\mu_r >> 1$ | 4 Relative permeability $\mu_r > 1$ | 4 Relative permeability $\mu_r >> 1$ |
| 5 Susceptibility $(\chi)$ is negative. | 5 Susceptibility $(\chi)$ is low and positive. | 5 Susceptibility $(\chi)$ is high and positive | 5 Susceptibility $(\chi)$ is low and positive. | 5 Susceptibility $(\chi)$ is high and positive |
| 6 When it is placed in magnetic field all magnetic lines of forces are reples | 6 When it is placed in magnetic field all magnetic lines of forces are in same direction | 6 When it is placed in magnetic field all magnetic domains aligned in a single direction | 6 It consisting of equal magnitude and parallel magnetic lines of forces | 6 It consisting of equal magnitude and anti parallel magnetic lines of forces |

|  |  |  |  |  |
|---|---|---|---|---|
| 7 Susceptibility ($\chi$) is independent of temperature | 7 $\chi = \frac{C}{T}$ which is Curie law where C is constant. | 7 $\chi = \frac{C}{T \pm T_C}$ which is curie Weiss law where $T_c$=Curie temperature. | 7 $\chi = \frac{C}{T + T_C}$ | 7 $\chi = \frac{C}{T \pm T_C}$ |
| 8 Intensity of magnetization M is negative. | 8 Intensity of magnetization M is positive and moderate. | 8 Intensity of magnetization M is positive and high. | 8 Intensity of magnetization M is positive and moderate | 8 Intensity of magnetization M is positive and high. |
| 9. E.g.: inert gases: He, Ar etc.<br>Metals: Au, Zn, Cu, Hg, Bi, Sb, Pb, Sn, | 9 E.g.: gases : O2, N2<br>Metals : Al, Pt, Mn, Cr, Pd<br>Alkali & alkaline earth metals<br>And rare earths | 9 E.g.: Fe, Co, Ni, Gadolinium (Gd), Dysprosium (Dy) alloys<br>Like Alnico | 9 Salts of transition elements | 9 Ferrites |

### 9 a) Explain hysteresis of ferromagnetic material.

in a magnetic field,

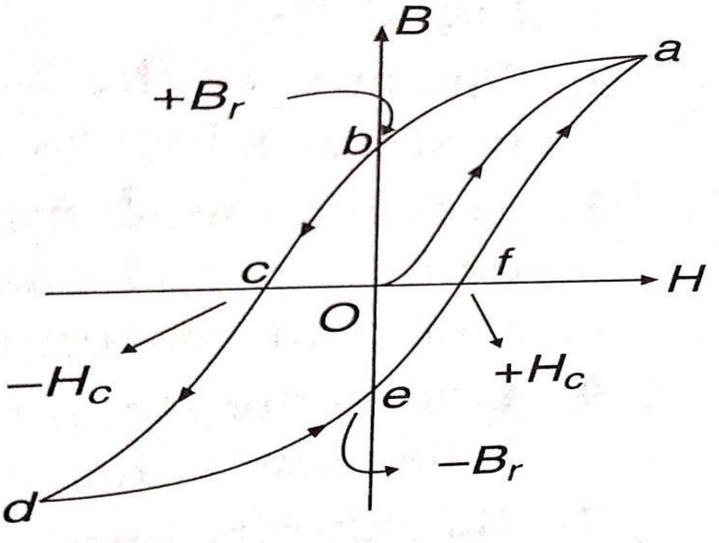


Figure 8.15 Hysteresis

When a specimen of ferromagnetic material is placed in a magnetic field, the specimen is magnetized by induction. As he magnetic intensity H is varied, the flux density B in the material does not vary linearly with H is shown in fig. The point O represents an initially unmagnetised specimen and a zero magnetic intensity. As H is increased, B also increases, but not uniformly, and a point such as ‘a’ is reached.

If H is now decreased, B also decreases but following a path ab. Thus, B lags behind H. When H becomes zero. B still has a value equal to Ob. This magnetic flux density remaining in the specimen in the absence of any external field is called the residual magnetism. The power of retaining this magnetism is call the retentivity of the specimen. Thus, the rentivity B, of specimen is a measure of the magnetic flux remaining in the specimen when the magnetising force is removed.

If the magnetic intensity H is now increased in the reverse direction, the value of B further decreases, still lagging behind H, and becomes zero when H has a value equal to OC. This value of magnetic intensity is called the coercive force or coercivity of the specimen. Thus coercivity $H_c$ is a measure of the magnetic intensity required to destroy the residual magnetism of the specimen.

As H is increased beyond OC, the specimen is increasingly magnetized in the opposite direction, and a point such as d is reached.

By taking H back from its negative maximum value, through zero, to its original positive maximum value, a similar curve defa is obtained. At point b and e where the specimen is magnetized in the absence of any external magnetic intensity, it is said to be a permanent magnet.

It is thus found that the flux density B always lags behind the magnetic intensity H. the lagging of B behind H is called Hysteresis. The closed curve abcdefa which represents a cycle of magnetization of the specimen is known as the hysteresis curve of the specimen.

b) A magnetic material has magnetization 3300A/m and flux density of 0.0044 $Wb/m^2$. Calculate the magnetizing force and relative permeability of the material.

Magnetization M = 3300A/m

Flux density B = 0.0044 $Wb/m^2$

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

$$H = \frac{B}{\mu_0} - M$$

$$H = \frac{0.0044}{4 \times 3.14 \times 10^{-3}} - 3300$$

$$H = 203 A/m$$

$$\mu_r = \frac{M}{H} + 1$$

$$\mu_r = \frac{3300}{200} + 1 = 17.5$$

**10 a Explain the domain concept of ferromagnetism.**

**Magnetic Domains**

*A ferromagnetic material is divided into a large number of small region is called domains (0.1 to 1 of area).* The direction of magnetization varies from domain to domain and the net magnetization is zero, in the absence external magnetic field. *The boundary line which separates two domains is called domain wall or Block wall.* When the magnetic field is applied to the Ferromagnetic material, the magnetization is produced by two ways.

- By the motion of domain walls.
- By the rotation of domains.

**By the motion of Domain walls**

When a small amount of magnetic field is applied, the dipoles in the domains are aligned parallel

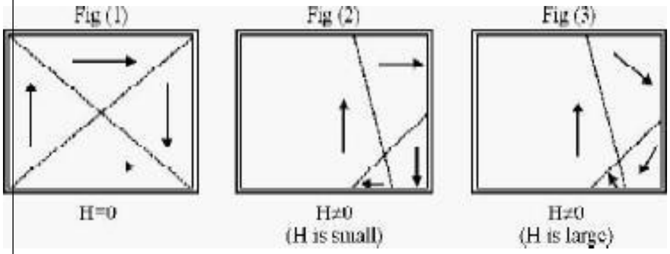
To the applied magnetic field. It increases domain are a by the motion of domain walls.

By the rotation of Domains

If the applied magnetic field is further increased, the domains are rotated parallel to the field direction by the rotation of domains.

**Energies involved in the domain growth (or)**

Origin of Domain theory of Ferromagnetism



We can understand the origin of domains from the thermodynamic principle i.e., in equilibrium, the total energy of the system is minimum. The total internal energy of the domain structure in a ferromagnetic material is made up from the following contributions.

1. Exchange energy(or)Magnetic field energy.
2. Crystalline energy(or)Anisotropy energy.
3. Domain wall energy(or)Bloch wall energy.
4. Magnetostriction energy

**1. Exchange energy(or)Magnetic Field energy**

"The interaction energy which makes the adjacent dipoles align themselves" is the called exchange energy (or) magnetic field energy. It arises from an interaction of electron spins. It depends upon the inter atomic distance. This exchange energy also called magnetic field energy. Whose energy is required in assembling the atomic magnets into a single domain and this work done is stored as potential energy. The volume of the domain may very between $10^{-2}$ to $10^{-6}$ $cm^3$.

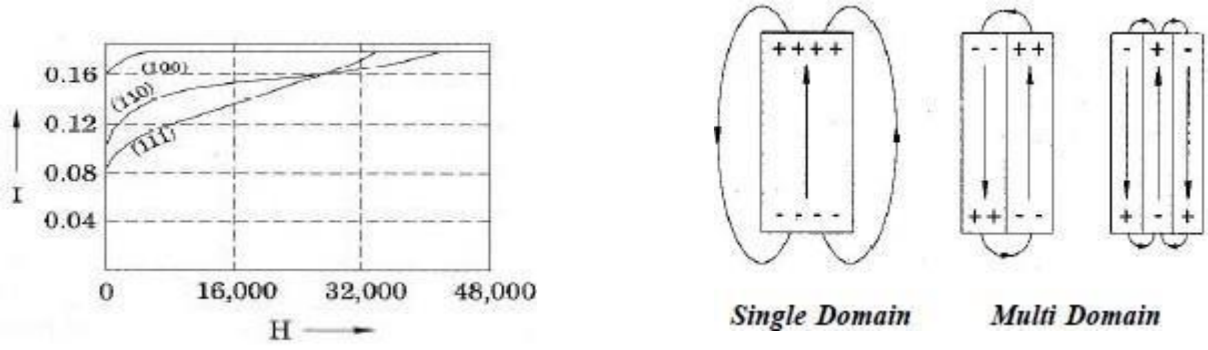


Fig:3.19

**2. Anisotropy energy**

The excess of energy is required to magnetize a specimen along the easy direction is called the crystalline anisotropy energy. In ferromagnetic materials there are two types of directions of magnetization namely,

- ❖ Easy direction and
- ❖ Hard directions.

In easy direction of magnetization, weak field can be applied and in hard direction of magnetization, strong field should be applied.

*Crystalline an isotropy energy* is energy of magnetization which is the function of crystal orientation.Asshowninfiguremagnetizationcurvesforironwiththeappliedfieldalongdifferent crystallographic direction crystallographic directions have been drawn. For example, in BCC iron the easy direction is [100], the medium direction is [110], and the hard direction [111]. This energy is very important in determining the characteristic domain boundaries.

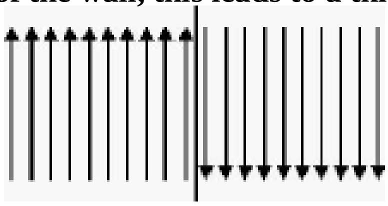
**3. Domain wall energy or Bloch wall energy**

A thin boundary or region that separates adjacent domains indifferent directions is called domain wall or Bloch wall. The size of the Bloch walls is about 200 to 300 lattice constant thickness. The energy of domain wall is due to both exchange energy and anisotropic energy. Based on the spin alignments, two types of Bloch walls may arise, namely

**Thick wall:** When the spins at the boundary are misaligned and if the direction of the spin changes gradually as shown in below figure, it leads to a thick Bloch wall. Here the misalignments of spins are associated with exchange energy.

**Fig:3.21**

**Thin wall: When the spins at the boundaries changes abruptly, then the anisotropic energy becomes very less. Since the anisotropic energy is directly proportional to the thickness of the wall, this leads to a thin Bloch wall.**



**4. Magetostriction energy**

When a material is magnetized, it is found that it suffers a change in dimensions. This phenomenon is known as Magneto striction. This de formation is different along different crystal directions. So if the domains are magnetized indifferent directions, they will either expand or shrink. This means that work must be done against the

Elastic restoring forces. The work done by the magnetic field again sttheseelasticre storing forces is called magneto- elastic energy or Magnetonstrictive energy.

b) A paramagnetic material has a magnetic field intensity of $10^4$ A/m. If the susceptibility of the material at room temperature is $3.7 \times 10^{-3}$. Calculate the magnetization and flux density in the material.

Intensity of magnetic field $H = 10^4$ A/m

Susceptibility $\chi = 3.7 \times 10^{-3}$

Magnetization (M) =?

flux density (B) =?

Magnetization M= $\chi H$

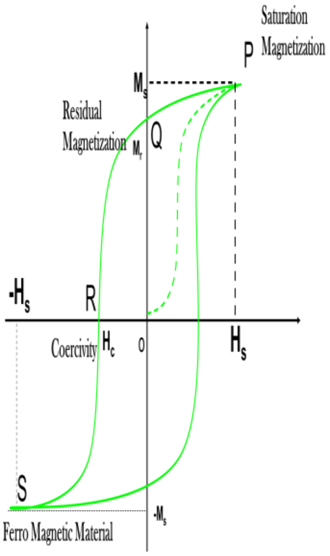
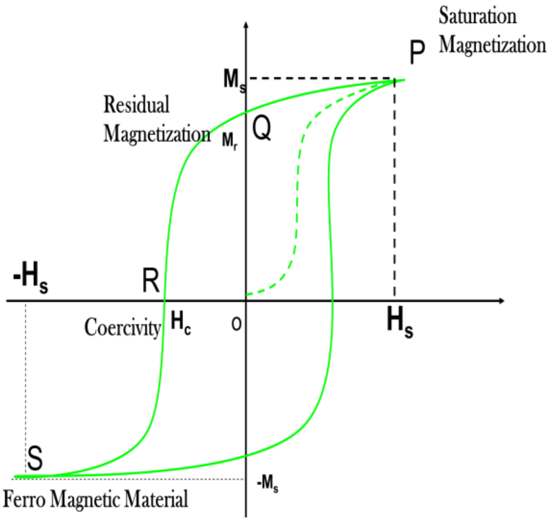
$$M = 3.7 \times 10^{-3} \times 10^4$$
$$M = 37 A/m$$

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

Flux density $B = 4 \times 3.14 \times 10^{-7} (10^4 + 37)$

$$B = 12.6 \times 10^{-3} wb/m^2$$

## 11 a Distinguish between Soft and Hard magnetic material.

| Soft magnetic materials | Hard magnetic materials |
|---|---|
|  <br>➢ Soft magnetic material can be easily magnetized and demagnetized.<br>➢ The nature of the hysteresis loop of a soft magnetic material is very steep.<br>➢ The hysteresis area is very small and hence the hysteresis loss is also small.<br>➢ These materials have large valves of |  <br>➢ Magnetized and demagnetized of hard magnetic material are very difficult.<br>➢ The nature of the hysteresis curve is very board and has a large area.<br>➢ The hysteresis loss is very large.<br>➢ These materials have low valve of susceptibility and permeability. |

| | |
|---|---|
| susceptibility and permeability.<br>➢ Their coercivity and retentivity values are small.<br>➢ These materials are free from irregularities like strain (or) impurities.<br>➢ These are used to make electromagnets.<br>➢ Soft magnetic materials are used in the preparation of magnetic core materials used transformers, electric motors, magnetic amplifiers etc.<br>➢ Ex: (1) Iron – Silicon alloys (2) Nickel – Iron alloys (3) Iron – Cobalt alloys. | ➢ Their coercivity and retentivity values are large.<br>➢ These materials have large amount of impurities and lattice defects.<br>➢ These are used to make permanent magnets.<br>➢ Hard magnetic materials are used in the preparation of permanent magnets which are used in loud speakers, microphones, magnetic detectors etc.<br>➢ Ex. Carbon Steels, Tungsten Steel, Chromium Steal, Alnico etc |

**b) A paramagnetic material has $10^{28}$ atoms per $m^3$. Its susceptibility at 350 K is 2.8 x $10^{-4}$. Calculate the susceptibility at 300 K.**

Number of atoms, N $=10^{28}$ atoms/$m^3$

Susceptibility at 350 K, $\chi_1 = 2.8\times10^{-4}$

Temperature $T_1$ =350 K

Temperature $T_2$ =300 K

Susceptibility at 300 K, $\chi_2 = ?$

$$\therefore \chi = \frac{C}{T} \Rightarrow C = \chi T$$

$$\chi_1 T_1 = \chi_2 T_2$$

$$\chi_2 = \frac{\chi_1 T_1}{T_2}$$

$$\chi_2 = \frac{2.8\times10^{-4}\times350}{300}$$

$$\chi_2 = 3.267\times10^{-4}$$

# UNIT-IV : QUANTUM MECHANICS & FREE ELECTRON THEORY

## 2 a) Derive the expression for de Broglie wavelength.

Ans. **De-Broglie Concept of Matter waves: -**

In 1924 de-Broglie suggest that an electron 'or' a material particle must exhibit wave like properties in addition to particle nature. The waves associated with material particles are called 'matter waves'

From theory of light considering a photon as a particle, the total energy of the photon is given by

$$E = mc^2 \qquad (1)$$

m = mass of the particle

c = velocity of light

Considering the photon as a wave the total energy is given by

$$E=hv \qquad (2)$$

h = planck's constant

$v$ = frequency of radiation

From equations (1) and (2)

$$mc=hv$$

$$mc.c=hv$$

$$pc=hv \qquad (\because mc = p)$$

$$p=\frac{hv}{c} \qquad [c=v\lambda]$$

$$p=\frac{h}{\lambda} \qquad \left[\lambda=\frac{c}{v}\right]$$

$$\lambda=\frac{h}{p} \qquad \left[\frac{1}{\lambda}=\frac{v}{c}\right]$$

$$\lambda=\frac{h}{mv} \qquad [\therefore p = mv]$$

**De – Broglie wave length interms of 'ENERGY': -**

We know that

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

Multiplying 'm' with both sides

$$m.\,KE=\frac{1}{2}m^2v^2$$

$$m.KE = \frac{1}{2} p^2 (\therefore mv = p)$$

$$2m.KE = p^2$$

$$\sqrt{2m.KE} = p$$

$$\sqrt{2m.KE} = \frac{h}{\lambda}$$

$$\lambda = \frac{h}{\sqrt{2mKE}}$$

**De – Broglie wave length interms of voltage: -**

If a charged particle of charge ‘e’ is accelerated through a potential difference ‘v’

We know that

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

Where v = velocity of electron

Also we know energy = eV

Where V = potential difference

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

Multiplying ‘m’ with both sides

$$meV = \frac{1}{2} m^2 v^2$$

$$2mev = p^2 \qquad (mv = p)$$

$$p = \sqrt{2mev}$$

$$\frac{h}{\lambda} = \sqrt{2mev} \left(\therefore p = \frac{h}{\lambda}\right)$$

$$\lambda = \frac{h}{\sqrt{2meV}}$$

**De – Broglie wave length of electron: -**

The charged particle is taken as electron then

$$\lambda = \frac{h}{\sqrt{2meV}}$$

h=6.626x$10^{-34}$ JS , m=9.1x$10^{-31}$ Kg , e = 1.6x$10^{-19}$ coulombs

sub these values in above equation , we get $\lambda = \frac{12.26 \text{ K } 10^{-10}}{\sqrt{V}} m$

$$\lambda = \frac{12.26}{\sqrt{V}} A^0$$

**b) Explain the properties of matter waves.**

**Properties of de-Broglie Waves: -**

The de-Broglie Wavelength $\lambda = \frac{h}{mV}$

1. The lighter the particle, the greater the wavelength associated with it
2. Lesser the velocity of the particle, longer the wavelength associated with it
3. When v = 0, $\lambda = \infty$ and if v = $\infty$ ,$\lambda$ = 0. This shows that matter waves are generated by the motion of the particles.
4. Matter waves are produced when the particles in motion are charged or uncharged.
5. Matter waves are not electromagnetic waves, they are pilot waves guiding the particle.
6. Matter waves travel faster than velocity of light i.e.

   $u = \frac{c^2}{v}$ as the particle velocity v cannot exceed the velocity of light.

7. While a position of a particle is confined to a particular location at any time, the matter wave associated with it has some spread as it is a wave. Thus the wave nature of matter introduces an uncertainly in the location of the position of the particle.

**3 a)Derive Schrodinger's Time – Independent Wave Equation.**

**ANS:**

**Schrodinger's One – Dimensional Time – Independent Wave Equation: -**

According to de Broglie hypothesis, the particle in motion is always associated with a wave. To describe the motion of a particle in terms of its associated wave, Schrödinger derived a wave equation which is termed as *Schrödinger's wave equation*.

Consider a particle of mass 'm' moving with velocity '*v*' along the *x* direction. It is associated with a wave. The displacement of a wave is given by the wave function Ψ.

Since the wave function depends upon the *x* coordinate of the moving particle and time 't', it is given by the complex form

$$\Psi(x, t) = Ae^{i(kx-\omega t)} \text{--------------------} \rightarrow (1)$$

where A is amplitude

diff eqn(1) w.r.t, *x* we get

$$\frac{dW}{dx} = \mathrm{i}k\,Ae^{\mathrm{i}(kx-\omega t)}$$

Again diff , we have $$\frac{d^2W}{dx^2} = \mathrm{i}^2k^2Ae^{\mathrm{i}(kx-\omega t)}$$

$$= \mathrm{i}^2k^2\Psi$$

$$\frac{d^2W}{dx^2} = -\,k^2\,\Psi$$

Since $k = \frac{2\pi}{}$, we get $$\frac{d^2W}{dx^2} = \frac{-\pi^2}{2}\,\Psi \text{ -------} \rightarrow (2)$$

de Broglie wavelength associated with the particle is

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

$$\frac{1}{2} = \frac{m^2v^2}{h^2} = \frac{2m(\frac{1}{2}mv^2)}{h^2} \quad \text{------------}\rightarrow (3)$$

Let E be the total energy of the particle and V be the potential energy of the particle. Then

$$\text{KE} = \frac{1}{2}\,mv^2 = E - V$$

Using the above value in eqn(3), we get

$$\frac{1}{2} = \frac{2m}{h^2}(E - V)$$

Using the above value in eqn(2), we get

$$\frac{d^2W}{dx^2} = \frac{-8\pi^2m}{h^2}(E - V)\Psi$$

$$\frac{d^2W}{dx^2} + \frac{8\pi^2m}{h^2}(E - V)\Psi = 0$$

$$\frac{d^2W}{dx^2} + \frac{2m}{h^2}(E - V)\Psi = 0 \;(\,\therefore\; h = \frac{h}{2\pi})$$

The above equation represents Schrödinger’s one-Dimensional time independent wave equation.

For three dimensional motion of the particle the above equation becomes

$$A^2T + \frac{2m}{h^2}(E - V)T = 0$$

Where $A^2 = \frac{d^2}{dx^2} + \frac{d^2}{dy^2} + \frac{d^2}{dz^2}$ is called **Laplace operator.**

### b) Explain the Physical Significance of Wave Equation.

**Physical Significance of Wave Equation: -**

1. The wave funcion $\psi$ has no direct physical meaning. It is a complex quantity representing the variation of matter wave. It connects the particle nature and its associated wave nature statistically.

2. $\psi\psi^{x} or |\psi|^{2}$ is the **probability density function**. $\psi\psi dxdydz$ gives the probability of finding the particle in the region of space between x and x+dx, y and y+dy and x and z+dz. If the particle is present.

$\boxed{\int \psi\psi^{x} dxdydz = 1}$ This is known as **normalized condition of wave function**.

3. It can be considered as probability amplitude since it is used to find the location of the particle.
4. It can be considered as probability amplitude since it is used to find the location of the particle.
5. It must be finite everywhere.
6. It must be single valued.
7. It must be continuous and have a continuous first derivative everywhere.

### 4 a) Derive Schrodinger time dependent wave equation.

ANS:

**Schrodinger time dependent wave equation:**

Let us eliminate the total energy E from time independent wave equation. The wave function is given by

$$\Psi(x, t) = Ae^{i(kx-\omega t)}$$

Diff the above eqn w.r.t, ‘t’, we get

$$\frac{dW}{dt} = -i\omega\, Ae^{i(kx-\omega t)}$$

$$= -\, i\, (2\pi P)\, Ae^{i(kx-\omega t)}$$

$$= -\, 2\pi i P\, \Psi$$

Since $E = hP$ , $P = \frac{E}{h}$

$$\frac{dW}{dt} = -\frac{2\pi i E}{h} T$$

$$= -\frac{2\pi i E}{2\pi h} T \quad \text{(since } h = 2\pi\hbar\text{)}$$

$$\frac{dW}{dt} = \frac{EW}{ih}$$

$$ET = \mathrm{i}h\,\frac{dW}{dt}$$

using the value of $ET$ in the eqn

$$\frac{d^2W}{dx^2} + \frac{2m}{h^2}(E - V)\Psi = 0$$

We get $$\frac{d^2W}{dx^2} + \frac{2m}{h^2}\left[\mathrm{i}h\,\frac{dW}{dt} - VT\right] = 0$$

$$\frac{d^2W}{dx^2} = -\frac{2m}{h^2}\left[\mathrm{i}h\,\frac{dW}{dt} - VT\right]$$

$$\frac{-h^2}{2m}\frac{d^2W}{dx^2} + VT = \mathrm{i}h\,\frac{dW}{dt}$$

The above equation represents time dependent Schrödinger’s one-dimensional wave equation.

For three dimensional motions, the above equation becomes

$$\frac{-h^2}{2m}\mathrm{A}^2T + VT = \mathrm{i}h\,\frac{dW}{dt}$$

$$H\psi = E\psi$$

$(\mathrm{V}-\frac{{}^{\prime\,2}}{2m}\frac{\partial^2}{\partial x^2}) = H$ is called Hamiltonian operator

$E = i' \frac{\partial}{\partial t}$ Is called energy operator

**b) An electron is moving under a potential field of 15 kV. Calculate the wavelength of an electron wave?**

**Solution:**

Given data:

Potential field V = 15 kV = 15000 Volts

Calculate the wavelength = ?

Formula Wavelength $\lambda = \frac{12.26}{\sqrt{V}}\,°A$

$$\lambda = \frac{12.26}{\sqrt{15000}}\,°A = 0.1\ °A$$

## 5 a) Explain Heisenberg uncertainty principle.

Heisenberg's uncertainty principle states that for particles exhibiting both particle and wave nature, it will not be possible to accurately determine both the position and velocity at the same time.

Mathematically,it is given as

$$\Delta x \,.\, \Delta p \geq \frac{h}{4\pi}$$

Where $\Delta x$ is uncertainty in position and $\Delta p$ is uncertainty in momentum

Consider a particle of mass '$m$' moving with velocity '$v$' along $x$ direction. According to classical theory, this moving particle will have specific position and momentum at any time $t$ i.e., its position is given by $x = vt$ and its momentum $p = mv$. Relating the position and momentum, we get

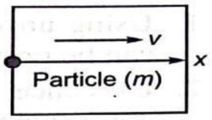


**Figure 6.2** Moving particle

$$x = \frac{p}{m}t$$

From this it is clear that any time, $t$, particle position and momentum can be measured accurately.

According to de Broglie hypothesis, this moving particle is associated with a matter wave. As this wave has some spread in the moving region, and even the particle is some where with in the wave spread region, it is difficult to locate its exact portion. Therefore, there is an uncertainty $\Delta x$ in its position. As a result, the momentum of the particle, cannot be determined precisely.

It means that the position and momentum of a matter wave associated particle cannot be simultaneously determined with accuracy. Any attempt to determine these parameters will lead to uncertainities in each of the parameter. This is known as Heisenberg's uncertainity principle for position and momentum and is stated as, "It is not possible to find simultaneously with the exact accuracy of both the position and momentum of a moving particle associated with matter wave."

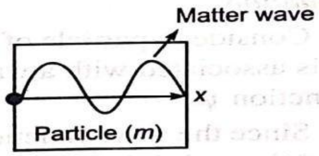


**Figure 6.3** Moving particle associated with matter wave

If $\Delta x$ and $\Delta p$ are the uncertainities in the position and momentum of a moving particle then according to Heisenberg's uncertainity principle, we get

$$\Delta x \Delta p \geqslant \frac{h}{4\pi}$$

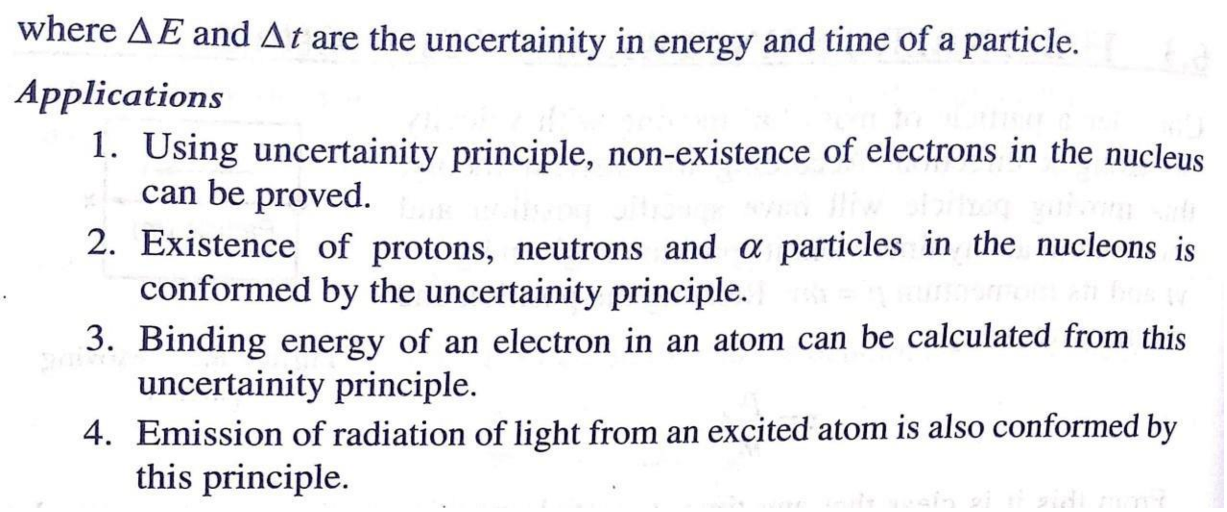
or

$$\Delta x \, \Delta p \geqslant \frac{\hbar}{2} \quad \left[\text{where } \hbar = \frac{h}{2\pi}\right]$$

From this it is clear that, if one parameter is measured accurately then the other associated parameter can not be measured accurately and vice versa. This gives only the probability of finding the particle in a spread region in stead of certainity.

The uncertainity relation for the simultaneous measurement of energy and time is given by

$$\Delta E \, \Delta t \geqslant \frac{\hbar}{2}$$



where $\Delta E$ and $\Delta t$ are the uncertainity in energy and time of a particle.

***Applications***

1. Using uncertainity principle, non-existence of electrons in the nucleus can be proved.
2. Existence of protons, neutrons and $\alpha$ particles in the nucleons is conformed by the uncertainity principle.
3. Binding energy of an electron in an atom can be calculated from this uncertainity principle.
4. Emission of radiation of light from an excited atom is also conformed by this principle.

**b) The position of electron in an atom is located within a distance of 0.1 $A^o$ using a microscope. What is the uncertainty in the momentum of the electron located in this way?**

**SOLUTION:**

Given data: The uncertainty in the position of an electron,

$\Delta x = 0.1 \text{ x } 10^{-10}$ m

Solution: According to the uncertainty principle $\Delta x \,.\, \Delta p = \dfrac{h}{2\pi}$

$$\Delta p = \frac{h}{2\pi\, \Delta x}$$

$$\frac{6.626\, X\, 10^{-34}}{2\, X\, 3.14\, X\, 0.1\, X\, 10^{-10}} = 1.054\, X\, 10^{-23}\ kgms^{-1}$$

The uncertainty in the momentum of the electron = $1.054\, X\, 10^{-23}\ kgms^{-1}$

**6. a)Describe the behavior of particle in one dimensional infinite potential well in terms Eigen values and functions.**

**ANS:**

## Particle in One Dimensional Box: -

Consider an electron of mass 'm' in an infinity deep one dimensional box with width of 'a' units which potential is constant and i.e. zero the motion of the electron is considered by walls of the box as shown in fig.

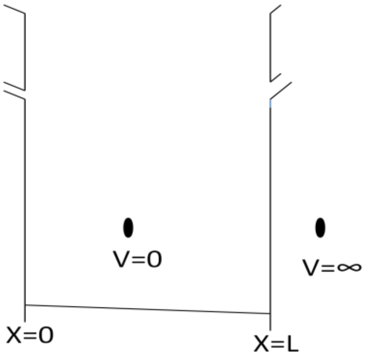


Fig.1. Energy of the particle present in a potential well.

The motion of the electron in one dimensional box can be described by the Schrödinger wave equation.

$$\frac{d^2\psi}{dx^2} + \frac{2m}{h^2}(E - V)\psi = 0 \qquad (1)$$

Inside the box the P.E. 'V' is zero hence the above equation written as

$$\frac{d^2\psi}{dx^2} + \frac{2m}{h^2}E\psi = 0 \qquad (2)$$

$$\frac{d^2\psi}{dx^2} + K^2\psi = 0 \qquad (3)$$

Where $K^2 = \frac{2mE}{h^2}$ (4)

The solution of equation (1) can be written as

$$\psi(x) = A\sin Kx + B\cos Kx \qquad (5)$$

Where A, B and K are unknown quantities these are calculated by using boundary conditions.

(i) When x = 0, then the wave function $\psi = 0$ i.e. $\psi^2 = 0$

(ii) When x = L then the wave function $\psi = 0$ i.e. $\psi^2 = 0$

Applying the (i) boundary condition for eq. 5

$$O = A \sin(0) + B \cos(0)$$

$$B=0 \qquad (6)$$

Sub Eq (6) in Eq (5)

$$\psi(x) = A \sin Kx \qquad (7)$$

Applying (ii) boundary condition to (7) equation

$$O = A \sin KL$$

Consider a particle is present inside the box and it cannot come out from the box, because the potential is infinite outside the box. Therefore 'A' cannot be zero. Hence

$$\sin KL = 0$$

$$KL = n\pi$$

$$K = \frac{n\pi}{L} \qquad (8)$$

**Calculation of Eigen Values of Energy: -**

From Equation (4)

$$K^2 = \frac{2mE}{h^2}$$

From equation (8)

$$K = \frac{n\pi}{L}$$

Then

$$\frac{n^2\pi^2}{L^2} = \frac{2mE}{h^2}$$

$$E = \frac{n^2\pi^2}{L^2} x \frac{h^2}{2m}$$

$$E = \frac{n^2\pi^2}{L^2}.\frac{h^2}{4\pi^2 m.2}$$

$$E = \frac{n^2 h^2}{8mL^2}$$

**The width is taken as ‘a’ i.e. L = a**

$$\boxed{E_n = \frac{n^2 h^2}{8ma^2}}$$ **( ENERGY IS QUANTIZED)**

From the above equation, it is clear that

1) The lowest energy of the particle is obtained by putting n=1

$$E_1 = \frac{h^2}{8ma^2} \text{ and } E_n = n^2 E_1$$

This is known **as zero point energy of the system**.

2) For n=1, 2, 3, we get discrete energy values of the particle in the box shown in Fig.2.

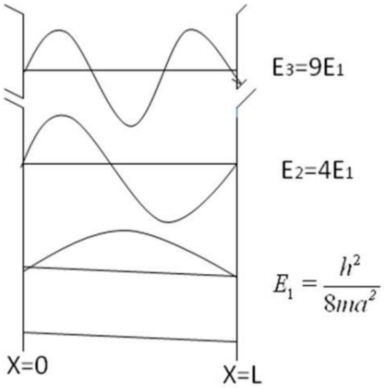


Fig.1. Energy of the particle present in a potential well.

$$E_1 = \frac{h^2}{8ma^2}$$

$$E_2 = 2^2.\frac{h^2}{8ma^2} = 4E_1$$

$$E_3 = 3^2.\frac{h^2}{8ma^2} = 9E_1$$

The eigenwave function for the motion of the particle are

$$T_n(x) = A \sin\frac{n\pi x}{a}$$ in the region 0<x<a

$$T_n(x) = 0$$ in the region $x \le 0 \; and \; x \ge a$

The total probability that the particle is somewhere in the box must be unity.

$$\int_0^a P_x dx = \int_0^a |T_n|^2 dx = 1$$

$$\int_0^a A^2 sin^2 \frac{n\pi x}{a} dx = 1$$

$$\frac{A^2}{2}\int_0^a \left[1 - \cos\frac{2n\pi x}{a}\right] dx = 1$$

$$\frac{A^2}{2}\left[x - \frac{a}{2\pi n}\sin\frac{2\pi n x}{a}\right]_0^a = 1$$

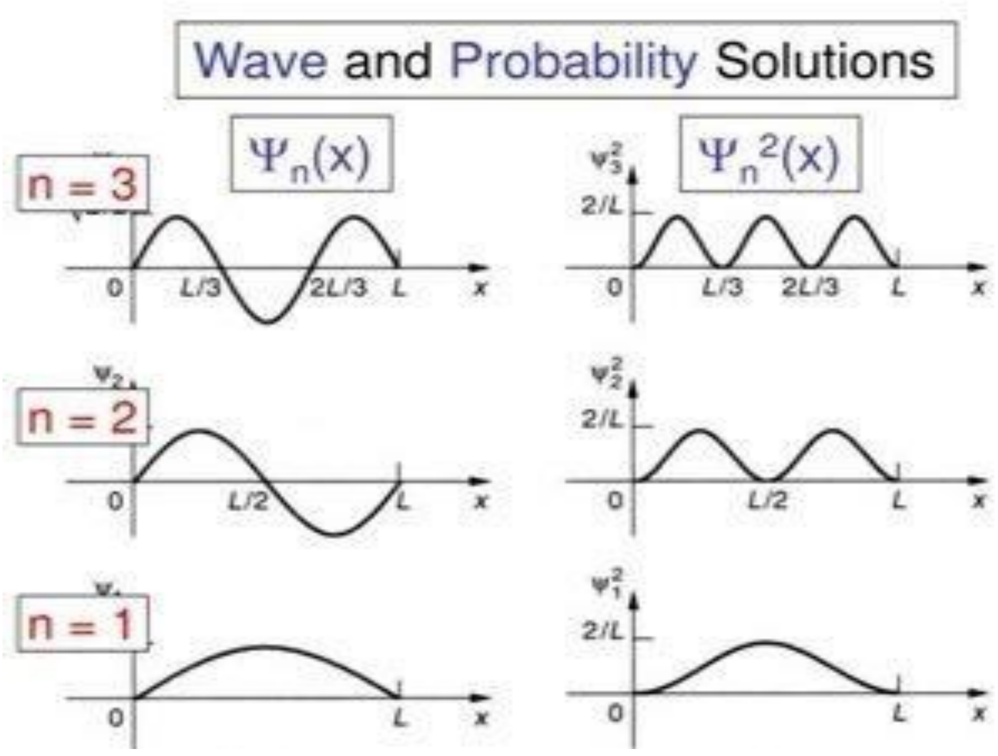
The second term becomes zero at both the limits

$$\frac{A^2 a}{2} = 1$$

$$A = \sqrt{\frac{2}{a}}$$

The normalized wave function is

$$T_n(x) = \sqrt{\frac{2}{a}} \sin\frac{n\pi x}{a}$$



**Probability of the location of the particle :**

The probability of finding a particle over a small distance dx at x is given by

$$P(x) = |T_n|^2$$

$$P(x) = \frac{2}{a} \sin^2 \frac{n\pi x}{a}$$

The probability density is maximum when

$$\frac{n\pi x}{a} = \frac{\pi}{2}, \frac{3\pi}{2,}, \frac{5\pi}{2}, \dots\dots$$

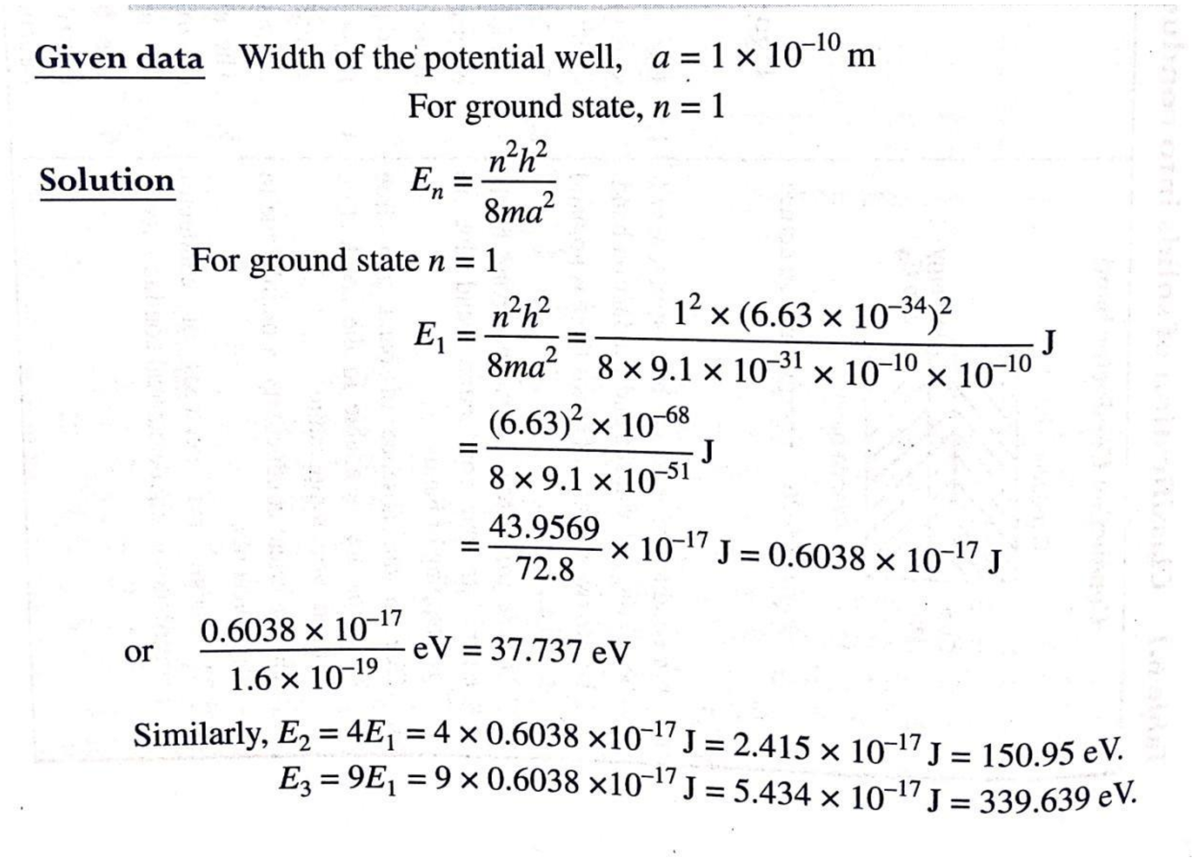
$$x = \frac{a}{2n}, \frac{3a}{2n,}, \frac{5a}{2n}, \dots\dots$$

**Case 1 :** if n = 1, then the probability of position of the particle is at $x = \frac{a}{2}$

**Case 2 :** if n = 2, then the probability of position of the particle is at $x = \frac{a}{4}, \frac{3a}{4}$

**Case 3 :** if n = 3, then the probability of position of the particle is at $x = \frac{a}{6}, \frac{3a}{6}, \frac{5a}{6}$

**b)An electron in bounded in a one dimensional infinite well having a width of 1 x 10-10 m. Find the energy values in(in eV) the ground state and the first two excited states.**



**Given data** Width of the potential well, $a = 1 \times 10^{-10}$ m

For ground state, $n = 1$

**Solution**

$$E_n = \frac{n^2 h^2}{8ma^2}$$

For ground state $n = 1$

$$E_1 = \frac{n^2 h^2}{8ma^2} = \frac{1^2 \times (6.63 \times 10^{-34})^2}{8 \times 9.1 \times 10^{-31} \times 10^{-10} \times 10^{-10}} \text{ J}$$

$$= \frac{(6.63)^2 \times 10^{-68}}{8 \times 9.1 \times 10^{-51}} \text{ J}$$

$$= \frac{43.9569}{72.8} \times 10^{-17} \text{ J} = 0.6038 \times 10^{-17} \text{ J}$$

or $$\frac{0.6038 \times 10^{-17}}{1.6 \times 10^{-19}} \text{ eV} = 37.737 \text{ eV}$$

Similarly, $E_2 = 4E_1 = 4 \times 0.6038 \times 10^{-17} \text{ J} = 2.415 \times 10^{-17} \text{ J} = 150.95 \text{ eV}.$

$E_3 = 9E_1 = 9 \times 0.6038 \times 10^{-17} \text{ J} = 5.434 \times 10^{-17} \text{ J} = 339.639 \text{ eV}.$

## 7.a) What are the postulates of classical free electron theory?

### Postulates of classical free electron theory:

Classical free electron theory proposed by **Drude and Lorentz.**

1.According to this theory the metal is composed of atoms or molecules similar in a perfect gas. Therefore the electrons are free and hence they are free electrons.

2. The outer most orbit electrons are called valance electrons of an atom and free to move about the whole volume of a metal.

3. According to this theory the metal is supposed to consists of +Ve ions fixed in the lattice whose free electrons move freely and randomly in the metal like gas molecules in a vessel.

4.The electron velocities in a metal obey the Classical Maxwell- Boltzmann distribution law of velocities.

5.The moments of free electrons obey the laws of Classical kinetic theory of gases.

$$\frac{1}{2}mv^2 = \frac{3}{2}k_BT$$

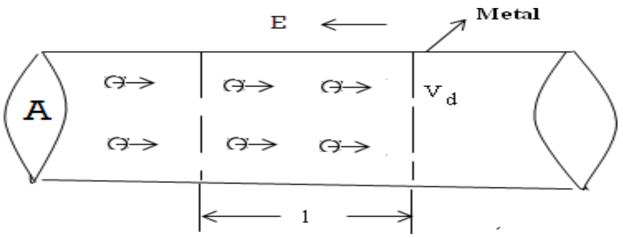
6. The free electrons move in a completely uniform potential field doe to ions fixed in the lattice.

7.When an electric field is applied to the metal, the free electrons are accelerated in the direction opposite to the direction of applied electric field. These accelerated electrons collide with the positive ions losing some of their energy and acquires a constant velocity along the metal. This constant velocity of electrons is known as drift velocity $v_d$.

8.The average distance travelled by the free electrons between two successive collisions is called mean free path λ. The time taken to travel means free paths λ is known as mean free time or relation time denoted by τ.

**b) Derive an expression for electrical conductivity in a metal by using classical free electron theory.**

**An expression for electrical conductivity(σ) in a metal:**



As shown in Fig.1, let an electric field E is maintained between two ends of a metal of area of cross section A.

Force acting on the electron in electric field = eE → (1)

Where, e is the charge of an electron

Then the acceleration of electron 'a' = $\frac{Force}{mass} = \frac{eE}{m}$ → (2)

If the electron collides with a positive ion then it's drifting tendency decreases and random motion increases at its next collision its velocity changes.

On an average its velocity = $a\tau$ → (3)

Where, τ is the time between two collisions. This average velocity is the drift velocity of electron.

$\therefore\ v_d = a\tau$ → (4)

$v_d = \frac{eE}{m}\tau$ → (5)

Let 'n' is number of electrons per unit volume of each charge "e" and mass "m"

In small time dt electrons move 'l' length

$\therefore\ l = v_d dt$ → **(6)**

Number of electrons crossing through the volume element = volume x number of electrons per unit volume

=Al X n = A $v_d dt$ (n) → (7)

Total charge cross through the volume element = Number of electrons crossing through the volume element X charge of one electron

= A $v_d dt$ (n) (e) → (8)

Current (i) = $\frac{total\ charge}{time}$ → (9)

$i = \frac{A\ (n)\ v_d dt(e)}{dt}$ → (10)

i = A $v_d$ (n) (e) → (11)

Current density $J = \frac{i}{A} = v_d \, ne \rightarrow (12) \quad (\because v_d = \frac{eE}{m}\tau)$

$$= \frac{eE}{m}\tau \, (ne)$$

$$J = \frac{ne^2 E\tau}{m} \rightarrow (13)$$

Conductivity $\sigma = \frac{J}{E} = \frac{ne^2 r E}{mE} = \frac{ne^2 r}{m}$ ----→(14)

Resistivity $\rho = \frac{1}{\sigma} = \frac{m}{ne^2\tau} = \frac{m\bar{c}}{ne^2\lambda} \quad (\because \tau = \frac{\lambda}{\bar{c}})$

From kinetic theory of gases we know root mean square velocity $\bar{c} = \sqrt{\frac{3k_BT}{m}}$

$\therefore$ Resistivity $\rho = \frac{m}{ne^2\lambda}\sqrt{\frac{3k_BT}{m}} = \frac{\sqrt{3mk_BT}}{ne^2\lambda} \quad --> (15)$

The steady state drift velocity per unit electric field is known mobility ($\mu$)

Mobility $\mu = \frac{v_d}{E} = \frac{eE}{mE}\tau = \frac{e\tau}{m} \quad ---> (16) \quad (\because v_d = \frac{eE}{m})$

$$\boxed{\text{Relation between conductivity and mobility } \because \sigma = \frac{ne^2\tau}{m} = \frac{ne\, e\tau}{m} = ne\mu \quad ---> (17)}$$

**8. a) Derive an expression for electrical conductivity in a metal by using Drude & Lorentz theory.**

**<u>Postulates of Drude and Lorentz theory:</u>**

1. According to this theory the metal is composed of atoms or molecules similar in a perfect gas.Therefore the electrons are free and hence they are free electrons.
2. The outer most orbit electrons are called valance electrons of an atom and free to move about the whole volume of a metal.
3. According to this theory the metal is supposed to consists of +Ve ions fixed in the lattice whose free electrons move freely and randomly in the metal like gas molecules in a vessel.
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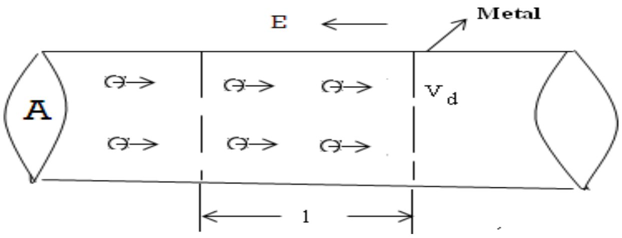
$$\frac{1}{2}mv^2 = \frac{3}{2}k_BT$$

6. The free electrons move in a completely uniform potential field doe to ions fixed in the lattice.
7. When an electric field is applied to the metal, the free electrons are accelerated in the direction opposite to the direction of applied electric field. These accelerated electrons collide with the positive ions losing some of their energy and acquires a constant velocity along the metal. This constant velocity of electrons is known as drift velocity $v_d$.
8. The average distance travelled by the free electrons between two successive collisions is called mean free path λ. The time taken to travel means free paths λ is known as mean free time or relation time denoted by τ.

**An expression for electrical conductivity(σ) in a metal:**



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Where, e is the charge of an electron

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On an average its velocity = $a\tau$ → (3)

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$\therefore\ v_d = a\tau$ → (4)

$v_d = \frac{eE}{m}\tau$ → (5)

Let 'n' is number of electrons per unit volume of each charge "e" and mass "m"

In small time dt electrons move 'l' length

$\therefore\ l = v_d dt$ → **(6)**

Number of electrons crossing through the volume element = volume x number of electrons per unit volume

$$=Al \times n = A v_d \, dt \, (n) \quad \rightarrow (7)$$

Total charge cross through the volume element = Number of electrons crossing through the volume element X charge of one electron

$$= A v_d \, dt \, (n)(e) \quad \rightarrow (8)$$

$$\text{Current (i)} = \frac{total\ charge}{time} \quad \rightarrow (9)$$

$$i = \frac{\mathrm{A\,(n)\,v_d dt(e)}}{\mathrm{dt}} \quad \rightarrow (10)$$

$$\mathrm{i} = A v_d \, (n)(e) \quad \rightarrow (11)$$

$$\text{Current density J} = \frac{i}{A} = v_d\, \mathrm{ne} \quad \rightarrow (12) \quad (\because v_d = \frac{eE}{m}\tau\ )$$

$$= \frac{eE}{m}\tau\ (\mathrm{ne})$$

$$J = \frac{ne^2 E\tau}{m} \quad \rightarrow (13)$$

$$\text{Conductivity } \sigma = \frac{J}{E} = \frac{ne^2 rE}{mE} = \frac{ne^2 r}{m} \quad \text{----}\rightarrow (14)$$

$$\text{Resistivity } \rho = \frac{1}{\sigma} = \frac{m}{ne^2\tau} = \frac{m\bar{c}}{ne^2\lambda} \quad (\because \tau = \frac{\lambda}{\bar{c}})$$

From kinetic theory of gases we know root mean square velocity $\bar{c} = \sqrt{\frac{3k_B T}{m}}$

$$\therefore \text{Resistivity} \quad \rho = \frac{m}{ne^2\lambda}\sqrt{\frac{3k_B T}{m}} = \frac{\sqrt{3mk_B T}}{ne^2\lambda} \quad --> \ (15)$$

**b) Find relaxation time of conduction electron in a metal if its resistivity is 1.54 x $10^{-8}$ $\Omega - m$ and it has 5.8 x $10^{28}$ conduction electron/$m^3$. Given m= 9.1x$10^{-31}$ kg, e = 1.6 x $10^{-19}$ C.**

Solution:
Given data:
Resistivity ( $\rho$ ) = 1.54 x $10^{-8}$ $\Omega - m$
Conduction electron/$m^3$ (n) = 5.8 x $10^{28}$
Mass of electron (m) = 9.1x$10^{-31}$ kg
Charge of electron (e) = 1.6 x $10^{-19}$ C
Find relaxation time ( $\tau$ )=

We know that resistivity $\rho = \frac{m}{ne^2\,\tau}$

From above equation relaxation time $\tau = \dfrac{m}{ne^2\ \rho}$ s

$$\tau = \frac{9.1\,X\,10^{-34}}{5.8\,X\,10^{28}\,(1.6X\,10^{-19})^2\ \ X\,1.54\,X\,10^{-8}}$$

$=3.97\ X\,10^{-14}$ sec.

**9. a) What are the advantages of quantum free electron theory over classical free electron theory?**

**ANS:**

**Advantages of quantum free electron theory:**

1. It explains the specific heat of metals
2. It explains the magnetic susceptibility and permeability of metals
3. It explains thermal of metals.
4. It explains electrical conductivity of metals
5. It explains photoelectric effect and thermionic emissions in a metal.
6. It derives Wiedemann – Franz law ( i.e relation between electrical conductivity and thermal conductivity).

**b) Derive an expression for electrical conductivity in a metal by quantum free electron theory.**

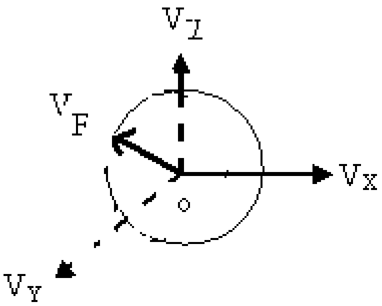
**ANS:**

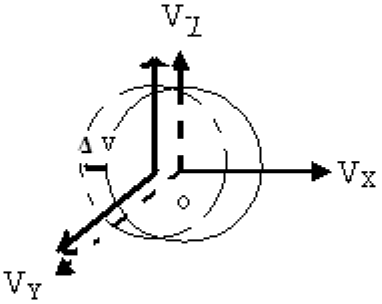
To overcome the drawbacks of classical free electron theory the scientist **Summerfield** introduced the Quantum free electron theory.

According to this theory :

1. Metal consists of positive ion cores and free electrons.
2. The free electrons bound to move with in the metal in a completely uniform potential field among these ion cores.
3. The free electrons obey Quantum Laws ( electron is associated with wave nature)(fermions).
4. The free electrons will have discrete energy levels in a metal.
5. The occupation of electrons in these energy levels obey Pauli's exclusion principle and Fermi-Dirac Stastistics.

In the absence of external electric field the free electrons are moving within the velocity space from origin of sphere. The velocity of electron at highest occupied energy level, Fermi energy level known Fermi velocity $V_F$.





**Under an Electric field :**

According to quantum mechanics the velocity of quantum particle is given as

$$\text{P=Momentum} = \hbar K \quad \begin{bmatrix} \hbar = \frac{h}{2\pi}, K = \frac{2\pi}{\lambda} \\ mv = \hbar K = \frac{h}{2\pi} X \frac{2\pi}{\lambda} \\ \Rightarrow mv = \frac{h}{\lambda} \Rightarrow \lambda = \frac{h}{mv} \end{bmatrix}$$

$$mv = \hbar K$$

$$v = \frac{\hbar}{m} K ---\rightarrow(1)$$

$$\Delta v = \frac{\hbar}{m}\Delta K \quad ---\rightarrow(2)$$

Force on quantum particle due to external electric fields E is F = eE --→ (3)

From Newton's second law F = ma --→ (4)

From equations 3 and 4 we get acceleration $a = \frac{eE}{m} ---\rightarrow(5)$

Differentiating the equation (1) with respect to time then we get $\frac{dv}{dt} = \frac{\hbar}{m}\frac{dk}{dt} ----> (6)$

From equation (5) and (6) we get $\frac{eE}{m} = \frac{\hbar}{m}\frac{dk}{dt}$

$$\frac{dk}{dt} = \frac{eE}{\hbar}$$

$$dk = \frac{eE}{\hbar} dt ---> (7)$$

Integrating the above equation with respect to time then we get

$$\text{K(t)-K(0)}= \Delta K = \frac{eE}{\hbar} t ---> (8)$$

At Fermi surface t $= \tau_F = \textit{Meancollission time}$ at Fermi surface $\tau_F = \frac{\lambda_F}{V_F}$

$$\Delta K = \frac{eE}{'}\tau_F \quad ---> (8)$$

Due to increasing electric field velocity of Fermi ions changes as

$$\Delta v = \frac{'}{m}\Delta K \text{ ---------}\rightarrow (9)$$

Substitute equation (8) in equation (9), we get $\Delta v = \frac{'}{m}\frac{eE}{'}\tau_F = \frac{eE}{m}\tau_F$

Current density J = ne $\Delta v$ = n $\frac{e^2E}{m}\tau_F$ ---- → (10)

We know that current density J = $\sigma E$ -------→ (11)

By comparing the equation (10) with equation (11)

we get conductivity of free electron (Fermi ion) in solids is

Conductivity $\boxed{\sigma = \frac{ne^2}{m^*}\tau_F}$ ( where $m^*$ = Effective mass)

**10. a) Write brief note on Fermi Dirac distribution. What is the effect of temperature on Fermi Dirac distribution function?**

**ANS:**

**Fermi – Dirac Distribution: -**

In the absence of an electric field. Free electrons move at random, similar to the behavior of the electron gas in metals. Since electrons are indistinguishable particles, they are known as fermions or Fermi particles. Hence, such an electron gas obeys Fermi-Dirac distribution.

- The Fermi-Dirac distribution describes the behaviour of free electron gas, taking into account the quantum theory and Pauli's exclusion principle.
- As shown in fig, According to to quantum mechanics , the electrons will have discrete energy states and the occupation of electrons among these energy levels will be governed by Pauli's exclusion principle, i.e. not more than two electrons can occupy the same energy level.

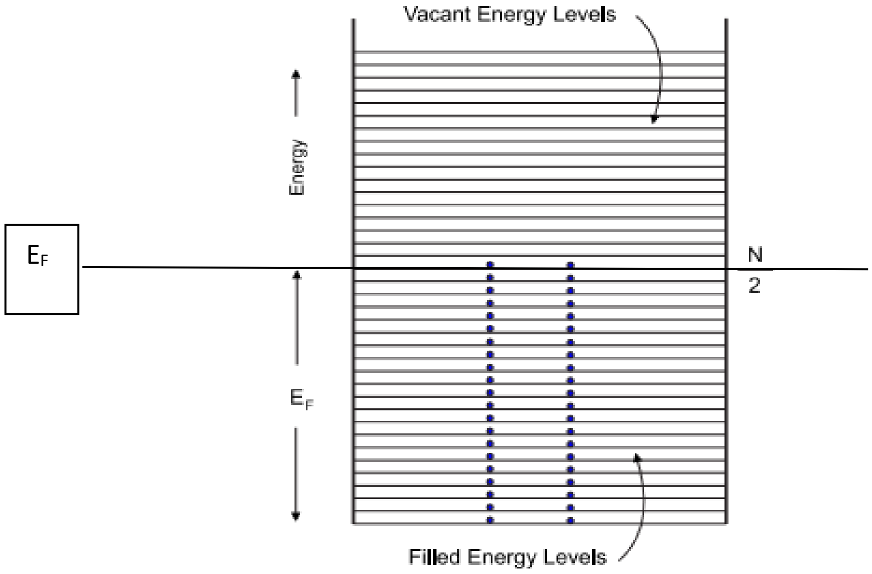


Figure 3.3: Distribution of Electrons at $T = 0K$

- At absolute zero temperature, two electrons occupy the ground state and two into each state of next higher energy levels.
- The highest energy level occupied by electrons at absolute zero is known as Fermi energy level which divides the occupied states from the an occupied states. The energy of Fermi level is denoted as $E_F$ .

The probability of the occupations of an energy level ‘E’ by an electron at temperature ‘T’ is given by

$$\boxed{F(E) = \frac{1}{1 + e^{\frac{(E-E_F)}{K_B T}}}}$$

Where F(E) is the Fermi Dirac distribution function, and

$K_B$ is the Boltzmann constant = 1.38 X $10^{-23}$ J/K

**Effect of temperature of Fermi-Dirac distribution Function:**

A graph has been plotted between F(E) and E, and different temperature OK, T,K, $T_2$K, $T_3$K is shown in figure.

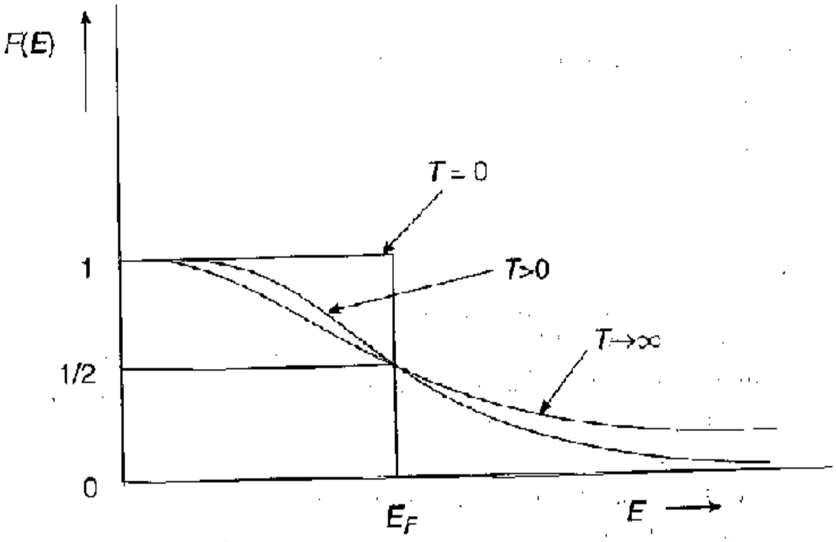


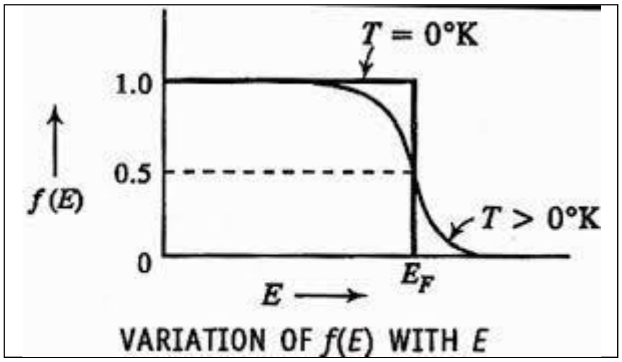
FIGURE. Variation of Fermi distribution function with energy

**i) At T= OK (E < $E_F$ )**

Substitute T = OK in the Fermi-Dirac distribution, we have

$$F(E) = \frac{1}{1+\exp\left(E-E_F/kBO\right)}$$

$= 1$



VARIATION OF f(E) WITH E

i.e **All the energy levels below the Fermi level are completely occupied**.

**ii) At T= OK (E > $E_F$ )**

Substitute T = OK in the Fermi-Dirac distribution, we have

$$F(E) = \frac{1}{1+\exp\left(E-E_F/kBO\right)}$$

$= 0$

i.e **All the energy levels above the Fermi level are completely empty.**

### iii) E = E_F at T > 0 K

At T > OK

$$F(E) = \frac{1}{1 + e^{\frac{(E-E_F)}{K_B T}}}$$

$$F(E) = \frac{1}{1 + e^{\frac{(0)}{K_B T}}}$$

$$= \frac{1}{1+e^0}$$

$$= \frac{1}{1+1}$$

$$= \frac{1}{2} \text{ for } E = E_F$$

As the temperature is raised from absolute zero to T,K the distribution cure begins to departs from step-like function and tails of smoothly to zero again with a further increase in temperature to $T_2$K and $T_3$K, the departure and higher energy states with an increase of temperature and as a consequence to no of vacancies below the Fermi level increase in the same proportion.

At non zero temperature, all these curves pass through a point whose F(E) = ½ at E = $E_F$.

So $E_F$ lies half way between the filled & empty states.

**b) Find the temperature at which there is 1 % probability that a state with energy 0.5 eV is above Fermi energy.**

Given data: Probability F(E)= 1% $= \frac{1}{100} = 0.01$

$E = E_F + 0.5$ eV

$E - E_F = 0.5$ eV

Solution :

$$\text{Probability } F(E) = \frac{1}{1+\exp^{\frac{E-E_F}{K_B T}}}$$

$$0.01 = \frac{1}{1+\exp^{\frac{0.05}{K_B T}}}$$

$$0.01 \exp^{\frac{0.05}{K_B T}} = (1 - 0.01)$$

$$\exp^{\frac{0.05}{K_B T}} = \frac{0.99}{0.01} = 99$$

$$\frac{0.5}{K_B T} = 2.303 X \log_{10} 99$$

$$K_B T = \frac{0.5}{2.303 X \log_{10} 99}$$

$$= \frac{0.5}{2.303 X 1.9956}$$

$$\frac{0.5}{4.5959} = 0.109\ eV$$

$$T = \frac{0.109 X 1.6 X 10^{-19}}{1.38 X 10^{-23}}$$

$$T = 1263 K$$

## 11. a) Define density of states in metals.

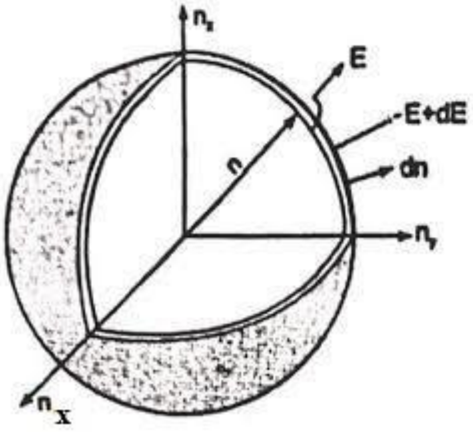
The density of states is defined as the number of energy states per unit volume per unit volume in an energy interval of a metal. It is used to calculate the number of charge carriers per unit volume of any solid.

$$N(E)dE = \frac{Number\ of\ energy\ states\ between\ E\ and\ E + dE}{Volume\ of\ the\ metal}$$

$$N(E)dE = \frac{D(E)dE}{V}$$

**b) Derive an expression for the number of allowed states per unit volume of a solid.**

**Derivation of density of Energy states**:



Let us consider a sphere of radius ‘n’ and ‘n+dn’ in space with quantum numbers $n_x$, $n_y$, $n_z$

Such that $$n^2 = n_x^2 + n_y^2 + n_z^2$$

Number of energy states within a sphere of radius’n’ $= \frac{4}{3}\pi n^3$

Consider a sphere of radius’n’ due to one octant $= \frac{1}{8}.(\frac{4}{3}\pi n^3)$

Similarly, Number of energy states within a sphere of radius ’n+dn’ $= \frac{1}{8}.[\frac{4}{3}\pi(n+dn)^3]$

Therefore

Number of energy states available in ‘n’ and ’n+dn’ is

$$D(E)dE = \frac{1}{8}.[\frac{4}{3}\pi(n+dn)^3] - \frac{4}{3}\pi n^3$$

$$= \frac{1}{8}.[\frac{4}{3}\pi(3\,n^2dn)] = \frac{\pi}{2}(n^2dn) \quad \text{-----------}\rightarrow \textbf{(1)}$$

($dn^2$ and $dn^3$ are very small, so they can be neglected)

From Schrodinger wave equation, allowed energy level is

$E = \frac{n^2h^2}{8mL^2}$ and it can be written as $n^2 = \frac{8mL^2}{h^2}E \Rightarrow n = \frac{(8mL^2E)^{\frac{1}{2}}}{h}$

Differentiating the above equation , we get

$$dE = \frac{h^2}{8mL^2}(2n\,dn)$$

n dn = $\frac{8mL^2}{2h^2} dE$

dn = $\frac{8mL^2}{2h^2} \frac{dE}{n}$

dn= $\frac{8mL^2}{2h^2} \left(\frac{h}{(8mL^2E)^{\frac{1}{2}}}\right) dE$

Substituting value of n and dn in **eq.(1),** we get

$$D(E)dE = \frac{\pi}{2} \left(\frac{8mL^2}{h^2}E\right) \left[\frac{8mL^2}{2h^2} \left(\frac{h}{(8mL^2E)^{\frac{1}{2}}}\right) dE\right]$$

$$= \frac{\pi}{4} \left(\frac{8mL^2}{h^2}\right)^{\frac{3}{2}} E^{\frac{1}{2}} dE$$

$$= \frac{\pi}{4h^3} (8m)^{\frac{3}{2}} L^3 E^{\frac{1}{2}} dE$$

Volume V= $L^3$=1 (per unit volume)

$$D(E)dE = \frac{\pi}{4h^3} (8m)^{\frac{3}{2}} E^{\frac{1}{2}} dE$$

This energy states accommodates 2 electrons as per Pauli's exclusion principle

$$D(E)dE = 2X \frac{\pi}{4h^3} (8m)^{\frac{3}{2}} E^{\frac{1}{2}} dE$$

Density of Energy states **D(E)dE** $= \frac{\pi}{2h^3} (8m)^{\frac{3}{2}} E^{\frac{1}{2}} dE$

# UNIT – V
# SEMICONDUCTORS

**2.a. What is Fermi level? Prove that the Fermi level is lies exactly in between conduction band and valance band of intrinsic semiconductor.**

**Fermi level**

The Fermi level indicates the probability of occupation of energy levels in conduction and valence bands. For an intrinsic semiconductor, hole and electron concentrations are equal, and it indicates that the probability of occupation of energy levels in conduction and valence bands are equal. Thus, the Fermi level lies in the middle of the energy gap $E_g$.

For an intrinsic semiconductor, $n = p$

$$N_C e^{-(E_C-E_F)/k_BT} = N_V e^{-(E_F-E_V)/k_BT}$$

$$\frac{e^{-(E_C-E_F)/k_BT}}{e^{-(E_F-E_V)/k_BT}} = \frac{N_V}{N_C}$$

$$e^{[2E_F-(E_C+E_V)]/k_BT} = \frac{N_V}{N_C}$$

Taking $log$ on both side, we get

$$\frac{[2E_F-(E_C+E_V)]}{k_BT} = \log log \left(\frac{N_V}{N_C}\right)$$

$$E_F = \frac{E_C+E_V}{2} + \frac{1}{2}k_BT \log log \left(\frac{N_V}{N_C}\right)$$

When $N_V = N_C$ then $E_F = \frac{E_C+E_V}{2}$

Thus, the Fermi energy level in an intrinsic semiconductor lies in the middle or centre of the energy gap.

Fermi level is lies exactly in between conduction band and valance band of intrinsic semiconductor.

**b. If $R_H$ of a specimen is 3.66 x $10^{-4}$ $m^3$ $c^{-1}$. Its resistivity is 8.93 x $10^{-3}\Omega$ m. Find mobility and electron concentration**.

**Solution:**

The relation between the Hall coefficient (Hall constant) and the doping concentration are related as:

**$R_h$ = -1/nq**

From these,$n_i$=. $\frac{1}{3.66\ x\ 10^{-4}\ X\ 1.6x\ 10^{-19}}$

**=0.17x$10^{23}$**

We know, **Mobility = Hall coefficient/resistivity**

**$\mu = R_h / \rho$**

Hall coefficent $R_h$ = 3.66 x 10-4 $m^3$ $c^{-1}$

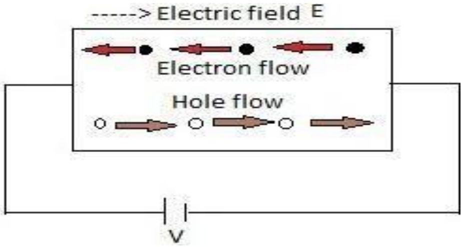
Resistivity, ($\rho$) =8.93 x $10^{-3}\Omega$ m

$$\mu = R_h/\rho = \frac{3.66\ x\ 10-4\ m^3c^{-1}}{8.93\ x\ 10^{-3}\,\Omega m}$$

**$\mu = 0.04\ m^2V^{-1}s^{-1}$.**

**3.a.Derive the expression for the conductivity of intrinsic semiconductor with relevant energy band diagrams**.

**Intrinsic conductivity**



Consider an intrinsic semiconductor to which a potential difference V is applied. It establishes an electric field E and the change carriers are forced to drift in the respective directions to constitute an electric current I. The drift velocity acquired by the change carrier is given by

$$v_d = \mu E$$

Where μ is the mobility of charge carriers.

Let n be the concentration of electrons in the semiconductor. Then the current density due to an electron is given by

$$J_n = nev_d = ne\mu_n E$$

Similarly, current density due to hole is given by

$$J_p = pe\mu_p E$$

Where $p$ is the hole concentration and $\mu_p$ is the mobility of the hole. Total current density

$$J = J_n + J_p$$

$$J = ne\mu_n E + pe\mu_p E$$

$$J = \left(n\mu_n + p\mu_p\right)eE \quad \text{------------------- (1)}$$

But total current density $J = \sigma E$---------------------- (2)

Where σ is the total conductivity

From (1) and (2), we get

$$\sigma = \left(n\mu_n + p\mu_p\right)e$$

For an intrinsic semiconductor, $n = p = n_i$

$$\sigma = \left(\mu_n + \mu_p\right)n_i e$$

But $n_i = (N_C N_V)^{1/2} e^{-E_g/2k_BT}$

$$\sigma = \left(\mu_n + \mu_p\right)e(N_C N_V)^{1/2} e^{-E_g/2k_BT}$$

$$\sigma = Ae^{-E_g/2k_BT}$$

where $A = (N_C N_V)^{1/2} e\left(\mu_n + \mu_p\right)$

**b. The following data are given for an intrinsic Ge at 300K. Calculate the conductivity of the sample? ($n_i$= 2.4 x10 $^{19}m^{-3}$,$\mu_e$ = 0.39 $m^2V^{-1}s^{-1}$,$\mu_p$ = 0.19 $m^2V^{-1}s^{-1}$).**

**Given data:**

Charge of electron (e) = 1.6 x $10^{-19}$ C

$n_i = 2.4 \times 10^{19}/m^3$,

$\mu_e = 0.39 m^2/V-S$,

$\mu_P = 0.19 m^2/V-S$).

Temperature T = 300K

**Solution:**

$$\sigma = n_i e(\mu_e + \mu_p)$$

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

$$\rho = \frac{1}{n_i e(\mu_e + \mu_p)} = \frac{1}{2.4 X 10^{19} X 1.6 X 10^{-19} (0.39 + 0.19)}$$

$$= 0.448\ \Omega - m$$

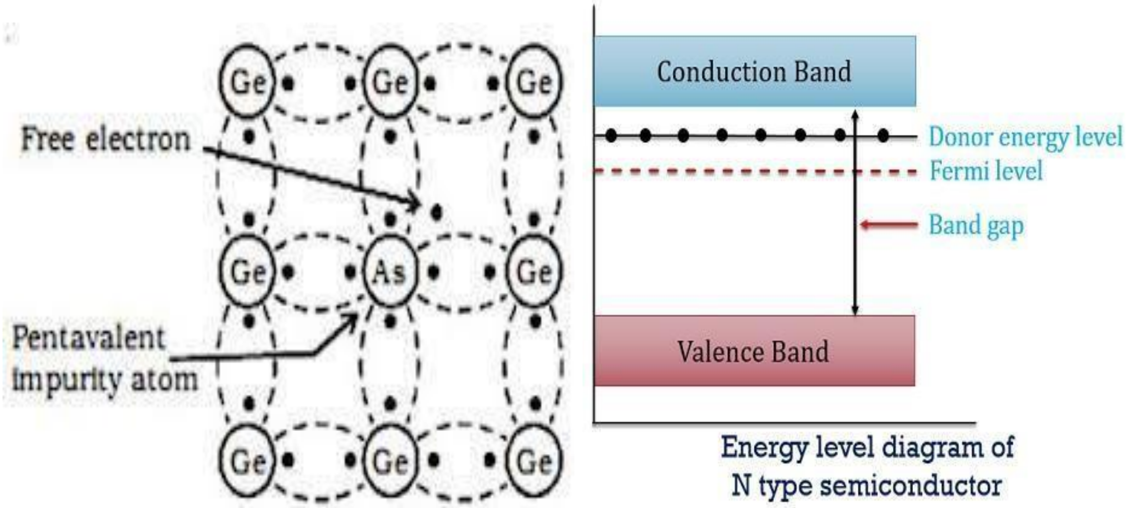
$$\sigma = \frac{1}{0.448}$$

$$\sigma = 2.083 / \Omega - m$$

## 4.a. Explain the formation of n-type semiconductors with band diagram

### n – type extrinsic semiconductor

- When a small quantity of **pentavalent** material is added to an intrinsic semiconductor during the process of crystallization, the resulting crystal is called n – type extrinsic semiconductor.
- When **penta valent impurity such as P, As, Sb, Bi** added to pure Ge or Si atoms then form four covalent bonds with neighboring atoms of Ge.
- The fifth atom electron of impurity atoms from a level is called *donor level*. Here impurity atom is donating the free electron so these atoms are called donor atoms.
- At room temperature, donor level is so closed to the bottom of the conduction band.
- If the thermal energy is sufficiently high, in addition to the ionization of donor impurity atoms, breaking of covalent bonds may also occur thereby giving rise to generation of electron – hole pair.
- **Hence, in n – type semiconductors electrons are majority charge carriers and holes are minority charge carriers**.



**b. In an Intrinsic semiconductor, the energy gap is 1.2 eV. Calculate the ratio between conductivity at 600K and at 300K.**

**Given:**

Energy gap in a semiconductor, Eg=1.2eV

For a temperature-dependent intrinsic semiconductor:

$n_i=n_0\exp(-E_g/2k_BT)$

Simplifying the equation:

$$\frac{ni1}{ni2} = \frac{Eg}{2k}\left[\frac{1}{T1}-\frac{1}{T2}\right]$$

$$\Rightarrow \frac{1.2}{2\times 8.62\times 10-5}\left[\frac{1}{300}-\frac{1}{600}\right]=11.59$$

Therefore,

$$\frac{ni1}{ni2} = e\frac{\frac{1.2eV}{2\times kB\times 600}}{\frac{1.2eV}{2\times kB\times 300}}$$

$$\frac{ni1}{ni2} = e\frac{1.2ev}{2xkB}\left[\frac{1}{600}-\frac{1}{300}\right]$$

$$= e\frac{1.2\times 1.6\times 10-19}{2\times 1.381\times 10-23\times 600}$$

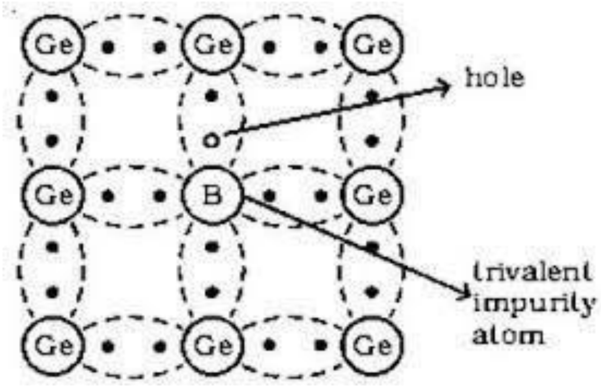
$$\frac{ni1}{ni2} = e_{11.59}$$

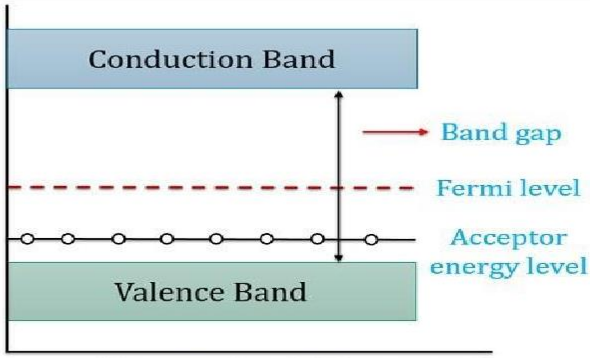
$$\Rightarrow \frac{ni1}{ni2} = \mathbf{1.072\times 10^{5}}$$

**5.a. Explain the formation of p-type semiconductors with band diagram**

**p – type extrinsic semiconductor**

- When a small quantity of **trivalent impurity** is added to an intrinsic semiconductor during the process of crystallization, the resulting crystal is called p – type extrinsic semiconductor.
- When any **tri valent impurity such as B, Al, Ga**, is added to pure Ge or Si atoms then form three covalent bonds with neighboring atoms of Ge.
- Impurity atom needed one more electron to complete its bond. This electron may be supplied by Ge, thereby creating a vacant electron site i.e., hole on the semiconductor atom.
- Since impurity atom accepts extra electron. So, it is called acceptor impurity and energy level of this impurity atom is called *acceptor level*.
- Even at low temperatures these acceptors atom get ionized taking electron from valence band and this giving rise to hole in valence band for conduction.
- In this process no electrons are created. If the temperature is sufficiently high, in addition to the holes, electron – hole pairs are generated due to breaking of covalent bonds.
- **Thus, holes are more in number than electrons and hence holes are majority carriers and electrons are minority carriers in p – type semiconductor**.





Energy level diagram of P type semiconductor

**b. The following data are given for an intrinsic Ge at 300K. Calculate the resistivity of the sample? ($n_i = 2.4 \times 10^{19} m^{-3}$, $\mu_e = 0.39\ m^2V^{-1}s^{-1}$, $\mu_p = 0.19\ m^2V^{-1}s^{-1}$)**

**Given data:**

Charge of electron (e) = $1.6 \times 10^{-19}$ C

$n_i = 2.4 \times 10^{19}/m^3$,

$\mu_e = 0.39\, m^2/V-S$,

$\mu_P = 0.19\, m^2/V-S$).

Temperature T = 300K

**Solution:**

$$\sigma = n_i e(\mu_e + \mu_p)$$

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

$$\rho = \frac{1}{n_i e(\mu_e + \mu_p)} = \frac{1}{2.4\,X\,10^{19}\,X\,1.6\,X\,10^{-19}\,(0.39 + 0.19)}$$

$$= 0.448\ \Omega - m$$

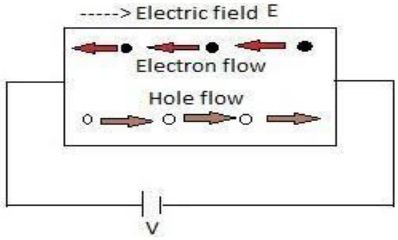
$$\sigma = \frac{1}{0.448}$$

$$\sigma = 2.083 / \Omega - m$$

**6.a. Enumerate the expression for current generated due to drifting of charge carriers in semiconductors in the presence of electric field**

**Drift**

Under the influence of an external electric field, the charge carriers are forced to move in a particular direction constituting electric current. This phenomenon is known as the drift.



Let there be ‘n’ electrons in a semiconductor. Under the electric field E, they are drifted with a drift velocity $v_d$. Then the current density

$$J = nev_d$$

Then conductivity $\sigma = \frac{J}{E} = \frac{nev_d}{E}$

The drift velocity is also given by $v_d = \mu_n E$ where $\mu_n$ is the mobility of electrons.

$$\therefore J = ne\mu_n E$$

$$\therefore \sigma = \frac{J}{E} = ne\mu_n$$

In the case of a semiconductor, the drift current density due to electrons is given by $J_n(drift) = ne\mu_n E$ and the drift current density due to hole is $J_p(drift) = pe\mu_p E$.

Then the total drift current density $J(drift) = J_n(drift) + J_p(drift)$

$$J(drift) = ne\mu_n E + pe\mu_p E$$

$$J(drift) = \left(n\mu_n + p\mu_p\right)eE$$

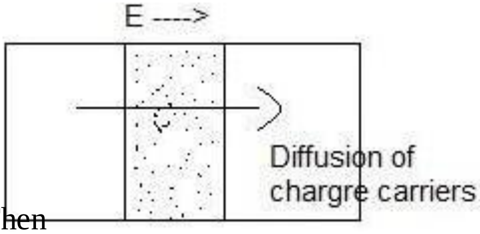
$$\sigma(drift) = \frac{J(drift)}{E} = \left(n\mu_n + p\mu_p\right)e$$

For an intrinsic semiconductor, $n = p = n_i$ then

$$\sigma_i(drift) = n_i e(\mu_n + \mu_p)$$

**b. Enumerate the expression for current generated due to diffusion of charge carriers in semiconductors in the absence of electric field**

**Diffusion**



Due to non – uniform carrier concentration in a semiconductor, the charge carriers moves from a region of higher concentration to a region of lower concentration. This process is known as diffusion of charge carriers.

Let $\Delta n$ be the excess electron concentration. Then according to Fick's law, the rate of diffusion of electrons $\propto \frac{-\partial(\Delta n)}{\partial x}$

$$= -D_n\frac{\partial(\Delta n)}{\partial x}$$

Where $D_n$ is the diffusion coefficient of electrons, the diffusion current density due to electrons is given by $J_n(diffusion)$

$$= -e\left[-D_n\frac{\partial(\Delta n)}{\partial x}\right] = eD_n\frac{\partial(\Delta n)}{\partial x}$$

The diffusion current density due to holes is given by $J_p(diffusion)$

$$= e\left[-D_p\frac{\partial(\Delta p)}{\partial x}\right] = -eD_p\frac{\partial(\Delta p)}{\partial x}$$

The total current density due to electrons is the sum of the current densities due to drift and diffusion of electrons.

$$J_n = J_n(drift) + J_n(diffusion)$$

$$= ne\mu_n E + eD_n\frac{\partial(\Delta n)}{\partial x}$$

Similarly, $J_p = pe\mu_p E - eD_p\frac{\partial(\Delta p)}{\partial x}$

**7.a. Derive Einstein's relation for charge carriers in semiconductor.**

**Einstein's Relation**

The relation between mobility μ and diffusion coefficient D of charge carriers in a semiconductor is known as Einstein's Relation.

At equilibrium with no applied electric field, if the charge distribution is uniform, there is no net current flow. Any disturbance in equilibrium state leads to diffusion current which creates an internal electric field. This field causes the drifting of charge carriers resulting in a drift current. At equilibrium condition, the drift and diffusion current balance each other.

Let $\Delta n$ be the excess electron concentration of a semiconductor. Then at equilibrium the drift and diffusion current densities due to excess electrons are equal.

i.e., $(\Delta n)e\mu_n E = eD_n\frac{\partial(\Delta n)}{\partial x}$

The force on excess electrons restoring equilibrium in equal to the product of excess charge and electric field i.e., $F = (\Delta n)eE$. From the above eqn

$$F = e\frac{D_n}{\mu_n}\frac{\partial(\Delta n)}{\partial x} \text{ ------------- (1)}$$

From kinetic theory of gases, the force on gas molecule is given by

$$F = k_B T \frac{\partial(\Delta n)}{\partial x} \quad \text{------------ (2)}$$

Comparing (1) and (2), we get

$$k_B T = e \frac{D_n}{\mu_n}$$

$$\frac{D_n}{\mu_n} = \frac{k_B T}{e}$$

Similarly for holes, we get

$$\frac{D_p}{\mu_p} = \frac{k_B T}{e}$$

$$\therefore \frac{D_n}{D_p} = \frac{\mu_n}{\mu_p}$$

The above relation is known as Einstein's Relation.

**b. Find the diffusion co-efficient of electron in Si at 300 K if $\mu_e$ =0.19 $m^2V^{-1}s^{-1}$**

**Given data:**

$$\mu_e = 0.19 m^2/V-S$$

Charge of electron (e) = 1.6 x $10^{-19}$ C

Temperature T= 300K

$K_B$ = 1.38 X $10^{-23}$J/K

Find diffusion coefficient $D_n$ = ?

**Solution:**

$$D_n = \frac{\mu_e K_B T}{e}$$

$$= \frac{0.19 X 1.38 X 10^{-23} X 300}{1.6 X 10^{-19}}$$

$$D_n = 4.9 X 10^{-3} m^2/\text{sec}$$

**8.a. Describe the Hall Effect in semiconductors.**

**<u>Hall Effect:</u>**

"When a current carrying a conductor is subjected to a transverse magnetic field, then a potential difference or electric field is developed across the semiconductor. This phenomenon is known as *Hall Effect.*

The potential difference is known as Hall voltage and electric field becomes Hall electric field.

Consider a semiconductor slab of thickness'd' and width 'w' in which a current I is flowing along X direction. It is subjected to magnetic field of strength B along Y direction. The charge carriers inside the semiconductor experience a force due to the applied magnetic field. As a result, electron will accumulated on the lower surface of the slab. Due to this fact the upper side will be positive charge of the semiconductor. Thus, a transverse potential difference is developed. This emf is known as Hall emf. If the charge carriers are

Due to displacement of charge carriers give rise to a transverse field known as Hall electric field $E_H$. This field acts inside the conductor to oppose the side way drift of the charge carrier.

When the equilibrium is reached, the magnetic deflecting forces on the charge carriers are balanced by the electric forces due to the electric field. Magnetic deflecting force will be $q(v_d x B)$

Hall electric deflecting force1 = $qE_H$

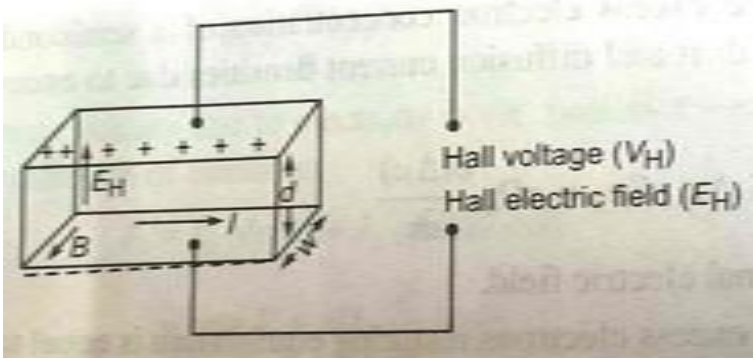
As the net force on the charge carriers becomes zero

$$q\left(v_d x B\right) + qE_H = 0$$

$$E_H = -\ (v_d x B)$$

In terms of magnitude $E_H = v_d B$ ------------(1)

We know that drift velocity $v_d$ is related to the current density $J$ is $v_d = \frac{J}{nq}$ --------- (2)



Where $n$ is the number of charge carriers per unit volume.

By eqn(2) in eqn(1), we get

$$E_H = \frac{1}{nq} JB \quad \text{----------- (3)}$$

If $V_H$ be the Hall voltage in equilibrium, then

$$E_H = \frac{V_H}{d} \quad \text{------------ (4)}$$

The ratio of Hall electric field $E_H$ to the product of current density $J$ and magnetic induction $B$ is known as Hall coefficients. This is denoted by $R_H$.

$$\text{So} \quad R_H = \frac{E_H}{JB}$$

$$\text{From eqn(3)} \ \frac{E_H}{JB} = \frac{1}{nq}$$

$$\therefore R_H = \frac{1}{nq}$$

**b. What are the applications of Hall Effect?**

**Applications of Hall Effect:**

- To determine the type of semiconductor
- To determine the carrier concentration
- To determine the power flow in an electromagnetic wave
- To determine the mobility of charge carriers
- To determine the sign of the current carrying charges

**9.a. Explain the formation of energy bands in solids.**

**Formation of energy bands in solid:**

In a single isolated atom, the electrons in each orbit have definite energy associated with it. But in the case of solids all the atoms are close to each other, so the energy levels of outermost orbit electrons are affected by the neighbouring atoms.

When two single or isolated atoms are brought close to each other than the outermost orbit. The electrons in the outermost orbit of one atom experience an attractive force from the nearest or neighbouring atomic nucleus. Due to this, the energies of the electrons will not be at the same level, the energy levels of electrons are changed to a value which is higher or lower than that of the original energy level of the electron.

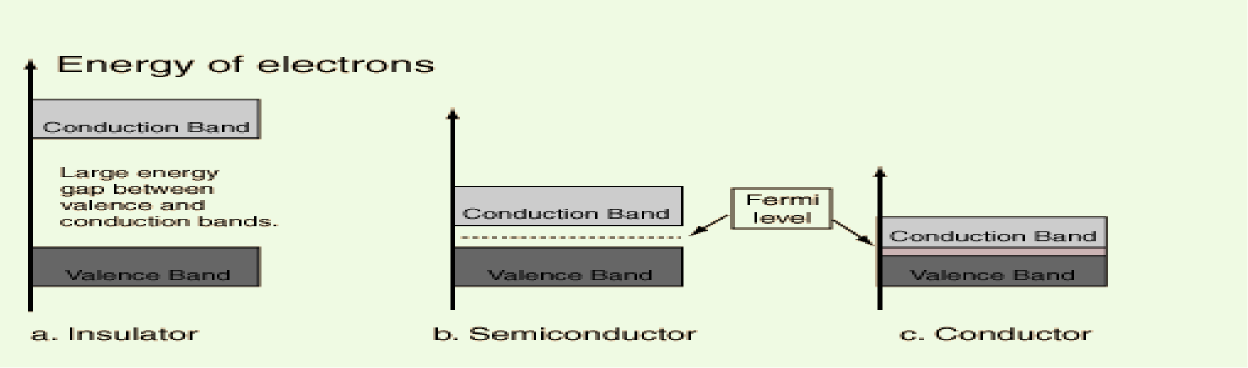
The electrons in the same orbit exhibit different energy levels.The grouping of this different energy levels is called energy band.

However, the energy levels of inner orbit electrons are not much affected by the presence of neighbouring atoms.

**Insultaor**: Insulator is material, in which there is a large energy gap between the conduction band and the valence band, A large amount of energy is required to shift the electron from valence band to conduction band.

**Semiconductor**:Semiconductor is the material, in which there is a less energy gap required with respect to the insulator, When some amount of energy flow in the semiconductor, then it allows to flow the electron from valence band to conduction band.

**Conductior**:Conductor is the material in which, there is no energy gap between the conduction band and valence band, so no extra energy is needed to flow the electron from valence band to conduction band.



**b. Classify the solids into conductor, semiconductor & insulators based on band theory of solids.**

**Classification of solids based on energy bands**

### 1. Conductors

**Definition**

Conductors are materials that allow current to flow easily.

When conductors and semiconductors are compared, conductors enable better current flow, and are said to be good electrical conductors.

**Categories of conductors**

### 1. Metals

Most conductive materials used in practical applications are metals. For example, the wiring used in a house probably employs copper wire or its alloy as a conductive material. The electric plug contains metal, and the internal mechanism of the electric iron also uses metal as a conductive material. This is because metals have many free electrons and promote mobility. A few of the best metal conductors are silver (Ag), copper (Cu), and gold (Au).

### 1. Nonmetals

Some nonmetals are very good conductors of electrical energy. For example, carbon in the form of graphite is a very good conductor. Looking at the structure of graphite, only three of the four carbon atoms are used for bonding. This releases the electrons and binds them together. Most nonmetals are poor conductors of electricity.

### 1. Ionic conductors

Conductors in a solution form are known as ionic conductors. For example, saltwater is an ionic solution and is an excellent electrical conductor.

Examples of conductors are gold, silver, aluminium, and copper;

## 2. Semiconductors

### Definition

Semiconductors are materials that exhibit conductivity between conductors or metals and non-conductors or insulators. Semiconductors are mixtures such as gallium arsenide or pure components such as germanium and silicon.

### Categories of semiconductors

**1. Intrinsic semiconductors:** Intrinsic semiconductor materials are chemically very purely made. They consist of only one element type. When the temperature rises due to collision, some electrons move freely in the lattice without being bound and do not exist in their original positions (holes). These free electrons and holes contribute to the conduction of electricity in the semiconductor. The number of negative and positive charge carriers is the same.

**2. Extrinsic semiconductors:** The conductivity of semiconductors can be significantly improved by introducing a small number of suitable surrogate atoms called impurities. The process of adding foreign atoms to a pure semiconductor is called doping.

Examples of semiconductors are gallium arsenide, germanium, and silicon

## 3. Insulators

### Definition

Electrical insulators are different from conductors. Conductors are materials that propagate the ease of current flowing through them. They allow charges to flow easily. Insulators, on the other hand, are materials that do not allow electric charges to flow freely.

Examples of insulators include rubber, plastic, wax, and wood.

While the classification of solids is done based on band energy into conductors, semiconductors, and insulators, they all have their respective applications in different fields. Examples of conductors are gold, silver, aluminium, and copper; semiconductors are gallium arsenide, germanium, and silicon; and insulators include rubber, plastic, wax, and wood.

## 10. a. Prove that Fermi Level $E_F = \frac{EC+EV}{2}$ in the case of an intrinsic semiconductor.

### <u>Fermi level</u>

The Fermi level indicates the probability of occupation of energy levels in conduction and valence bands. For an intrinsic semiconductor, hole and electron concentrations are equal, and it indicates that the probability of occupation of energy levels in conduction and valence bands are equal. Thus, the Fermi level lies in the middle of the energy gap $E_g$.

For an intrinsic semiconductor, $n = p$

$$N_C e^{-(E_C-E_F)/k_BT} = N_V e^{-(E_F-E_V)/k_BT}$$

$$\frac{e^{-(E_C-E_F)/k_BT}}{e^{-(E_F-E_V)/k_BT}} = \frac{N_V}{N_C}$$

$$e^{[2E_F-(E_C+E_V)]/k_BT} = \frac{N_V}{N_C}$$

Taking $log$ on both side, we get

$$\frac{[2E_F-(E_C+E_V)]}{k_BT} = \log log\left(\frac{N_V}{N_C}\right)$$

$$E_F = \frac{E_C+E_V}{2} + \frac{1}{2}k_BT \log log\left(\frac{N_V}{N_C}\right)$$

When $N_V = N_C$ then $E_F = \frac{E_C+E_V}{2}$

Thus, the Fermi energy level in an intrinsic semiconductor lies in the middle or centre of the energy gap.

**b. Mobilities of electrons and holes in an intrinsic germanium at 300K are 0.36 m$^2$V$^{-1}$s$^{-1}$ and 0.17 m$^2$V$^{-1}$s$^{-1}$ respectively. If the resistivity is 2.12 Ω -m . Calculate the intrinsic concentration.**

**Given data**

$$\text{Mobility of electron}\,\mu_e = 0.36 m^2/v-s$$

$$\text{Mobility of electron}\,\mu_p = 0.17 m^2/v-s$$

$$\text{Re}\,sistivity\,\sigma = 2.12\Omega - m$$

**Solution:**

$$\text{Conductivity}\,\sigma = \frac{1}{\rho} = n_i e(\mu_n + \mu_p)$$

$$\frac{1}{2.12} = n_i \times 1.6 \times 10^{-19}(0.36+0.17)$$

$$n_i = 556.25 \times 10^{16}/m^3$$

**11.a. Derive the expression for energy gap(Eg) of an intrinsic semiconductor**.

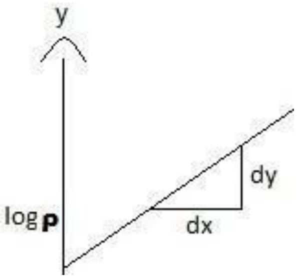
**Expression for Energy band gap**

The energy gap between valence and conduction bands is the energy band gap $E_g$.

From the equation $\sigma = Ae^{-E_g/2k_BT}$, we get

$$\rho = \frac{1}{\sigma} = \frac{1}{A}e^{E_g/2k_BT} = Be^{E_g/2k_BT}$$

where $B = \frac{1}{A} - constant$



Taking *log* on both side, we get

$$\log log\, \rho = \log log\, B + E_g / 2k_B T$$

*log* of the resistivity when plotted with *1/T*, produces a straight line. The slope of the line gives the energy band gap of the semiconductor.

From fig. $$\frac{E_g}{2k_B} = \frac{dy}{dx}$$

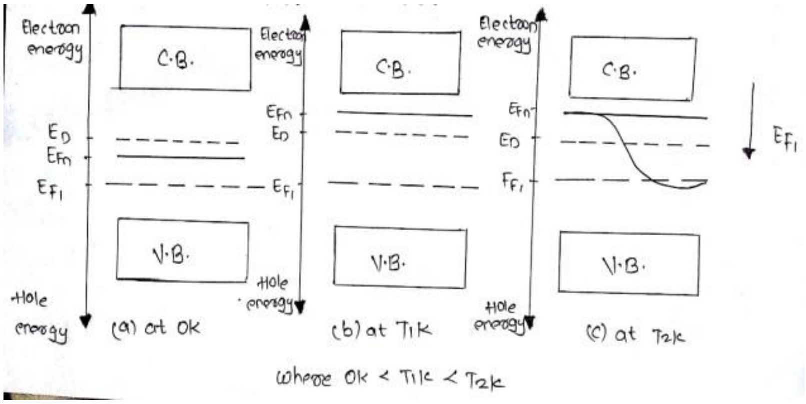
$$E_g = 2k_B \frac{dy}{dx}$$

**b Explain the temperature dependence of Fermi Energy Level (Ef) in an Extrinsic semiconductor**.

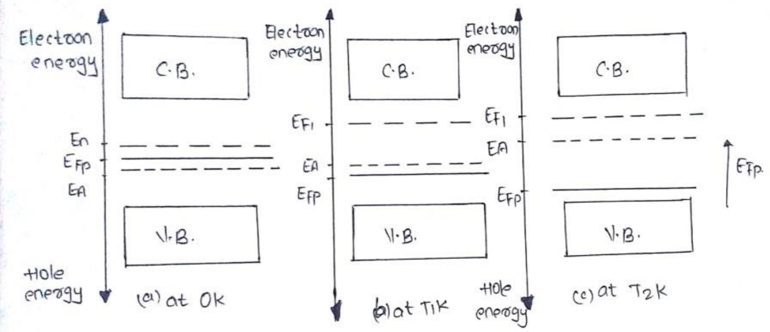
### IN n-TYPE SEMICONDUCTOR.

- At 0K the fermi level E_{Fn} lies between the conduction band and the donor level.
- As temperature increases more and more electrons shift to the conduction band leaving behind equal number of holes in the valence band. These electron hole pairs are intrinsic carriers.
- With the increase in temperature the intrinsic carriers dominate the donors.
- To maintain the balance of the carrier density on both sides the fermi level EFn gradually shifts downwards.
- Finally at high temperature when the donor density is almost negligible E_Fn is very close toEFi.

### IN p-TYPE SEMICONDUCTOR.



- At 0K the fermi level EFp in a p-type semiconductor lies between the acceptor level and the valence band.
- With the increase in temperature more and more holes are created in the valence band as equal number of electrons move to the conduction band.
- As temperature increases the intrinsic holes dominate the acceptor holes.
- Hence the number of intrinsic carriers in the conduction band and in the valence band become nearly equal at high temperature.
- The fermi level EFp gradually shifts upwards to maintain the balance of carrier density above and below it.
- At high temperature when the acceptor density become insignificant as compared to the intrinsic density, EFp is positioned very close to the intrinsic fermi level EFi but little below it.



(a) at 0K (b) at T1K (c) at T2K

Where 0K < T1k < T2k