UNIT-I PROPERTIES OF MATTER

1. Define elasticity.

The property of the body to regain its original shape and size, after the removal of deforming force is called elasticity

2. Define stress and strain and write down their units.

Stress: Stress is defined as the restoring force per unit area which brings back the Body to its original state from the deformed state. **Unit for stress:** N/m^2

Strain: Strain is defined as the change in dimension produced by the external force on the body. It can also be defined as the ratio of the change in dimension to the original dimension. **No unit**
Strain= Change in dimension / original dimension

3. State Hooke's Law

Stress is directly proportional to the strain produced, within the elastic limit
i.e., Stress α Strain

$$E = \frac{Stress}{Strain} Nm^{-2}$$

Where is E is a constant modulus of elasticity.

**4. Define Poisson's Ratio and Poisson's Number.**

It is defined as the ratio between the lateral strains per unit stress (β) to the longitudinal strain per unit stress (α), within the elastic time.

$$Poisson's\ ratio\ (\sigma) = \frac{Lateral\ Stain}{Longitudinal\ Strain} = \frac{\beta}{\alpha} = a\ constant$$

The **inverse of Poisson's ratio** is Poisson number.

5. What do you infer from Stress-Strain diagram?
   1. The Stress is directly proportional to the strain, Within elastic limit.
   2. It distinguishes the elastic and plastic limit of a material.
   3. It determines the ultimate strength of the material.
   4. The stress-Strain diagram also helps us to distinguish the material based on the properties such as ductility   and brittleness

Figure 1
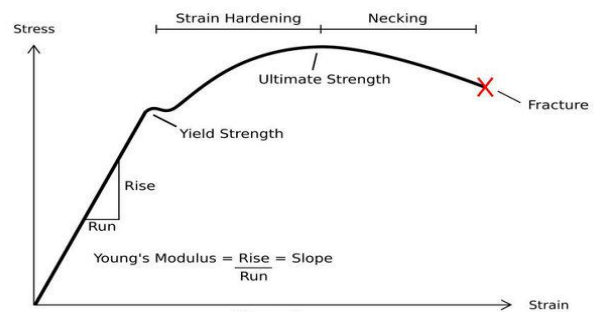
6. Define Yield point

The point at which the body loses its elasticity (elastic nature) is called as yield point.

7. Define Elastic Fatigue

If a body is continuously subjected to stress (or) strain, it gets fatigued (weak) called as elastic fatigue.

8. **Define elastic limit and plastic limit.**

The maximum stress up to which a body can recover its original shape and size, after removing the external forces is called as elastic limit. After elastic limit, if the elasticity of the body is completely lost, then the body will be in a limit called as plastic limit.

9. **What are the factors affecting elasticity?**

Effect of stress, Effect of annealing, Effect of temperature and Presence of impurities.

10. **Explain neutral axis (or) How are the various filaments of a beam affected when the beam is loaded?**

The middle layer (or) filament of a beam which remains unaltered even with the presence of load on the beam is called neutral axis. Filaments which are lying above it are elongated and those are lying below it are compressed

11. **What is moment of a force?**

The moment of a force about a point is defined as the product of the magnitude of the force and perpendicular distance from the point to the line of action of force.

12. **Define Torque**

Torque is the rotating force and is equal to the moment of the couple. Torque is the product of one of the forces forming couple and the perpendicular distance between the two opposite forces.

13. **Explain bending moment of beam**

The Moment of the couple due to the elastic reactions which balances the external Couple due to the applied load is called the bending moment.

14. **How do temperature and impurity in a material affect the elasticity of the materials?**

Effect of temperature: The rise in temperature decreases elasticity and vice versa.

Example**:** The carbon filament becomes plastic at higher temperatures.

Effect of impurities: The addition of impurities produces variation in the elastic property of the materials. The increase and decrease in elasticity depends on the type of impurity added to it.

Example: When potassium is added to gold, the elasticity property of gold increases.

15. **Define I-shape girder and Write down its advantages and Applications.**

The girder is the one in which the upper and lower sections are broadened and the middle of the section is tapered so that it can withstand heavy loads over it. Since the girder looks like letter I, it is called as I shape girder. I-Shape girders are made by the reducing the area of the neutral axis.

(1)More stability
(2)More Strength and
(3)High durability

Applications:
1. They are used in the construction of bridges over the rivers.
2. They are very much used in the production of iron rails which are employed in railway tracks.
3. They are used as supporting beams for the ceilings in the construction of buildings.

16. **An elastic wire is cut into half of its original length. How will it affect the maximum load the wire can support?**

$$E = \left(\frac{Load}{Area}\right) * \left(\frac{Original\ length}{change\ in\ length}\right)$$

We Know

Tensile Strength $= \dfrac{Maximum\ tensile\ load}{Original\ cross\ sectional\ area}$

When original length is halved, strain is changed so that the maximum load that the wire can support will remain the same as Elastic modulus is constant

17. **Define buckling.**

The depression in the beam s can be reduced by increasing thickness rather than increasing the breadth. But on increasing the thickness the beam bend at the centre part. This is called as buckling.

18. **How will you identify the brittle material from the stress strain diagram?**

Brittle materials do not have the yield point. A typical stress strain curve for a brittle material will be linear.

19. **What is the principle behind the tensional pendulum**

When a disc is rotated in a horizontal plane, the disc executes simple harmonic oscillation due to the restoring couple produced in the wire.

20. **Define Torsional stress in material**

The stress or deformation caused when one end of an object is twisted in one direction and the other end is held motionless or twisted in the opposite direction is known as tensional stress.

21. **Define Torsion in a material**

The act of twisting or turning is known as torsion.

22. **What are the uses of torsional pendulum?**

It is used to determine
    1. Rigidity modulus of the wire
    2. Moment of inertia of the disc and
    3. Moment of inertia of an irregular body.

23. **When a wire is bent back and forth, it becomes hot. Why?**

When a wire is bent back and forth, heat is generated due to the area of the elastic hysteresis and frictional force. Hence it becomes hot.

UNIT-II WAVES AND FIBER OPTICS

1. **Define Simple Harmonic Motion.**

SHM is the motion in which the acceleration of a body is directly proportional to the displacement from a fixed point and is always directed towards the fixed point (or) equilibrium position.

2. **What are the types of motion? Give Examples.**

Based on the motion of the Physical bodies, it can be classified into two types
    i) Translational motion, in which the motion of the body moves linearly with time.

Ex: Train moving in track, Rocket launching etc.
ii) Rotational motion, in which the motion of the body repeat itself after regular interval of time.
Ex: Bob moving in a pendulum clock, Beating of heart, Movement of earth around the sun etc.

3. Write down the characteristics of SHM.
There are five characteristics for the simple Harmonic motion viz,
i) Displacement, ii) Amplitude, iii) Time period iv) Frequency and v) Phase

4. Define Amplitude and Phase.
Amplitude: The maximum distance covered by the body on either side of its mean position is called its Amplitude.
Phase: It is the physical quantity that expresses the instantaneous position and direction of motion of an oscillating system

5. List out the types of oscillatory motion.
There are three types of oscillatory motion, based on the force that is acting on the system, viz.
i) Free Vibration   ii) Damped Oscillation & iii) Forced Oscillation

6. What is meant by free vibration?
A system (or) body which vibrates freely without any resistance (Even air) (or) Frictional force is called free Vibrations. In real situation this is not possible, because by nature always some resistance is offered to the oscillating system.

7. What is meant by Damped oscillations?
In real situation, if a body is set into vibrations, the amplitude keeps on decreasing of frictional resistance to the motion and hence after some time the vibrations (or) oscillations will die. This type of oscillation is said to be a **Damped Oscillation.** In this oscillation (or) vibration, the body vibrates with its natural frequency.

8. What is meant by Forced Vibrations?
There are situations in which we need to give external force for the oscillations to sustain. This type of oscillations to sustain. This type of oscillation in which the body vibrates with a frequency other than natural frequency due to the external force applied in equal interval of time is called Forced Oscillation.

9. What do you understand by the term DEAD BEAT? Give Examples.
During oscillation motion, when the displacement decreases drastically without performing any oscillations, then the motion is set to be Over Damped Oscillation (or) DEAD BEAT.
Ex: 1. Pendulum moving in a very thin coil media.
      2. Dead Beat moving coil galvanometer.

10. What is meant by critical damped motion? Give examples.
During the oscillatory motion, when the displacement decreases to zero rapidly, then it is called critical damped motion.
 Ex: 1. Movement of pointer in Voltmeter, Ammeter etc.
      2. Sensitive Galvanometers.

11. What is meant by under damped motion? Give examples.
During oscillatory motion, when the displacement (or) Amplitude decay's with respect to the damping factor, then it is termed as under damped motion.

Ex: 1. Motion of simple pendulum in air.   2. Motion of the coil in ballistic galvanometer.

12.   Define Plane progressive wave.
   A plane progressive wave is the simplest wave in which the particles of the medium perform Simple Harmonic Motion.

13.   Define Particle Velocity.
   Particle velocity is defined as the rate of change of displacement 'y' with respect to time 't'.
   Particle velocity (dy /dt) = wave velocity (v) X slope of displacement (dy / dt)

14.   What are the Characteristics of laser?
   a. Highly Intense   b. Coherence   c. Monochromatic   d. Highly directional

15.   Distinguish between spontaneous and stimulated emission.

S.NO	Spontaneous emission	Stimulated emission
1	The atoms in the excited state moved to ground state without any external force is called spontaneous emission	The atoms in the excited state moved to ground state with some external force are called stimulated emission.
2	During this process, one photon of energy is emitted.	During this process, two photons are emitted.
3	The emitted photons move in random manner.	The emitted photons are highly directional
4	Photons are not in phase	Photons are in phase.

16.   What are the applications of laser?
   1. Medical applications:
   1. It is used for the treatment of **retinal detachment.**
   2. It is used for performing **microsurgery** and **bloodless surgery**.
   3. It is used in the treatment of human and animal **cancers** and **tumors.**
   2. Industrial applications:
   1. It is used in **metal welding** and also used in making the metals from solid state in to melt.
   2. It is used **to test the quality** of the materials.
   3. Used in making **holes in diamond** and hard steels.
   3. Scientific and Engineering applications:
   1. Communication between planets can be possible by the use of laser.
   2. Used in **computer printers**.
   3. Used in three dimensional **lens less photography**.
   4. Biological applications:
   1. Used in **drilling** minute holes **in cell walls** without damaging the cell itself.
   2. micro surgical operations within cells can be possible.
   5. Military applications:
   a. It is being developed to serve as **war weapon**. (**Death ray-**It can destroy aero planes, missiles in few seconds.)
   b. Like radar **LIDAR** is used in determining the distance, velocity and direction precisely.

17. **What are the conditions to achieve laser action?**
    a. Population inversion should be achieved.
    b. Stimulated emission should be predominant over spontaneous emission.

18. **What is pumping? Give an account of different methods of pumping.**
      The process of raising the atoms from ground state to excited state by external methods is called pumping.
    1. Optical pumping method
    2. Direct electron excitation
    3. Inelastic atom-atom collision
    4. Direct conversion
    5. Chemical process

19. **Distinguish between LED and LASER.**

S.NO	LED	LASER
1	It requires low current density	It requires high current density
2	Junction is not necessary to polish	Junction current should be polished
3	Power output is low.	Power output is high.
4	Intensity is less.	Intensity is high

20. **What is normal population, population inversion and metastable state?**

    Normal population: If the number of atoms in the ground state is greater than the number of atoms in the excited state, it is called normal population. **$N_1 > N_2$**

    Population inversion: If the number of atoms in the excited state is greater than the number of atoms in the ground state, it is called normal population. **$N_1 < N_2$**

    Metastable state: For achieving population inversion, more atoms are required in excited state for longer life time. Atoms stay more time in a particular excited state such state is called Meta stable state.

21. **Distinguish between homo junction and hetero junction semiconductor laser.**

S.no	Homojunction laser	Heterojunction laser
1	It is made by single crystal materials	It is made by different crystal materials
2	It has one junction	It has more than one junction.
3	Cost is low	Cost is high
4	The life time is less	It has extended life time
5	Example: GaAs, InP	Example: GaAlAs, InAlP

22. **Can a two-level system be used for the production of laser? Why?**
      No, two-level system cannot be used for the production of laser, because for population inversion to be achieved at least three levels are required.

23. **What is the principle of semiconductor laser?**
    1. When the power supply is switched ON the electrons in the conduction band combines with holes in the valence band, hence the recombination process occurs.

2. During this recombination it produces energy in the form of (photon) light.

3. This emitted photon induces another electron in the valence band to conduction band and thus Stimulated emission occurs.

24. Define Numerical aperture and acceptance angle.

Acceptance angle: The maximum angle at or below which the light, that undergoes total internal reflection is called acceptance angle.

Numerical aperture: It is defined as sine of acceptance angle of the fiber. $NA = \sin i_{max}$

25. Mention few applications of fiber optic sensor.

1. Used in fluid level detector, temperature and pressure measurement.
2. Used in gyroscopy.
3. Used in determining the distance and displacement.

26. What is the basic principle of fiber optic communication?

When light passes through the fiber cable, if the angle of incidence is greater than the critical angle, then the light undergoes total internal reflection in the same medium is the principle of fiber optic communication.

27. Distinguish between step index fiber and graded index fiber.

S.NO	Step index fiber	Graded index fiber
1	The refractive index of core, cladding and air decreases as steps are called step index	The refractive index of core and cladding decreases gradually from centre of the core to cladding gradually.
2	The light rays pass through the axis of the fiber.	The light rays propagates in the form of skew rays
3	The light Zigzag path.	The light has Spiral path (Helical path).
4	It has low band width	It has high band width.

28. What is meant by attenuation?

It is the ratio between power outputs from the length of the fiber L to the power input.

$$\textbf{Attenuation } (\alpha) = -10 \log \frac{P_{out}}{P_{in}} \ \ dB/Km$$

29. Mention few applications of fiber optic sensor.

a. No external interference   b. It is used in remote sensing   c. Safety data transfer d. small in si

30. What are the conditions required for total internal reflection?

a. The angle of incidence should be greater than the critical angle

b. The refractive index of core should be greater than the refractive index of cladding $(n_1 > n_2)$

31. What are active and passive sensors?

a. **Active sensors:** The sensors which sense the physical parameters directly are called active sensors. Example: Temperature sensor, pressure sensor.

b. **Passive sensors:** Separate sensing elements are used along with fibre. Here the fibre acts as

guiding medium. Example: Displacement sensor.

32. **What is the role of cladding in an optical fiber?**
 a. It is **transparent dielectric** material.
 b. It surrounds over the core in cylindrical form, acts as a **protection layer** for core.
 c. It has **lower refractive index** than core in order to produce **total internal reflection** within the core**.**

33. **List the four factors that cause loss in optical fibers?**
 a. Absorption b. Rayleigh scattering c. Geometric cause due to micro and macroscopic bending
 d.Dispersion

34. **Distinguish single mode fiber and multimode fiber.**

S.No	Single Mode fiber	Multimode fiber
1	It uses only one mode of propagation.	It uses a large number of modes of light to propagate through it.
2	It has small core diameter	It has large core diameter.
3	No dispersion	Dispersion is more.
4	Transmission is inversely proportional to dispersion. So transmission capacity is more	Transmission capacity is less.
5	Launching of light in fibers and connecting fibers is difficult.	Launching of light and connecting of fibers is easy

35. **Write any four major advantages of optical fiber communication over other communication systems.**

 a.   Optical communication can be made even in the absence of electricity.
 b.   The Optical signals are not affected by any electrical signals (or) lightening
 c.   Optical fiber communication is free from electromagnetic interference (EMI)
 d.   This type of communication is suitable to any environmental conditions

UNIT-III THERMAL PHYSICS

1. **What are the basic entities responsible for thermal condition of a solid**
 1. Area of cross section (A)
 2. Temperature difference between the hot and cold layers of the solid (01-02)
 3. Time of conduction(t)
 4. Thickness of the solid(x)

2. **Distinguish between conduction and convection and radiation**
 Conduction: The heat is transferred from hot end to cold end without the actual movement of the particles.
 Convection: The heat is transmitted from the hot end to cold end by the actual movement of the particles.
 Radiation: The heat is transmitted from one place to another without the necessity of the intervening medium.

3. **Define Coefficient of thermal conductivity.**

   The Coefficient of thermal conductivity is defined as the amount of heat conducted per second normally across the unit area of cross section, maintained at unit temperature gradient.

   The unit of thermal conductivity is **$Wm^{-1}K^{-1}$**

4. **What is meant by temperature gradient?**

   The rate of fall of temperature with respect to the distance is called as temperature gradient. In general it is denoted as $-\frac{d\theta}{dx}$. The negative sign indicates the fall of temperature with the increase in distance.

5. **Define Newton's Law of Cooling**

   The rate of loss of heat of a body is directly proportional to the temperature difference between the body and its surrounding of same nature.

6. **Why the specimen used to determine thermal conductivity of a bad conductor should have a larger area and smaller thickness?**

   For a bad conductor with a smaller thickness and larger area of cross section, the amount of heat conducted will be more.

7. **What is the basic principle employed in Lee's disc method for bad conductors?**

   The amount of heat conducted
   through the bad conudctor per second = Amount of heat lost per second by the disc

8. **Define thermal diffusivity.**

   It is defined as the ratio of thermal conductivity to the thermal capacity per unit volume of the material

   $$\textbf{Thermal diffusivity (h)} = \frac{\textbf{Thermal conductivity}}{\textbf{Thermal capacity}}$$

9. **Explain radial flow of heat**

   In this method, heat flows from inner sphere (or) cylinder towards the outer sphere (or) cylinder along the radius and hence the heat is radiated radially across all layers. Thus it is called as radial flow method.

How are heat conduction and electrical conduction analogous to each other?

S.No	Head conduction	Electrical conduction
1	Heat is conducted from a point of higher temperature to a point of lower temperature	Electricity is conducted from a point at higher potential to a point at lower potential
2	In metals heat conduction is mainly due to free electrons.	In metals electrical conduction is due to free charge carriers namely electrons.
3	The ability to conduct heat is measured by thermal conductivity	The ability to conduct electricity is measured by electrical conductivity.

11. **The ends of two rods A and B with thermal conductivities K_1 and K_2 respectively ate maintained at temperatures Θ_1 and Θ_2. The rods are of equal length. What is the condition under which there will be equal rate of flow of heat through both the rods?**

If Θ_1 and Θ_2 are end temperature of the two rods. Then, the condition for equal rate of flow of heat through both the rod is

$$\theta_1 - \theta_2 = \frac{Ql}{A}[\frac{1}{K_1} + \frac{1}{K_2}]$$

12. **What is the purpose of thermal insulation?**

The purpose of thermal insulation in a building is to minimize the transfer of heat between outside and inside of the building. Due to thermal insulation, the room remains cool in summer and warm in winter than outside.

13. **Name the thermal insulation materials.**

The porous materials have air gaps which prevent conduction of heat through them. The popular thermal insulating materials are felt, fur, hair and wool. Similarly granular thermal insulating materials are sand and saw dust.

14. **What are the applications of thermal insulation?**

The thermal insulation can be applied on the walls, floors, ceilings, windows and doors of a house so that the amount of heat at outside will not enter into the house during summer.

15. **What are heat exchangers?**

A heat exchanger is a device designed to efficiently transfer or exchange heat from a hot fluid to a cold fluid with maximum rate and minimum investment and running costs.

16. **What is refrigerator?**

Refrigerators are machines devised for the production of artificial coldness required to maintain a chamber for the storage of perishable food at low temperature.

17. **What is meant thermal expansion in solids?**

When a metal is heated, due to increase in temperature it will expand and when it is cooled it contracts. However, in internal force will always act so as to keep the metal to regain its original length/position.
Thermal expansion: The expansion of a metal, when subjected to heat is called thermal expansion.

18. **Define co-efficient of Thermal expansion (α)**

The co-efficient of thermal expansion can be defined as the ratio between the change in length to the original length per unit rise of temperature.

$$\alpha = \frac{dl}{l}$$

19. **Define co-efficient of volume expansion**

The co-efficient of volume expansion 'β' is defined as ratio between the fractional change (ΔV) in volume to the original volume (V) per unit rise of temperature (ΔT)

$$\beta = \frac{\Delta V}{V}$$

20. **What you understand by the term bimetallic strip and Give its use.**

Bimetallic strips are made up of two thin metal strips with different coefficient of thermal expansion. Bimetallic strips are commonly used in water heaters as a temperature controller.

21. **What is the principle behind Forbes's method for determining the absolute conductivity of metals?**

The amount of heat flowing per second across the cross section of the rod is calculated. The heat lost by radiation by the rod beyond this section is calculated. Under steady state condition, the amount of heat conducted is equal to the heat radiated. Applying this condition the absolute thermal conductivity of metals can be calculated.

22. **What is meant by thermal resistance?**

The thermal resistance of the body is a measure of its opposition to the flow of heat through it (i.e) everybody posses some resistive power when it is subjected to heat. This resistive power is termed as thermal resistance.

23. **What are the factors to be considered in order to maintain a comfortable condition inside a building?**
    1. Thermal regulation 2. Thermal comfor 3. Thermal resistivity 4. Thermal insulation

24. **What is meant by solar power? How will you estimate it?**

Solar power is the process of converting (or) utilizing the abundantly available solar energy either directly as heat (or) indirectly by converting it into electrical power using photo voltaic cells.

This solar energy reaches the earth at the rate of 1.4 KW per square meter of surface perpendicular to the direction of the sun ray.

The total solar power = 4×10^{26} Watts

25. **Give the principle of solar water heaters.**

Solar water heater is based on the principle of converting solar energy (sunlight) into electrical energy and then into heat energy, using solar electric panels, so called solar cells (or) Photo voltaic cells. Nowadays, solar thermal panels were widely used, which converts the solar energy directly into heat energy.

UNIT IV- QUANTUM PHYSICS

1. **What is the physical significance of a wave function?**
   1. Wave function gives the information about the particle.
   2. It relates the particle and the wave statistically.

   It is a complex quantity. $|\Psi|^2 = \Psi* \Psi$ is the probability density.

2. **What is a black body and what are its characteristics?**

   A black body is one it completely absorbs the radiations falls on it and emits the radiations when it is heated. In practice, no black body is perfectly black. It acts as a perfect absorber and a perfect emitter.

3. **State De Broglie's hypothesis (or) Give the origin of matter waves.**

   Light has two natures: Particle nature and Wave nature. From the concept of De Broglie a particle also behaves as a wave that exhibit dual nature.
   The wave associated with a material particle called matter waves.
   De Broglie wavelength for matter waves is $\lambda = h/mv$ (or) h/P

   Where, 'λ' is the wavelength, 'm' the mass of the particle and 'v' the velocity of the particle.

4. **Define Compton Effect and Compton shift**

   When a beam of X-rays is scattered by a substance of low atomic number, the scattered X-ray radiation consists of two components, one component has the same wavelength as the incident ray and the other component has a slightly longer wavelength. This change in the wave length of scattered X-rays is known as Compton shift. The phenomenon is called Compton Effect.

5. **State Planck's quantum theory (or) State Planck's hypothesis (or) What are the postulates of Planck's quantum theory? (or) What are the assumptions of quantum theory of black body radiation? (or) Give the special features of Quantum theory.**
   (i) The electrons in the black body are assumed as simple harmonic oscillators.
   (ii) The oscillators will not emit energy continuously.
   (iii) The emit radiation in terms of quantas of magnitude 'hυ', discretely.
   i.e. $E = nh\upsilon$, where $n = 0, 1, 2, 3, \ldots$

6. **What is Compton wavelength? Calculate its value.**

   The shift in wavelength corresponding to the scattering angle of 90° is called Compton wavelength.

   $$\text{Compton's shift } \Delta\lambda = \frac{h}{m_0 c} (1 - cos\theta)$$
   When θ=90° and $cos\theta = 0$
   $$\text{Compton's shift } \Delta\lambda = \frac{h}{m_0 c}$$
   $$\text{Compton's shift } \Delta\lambda = \frac{6.626 X 10^{-34}}{9.11 X 10^{-31} \, X \, 3 X 10^8}$$

   $\Delta\lambda$ = **0.02424** Å

7. **What are the properties of matter waves?**
   - Matter waves are not electromagnetic waves.
   - Matter waves are new kind of waves in which due to the motion of the charged particles, electromagnetic waves are produced.
   - Lighter particles will have high wavelength.
   - Particles moving with less velocity will have high wavelength.
   - The velocity of matter wave is greater than the velocity of light.

8. **What is meant by degenerate and Non- degenerate states?**

   Degenerate state: For different combination of quantum numbers if we get the same energy eigen value and different wave function (eigen functions) is called degenerate state.

   (i.e) $E_{112} = E_{121} = E_{211}$ but $\Psi_{112} \neq \Psi_{121} \neq \Psi_{211}$

   Non - Degenerate state: For different combination of quantum numbers if we get the same energy eigen value and same wave function (eigen functions) is called degenerate state. (i.e) E_{222} and $\Psi222$.

9. **Give any two applications of Schrodinger's wave equation.**
   - It is used to find the electrons in the metal.
   - It is used to find the energy levels of an electron in an infinite deep potential well.

10. **What is the principle used in STM.**

    The basic principle used in Scanning Tunneling Microscope is the tunneling of electron between the sharp metallic tip of the probe and the surface of a sample.
    Here, constant tunneling current is maintained by adjusting the distance between the tip and the sample with an air gap for electron to tunnel. In a similar way the tip is used to scan atom by atom and line of the sample and the topography of the sample is recorded in the computer.

11. **What are the postulates of Planck's Quantum theory (or) Planck's Hypothesis?**
    - The electrons in the black body are assumed as simple harmonic oscillators.
    - These oscillators will not emit energy continuously. $E = nh\gamma$ n= 1,2,3……
    - The frequency of emitted radiations is same as that of the frequency of the vibrating particles.

12. **What is meant by photon? Give any two properties.**

    Photon means bunch of energy or packets of energy or discrete energy values having definite frequency or wavelength.
    Properties:
    - It has no charge.
    - Energy of photon $E = nh\gamma$.
    - It is not deviated from its path.
    - It travels with the velocity of light.
    - It doesn't ionize the gases.

13. **For a free particle moving within a one dimensional potential box , the ground state energy cannot be zero, Why?**

For a free particle moving within a one dimensional potential box ,When n=0 the wave function is zero for all values of x(i.e) it is zero even within the potential box. This would mean that the particle is not present within the box. Therefore the state with n=o is not allowed. As energy is proportional to n^2 The ground state energy cannot be zero since n=0 is not allowed.

14. **Define Rayleigh-Jeans law. Give its limitations.**

It is defined as the energy is directly proportional to the absolute temperature and is inversely proportional to the fourth power of the wavelength.
Limitation: It holds good only for longer wavelengths.

15. **Define Wien's displacement law. Give its limitations**.

It is defined as the product of the wavelength of maximum energy emitted and the absolute temperature is a constant.

$$\lambda m \ T = Constant.$$

Limitation: It holds good only for shorter wavelength.

16. **Define normalization.**

Normalization is the process by which the probability of finding a particle inside any potential well can be done.

17. **What is meant by tunnelling effect?**

In quantum mechanics a particle having lesser energy (E) than the barrier potential (V) can easily cross over the potential barrier having a finite width (l) even without climbing over the barrier by tunneling through the barrier. This process is called Tunneling.

18. **What are the advantages and disadvantages of STM?**
    Advantages
    - It can scan the positions and topography atom by atom or even electrons.
    - It is the latest techniques used in research lab for scanning the materials.
    - Very accurate measurement shall be obtained.
    - Magnification is upto nano-scale.

    Disadvantages
    - Even very small vibrations will disturb the measurement setup.
    - It should be kept in vacuum, as even a single dust particle may damage the tip of the probe.
    - Cost is high.
    - More complexity.

19. **Give the applications of STM.**
    - It is used to produce Integrated circuit.
    - It is used in biomedical devices.
    - Research labs are the major areas in which it is used
    - They are used in material science studies for both bump and flat surfaces.

20. **Define Eigen value and Eigen function.**

Eigen value is defined as energy of the particle and is denoted by the letter E_n

Eigen function is defined as the wave function of the particle and is denoted by Ψ_n

UNIT - V – CRYSTAL PHYSICS

Define lattice points, basis.

Lattice points: a. imaginary point's **b.** used to designate the position of atoms in the crystal **c.** Every lattice point has the same environment.

Basis: These are atoms or molecules and can be easily identified by using the lattice points.

Define Space lattice (or) crystal lattice.

A three dimensional collection of points in space is called a space lattice (or) crystal lattice. The environment about any particular point is in every way the same.

Define the terms a. Effective number b. Atomic radius c. Coordination number d. Atomic Packing Factor.

a. Effective number: The total numbers of atoms present in or shared by a unit cell is known as effective number (or) number of atoms per unit cell.

b. Atomic radius: It is defined as the half of the distance between any two nearest neighbour atoms which have direct contact with each other.

c. Co-ordination number: It is the number of nearest neighbouring atoms to a particular atom.

d. **Atomic packing factor:** It is the ratio of total volume occupied by number of atoms per unit cell to the total volume of the unit cell.

$$APF = \frac{No\ of\ atoms\ per\ unit\ cell\ X\ Volume\ of\ one\ atom}{Volume\ of\ the\ unit\ cell}$$

1. **What are the Miller indices? Define the same.**

   Miller indices: These are set of three numbers used to designate a plane in a crystal. These sets of three numbers are called miller indices.

   Definition: A Miller index is defined as the reciprocal of the intercepts made by the plane in crystallographic axes

2. **A crystal plane cut at 3a, 4b and 2c distances along the crystallographic axes. Find the Miller Indices of the plane.**

   Given data : Intercepts = 3a: 4b : 2c

   Solution

   Step (i) : Co-efficients of intercepts = 3: 4: 2

   Step (ii) : Reciprocal of intercepts = 3 : 4 : 2

   Step (iii) : LCM = 12

   Step (iv) : Multiplying by LCM with the reciprocals $12X\frac{1}{3} : 12X\frac{1}{4} : 12X\frac{1}{2}$

   We have 4 3 6

   Miller Indices = (4 3 6)

3. **A unit cell has the dimensions a = b = c = 4.74 A and α ≠ β ≠ γ ≠ 60⁰, what is the crystal structure?**
    For a = b = c = 4.74 A and α ≠ β ≠ γ ≠ 60⁰, the crystal structure is Trigonal (or)Rhombohedral

4. **Define Unit cell.**
    It is the smallest geometry; the repetition of these small structures in three dimensions gives the complete crystal structure.

5. **What is meant by Bravais lattice?**
    It is the possible 14 ways of arranging the lattice points in space and these points have the same surroundings. These 14 lattices are called Bravais lattice.
    (OR)
    According to Bravais, there are fourteen possible independent ways of arranging points in three dimensional spaces. These fourteen possible space lattices of seven crystal systems are called Bravais Lattices.

6. **Define primitive cell and non-primitive cell. Give Example.**
    Primitive cell: If the total number of atoms present in a **unit cell is one**, it is called primitive. E.g.: simple cubic.
    Non-primitive cell: If the total number of atoms present in a **unit cell is more than one**, it is called non- primitive. E.g.: BCC, FCC.

7. **Draw the structures of planes (1 0 0), (1 1 0), (1 1 1), (1 0 1).**
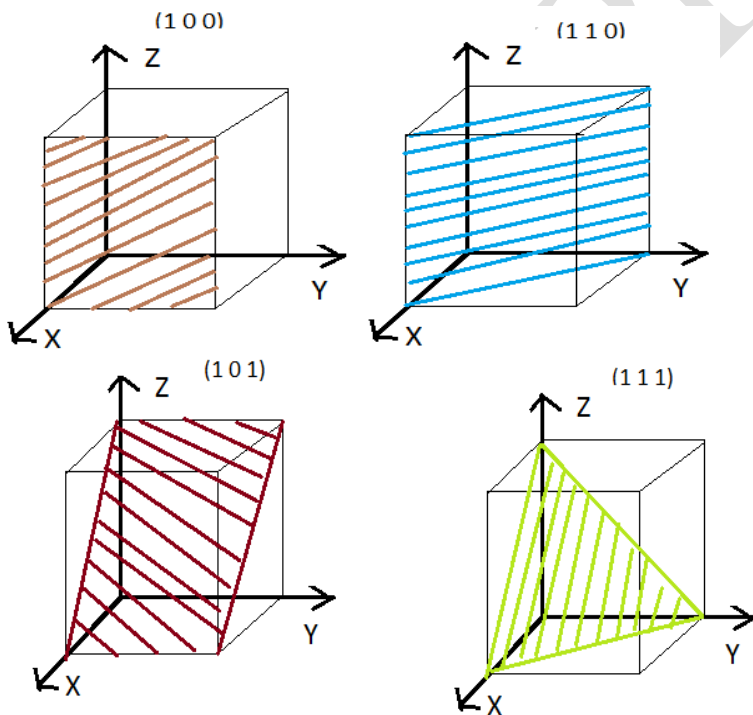
8. **Calculate the value of d-spacing for (100) planes in a rock salt crystal of a = 2.814 A.**

    Given: a = 2.814 A

    h = 1

    k = 0

    l = 0

    d spacing or $d_{hkl} = \frac{a}{\sqrt{h^2+k^2+l^2}}$

    d spacing or $d_{hkl} = \frac{2.814 X 10^{-10}}{\sqrt{1^2+0^2+0^2}}$

    d = 2.814 A

9. **What are the techniques adopted for crystal growth.**
    - Solution growth
    - Melt growth
    - Vapour growth

10. **What is meant by solution growth?**

    The material to be grown is dissolved using a solvent and is kept ideal until the super saturation state is achieved. At some degree of super saturation, parent nuclei is formed, which leads to further growth of crystal.

11. **What is melt growth?**

    Melt growth is the process of crystallization by fusion and resolidification of the starting materials.

12. **List out the various types of melt growth? (Or) Name few techniques of crystal growth from melt.**

    The various melt growth techniques are

    (a) Normal freezing

    (b)Crystal pulling

    (c)Zone melting and

    (d) Flame fusion.

13. **What is the principle used in Bridgman technique for growing crystal?**

    A common technique for growing single, crystals involves selective cooling of the molten materials, so that solidification occurs along a particular crystal direction. In this technique, the melt in a sealed crucible is progressively frozen from one end.

14. **What is the basic principle of Czochralski method growing crystal?**

    The Czochralski method is a crystal pulling technique from the melt. The process is based on a liquid-solid phase transition driven by a seed crystal in contact with the melt.

15. **Defects in crystals are not always harmful. Justify.**

    Doping in pure semiconductors increases their electrical conductivity and given boundaries increases the mechanical strength of the material. Hence, the crystals are not always harmful.

16. **What are point defects or zero dimensional defects?**

    The defects which take place due to imperfect packing of atoms during crystallization are known as point defects.

17. What is a line defect or one dimensional defect?

The defects which take place due to dislocation or distortion of atoms along a line in some direction is called line defect.

18. Define Burger vector.

The vector which indicates the direction and the magnitude of the shift of the lattice on the slip plane is called Burger vector.

19. What are twin boundaries?

If the atomic arrangement on one side of the boundary is the mirror image of the arrangement on the other side the defect is called twin boundaries.

20. What is impurity defect? What are types of impurity defects?

A foreign substance added to a crystal is called impurity. The impurity atom may fit in the structure in two ways giving rise to impurity defects
- Substitution impurity defect
- Interstitial impurity defect.

21. What is meant by stacking fault?

The stacking faults are planar surface imperfection and are caused by faults in stacking sequence of atomic planes in crystals of FCC and HCP materials.

22. What are Frenkel and Schottky imperfections?

Frenkel defect is an ionic crystal imperfections that occurs when an ion moves into an interstitial site, thereby creating two defects simultaneously i.e., one vacancy and the other self interstitial.
A pair of ion vacancies in an ionic crystal is termed as Schotty defect.

23. List the different types of point defects.
- Schottky defect,
- Frenkel defect,
- Substitutional impurities,
- Interstitial impurities.

24. How carbon atoms are arranged in diamond structure?

Diamond has FCC structure with the basis of two carbon atoms, viz,, 'X' and 'Y'. The X atom is located with an origin of (0,0,0) and the Y atom is located with an origin of (a/4,a/4,a/4) i.e. one quarter of the way along the body diagonal.

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DEPARTMENT OF PHYSICS
PH8151- ENGINEERING PHYSICS IMPORTANT 16 MARK QUESTIONS AND ANSWERS

1. EXPRESSION FOR THE BENDING MOMENT OF BEAM

Let us consider a beam under the action of deforming forces. The beam bends into a circular arc. Let AB be the neutral axis of the beam. The filament AB remains unchanged. Let PQ be the arc chosen from the neutral axis.
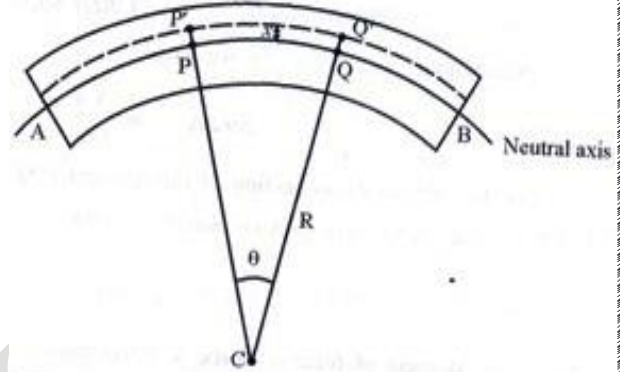
If   R --- radius of curvature

θ --- Angle

Then we can write the original length PQ $=$ Rθ $-$
$- \longrightarrow (1)$

Let us consider a filament P$^{|}$Q$^{|}$ at a distance 'x' from the neutral axis.

$\therefore$ We can write the extended length $= P^{'}Q^{'} = (R + x)\theta$ $- - \longrightarrow (2)$

From eqn.(1) and eqn.(2) we have

Increase in its length $= P^{'}Q^{'} - PQ$

Increase in its length $= (R + x)\theta - R\theta$

$\therefore$ Increase in its length $= x\theta$ $- - \longrightarrow (3)$

$$We\ know\ that\ \ Linear\ strain\ \ = \frac{increase\ in\ length}{original\ length}$$

$$Linear\ strain\ \ = \frac{x\theta}{R\theta}$$

$$Linear\ strain\ = \frac{x}{R} - - \longrightarrow (4)$$

$$The\ young's\ modulus\ of\ the\ beam\ \ \ Y = \frac{Linear\ stress}{Linear\ strain}$$

Sub. Eqn. (4) in eqn. (5), we have

$$Linear\ stress\ \ = \frac{Yx}{R}$$

If δA is the area of cross section of the filament $P^{'}Q^{'}$, then the force on the area $\delta A =$ $stress\ \times\ Area$

$$Force = \frac{Yx}{R} \; \delta A$$

Therefore moment of force about neutral axis PQ is given by

$$Moment \; of \; force = Force \; \times Perpendicular \; distance$$

$$= \frac{Yx}{R} \delta A \; \times (x) \; = \; \frac{Y}{R} \; \delta A x^2$$

∴ The sum of moment forces acting on all layers about the neutral axis

$$= \; \frac{Y}{R} \; \Sigma \; x^2 \delta A$$

Where $I = \; \Sigma x^2 \delta A = AK^2$ is called geometrical moment of inertia.

∴ Total moment of all the forces (or) Internal bending moment

$$= \frac{Y\,I}{R} \quad ---\rightarrow (5)$$

Special cases
Rectangular cross section:

If 'b' the breadth and 'd' is the thickness of the beam, then $I = \frac{bd^3}{12}$ Sub. the value of I eqn.(5) we can write

Bending moment for a rectangular cross section

$$= \frac{Ybd^3}{12R} \quad -\rightarrow (6)$$

Circular cross section:

If 'r' is the radius of the circular cross section then area A= πr^2 and $I = \frac{\pi r^4}{4}$; Sub. the value of I eqn.(5) we can write

Bending moment for a circular cross section

$$= \frac{\pi Y r^4}{4R} \quad ---\rightarrow (7)$$

2.CANTILEVER

Cantilever

A cantilever is a beam fixed horizontally at one end and loaded at the other end. This type of bending is known as cantilever.
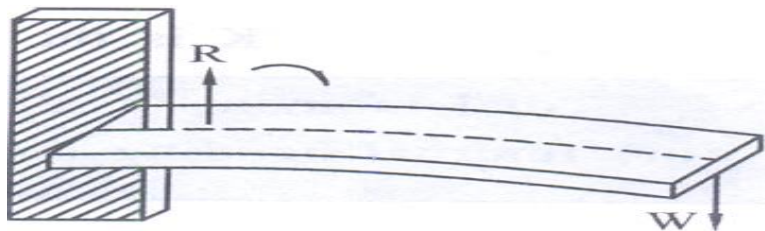
DERIVATION FOR DEPRESSION OF A CANTILEVER - LOADED AT ITS ENDS

Theory

Let 'l' be the length of the cantilever AB fixed at 'A'. Let 'W' be the weight suspended (loaded) at the free end of the cantilever. Due to the load applied the cantilever moves to a new position ' BB$^!$'.
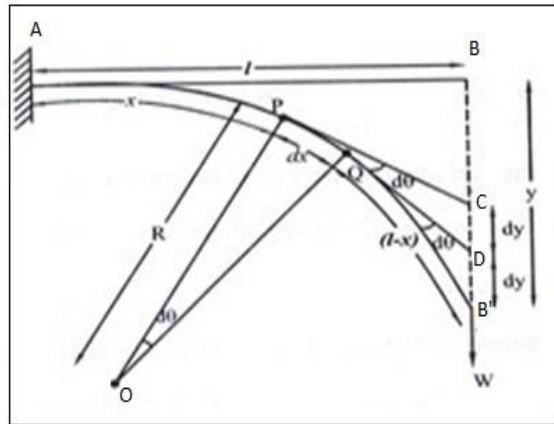
Let us consider the section of cantilever **P** at a distance x from the fixed end A. It is a distance *(l-x)* from the loaded end B$^!$

∴ The external bending moment $= W \times PB^! = W \times (l - x)$ $- - \rightarrow (1)$

We know the internal bending moment $= \frac{YI}{R}$ $- - \rightarrow (2)$

Under equilibrium condition,

External bending moment = Internal bending moment

$$W \times (l - x) = \frac{YI}{R} \quad - - \rightarrow (3)$$

Let Q is the other point at a distance dx from P

The arc length $PQ = dx$

Let 'O' be the centre of curvature of the element PQ and let 'R' be the radius of curvature.

The angle ∠POQ =dθ

$$dx = R \ d\theta \ - - \rightarrow (4)$$

The tangents are drawn at P and Q meeting the BB$^!$At C and D

$$d\theta = \frac{dx}{R} \quad - - \rightarrow (5)$$

Vertical depression $CD = dy = (l - x)d\theta \quad --\rightarrow (6)$

From eqns. (4) and (5)

$$\frac{dx}{dy} = \frac{R \; d\theta}{(l - x)d\theta}$$

$$R = (l - x)\frac{dx}{dy} \quad --\rightarrow (5)$$

Substitute equation (5) in equation (3)

$$W \times (l - x) = \frac{YI}{(l - x)\dfrac{dx}{dy}} \quad --\rightarrow (6)$$

$$W \times (l - x)^2 \; dx = YI \; dy$$

$$dy = \frac{W}{YI} \times (l - x)^2 \; dx$$

$\therefore$ Total depression at the free end of the cantilever can be derived by integrating within the limits '0' to 'l'

$$y = \frac{W}{YI_g} \int_0^l (l - x)^2 dx$$

$$y = \frac{W}{YI_g} \int_0^l (l^2 - 2lx + x^2)dx$$

$$y = \frac{W}{YI_g} \int_0^l (l^2 x - \frac{2lx^2}{2} + \frac{x^3}{3})$$

$$y = \frac{W}{YI_g} (l^3 - l^3 + \frac{l^3}{3})$$

$$y = \frac{W}{YI_g} \frac{l^3}{3}$$

Therefore depression of the cantilever at free end

$$y = \frac{Wl^3}{3YI_g} \quad --\rightarrow (8)$$

Determination of young's modulus of the Cantilever

The young's modulus of the beam is determined by using the depression produced in the cantilever $\quad y = \dfrac{Wl^3}{3YI_g}$

The young's modulus of the beam $\quad Y = \dfrac{Wl^3}{3yI_g}$

Special cases

(i) Rectangular cross section:

If 'b' the breadth and 'd' is the thickness of the beam then $I = \dfrac{bd^3}{12}$, and the weight W=Mg,

Substituting this value in equation (5)

Depression of the cantilever at free end $\quad y = \dfrac{Wl^3}{3YI_g}$

The young's modulus of the beam $\quad Y = \dfrac{Wl^3}{3yI_g}$

$$Y = \dfrac{Mg\, l^3}{3y\left(\dfrac{bd^3}{12}\right)}$$

The young's modulus of the beam $\quad Y = \dfrac{4Mg\, l^3}{bd^3 y}$

(ii) Circular cross section:

If 'r' is the radius of the circular cross section then, $I = \dfrac{\pi r^4}{4}$

Depression of the cantilever at free end $\quad y = \dfrac{Wl^3}{3YI_g}$

The young's modulus of the beam $\quad Y = \dfrac{Mgl^3}{3y\left(\dfrac{\pi r^4}{4}\right)} = \dfrac{4\,Mgl^3}{3\pi r^4 y}$

Experimental determination of young's modulus of the

Cantilever

- The given bar is fixed rigidly at one end and weight hanger is suspended at the other end.
- A pin is fixed vertically at the free end of the beam. A travelling microscope (T) is

Cantilever (beam)

T

Pin

G

Load → W
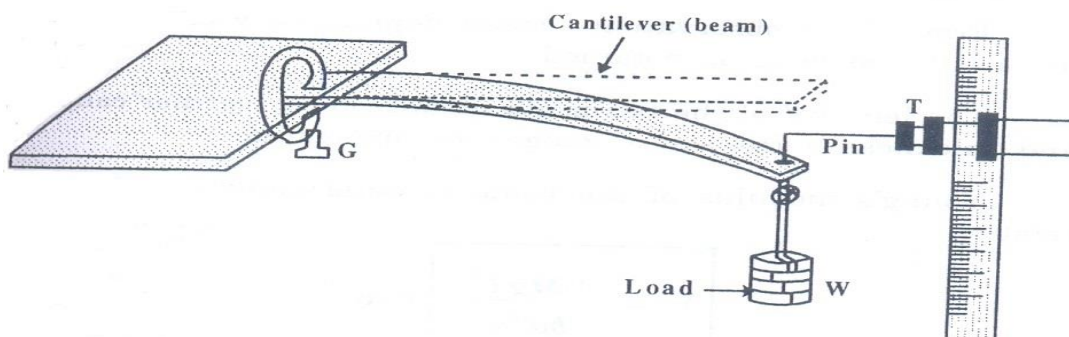
focused on the pin.

- The microscope is adjusted in such a way that horizontal cross wire coincides with the tip of the pin.
- The initial reading in the microscope on vertical scale is noted. A suitable mass M is placed on the hanger.
- The reading in the microscope is again noted. The difference between two readings of microscope gives the depression y corresponding to load M.
- Now the weight is added in steps of 50grams. Each time the tip of the pin is made to touch the horizontal cross wire and the readings are noted from the vertical scale of the microscope.
- Then, the experiment is also repeated by decreasing the weights. The observation are tabulated as follows

S.No	Load (M)	Microscope Readings			Mean depression y for a load of M Kg
		Increasing Load	Decreasing Load	Mean	
Unit	10^{-3}Kg	10^{-2}m	10^{-2}m	10^{-2}m	10^{-2}m
	W				
1	W+50				
2	W+100				
3	W+150				
4	W+200				
5	W+250				
				Mean y	

The young's modulus of the beam by Cantilever method is determined by using the relation

$$Y = \frac{4Mg\ l^3}{bd^3 y}$$

3. YOUNG'S MODULUS BY UNIFORM BENDING

(Elevation at the Centre of the beam loaded at both ends)

Uniform Bending

- The beam is loaded uniformly on its both ends; the bent beam forms an arc of a circle. The radius of curvature of the bent beam is constant for given load.
- The elevation produced in the beam. This type of bending is called uniform bending.

Theory:

Let us consider a beam of negligible mass supported symmetrically on the two knife edges C and D.
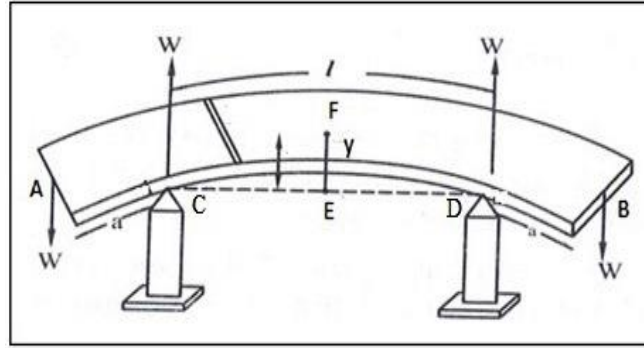
Let '*l*' be the length between C and D and the distance   AC = BD = a   the beam is loaded with equal weights W at each ends A and B. The reaction of on the knife edges a C and D are equal to W and they are acting vertically upward.

The external bending moment on the part AF of the beam about the F is

$$= W \times AF - W \times CF = W(AF - CF)$$

$$W \times AC = W \times a = Wa \quad - -\!\rightarrow (1)$$

We know the internal bending moment $= \dfrac{YI}{R} \quad - -\!\rightarrow (2)$

Under equilibrium condition

External bending moment = Internal bending moment

We can write, $Wa = \dfrac{YI}{R} \qquad - -\!\rightarrow (3)$

Since for a given load (W) the value of Y,I, a and R are constants. The bending is called as uniform bending. Here it is found that the elevation '*y*' forms an arc of the circle of radius 'R'

CD=*l* and '*y*' is the elevation of the midpoint E of the beam so that y=EF.

Then from the property of a circle

$$FE \times EG = CE \times ED$$

$$EF(2R - EF) = (CE)^2$$

$$(CE = ED \;\; and \;\; EG = 2R - EF)$$

$$y(2R - y) = \left(\frac{l}{2}\right)^2$$
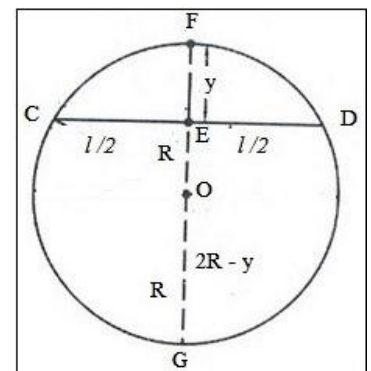
$$\therefore \left[\frac{l}{2}\right]^2 = (2Ry - y^2)$$

If the elevation 'y' is very small, then the term y^2 can be neglected. We can write

$$\frac{l^2}{4} = 2Ry$$

$$R = \left[\frac{l^2}{8y}\right]$$

Substitute the value of 'R' value, we have,

$$Wa = \frac{YI}{\left[\frac{l^2}{8y}\right]}$$

$$Wa = \frac{8y}{l^2} YI$$

The elevation of point 'F' above 'E' is

$$y = \frac{Wal^2}{YI}$$

Then the young's modulus of the of the beam by uniform bending

$$Y = \frac{Wal^2}{8Iy}$$

Special cases

(i). Rectangular cross section:

If 'b' the breadth and 'd' is the thickness of the beam $I = \frac{bd^3}{12}$ and the weight W=Mg, where M is the mass suspended at the free end and g is acceleration due to gravity. Substituting these above value

The young's modulus by uniform bending $Y = \frac{Wal^2}{8I_g y}$

$$Y = \frac{Mg\,a\,l^2}{8y\left(\frac{bd^3}{12}\right)} = \frac{12Mg\,a\,l^2}{8bd^3y}$$

The young's modulus by uniform bending $\quad Y = \frac{3Mg\,al^2}{2bd^3y}$

(ii). Circular cross section:

If 'r' is the radius of the circular cross section then, $I = \frac{\pi r^4}{4}$

$$Y = \frac{Mg\,a\,l^2}{8x\left(\frac{\pi r^4}{4}\right)} = \frac{4Mg\,a\,l^2}{8\pi r^4 y}$$

The young's modulus by uniform bending

$$Y = \frac{2Mg\,a\,l^2}{4\pi r^4 y}$$

4. DIFFERENTIAL EQUATION AND ITS SOLUTION – TO DAMPED OSCILLATIONS

Let us consider a spring-mass system as shown in figure. Let 'm' is the mass suspended over the spring. Due to the applied mass (load), the system exhibits two types of forces on it, namely Restoring force and Friction force.
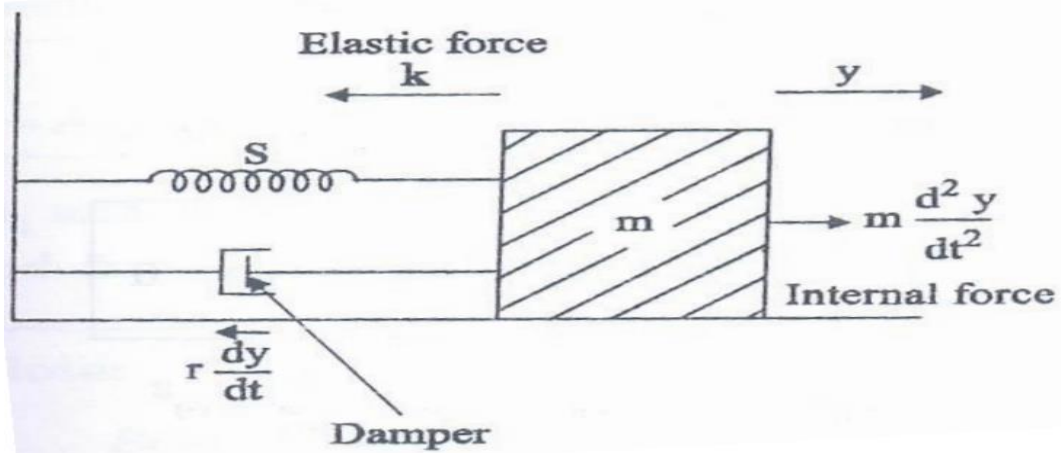
Restoring force:

A restoring is the force takes place on the opposite direction to the displacement of the object (spring) in order to restore its original position.

$$F \ \alpha - y$$
$$F_1 = - Ky \qquad - - \rightarrow (1)$$

Where, K is the force constant and y is the displacement.

Friction force:

Friction force or damping force is due to presence of air resistance, which also acts opposite to the direction of motion. It is given by $\qquad F_2 = -r \frac{dy}{dt} \qquad - - \rightarrow (2)$

Where, r is the friction force and $\frac{dy}{dt}$ is the velocity.

∴The total force in the body along the oppositely directed is given by
$$F = F_1 + F_2 \qquad - - \rightarrow (3)$$

Sub the values from (1) and (2) in (3), we get
$$F = - Ky - r \frac{dy}{dt} \qquad - - \rightarrow (4)$$

Since, we know from the Newton's law,
$$F = m \times a$$

Where, a is the acceleration, it is given by $a = \frac{d^2y}{dt^2}$, therefore
$$F = m \times \frac{d^2y}{dt^2} \qquad - - \rightarrow (5)$$

Comparing eqn. (4) & (5), we have
$$m \times \frac{d^2y}{dt^2} = - Ky - r \frac{dy}{dt}$$
$$\frac{d^2y}{dt^2} = -\left(\frac{K}{m}\right) y - \left(\frac{r}{m}\right)\frac{dy}{dt}$$
$$\frac{d^2y}{dt^2} + \left(\frac{r}{m}\right)\frac{dy}{dt} + \left(\frac{K}{m}\right) y = 0 \qquad - - \rightarrow (6)$$

Put, $\frac{r}{m} = 2b$ and $\frac{k}{m} = \omega^2$

Then, $\frac{d^2y}{dt^2} + 2b\frac{dy}{dt} + \omega^2 y = 0$ $- -\to$ (7)

Thus, Equation (6) is the 2ⁿᵈ order differential equation.

The solution for the above equation can be written as
$$y = A e^{\alpha t} \quad - -\to (8)$$
Where, A and α are the arbitrary constants.
Differentiating twice the equation (8) with respect to time, we get
$$\frac{dy}{dt} = A e^{\alpha t} \alpha \quad - -\to (9)$$
$$\frac{d^2y}{dt^2} = A e^{\alpha t} \alpha^2 \quad - -\to (10)$$
Sub eqns.8, 9 & 10 in 7, we get
$$A\alpha^2 e^{\alpha t} + 2b A\alpha e^{\alpha t} + \omega^2 A e^{\alpha t} = 0$$

$$Ae^{\alpha t} (\alpha^2 + 2b + \omega^2) = 0$$
Here, $Ae^{\alpha t} \neq 0$
$$\therefore \alpha^2 + 2b\alpha + \omega^2 = 0$$
By solving the above term, we get
$$\alpha = -b \pm \sqrt{(b^2 - \omega^2)} - -\to (11)$$

Sub eqn.10 in eqn.7, we get the general solution for damped oscillation as

$$y = A e^{\left(-b \pm \sqrt{(b^2 - \omega^2)}\right)t}$$

$$y = A_1 e^{\left(-b + \sqrt{(b^2 - \omega^2)}\right)t} + A_2 e^{\left(-b - \sqrt{(b^2 - \omega^2)}\right)t} \quad - -\to (12)$$

Where A_1 and A_2 are the arbitrary constants

Eqn. 12, gives the general solution for damped oscillation, which is based on the value of b and ω.
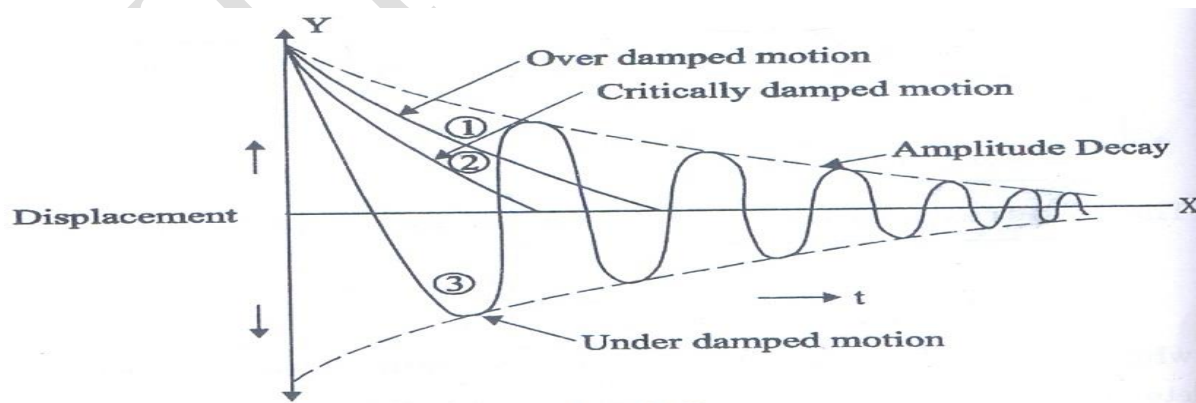
5. DIFFERENTIAL EQUATION AND ITS SOLUTION OF FORCED OSCILLATIONS

Let as consider a mass "m" connected to a spring and an external force is applied as shown in figure.

There are three type of forces act on it, viz.

A Restoring force $F_1 = -Ky \quad - -\rightarrow$ (1)

Damping or Friction force $F_2 = -r \frac{dy}{dt} \quad - -\rightarrow$ (2)

External force $F_3 = F_0 \sin \omega t \quad - -\rightarrow$ (3)
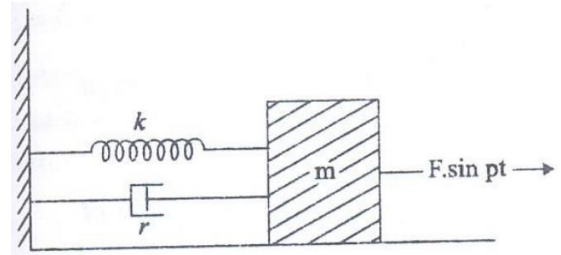
Where, ω is the angular frequency of the applied external periodic force.

$\therefore$ The total force in the body along the oppositely directed is given by
$$F = F_1 + F_2 + F_3$$
Then, the equation of motion of the system becomes

$$F = -Ky - r\frac{dy}{dt} + F_0 \sin \omega t \quad - -\rightarrow (4)$$

Since, we know from the Newton's law,
$$F = m \times a \quad - -\rightarrow (5)$$
Where, a is the acceleration, it is given by
$$a = \frac{d^2y}{dt^2}$$

$$F = m \times \frac{d^2y}{dt^2} \quad - -\rightarrow (6)$$

Sub eqn. 6 in 5, we get

$$m \times \frac{d^2y}{dt^2} = -Ky - r\frac{dy}{dt} + F_0 \sin \omega t$$

$$\frac{d^2y}{dt^2} = \frac{-k}{m}y - \frac{r}{m}\frac{dy}{dt} + \frac{F_0}{m}\sin \omega t$$

$$\frac{d^2y}{dt^2} + \frac{k}{m}y + \frac{r}{m}\frac{dy}{dt} = \frac{F_0}{m}\sin \omega t \quad - -\rightarrow (7)$$

$$Let, \frac{r}{m} = 2b \; ; \; \frac{k}{m} = \omega_0^2 \; and \; \frac{F_0}{m} = f$$

Therefore, eqn.7 becomes

$$\frac{d^2y}{dt^2} + \omega_0^2 y + 2b\frac{dy}{dt} = f \sin \omega t$$

$$\frac{d^2y}{dt^2} + 2b\frac{dy}{dt} + \omega_0^2 y = f \sin \omega t \quad - -\rightarrow (8)$$

Thus General Solution for the particular solution of Eqn. (8) is

$$y = A \sin (\omega t - \theta) \quad --\rightarrow (9)$$

Where, A is the amplitude and θ is the angle at which the displacement lags behind the applied force.

Differentiating twice the equation (9) with respect to time, we get

$$\frac{dy}{dx} = A \cos (\omega t - \theta)\omega --\rightarrow (10)$$

$$\frac{d^2y}{dt^2} = -A \sin (\omega t - \theta)\omega^2 \quad --\rightarrow (11)$$

Sub eqns. 9, 10, 11 in 8, we get

$$-A\sin (\omega t - \theta)\omega^2 + 2b \ A \cos (\omega t - \theta) \omega + \omega_0{}^2 A \sin (\omega t - \theta) = f \sin \omega t$$

For simplicity, we can write above term as

$$-A\omega^2 \sin (\omega t - \theta) + 2b \ \omega \ A \cos (\omega t - \theta) + \omega_0{}^2 A \sin (\omega t - \theta) = f \sin [\omega t - \theta + \theta]$$

$$A (\omega_0{}^2 - \omega^2) \sin(\omega t - \theta) + 2b \ \omega \ A \cos (\omega t - \theta)$$

$$= f \sin (\omega t - \theta) \cos\theta + f \cos (\omega t - \theta) \sin\theta \ --\rightarrow (12)$$

Eqn.12 shows well for all the values of t. so the coefficients $\sin (\omega t - \theta)$ and $\cos (\omega t - \theta)$ must be equal on both the sides.

For simplicity, we can write

$$A (\omega_0^2 - \omega^2) = f \cos \theta \quad --\rightarrow (13)$$

$$2b\omega A = f \sin\theta \quad --\rightarrow (14)$$

Squaring and addition the above equations, we get

$$A^2 (\omega_0^2 - \omega^2)2 + 4b^2\omega^2 A^2 = f^2(\cos^2 \theta + \sin^2 \theta)$$

$\therefore$Amplitude (A) $\quad A = \dfrac{f}{\sqrt{((\omega_0^2 - \omega^2)^2 + 4b^2\omega^2)}} \quad --\rightarrow (15)$

Dividing eqns. (14) by (13), we get

$$\frac{2b\omega A}{A(\omega_0^2 - \omega^2)} = \frac{f \sin\theta}{f \cos\theta}$$

$$\tan\theta = \frac{2b\omega}{(\omega_0^2 - \omega^2)}$$

$$Phase, \ \theta = \tan^{-1}\left[\frac{2b\omega}{(\omega_0^2 - \omega^2)}\right] \quad --\rightarrow (16)$$

Thus, from eqn.15 and 16, it shown that the amplitude and phase of the forced oscillation depends on $(\omega_0^2 - \omega^2)$.

6. EINSTEIN'S "A& B" COEFFICIENTS - DERIVATION

Let us consider an atom exposed to light photons of energy, three distinct processes take place. *(a). Absorptio (b). Spontaneous emission (c). Stimulated Emission*

a). Absorption

An atom in the lower energy level or ground state energy level E_1 absorbs the incident
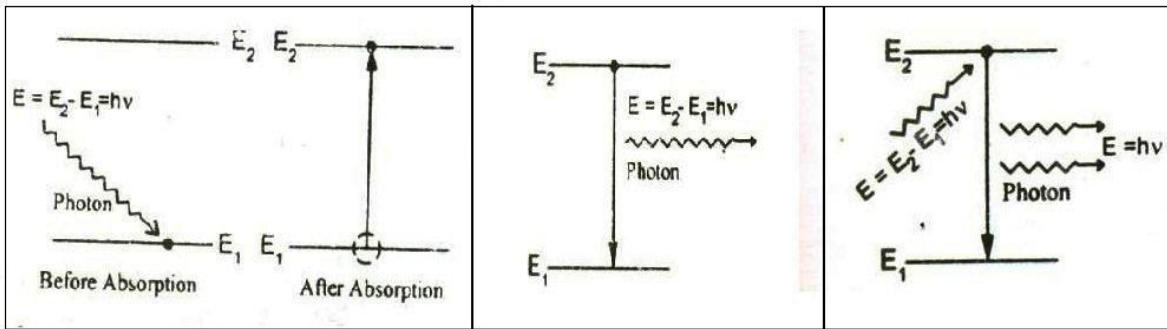
photon radiation of energy $h\nu$ and goes to the higher energy level or excited level E_2 as shown in figure. This process is called absorption.

The rate of absorption (R_{12}) is proportional to the following factors.

$$R_{12} \propto \rho_v N_1 \qquad ---\!\to (1)$$

$$R_{12} = B_{12}\rho_v N_1 \qquad ---\!\to (2)$$

Where ρ_v = Energy density of incident radiation,

N_1 = no. of atoms in the ground state and B_{12}- is a constant which gives the probability of absorption transition per unit time.

b). Spontaneous emission:

The atom in the excited state returns to the ground state by emitting a photon of energy $E = (E_2 - E_1) = h\nu$ spontaneously without any external triggering as shown in the figure. This process is known as spontaneous emission.

The rate of spontaneous emission is $R_{21}(Sp) \propto N_2 \qquad ---\!\to (3)$

$$R_{12}(Sp) = A_{21} N_2 \ ---\!\to (4)$$

Where A_{21}- is a constant which gives the probability of spontaneous emission transitions per unit time.

c). Stimulated Emission:

The atom in the excited state can also return to the ground state by external triggering or inducement of photon thereby emitting a photon of energy equal to the energy of the incident photon, known as stimulated emission.

Therefore, the rate of stimulated emission is given by

$$R_{21}(St) \propto \rho_v N_2 \qquad --\to (5)$$

$$R_{21}(St) = B_{21}\rho_v N_2 \qquad --\to (6)$$

Where B_{21} is a constant which gives the probability of stimulated emission transitions per unit time.

Einstein's theory

Under thermal equilibrium

$$The\ rate\ of\ Absorption\ =\ The\ rate\ of\ Emission$$

$$B_{12}\rho_v N_1 = A_{21}\ N_2 + B_{21}\rho_v N_2$$

$$B_{12}\rho_v N_1 - B_{21}\rho_v N_2 = A_{21}\ N_2\ (or)\ \rho_v(B_{12}N_1 - B_{21}N_2) = A_{21}\ N_2$$

$$\rho_v = \frac{A_{21}\ N_2}{(B_{12}N_1 - B_{21}N_2)}$$

$$\rho_v = \frac{A_{21}}{\left(B_{12}\dfrac{N_1}{N_2} - B_{21}\right)} \qquad --\to (7)$$

We know from the Boltzmann distribution law

$$N_1 = N_0\ e^{-E_1/K_B T}$$

$$N_2 = N_0\ e^{-E_2/K_B T}$$

Where K_B is the Boltzmann Constant, T is the absolute temperature and N_0 is the number of atoms at absolute zero.

At equilibrium, we can write the ratio of population levels as follows

$$\frac{N_1}{N_2} = e^{\frac{(E_2 - E_2)}{K_B T}}$$

$$\frac{N_1}{N_2} = e^{\frac{h\nu}{K_B T}} \qquad --\to (8)$$

Substituting equation (8) in equation (9)

$$\rho_v = \frac{A_{21}}{\left(B_{12}\left(e^{\frac{h\nu}{K_B T}}\right) - B_{21}\right)}$$

$$\rho_v = \frac{A_{21}}{B_{21}}\frac{1}{\left(\dfrac{B_{12}}{B_{21}}\left(e^{\frac{h\nu}{K_B T}}\right) - 1\right)} \qquad --\to (10)$$

This equation has a very good agreement with Planck's energy distribution radiation law.

$$\rho_v = \frac{8\pi h v^3}{C^3} \frac{1}{e^{\frac{hv}{K_B T}} - 1} \quad ---\rightarrow (11)$$

Therefore comparing equations (6) and (7) , we can write

$$B_{12} = B_{21} = B \quad \text{and} \quad \frac{A_{21}}{B_{21}} = \frac{8\pi h v^3}{C^3} \quad ---\rightarrow (12)$$

Taking $A_{21} = A$

The constants A and B are called as Einstein Coefficients, which accounts for spontaneous and stimulated emission probabilities.

7. PROPAGATION OF LIGHT IN OPTICAL FIBER

(Acceptance Angle and Numerical Aperture Derivation)

Let as consider an optical fiber through which the light is being sent. Let the refractive indices of the core and cladding be n_1 and n_2 respectively; $n_1 > n_2$. Let the refractive index of the

Medium from which the light is launched be n_0
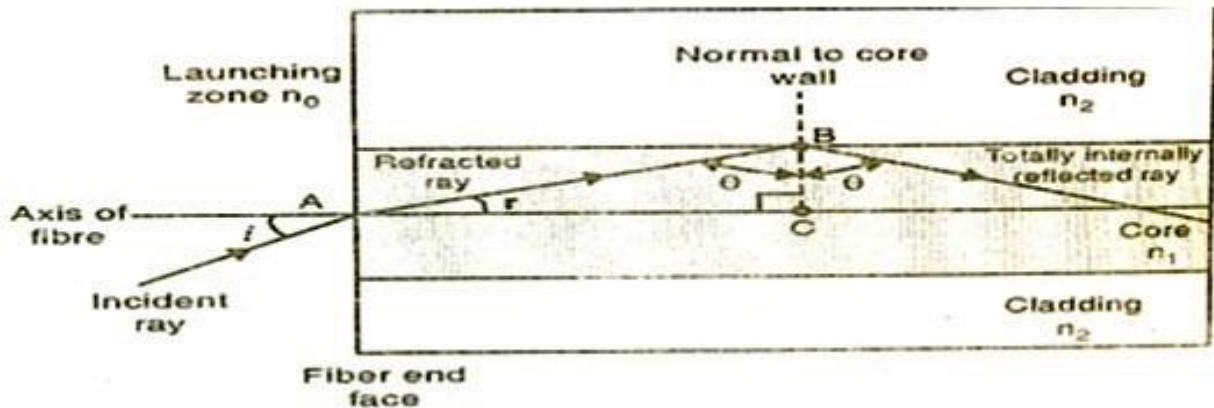
Let the light ray enter at an angle 'i' to the axis of the fiber. The ray is refracted along OB at an angle θ in the core as shown in the figure.

The angle of incidence $\phi = (90 - \theta)$ at interface of the core and cladding this angle is more than the critical angle ϕ_c. Hence the ray is totally internally reflected

Applying Snell's law at the point of the entry of ray (AO)

$$n_0 \sin i = n_1 \sin\theta$$
$$\sin i = \frac{n_1}{n_0} \sin\theta$$

$$\sin i = \frac{n_1}{n_0}\left(\sqrt{1 - cos^2\theta}\right) \quad ---\!\rightarrow (1)$$

Applying Snell's law at the point B (on interface) $\quad n_1 \sin\phi = n_2 \sin 90^0$

$$\sin\phi = \frac{n_2}{n_1}$$

$$\sin(90 - \theta) = \frac{n_2}{n_1}$$

$$cos\theta = \frac{n_2}{n_1} \quad ---\!\rightarrow (2)$$

Substituting eqn, (2) in equ. (1)

$$\sin i = \frac{n_1}{n_0}\left(\sqrt{1 - \left(\frac{n_2}{n_1}\right)^2}\right)$$

$$\sin i = \frac{n_1}{n_0}\frac{1}{n_1}\sqrt{n_1{}^2 - n_2{}^2}$$

$$i = sin^{-1}\left(\frac{\sqrt{n_1{}^2 - n_2{}^2}}{n_0}\right)$$

If the refractive index of the air $n_0 = 1$ then the maximum value of **Sin i_m** is given as

$$\sin i_{max} = \sqrt{n_1{}^2 - n_2{}^2} \quad ---\!\rightarrow (3)$$

ACCEPTANCE ANGLE
Definition

The maximum angle at or below which the light can suffer Total Internal Reflection is called acceptance angle.

NUMERICAL APERTURE

Definition

Numerical aperture (NA) is the light gathering capacity of the fiber, which depends on the acceptance angle.

*It is also defined as the **Sine** of the acceptance angle of the fiber.*

Numerical aperture determines the light gathering ability of the fiber.

$$NA = \sin i_{max}$$

$$NA = \sin i_{max} = \sqrt{n_1{}^2 - n_2{}^2} \;) \quad ---\!\rightarrow (4)$$

FRACTIONAL INDEX CHANGE

It is the ratio of refractive index difference in core and cladding to the refractive index of the core.

$$\Delta = \frac{(n_1 - n_2)}{n_1} \quad ---\!\rightarrow (5)$$

Relation between NA and Δ

$$n_1\Delta = n_1 - n_2 \qquad - - \to (6)$$

$$NA = \sqrt{n_1{}^2 - n_2{}^2}$$

$$NA = \sqrt{(n_1 + n_2)(n_1 - n_2)} \qquad - - \to (7)$$

$$NA = \sqrt{(n_1 + n_2)n_1\Delta}$$

If $n_1 \approx n_2$

$$NA = \sqrt{2n_1{}^2\Delta}$$

$$NA = n_1\sqrt{2\Delta} \qquad - - \to (8)$$

The above equation gives the relation between Numerical aperture and fractional index change of optical fibre.

7. THERMAL CONDUCTIVITY FOR GOOD CONDUCTORS – METALS -FORBES METHOD- THEORY AND EXPERIMENT

This is the one of the earliest method to find the absolute thermal conductivity of metals.

Theory and experiments

Consider a long road. This rod is heated at one end and a steady state is reached after some time.
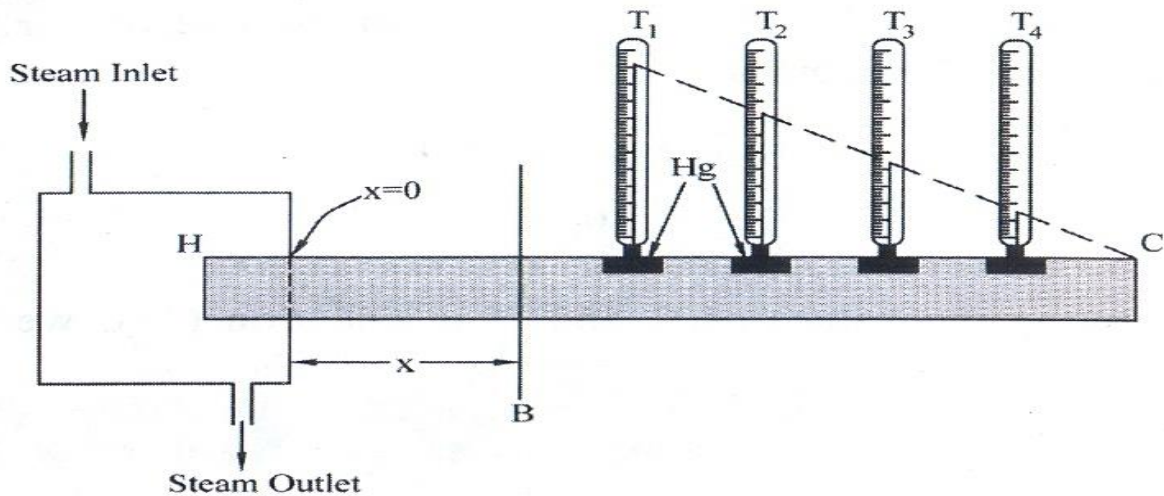
The amount of heat flowing per seconds across the cross-sections B at the distance x from the hot end $Q = KA \left(\dfrac{d\theta}{dx}\right)_B - - \to (1)$

This amount of heat flowing across the section B is equal to the heat lost between B and C, therefore

The amount of heat lost per seconds by radiation by the rod beyond the section 'B'

$$= \int_B^C m \times s \times \left(\frac{d\theta}{dt}\right)$$

Since Mass = volume ×Density then Mass of the element $= (A\,dx)\,\rho$

$$\text{Heat lost per seconds } = \int_B^C (A\,dx) \times \rho \times s \times \left(\frac{d\theta}{dt}\right) ---\to (2)$$

$Where$ $\left(\frac{d\theta}{dt}\right)$- Rate of fall of temperature of the element and S specific heat capacity of the rod

$$\begin{pmatrix} Amount\ of\ heat\ flowing\ per\ seconds \\ across\ the\ section\ at\ the\ point\ \ B \end{pmatrix} = \begin{pmatrix} Heat\ lost\ by\ radiation\ by\ the \\ rod\ beyond\ the\ section\ B \end{pmatrix}$$

$$KA \left(\frac{d\theta}{dx}\right)_B = \int_B^C (A\,dx)\,\rho\,s \left(\frac{d\theta}{dt}\right)$$

$$K = \frac{\rho s \int_B^C \frac{d\theta}{dt}\,dx}{\left(\frac{d\theta}{dx}\right)_B} ---\to (3)$$

The Experiments consists of two parts

1. Static experiment to find $\left(\frac{d\theta}{dx}\right)_B$

2. Dynamic experiments to find $\left(\frac{d\theta}{dt}\right)$ and $\int_B^C \frac{d\theta}{dt}\,dx$

1. Static experiment

The specimen metal is taken in the form of a long road. One end of this rod is headed up to six (or) seven hours by a steam chamber. The rod has a series of holes into which thermometers are fitted. These thermometer record temperatures (T_1, T_2, T_3, T_4) at different points along the rod.

If the tangent makes an angle α with the x axis, then from the greaph $\left(\frac{d\theta}{dx}\right)_B = \frac{BD}{BE} = \tan\alpha$ $---\to (4)$
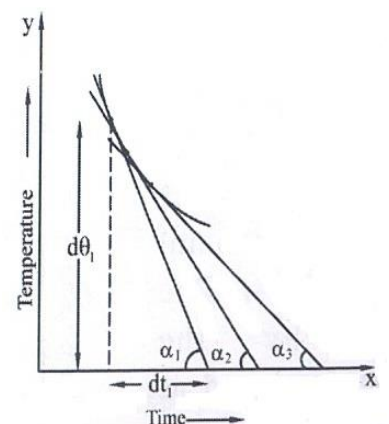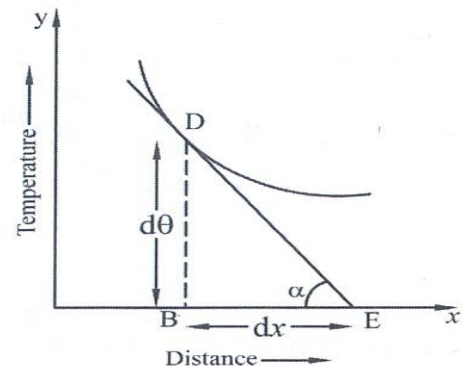
2. Dynamic experiments

A piece of the original rod is heated to the same temperature as that of the hot end in the static experiments. The heated piece of the rod suspended in air. Now it is allowed to cool. Its temperature is noted at regular intervals of time by a thermometer placed in a hole at the centre.

$$\text{Now we get the} \left(\frac{d\theta}{dt}\right)_{x_1} = \tan\alpha_1, \left(\frac{d\theta}{dt}\right)_{x_1} = \tan\alpha_2 \text{ ....etc.}$$

Rate of cooling at that corresponding distances beyond the section in static experiment is obtained.

With the above data a third curve is plotted taking x from the hot end beyond the section B along x- axis and $\left(\frac{d\theta}{dt}\right)_{x_1}, \left(\frac{d\theta}{dt}\right)_{x_1}$ etc. along y axis as shown in figure.

$$Area\ of\ the\ shaded\ portion = \int_B^C \frac{d\theta}{dt}\ dx \quad -$$
$$\longrightarrow (5)$$

Substituting equation (4) and (5) in equation (3)

The thermal conductivity K
$$= \frac{\rho \times S \times Area\ of\ the\ shaded\ portion}{\left(\frac{BD}{BE}\right)}$$
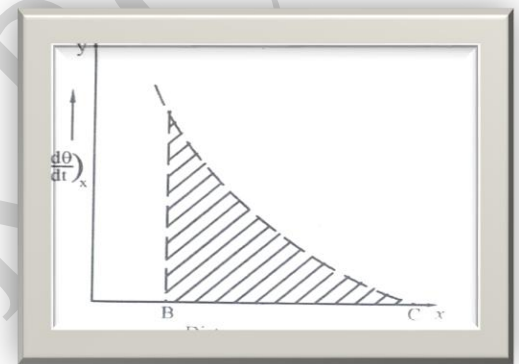
The experiment is repeated by choosing the B at different distance from the hot end and average value of K is determined.

8. THERMAL CONDUCTIVITY OF A BAD CONDUCTOR – LEE'S DISC METHOD

Principle

In the steady state, the quantity of heat flowing across the bad conductor in one second is equal to the quantity of heat radiated in one second from the lower face area and edge area of the metal disc in the Lee's disc method.

Description: The given bad conductor (B) is shaped with the diameter as that of the circular slab (or) disc 'D'. The bad conductor is placed in between the steam chamber (S) and the slab (or) disc (D), provided the bad conductor, steam chamber and the slab should be of same diameter.

Holes are provided in the steam chamber (S) and the slab (or) disc (D) in which the thermometers are inserted to measure the temperatures. The total arrangement is hanged over the stand as shown in fig.
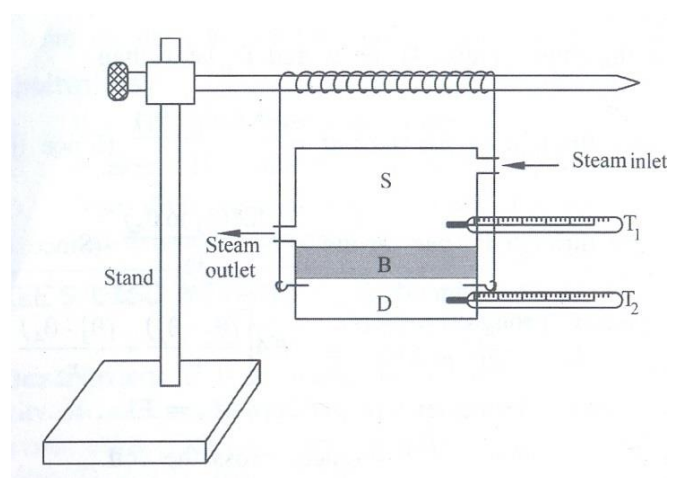
Working

Steam is passed through the steam chamber till the steady state is reached i.e., the thermometer show constant temperature. Let the temperature of the steam chamber (hot end) and the disc or slab (cold end) be θ_1 and θ_2 respectively.

Calculation:

Let 't' be the thickness of the bad conductor (B), 'm' is the mass of the slab, and 'S' be the specific heat capacity of the slab. 'r' is the radius of the slab and 'h' be the height of the slab, then,

Amount of heat conducted by the bad conductor *per second* $= \dfrac{K A (\theta_1 - \theta_2)}{t}$

Since the Area of cross section is $= \pi r^2$

Amount of heat conducted per second $= \dfrac{K \pi r^2 (\theta_1 - \theta_2)}{t}$ $- - \to$ (1)

The amount of heat lost by the slab *per second*

$$= m \times S \times \text{Rate of cooling}$$

The amount of heat lost by the slab *per second*

$$= m \times S \times R_c \quad - - \to (2)$$

Under steady state
$\therefore$ We can write eqn. (1) = eqn. (2)

$$\dfrac{K \pi r^2 (\theta_1 - \theta_2)}{t} = m S R_c$$

$$K = \dfrac{m S t R_c}{\pi r^2 (\theta_1 - \theta_2)} \quad - - \to (3)$$

To find the rate of cooling (R_c)

In eqn. (3) R_c represents the rate of cooling of the slab along with the steam chamber. To find the rate of cooling for the slab alone, the bad conductor is removed and the steam chamber is directly placed over the slab and heated.

When the temperature of the slab attains 5°C higher than θ_2, the steam chamber is removed. The slab is allowed to cool, as shown in the fig, simultaneously starting stop watch.

A graph is plotted taking time along 'x' axis and temperature along 'y' axis, the rate of cooling for the slab alone. i.e., $\dfrac{d\theta}{dt}$ is found from the graph as shown in the fig. The rate of cooling is directly proportional to the surface area exposed
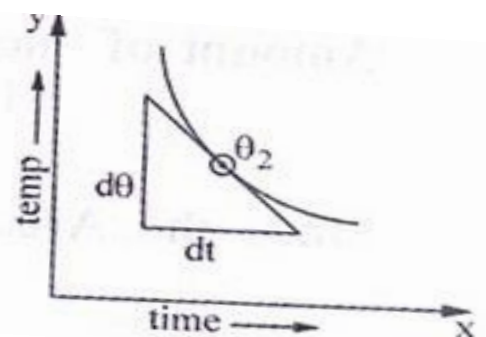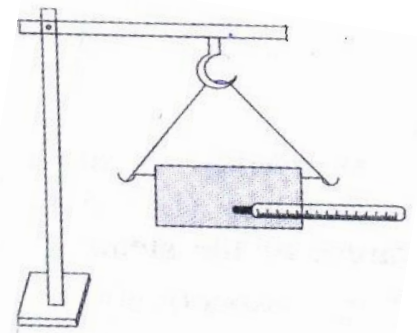
Case (i)

Steam chamber and bad conductor are placed over slab, in which radiation takes place from the bottom surface of the area (πr^2) of the slab and the sides of the slab of area ($2\pi r h$).

$$\therefore R_c = \pi r^2 + 2\pi r h$$

$$R_c = \pi r (r + 2 h) \ \ - - -\to (4)$$

Case (ii)

The heat is radiated by the slab alone, i.e., from the bottom of area (πr^2), top surface of the slab of area πr^2 and also through the sides of the slab area $2\pi r h$.

$$\left(\frac{d\theta}{dt}\right)_{\theta_2} = \pi r^2 \ + \pi r^2 + \ 2\pi r h$$

$$\left(\frac{d\theta}{dt}\right)_{\theta_2} = \ 2\pi r (r + h) - - \to (5)$$

From eqn (4) and (5)

$$\frac{R_c}{\left(\frac{d\theta}{dt}\right)_{\theta_2}} = \frac{\pi r (r + 2 h)}{2\pi r (r+h)}$$

$$R_c = \frac{(r + 2 h)}{2 (r + h)}\left(\frac{d\theta}{dt}\right)_{\theta_2} - - \to (6)$$

Substituting eqn. (6) in eqn. (3),

$$K = \frac{m\, s\, t\, \left(\frac{d\theta}{dt}\right)_{\theta_2} (r + 2h)}{\pi r^2 (\theta_1 - \theta_2)\, 2\, (r + h)} W\, m^{-1} K^{-1} \ \ \ - - \to (6)$$

Hence the thermal conductivity of the given bad conductor can be determined from the above formula.

9. PLANCK'S QUANTUM THEORY OF BLACK BODY RADIATIONS

Assumptions

Plank derived an expression for the energy distribution, with the following assumptions.

i) A black body radiator contains electrons (or) so simple called simple harmonic oscillators, which are capable of vibrating with all possible frequencies.

ii) The frequency of radiation emitted by an oscillator is the same as that of the frequency of its vibration.

iii)   The oscillators (electrons) radiate energy in a discrete manner and not in a continuous manner.

iv)   The oscillators exchanges energy in the form of either absorption or emission within the surroundings in terms of quanta of magnitude 'hv' as shown in the fig.i.e., **E = nhv**

PLANCK'S RADIATION LAW (DERIVATION)

To derive the Planck's radiation law, let us consider 'N' number of oscillators with their total energy as E_r. Then, the average energy of an oscillator is given by

$$\overline{E} = \frac{E_T}{N} \qquad ---\to (1)$$

If N_0, N_1, N_2, N_3, ...N_r are the oscillators of energy 0, E, 2E,3E, ...rE respectively then we can write, The total number of oscillators

$$N = N_0 + N_1 + N_2 + N_3 +..... +N_r \quad ---\to (2)$$

Total energy of oscillators

$$E_r = 0N_0 + EN_1 +2EN_2 +3EN_3 +..... +rEN_r \; ---\to (3)$$

According to Maxwell's distribution formula, the number of oscillator having an energy rE is given by

$$N_r = N_0 e^{-rE/K_B T} ---\to (4)$$

Where, K_B is called Boltzmann constant and r = 0, 1, 2, 3...

∴ For various of r, i.e., r = 0, 1, 2, 3, ... r, the number of oscillators N_0, N_1, N_2, N_3, ...N_r can be got as follows:

i)   For r = 0 ; $N_r = N_0 e^0$
ii)   For r = 1 ; $N_1 = N_0 e^{-1E/K_B T}$

Similarly, for r = r; $N_r = N_0 e^{-rE/K_B T}$

∴ The total number of oscillators can be got by substituting the values of N_0, N_1, N_2, N_3 ...N_r in equation (2)

$$N = N_0 e^0 + N_0 e^{-1E/K_B T} + N_0 e^{-2E/K_B T} + N_0 e^{-3E/K_B T} + \cdots + N_0 e^{-rE/K_B T}$$

$$N = N_0 \left[1 + e^{-1E/K_B T} + e^{-2E/K_B T} + e^{-3E/K_B T} + \cdots + e^{-rE/K_B T}\right] \quad ---\to (5)$$

We know $1 + x + x^2 + x^3 + ... = \frac{1}{(1-x)}$

we can write equation (5) as, The total number of oscillators,

$$N = N_0 \left[\frac{1}{1 - e^{-E/K_B T}}\right] \quad ---\to (6)$$

Similarly, by substituting the values of $N_0, N_1, N_2, N_3, \ldots N_r$ in equation (3), the total energy can be written as,

$$E_r = 0N_0e^0 + EN_0e^{-E/K_BT} + 2EN_0e^{-2E/K_BT} + 3EN_0e^{-3E/K_BT} \ldots + rEN_0e^{-rE/K_BT}$$

$$E_r = N_0 [0 + Ee^{-E/K_BT} + 2Ee^{-2E/K_BT} + 3Ee^{-3E/K_BT} + \cdots + rEe^{-rE/K_BT}$$

$$E_T = N_0Ee^{-E/K_BT} [0 + 1 + 2e^{-\frac{E}{K_BT}} + 3e^{-\frac{2E}{K_BT}} + \cdots + re^{-\frac{(r-1)E}{K_BT}} - - \rightarrow (7)$$

We know that, $1 + 2x + 3x^2 + 4x^3 + \ldots \ldots + r\, x^{r-1} = \frac{1}{(1-x)^2}$

Equation (7) becomes, the total energy of oscillators

$$E_T = N_0Ee^{-E/K_BT} \left[\frac{1}{(1 - e^{-E/K_BT})^2} \right] - - \rightarrow (8)$$

Substituting the values of eqn.(6) and (8) in eqn.(1), we get

The average energy of oscillator

$$\bar{E} = \frac{E_T}{N} = \frac{N_0Ee^{-E/K_BT}}{N_0 \left(\frac{1}{1 - e^{-E/K_BT}} \right)} \left[\frac{1}{(1 - e^{-E/K_BT})^2} \right]$$

$$\bar{E} = \frac{Ee^{-E/K_BT}}{(1 - e^{-E/K_BT})} = \frac{E}{\left(\frac{1 - e^{-E/K_BT}}{e^{-E/K_BT}} \right)}$$

$$\bar{E} = \frac{E}{\left(\frac{1}{e^{-E/K_BT}} - 1 \right)} - - \rightarrow (9)$$

Substituting the values of $E = h\nu$ we get

The average energy of oscillator $\overline{E} = \frac{h\nu}{\left(e^{(h\nu/K_BT)} - 1 \right)} - - \rightarrow (10)$

Equation (10) represents the average energy of the oscillator.

The number of oscillators per unit volume within the range of frequency ν and $\nu + d\nu$ is given by

$$N = \frac{8\pi\nu^2}{C^3} d\nu - - \rightarrow (11)$$

$\therefore$ Energy density ($E_\nu d\nu$) or Total energy per unit volume =

$$\begin{pmatrix} \text{Energy density (Evdν) or} \\ \text{Total energy per unit volume} \end{pmatrix} = \begin{pmatrix} \text{No. of oscillators per unit volume} \\ \times \\ \text{Average energy of an oscillator} \end{pmatrix}$$

$$E_\nu d\nu = N\bar{E} \quad - -\rightarrow (12)$$

Substituting equations (10) and (11) in equation (12) we get,

$$E_\nu d\nu = \frac{8\pi \nu^2}{C^3} d\nu \frac{h\nu}{(e^{(h\nu/K_B T)} - 1)} \quad - -\rightarrow (13)$$

$$E_\nu = \frac{8\pi h \nu^3}{C^3(e^{(h\nu/K_B T)} - 1)} \quad - -\rightarrow (14)$$

Equation (14) represents the Planck's radiation law in terms of frequency.

Planck's radiation law in terms of wavelength (λ)

We know, $\nu = \frac{c}{\lambda}$

Differentiating, we get $\nu = \frac{-c}{\lambda^2} d\lambda$

Numerically, we can write $|d\nu| = |\left(\frac{-c}{\lambda^2}\right) d\lambda|$

$$|d\nu| = [\frac{c}{\lambda^2}]d\lambda$$

Substituting the values of **ν** and **dν** in RHS of eqn. (13), we get,

The energy density

$$E_\lambda d\lambda = \frac{8\pi h c^3}{c^3 \lambda^3}\left(\frac{-C}{\lambda^2}\right) d\lambda \frac{1}{(e^{(hc/\lambda K_B T)} - 1)}$$

$$E_\lambda = \frac{8\pi h c}{\lambda^5}\left[\frac{1}{(e^{hc/\lambda K_B T} - 1)}\right] \quad - -\rightarrow (15)$$

Equation (15) represents the ***Planck's radiation law in terms of wavelength.*** This law has good agreements with all the experimental result.

DEDUCTION OF WIEN'S DISPLACEMENT LAW FROM PLANCK'S THEORY

We know that Wien's law holds good only at shorter wavelength. Therefore, when λ is very small hence $\frac{hc}{\lambda K_B T} \gg 1$ and $e^{hc/\lambda K_B T}$ is large when compared to 1

$$E_\lambda = \frac{8\pi h c}{\lambda^5}\left[\frac{1}{(e^{hc/\lambda K_B T})}\right]$$

This is Wien's displacement law. Therefore Planck's law reduces to Wien's displacement law for smaller wavelengths

DEDUCTION OF RAYLEIGH JEANS LAW

We know that Wien's law holds good only at longer wavelength. Therefore, when λ very large and ν very small and hence $\frac{hc}{\lambda K_B T} \ll 1$ and $e^{hc/\lambda K_B T} = 1 + \frac{hc}{\lambda K_B T}$

$$E_\lambda = \frac{8\pi h c}{\lambda^5}\left[\frac{1}{(e^{hc/\lambda K_B T} - 1)}\right]$$

$$E_\lambda = \frac{8\pi h c}{\lambda^5}\left[\frac{1}{\left(1 + \frac{hc}{\lambda K_B T} - 1\right)}\right]$$

$$E_\lambda = \frac{8\pi h c}{\lambda^5}\left[\frac{1}{\left(\frac{hc}{\lambda K_B T}\right)}\right]$$

$$E_\lambda = \frac{8\pi K_B T}{\lambda^4} \quad ---\to (16)$$

10. COMPTON EFFECT

When a beam of monochromatic radiation such as X-rays, γ-ray, etc., of high frequency is allowed to fall on a fine scatter, the beam is scattered into two components namely, One component has the same frequency or wavelength as that of the incident radiation, so called

unmodified radiation and the other component having lower frequency or higher wavelength compared to incident radiation, so called *modified radiation*.
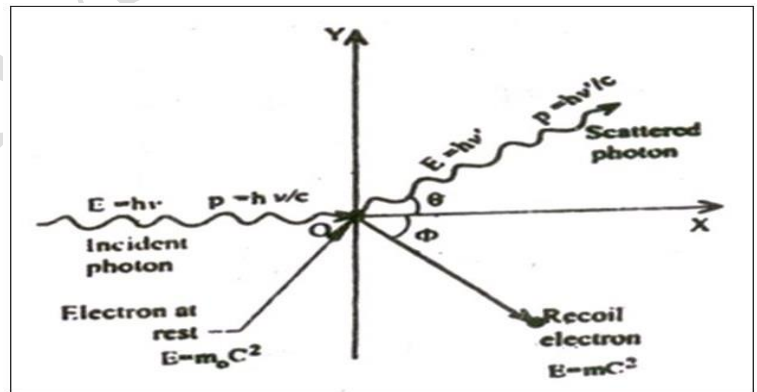
Energy before collision:

Energy of the incident photon $= h\nu$
Energy of the electron at rest $= moc^2$
Therefore total Energy before collision $= h\nu + moc^2 \quad ---\to (1)$

Energy after collision:

Energy of the scattered photon $= h\nu'$

Energy of the recoil electron $= mc^2$

Therefore total Energy after collision $= h\nu' + mc^2 - - \to (2)$

According to law of conservation of energy

Total Energy before collision = Total Energy after collision

$$h\nu + m_oc^2 = h\nu' + mc^2 - - \to (3)$$

Momentum:

COMPONENT	BEFORE COLLISION	AFTER COLLISION
X	Photon $= \dfrac{h\nu}{c}$ *Electron $= 0$*	Photon $= \dfrac{h\nu'}{c}\cos\theta$ *Electron $= mv\cos\phi$*
Y	Photon $= 0$ *Electron $= 0$*	Photon $= \dfrac{h\nu'}{c}\sin\theta$ *Electron $= = -mv\sin\phi$*
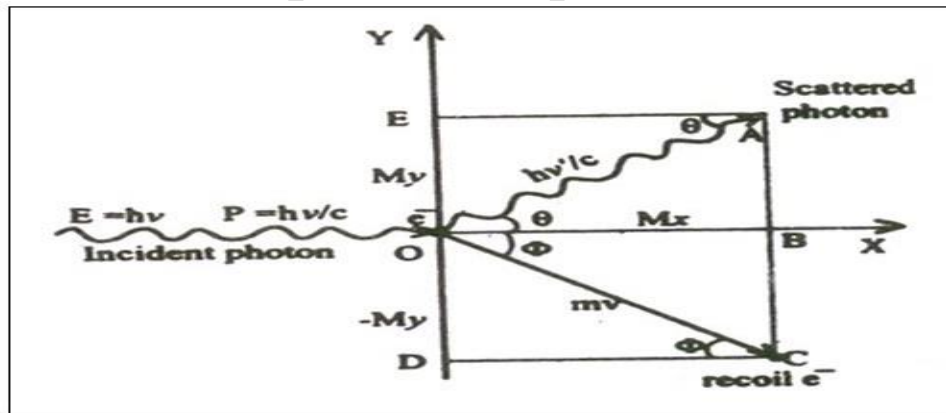
X-component of Momentum:

According to law of conservation of Momentum,

Total Momentum before collision=Total Momentum after Collision

$$\text{Therefore, } \frac{h\nu}{c} = \frac{h\nu'}{c}\cos\theta + mv\cos\phi - - \to (4)$$

Y-component of Momentum :

According to law of conservation of Momentum,

Total Momentum after collision = Total Momentum after collision

$$0 = \frac{h\nu'}{c}\sin\theta - mv\sin\phi \quad ---\to (5)$$

From eqn.(4) we can write,

$$mv\cos\phi = h(\nu - \nu'\cos\theta) \quad ---\to (6)$$

From eqn.(5) we can write,

$$mvc\sin\phi = h\nu'\sin\theta \quad ---\to (7)$$

Squaring and adding eqn (6) and eqn (7), we get,

$$m^2c^2v^2(\cos^2\theta + \sin^2\theta) = h^2[\nu^2 - 2\nu\nu'\cos\theta + (\nu')^2\cos^2\theta]h^2(\nu')^2\sin^2\theta$$

$$m^2c^2v^2 = h^2[\nu^2 - 2\nu\nu'\cos\theta + (\nu')^2] \quad ---\to (8)$$

From eqn.(3) we can write

$$mc^2 = moc^2 + h(\nu - \nu')$$

Squaring on both sides, we get

$$m^2c^4 = mo^2c^4 + 2hmoc^2(\nu - \nu') + h^2[\nu^2 - 2\nu\nu' + (\nu')^2] \quad ---\to (9)$$

Subtracting eqn.(12) from eqn.(13), we get

$$m^2c^2(c^2 - v^2) = mo^2c^4 + 2hmoc^2(\nu - \nu') - 2h^2\nu\nu'[1 - \cos\theta] \quad ---\to (10)$$

From the theory of relativity $m = \dfrac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$

Squaring we get, $\qquad m^2(c^2 - v^2) = mo^2c^2 \quad ---\to (11)$

$$m^2c^2(c^2 - v^2) = mo^2c^4 \quad ---\to (12)$$

Equating equations (16) and (14) we can write

$$m_0^2c^4 = mo^2c^4 + 2hmoc^2(\nu\text{-}\nu') - 2h^2\nu\nu'[1 - \cos\theta]$$
$$2hmoc^2(\nu\text{-}\nu') = 2h^2\nu\nu'[1 - \cos\theta]$$
$$\frac{1}{\nu'} - \frac{1}{\nu} = \frac{h}{m_0^2}(1 - \cos\theta)$$

Multiplying both sides by 'c' we get,

$$\frac{c}{v'} - \frac{c}{v} = \frac{h}{m_0 c^2}(1 - cos\theta) \quad ---\rightarrow (13)$$

$$since \, \lambda' = \frac{c}{v} \quad and \quad \lambda = \frac{c}{v} \qquad \text{Eqn. (13) becomes}$$

$$\lambda' - \lambda = \frac{h}{moC}(1 - cos\theta)$$

Therefore change in wavelength $\quad \mathbf{\Delta\lambda = \frac{h}{moC}(1 - cos\theta) \quad ---\rightarrow (14)}$

Equation (14 represents the change in wavelength and it does not depend on wavelength of the incident radiations and the nature of scattering substance. But it is dependent on scattering angle.

Special cases:

Case (i): when θ=0; Cosθ=1 , then Eqn.(18) becomes

$$\Delta\lambda = 0$$

Case (ii): when θ=90; Cosθ=0, then Eqn.(18) becomes

$$\Delta\lambda = \frac{h}{moC} \Delta\lambda = 0.02424 \ A^o$$

Case (iii): when θ=180; Cos θ= -1, then Eqn. (18) becomes

$$\Delta\lambda = \frac{2h}{moC} \Delta\lambda = 0.04848 \ A^o$$

EXPERIMENTAL VERIFICATION OF COMPTON EFFECT

Principle

Construction

It consists of an X-ray tube for producing X-rays. A small block of carbon C (scattering element) is mounted on a circular table.

A Bragg's spectrometer (B$_s$) is allowed to freely swing in an ars about the scattering element to catch the scattered photons. Slits S$_1$ and S$_2$ helps to focus the X-rays onto the scattering element.
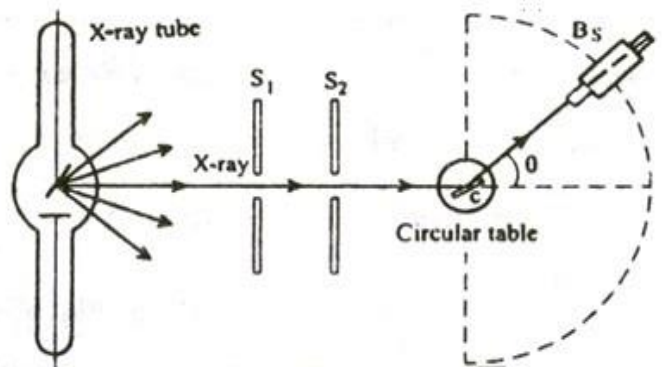
Working

X-rays of monochromatic wavelength 'λ' is produced from an X-ray tube and is made to pass through the slits S_1 and S_2. These X-rays are made to fall on the scattering element. The scattered X-rays are received with the help of the Bragg's spectrometer and the scattered wavelength is measured. The experiment is repeated for various scattering angles and the scattered wavelengths are measured.

In this figure when the scattering angle θ=0°, the scattered radiation peak will be the same as that of the incident radiation peak 'A'. Now, when the scattering angle is increased, for one incident radiation peak A of wavelength (λ) we get two scattered peaks A and B. Here the peak
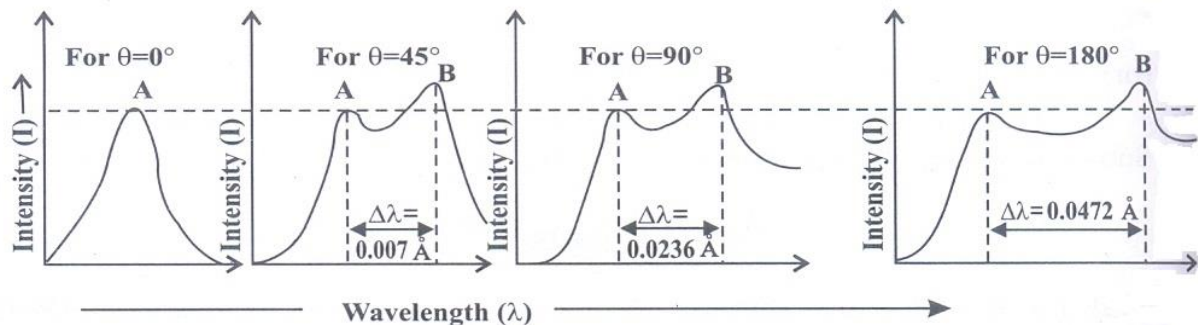
'A' is found to be of same wavelength as that of the incient wavelength and the peak 'B' is of greater wavelength than the incident radiation.

At θ=90°, the Δλ is found to be 0.0236 ≈ 0.02424, which has good agreement with the theoritical results. Hence this wavelength is called Compton wavelength and the shift in wavelength is called Compton shift.

11.SCANNING TUNNELLING MICROSCOPE (STM)

Introduction

A microscope is a device which is used to view the magnified image of a smaller object which cannot see through naked eye.

In 1981 Gerd Binning and Heinrich Rohrer developed the scanning microscope (STM) a significantly superior tool for observing surface atom by atom.

STM is the highest resolution imaging and nano fabrication technique available. It depends on quantum tunneling of electron from a sharp metal tip to a conducting surface.

Principle

The basic principle used in Scanning Tunnelling Microscope (STM) is the tunneling of electron between the Sharpe metallic tip of the probe and surface of the sample.

STM has a metal needle that scans a sample by moving back and forth and gathering information about the curvature of the surface. It follows the smallest changes in the contours of a sample.

The needle doesn't touch the sample, however, but stays about the width of two atoms about it.

Instrumentation

A schematic of STM is shown in figure. It has the following components. Piezoelectric tube with the tip and electrode. Capable of moving in X,Y, Z direction. Fine needle tip for scanning the sample surface. A macro scale image of an etched tungsten STM tip is shown in figure.

Tip is affixed to the piezoelectric tube in order to control it position and movement on an atomic scale. Piezoelectric materials exhibit an elongation or contraction along their length when an electric field is applied.
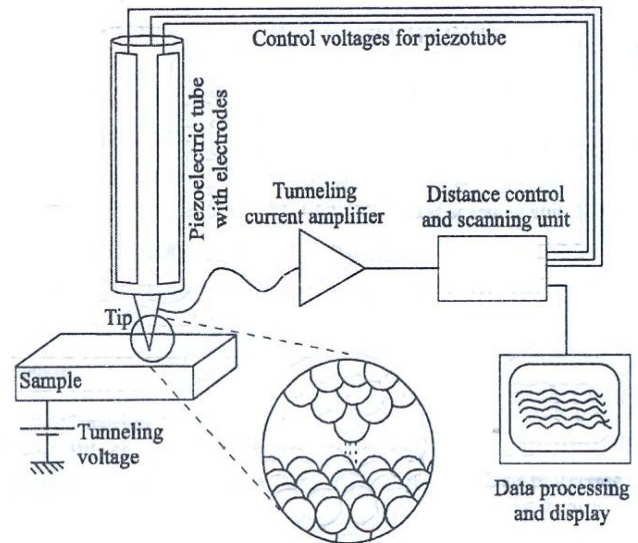
Working

The tip is mechanically connected to the scanner, an XYZ positioning device. The sharp metal needle is brought close to the surface to be imaged. The distance is of the order of a few angstroms.

A bias voltage is applied between the sample and the tip. When the needle is at a potential with respect to the surface, electrons can tunnel through the gap and set up a small tunneling current in the needle. This feeble tunneling current is amplified and measured.

With the help of the tunneling current the feedback electronics keeps the distance between tip and sample constant. The sensitivity of the STM is so large that electronic corrugation of the surface atoms and the electron distributions around them can be detected.

Application of STM

1. The STM shows the positions of atoms – more precisely, the positions of some of the electrons.

2. STMs are versatile. They can be used in ultra-high vacuum, air, water and other liquids and gases.

3. STMs give the 3 dimensional profile of a surface, which allows researchers to examine a multitude of characteristics, including roughness, surface defects and molecule size.

Disadvantages

1. It is very expensive

2. It needs specific training to operate effectively.

12 .CHARACTERISTICS OF SIMPLE CUBIC CRYSTAL (SC)

In Simple Cubic crystal structure, a unit cell contains only one type of atoms called

corner atoms. Each corner atom located at the eight corners of the unit cell of SC..

.
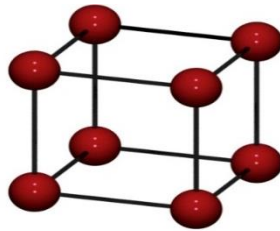
Number of atoms per unit cell (N):

It is defined as the **number of atoms present in (or) shared by the unit cell**.

Thus the total numbers of atoms in SC crystal is given by

$N = 8 \times \frac{1}{8} = 1$

Therefore, the number of atoms per unit cell for SC crystal is One Atom.

Atomic Radius (r):

Atomic radius is defined as half of the distance between any two nearest neighbor atoms which have direct contact with each other

Let 'a' and 'r' are the side of the cubic unit cell and radius of the atoms in the unit cell respectively.   From figure the atomic radius for simple cubic crystal is given by

$$2r = a$$

$$\text{Atomic Radius } r = \frac{a}{2}$$
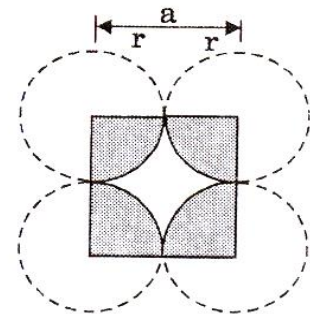
Coordination Number (CN):
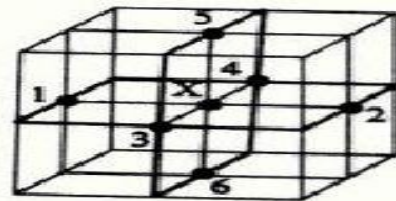
Co-ordination number is the number of nearest neighboring atoms to
a particular atom
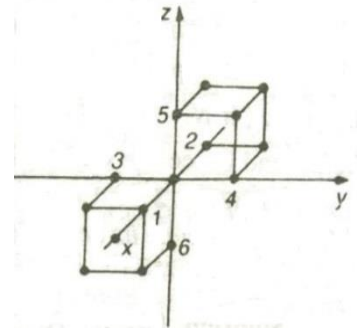
Simple cubic unit cell consists of 8 corner atoms. Let as consider any
one corner atom say X shared by 8 unit cells as shown in figure.
For this particular atom X there are 4 nearest neighbor atoms, shown
1,2,3,and 4 in its own plane (horizontal) and there are 2 more nearest atoms, one directly above
(atom 5) and other one directly below (atom 6).Thus, from the above shown figure the
coordination number for SC structure is=**6**

Atomic Packing Factors (APF)

$$APF = \frac{Total\ Number\ of\ atom\ per\ unit\ cell\ \times\ Volume\ of\ one\ atom}{Total\ volume\ of\ the\ unit\ cell}$$

For simple cubic structure

Number of atom per unit cell = 1

Volume of one atom$= \frac{4}{3}\pi r^3$

Volume of the unit cell (sc) V$=a^3$

Atomic Packing Factors (APF) $= \frac{1 \times \frac{4}{3}\pi r^3}{a^3} = \frac{\pi}{6} = 0.52$

Therefore, the atomic Packing factor for SC crystal is 0.52. This indicates that only 52%
of the volume is occupied by the atoms and remaining 48 % is vacant.

BODY CENTERED CUBIC CRYSTAL (BCC)

In BCC crystal structure the unit cell contains of two types of atoms namely, **corner
atoms and Body centered atom.** In BCC unit cell, the atoms occupy the corners as well as the
body centre of the unit cell. To define the structure of the BCC crystal, let us evaluate the crystal
parameters,
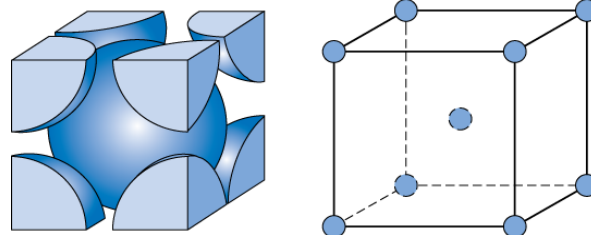
Number of atoms per unit cell (N)

In BCC structure, an unit cell consists of two types of atoms, namely Corner atoms and Body centered atoms.

Corner atoms: In an unit cell of BCC, each corner atom located at each corners of an unit cell, therefore the total numbers of corner atoms in BCC crystal is N= $8 \times \frac{1}{8} = 1$ atom

Body centered atom:

In BCC structure, in addition to the corner atoms there is another one atom which present at the center of the unit cell. This atom does not share with other unit cells. Therefore the number of Body centered atom in unit cell is given by   N= $1 \times \frac{1}{1} = 1$ atom

Therefore, the total numbers of corner atoms for BCC structure is the combination of corner atoms and body centered atom, N = 1+1=2 atoms
Thus, the number of atoms per unit cell for BCC is = 2 atoms
Atomic Radius (r)

From the geometry

$AD^2 = AC^2 + CD^2$

$AD^2 = AB^2 + BC^2 + CD^2$

$(4r)^2 = a^2 + a^2 + a^2$

$(4r)^2 = 3a^2$

Taking square root on both side

$$4r = a\sqrt{3}$$

Atomic Radius r = $a\frac{\sqrt{3}}{4}$

Coordination Number (CN)

It is the **number of nearest neighbour atoms with respect to any atom in the lattice**. It varies with one structure to another. To find the coordination number, let us consider body centered atom as reference atom.
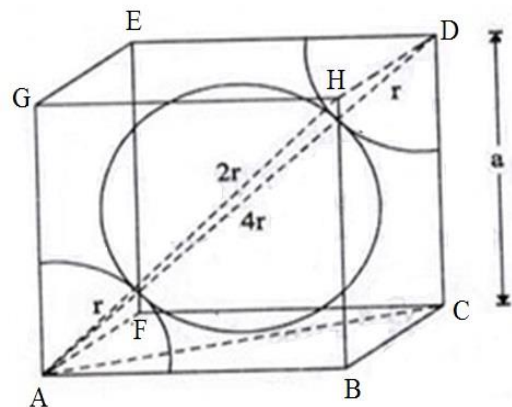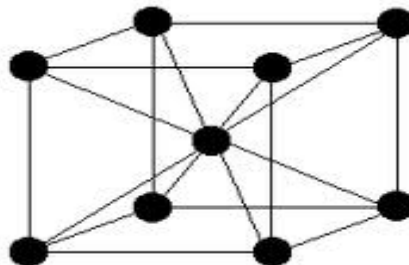
For this reference atom, the eight nearest neigbours are the corner atom. Therefore the coordination number for BCC is 8.

Coordination Number in Bcc structure is = **8 atoms**

Atomic Packing Factor

$$APF = \frac{Total\ Number\ of\ atom\ per\ unit\ cell \times Volume\ of\ one\ atom}{Total\ volume\ of\ the\ unit\ cell}$$

For Body centered cubic structure

Number of atom per unit cell = 2

Volume of one atom $= \frac{4}{3}\pi r^3$

Volume of the unit cell (sc) V=a^3

Atomic Packing Factors (APF) $= \frac{2 \times \frac{4}{3}\pi\left(a\frac{\sqrt{3}}{4}\right)^3}{a^3} = \frac{\sqrt{3}\pi}{8} = 0.68$

Therefore, the atomic Packing factor for BCC crystal is 0.68. Thus, this indicates that only 68% of the volume is occupied by the atoms and remaining 32% is vacant.

Face Centered Cubic (FCC) Structure:

In FCC structure, the atoms are located at each of the eight (8) corners and six (6) atoms at the centers of all cube faces of the unit cell.

Number of atoms per unit cell (N)

In FCC structure the unit cell consists of two types of atoms, namely Corner atoms and Face centered atoms. The total number of corner atoms per unit cell N = $8 \times \frac{1}{8} = 1$

Similarly, there are six face atoms. Each atom shares with two adjacent unit cells, therefore the total numbers of face atoms in FCC unit cell is six.

The total number of Face atoms per unit cell N = $6 \times \frac{1}{2} = 3$

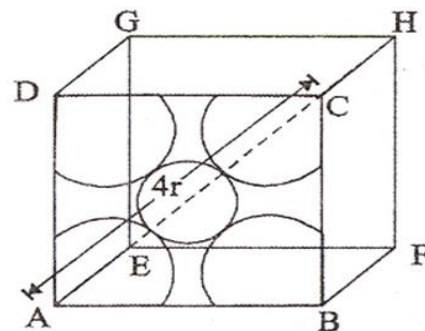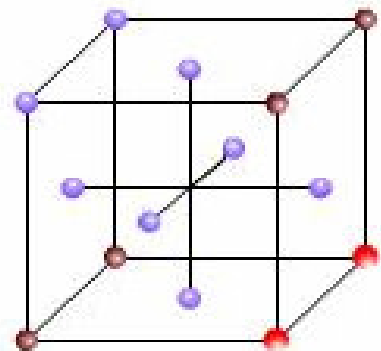Thus, the total numbers of atoms per unit cell FCC atoms in an unit cell is N = 1+3 = 4

Atomic Radius (r):

The two corner atoms (A & C) situated at the opposite ends of the same face can be joined by drawing a diagonal.

From the geometry

AC^2=AB^2+BC^2

$4r^2 = a^2+a^2$

$4r = a\sqrt{2}$

Atomic Radius $r = a\frac{\sqrt{2}}{4}$

Coordination Number (CN)

It is the **number of nearest neighbour atoms with respect to any atom in the lattice**. It varies with one structure to another. To find the coordination number, let us consider Corner atom as reference atom. Hence, the **coordination number is 12.** Due to its highest CN, this is a closed packed structure.
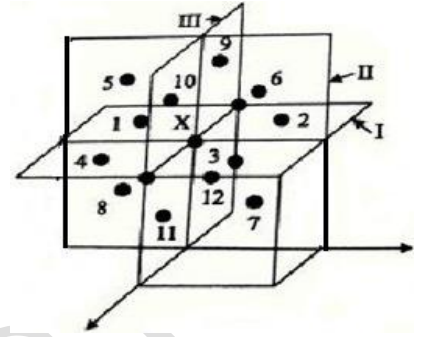
Atomic Packing Factor

$$APF = \frac{Total\ Number\ of\ atom\ per\ unit\ cell \times Volume\ of\ one\ atom}{Total\ volume\ of\ the\ unit\ cell}$$

For Face centered cubic structure

Number of atom per unit cell = 4
Volume of one atom = $\frac{4}{3}\pi r^3$
Volume of the unit cell (sc) V=a^3

Atomic Packing Factors (APF)= $\frac{4 \times \frac{4}{3}\pi\left(a\frac{\sqrt{2}}{4}\right)^3}{a^3} = \frac{\pi}{3\sqrt{2}} = 0.74$

Therefore, the atomic Packing factor for FCC crystal is 0.74. Thus, this indicates that only 74% of the volume is occupied by the atoms and remaining 26% is vacant.

## 13.HEXAGONAL CLOSE PACKED (HCP) STRUCTURE

The unit cell of HCP system has 12 corner atoms, one at each and every corner of the hexagon with two base centered atoms, one at the top face of the hexagon and another at the bottom face of the hexagon as shown in figure.

In addition to the corner and base atoms, there are three symmetrically arranged atoms in between the top and bottom face of the hexagon..

Number of atoms per unit cell (N):

In HCP structure, an unit cell consists of three types of atoms, namely Corner atoms. Base atoms and Middle layered atoms. One half of the each of the 2 base centre atoms ($2\times\frac{1}{2} = 1$)

One six of the each of the 12 corner atoms ($12\times\frac{1}{6} = 2$) All the 3 mid plane interior atoms contribute to the HCP unit cell. Thus, the effective number of atoms per unit cell of HCP is 6.
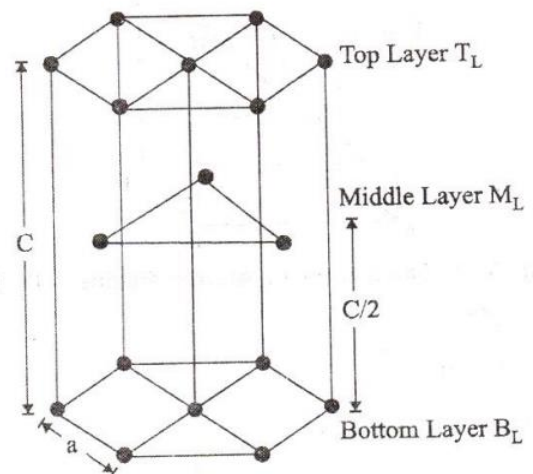
Coordination Number (CN):

In HCP unit cell, the base centered atom touches six corner atoms in the same plane, three atoms in a plane above and three more atoms in a plane below it. Therefore, each atom has 12 nearest neighbors. So, the coordination number is 12.
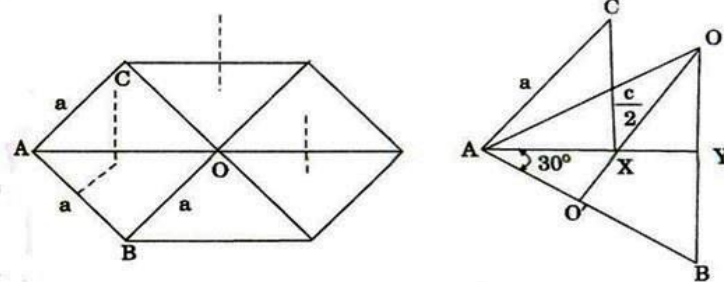
Atomic Radius (r)

To find the atomic radius of the HCP structure, consider any two corner atoms, it has to be noted that the corner atoms touch each other, therefore they are nearest neighbours.
From the figure we can write $2r = a$

$$\text{Therefore the Atomic radius } r = \frac{a}{2}$$

Relation between c and a $\left[\frac{c}{a} \text{ ratio}\right]$

Here, A, B and O are the atoms of the bottom layer and y is the next layer atom which lies exactly above this plane at a distance C/2. Δ ABO is the equilateral triangle. A line AY is drawn perpendicular to BO. Then $COS\theta = \frac{AY}{AB}$

From figure $AB = a$ and $\left[Cos30^o = \frac{\sqrt{3}}{2}\right]$

$$AY = AB \ Cos \ 30^0 = \frac{a\sqrt{3}}{2}$$

$$AY = \frac{a\sqrt{3}}{2} \qquad ---\to (1)$$

$$AX = \frac{2}{3} AY \qquad ---\to (2)$$

$$AX = \frac{2}{3} \times \frac{a\sqrt{3}}{2} = \frac{a}{\sqrt{3}} \qquad ---\to (3)$$
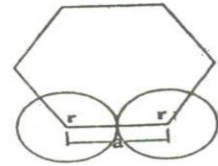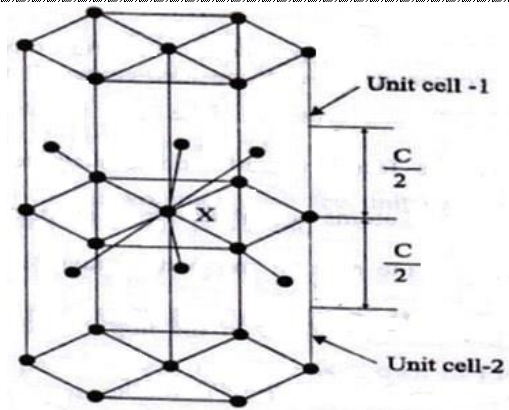
Similarly, from triangle AXC

$$AC^2 = AX^2 + CX^2 ---\to (4)$$

Substituting the value of $AC = a$, $AX = \frac{a}{\sqrt{3}}$ and $CX = \frac{c}{2}$

$$a^2 = \left(\frac{a}{\sqrt{3}}\right)^2 + \left(\frac{c}{2}\right)^2$$

$$a^2 = \frac{a^2}{3} + \frac{c^2}{4}$$

$$\frac{c^2}{4} = a^2 - \frac{a^2}{3}$$

$$\frac{c^2}{4} = \frac{3a^2 - a^2}{3}$$

$$\frac{c^2}{a^2} = \frac{2 \times 4}{3}$$

$$\frac{C^2}{a^2} = \frac{8}{3}$$

$$\frac{C}{a} = \sqrt{\frac{8}{3}} = 1.6329$$

Atomic Packing factor:

In HCP, the number of atoms per unit cell = 6.

At first, we have to find the volume of a HCP unit cell (V) that is

Volume of a HCP unit cell (V) = Area of hexagonal face × height of the hexagon

V = Area of each triangle × 6 × height of the hexagon

V = ½× base × height × 6 × C

V = 3× a × a$\frac{\sqrt{3}}{2}$ × C

$$V = \frac{3\sqrt{3}}{2}a^2 c$$

Number of atom per unit cell = 6 and Volume of one atom = $\frac{4}{3}\pi r^3$

$$APF = \frac{Total\ Number\ of\ atom\ per\ unit\ cell\ \times\ Volume\ of\ one\ atom}{Total\ volume\ of\ the\ unit\ cell}$$

Atomic Packing Factor (APF) = $\dfrac{6 \times \frac{4}{3}\pi\left(\frac{a}{2}\right)^3}{\frac{3\sqrt{3}}{2}a^2 c} = \dfrac{2 \times 6 \times 4 \times \pi a^3}{8 \times 3\sqrt{3}a^2\ c}$

$$APF = \frac{2\pi a^3}{3\sqrt{3}a^2\ c} = \frac{2\pi a}{3\sqrt{3}\ c}$$

Since r = $\frac{a}{2}$ and substituting for $\frac{c}{a} = \sqrt{\frac{8}{3}}$ value

Atomic Packing Factors (APF) = $\frac{2\pi}{3\sqrt{3}}\sqrt{\frac{3}{8}} = \frac{\pi}{3\sqrt{2}} = 0.74 = 74\%$

Therefore, we can say that 74% volume of the unit cell of HCP is occupied by atoms and remaining 26% volume is vacant which implies that HCP structure can be termed as tightly or closely packed structure.

14. DIAMOND CUBIC STRUCTURE

Diamond has FCC structure with the basis of two carbon atoms, viz, X and Y. The X is located with an origin of (0,0,0) the other Y atom is located with an origin of $\left(\frac{a}{4}, \frac{a}{4}, \frac{a}{4}\right)$ i.e one quarter of the way along the body diagonal as shown in figure.

Therefore the diamond structure can be arrived at by attaching one atom to each FCC lattice point (x,y,z) and the other at a point $(x + \frac{a}{4}), (y + \frac{a}{4}), (z + \frac{a}{4})$

An alternative way of describing the diamond structure is to as one with 2 interpenetrating FCC sub-lattices with one FCC penetrating upto $\frac{1}{4}$th the body diagonal of the other. Let us now discuss some important parameter of the diamond.

(a)   (b)
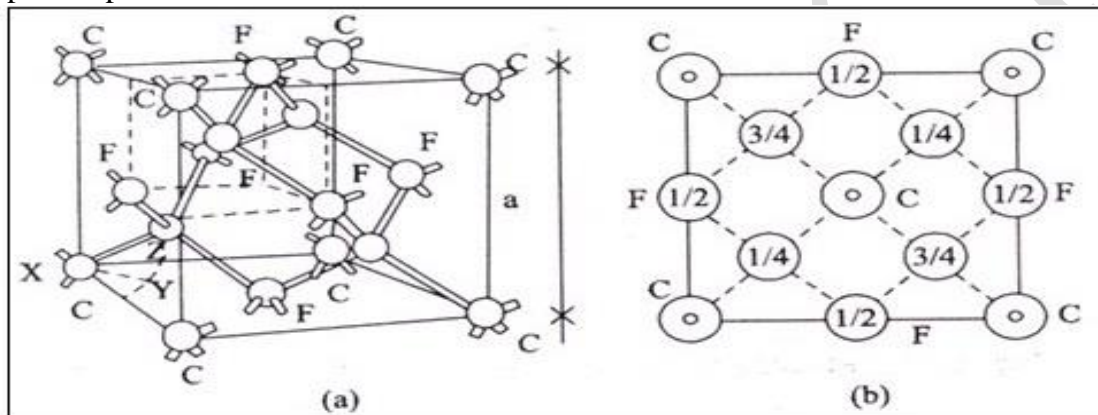
1. Number of atom per unit cell:

In diamond we have three types of atoms. Viz., Corner atoms (8), face centered atoms (6) and inside atoms (4). Therefore the no. of atoms per unit cell = 1+3+4 = 8

2. Atomic radius:

In diamond structure the corners atoms do not have contact with each other and face centered atom also do not have contact with each other. But both face centered atom and corner atoms has contact with 4 inside atoms.

Therefore the atomic radius $r = \dfrac{a\sqrt{3}}{8}$

3. Co-ordination number:

The coordination of diamond structure = 4.

4. Packing factor:

Number atoms per unit cell = 8

Volume of the unit cell V = a³

We know the atomic radius of diamond structure is $r = \dfrac{a\sqrt{3}}{8}$

$$APF = \frac{Total\ Number\ of\ atom\ per\ unit\ cell\ \times\ Volume\ of\ one\ atom}{Total\ volume\ of\ the\ unit\ cell}$$

Atomic Packing Factors$(APF) = \dfrac{8 \times \frac{4}{3}\pi \left(\frac{a\sqrt{3}}{8}\right)^3}{a^3} = \dfrac{\pi\sqrt{3}}{16} = 0.34 = 34\%$