DMI COLLEGE OF ENGINEERING

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DEPARTMENT OF SCIENCE AND HUMANITIES

ENGINEERING PHYSICS - UNIT: I-MECHANICS

Part – 'A' '2' Marks Questions with Answers

1. Define multiparticle dynamics.

The study of dynamics of a system which consists of two or more particles is known multiparticle dynamics.

2. Define centre of mass of the system.

Consider the motion of a system consisting of a large number of particles. There is one point in it which behaves as though the entire mass of the system were concentrated there and all the external forces were acting at this point. This point is called the centre of mass of the system.

3. What is centre of mass (CM)?

A point in the system at which whole mass of the body is supposed to be concentrated is called centre of mass of the body.

4. Give the example for motion of centre of mass.

Examples for motion of centre of mass

(i) Motion of planets and its satellite (ii) Projectile Trajectory (iii) Decay of a Nucleus

5. How centre of mass is determined for rigid body and regular shape?

Centre of mass of some regular objects.

• For a rigid body, the centre of mass is a point at a fixed position with respect to the body as a whole. Depending on the shape of the body and the way the mass is distributed in it, the centre of mass is a point may or may not be within the body.

• If the shape is symmetrical and the mass distribution is uniform, we can usually find the location of the centre of mass quite easily. •

For a long thin rod of uniform cross section and density, the centre of mass is at the geometrical centre. • For a thin circular plane ring, It is again at the geometrical centre of the circle. • For a rectangle, again the centre of mass is at the geometrical centre.

6.What is the difference between centre of gravity and centre of mass?

• The centre of gravity of a body is a point, where the whole weight of the body is supposed to be concentrated.• The centre of mass of a body is that point, where the whole mass of the body is supposed to be concentrated.

7. Define rigid body.

A rigid body is defined as that body which does not undergo any change in shape or volume when external forces are applied on it.

8. Define rigid body rotation.

When a body rotates about a fixed axis, its motion is known as rotatory motion.A rigid body is said to have pure rotational motion, if every particle of the body moves in a circle, the centre of which lies on a straight line is called the axis of rotation (Fig).

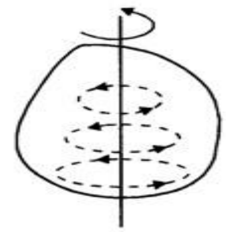


Fig. Rotational motion

9. Write down the equation of motion for rotational motion.

$$\omega = \omega_0 + \alpha t \quad \ldots (1)$$

$$\theta = \omega_0 t + \frac{1}{2}\alpha t^2 \quad \ldots (2)$$

$$\omega^2 = \omega_0^2 + 2\alpha\theta \quad \ldots (3)$$

10. Define moment of inertia of a body.

The property of a body by which it resists change in uniform rotational motion is called rotational inertia or moment of inertia.

11. Define moment of inertia of a particle

The moment of inertia of a particle about an axis is defined as the product of the mass of the particle and square of the distance of the particle from the axis of rotation.

If '*m*' is the mass of the particle and '*r*' is the distance of the particle from the axis of rotation, then The moment of inertia of the particle $\boxed{I = mr^2}$

12. Define moment of inertia of a rigid body.

The moment of inertia of a rigid body about a given axis is the sum of products of masses of its particles and the square of their respective distances from the axis of rotation.

13. What are the factors the moment of inertia depends on?

Moment of inertia depends on mass, distribution of mass and on the position of axis of rotation.

14. What are the physical significance of moment of inertia?

The property which opposes the change in rotational motion of the body is called the moment of inertia. Greater is moment of inertia of the body about the axis of rotation, greater is the torque required to rotate the body.

Thus it is clear that the moment of inertia of a body has the same role in rotational motion as that of mass (or inertia) is linear motion.

15. What is radius of gyration?

The radius of gyration is defined as the distance from the axis of rotation to the point where the entire mass of the body is assumed to be concentrated.

K is called the Radius of Gyration of the body about the axis of rotation. It is equal to the root mean square distance of all particles from the axis of rotation of the body.

16. What are the theorems on moment of inertia?

There are two important theorems which help to find the moment of inertia of a body about some other axis if moment of inertia about any symmetrical axis of the body is given. These are called theorem of parallel and perpendicular axes.

They are 1. Parallel axes theorem and 2. Perpendicular axes theorem

17. State parallel axis theorem.

The moment of inertia of a body about any axis is equal to the sum of its moment of inertia about a parallel axis passing through its centre of gravity of the body and the product of its mass of the body with the square of the distance between the two axes.

18. State perpendicular axis theorem.

It states that the moment of inertia of a plane lamina about an axis perpendicular to its plane is equal to the sum of the moments of inertia of the plane lamina about any two mutually perpendicular axes in its own plane and intersecting each other at the point where the perpendicular axis passes through it.

19. Define angular momentum.

Angular momentum of a particle is defined as its moment of linear momentum it is given by the product of linear momentum and perpendicular distance of its line of action from the axis of rotation. It is denoted by $\vec{L}$.

20. Define torque.

The moment of the applied force is called torque. It is represented by the symbol ‘τ’.

If *F* is the force acting on a body at a distance *r* then,

Torque = Force × distance i.e., $\vec{\tau} = \vec{F} \times \vec{r}$

The rotational motion is due to only when the torque acts on the body.

21. State conversation of angular momentum.

The law of conservation of angular momentum states that in the absence of an external torque, the angular momentum of a body or a system of bodies remains conserved.

22. What is gyroscope?

A gyroscope is a device used for measuring or maintaining orientation and angular velocity. It is a spinning wheel or disc in which the axis of rotation (spin axis) is free to assume any orientation by itself.

23. What are the uses of gyroscope?

1. In view of the property of stability, the gyroscope are used as stabilizers in ships, boats and aero planes.
2. Due to the inherent stability of the gyroscope, it is used as a compass, and a gyro-compass is preferable to the magnetic compass in many respects.
3. Another important application of the directional stability of a rapidly spinning (rotating) body is the rifling of the barrels of the rifles.

24. What is torsional pendulum?

A circular metallic disc suspended using a thin wire that executes torsional oscillation is called torsional pendulum.

25. What are the uses of torsional pendulum?

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

26. What is double pendulum?

A double pendulum is a pendulum with another pendulum attached to its end.

The pendulum behaves like a linear system for small angles. When the angels are small in the double pendulum, the system behaves like the linear double spring. In this case, the motion is determined by simple sine and cosine functions. On the otherhand for large angles, the pendulum is non-linear and the phase graph becomes much more complex.

Part - B '16' Marks Questions

1. Discuss the Centre of mass and obtain the expression for the same for a system of particles. Also, outline the motion of Centre of mass.

(i) When the masses are on positive *X*-axis – 4 mark

$$\boxed{X_{CM} = \frac{m_1 x_2 + m_2 x_2}{m_1 + m_2}}$$

(ii) When the origin coincides with any one of the masses – diagram & concept-6 marks

(iii) When the origin coincides with the centre of mass itself-6marks

2. Derive an expression for kinetic energy of system of particles.

Diagram – 3marks, derivation & explanation – 10marks, final equation-3marks

$$E'_k = \sum_{i=1}^{n} \frac{1}{2} m_i \vec{v}_i^{\,2} \qquad \text{... (7)}$$

3. Derive the relation between rotational kinetic energy and moment of inertia.

Rotational kinetic energy – 6marks

Moment of Inertia=**I = mr^2** – 6marks

Relation -4marks

i.e., $E_K = \frac{1}{2} I \omega^2$

$$\text{Rotational kinetic energy} = E_R = \frac{1}{2} I \times \omega^2 = \frac{1}{2} I \times 1^2 = \frac{1}{2} I \qquad \text{... (2)}$$

Therefore, $I = 2E_R$

4. State and prove the theorem of parallel axes and perpendicular axis for the moment of inertia of a rigid body.

Parallel Theorem – statement-2marks

Explanation and proof – 6marks

$$I = I_G + Ma^2$$

Perpendicular theorem – statement – 2 marks

Explanation and proof – 6marks

ie, $I_z = I_x + I_y$

5. Derive an expression for the moment of inertia of a uniform rod. i) About an axis through its centre and perpendicular to its length ii) About an axis passing through one end of the rod and perpendicular to its length.

(i) About an axis through its centre and perpendicular to its length (I=Ml^2/12)-8marks

(ii) About an axis through on end of the rod and perpendicular to its length-(I=Ml^2/3)8marks

6. Derive an expression for the moment of inertia of thin ring about. (a) an axis through its centre and perpendicular to its plane. (b) Diameter (c) a tangent in the plane of the ring.

(a) An axis through its centre and perpendicular to its plane – 5marks

(b) About a diameter – 5marks

(c) About a tangent in the plane of the ring-6marks

7. Derive an expression for the moment of inertia of a thin circular disc (a) about an axis through its centre and perpendicular to its plane. (b) about a diameter.

(a) About an axis through its centre and perpendicular to its plane – ($I=MR^2/2$)-8marks

(b) About a diameter-($I=MR^2/4$)-8marks

8. Derive an expression for the moment of inertia of a solid sphere. (a) about diameter (b) about a tangent

(a) About a diameter- ($I=2/5\ MR^2$)8marks

(b) About a tangent-($I=7/5\ MR^2$)8marks

9. Derive an expression for the moment of inertia of a solid cylinder, the centre and

(a) About an axis passing through perpendicular to its length (b) about the axis of cylinder.

(a) About an axis passing through perpendicular to its length $=I=M(r^2/4+l^2/12)$-8marks

(b) About the axis of cylinder$=I=Mr^2/2$

10 a). Discuss the moment of inertia of a diatomic molecule. b) Discuss the rotational energy states of a rigid diatomic molecule.

Diagram-4mark, Derivation MI-6mark Derivation –E-6marks

$$I = \mu K^2$$

$$E_l = \frac{l(l+1)\hbar^2}{2I}$$

$\vec{L} = mv \times r$

$= mr\omega \times r$

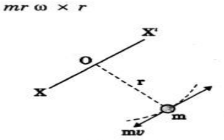
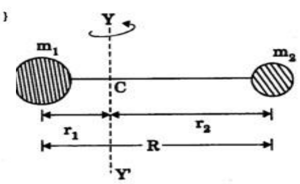


Fig. 1.37

... (6) lar momentum $= mr^2\omega$

$\{\because v = r\omega\}$



...ment of Inertia of a diatomic molecule

11. Describe principle, construction and working of gyroscope. Mention its application in various fields.

Principle- conservation of angular momentum-4mark, Description and working with diagram-6marks, Applications-any six-6marks

12. Derive an expression for time period of torsion pendulum. Explain how it is used to find rigidity modulus of a wire.

Description-4mark, period of Oscillation-6mark, rigidity modulus-6mark,

$$T = 2\pi\sqrt{\frac{I}{C}} \quad \ldots (1)$$

$$n = \frac{8\pi I}{r^4}\left(\frac{l}{T^2}\right) \quad \ldots (6)$$

Part - 'A' ; '2' Marks Questions with answers

1. Write Maxwell's equation - I from Gauss's law in electrostatics.

$$\oint\!\!\oint_S \vec{D}\cdot\vec{ds} = \iiint_V \rho\, dV$$

Integral form

Gauss's law in electrostatics states that the total electric flux through any closed surface is equal to the charge enclosed by it.

Differential form $\vec{\nabla}\cdot\vec{E} = \frac{\rho}{\varepsilon_o}$

This is Maxwell's equation from Gauss's law in electrostatics in differential form

Statement: The total electric displacement through the surface enclosing a volume is equal to the total charge within the volume.

2. Write Maxwell's equation · II from Gauss's law in magnetostatics.

Statement The total magnetic flux through any closed surface in a magnetic field is zero ie.,

This is Maxwell's equation in integral form from Gauss's law in magnetostatics. $\oint\!\!\oint_S \vec{B}\cdot\vec{ds} = 0$

This is Maxwell's equation in differential form from Gauss's law in magnetostatics $\vec{\nabla}\cdot\vec{B} = 0$

Statement: The net magnetic flux 'emerging through any closed surface is zero.

3. Write Maxwell's equation - III from Faraday laws of electromagnetic induction.

$$\oint_C \vec{E}\cdot\vec{dl} = -\iint_S \frac{\partial\vec{B}}{\partial t}\cdot\vec{ds})$$

This is Maxwell's equation in integral form from Faraday's law of electromagnetic induction.

$$\vec{\nabla}\times\vec{E} = -\frac{\partial\vec{B}}{\partial t}$$

This eqn represents Maxwell's equation from Faraday's law of electromagnetic induction in differential form.

Statement: The electromotive force around a closed path is equal to the rate of magnetic displacement (flux density) through that closed path.

4. Write Maxwell's equation · IV from Ampere's circuital law.

Ampere's law states that the line integral of magnetic field intensity H on any closed path is equal to the current (*I*) enclosed by that path

$$\oint \vec{H} \bullet \vec{dl} = I$$

then, $$\oint \vec{H} \bullet \vec{dl} = \iint_S \left(\vec{J} + \frac{\partial \vec{D}}{\partial t} \right) ds$$

This is Maxwell's equation in integral form from Ampere's circuital law.

or $$\vec{\nabla} \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t}$$

$$\vec{\nabla} \times \vec{H} = \sigma \vec{E} + \varepsilon \frac{\partial \vec{E}}{\partial t}$$

The above equations are Maxwell equations in differential form from Ampere's circuital law

Statement

The magneto motive force around a closed path is equal to the sum of the conduction current and displacement current enclosed by the path.

5. Give the Maxwell's equations in differential form.

$$\vec{\nabla} \bullet \vec{D} = \rho$$

$$\vec{\nabla} \bullet \vec{B} = 0$$

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\vec{\nabla} \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t}$$

6. Give the Maxwell's equations in integral form.

$$\oiint_S \vec{D} \bullet \vec{ds} = \iiint_V \rho \, dV$$

$$\oiint_S \vec{B} \bullet \vec{ds} = 0$$

$$\oint \vec{E} \bullet \vec{dl} = -\iint_S \frac{\partial \vec{B}}{\partial t} \bullet \vec{ds}$$

$$\oint \vec{H} \bullet \vec{dl} = \iint_S \left(\vec{J} + \frac{\partial \vec{D}}{\partial t} \right) \vec{ds}$$

7. Write the Maxwell's equations for free space.

$$\vec{\nabla} \bullet \vec{D} = 0$$

$$\vec{\nabla} \bullet \vec{B} = 0$$

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\vec{\nabla} \times \vec{H} = \frac{\partial \vec{D}}{\partial t}$$

8. Write the Maxwell's equations for conducting medium.

$$\vec{\nabla} \bullet \vec{D} = \rho$$

$$\vec{\nabla} \bullet \vec{B} = 0$$

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\vec{\nabla} \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t}$$

9. What are the characteristics of Maxwell's First equation $\vec{\nabla} \times \vec{E} = \frac{\rho}{\varepsilon_o}$ **?**

• It explains Gauss's law in electrostatics.

• It is time independent or steady state equation.

• The flux of the lines of electric force depends upon charge density.

• Charge acts as a source or sink for the lines of electric force.

10. What are the characteristics of Maxwell's second equation $\vec{\nabla} \cdot \vec{B} = 0$ **?**

• It expresses a well known observation that *isolated magnetic poles do not exist.*

• It states that total magnetic flux entering and leaving a given volume is equal.

• There is no source or sink for lines of magnetic force.

• It is a time independent equation.

• It explains Gauss's law in Magnetostatics.

11. What are the characteristics of Maxwell's Third equation $\vec{\nabla} \times \vec{E} = \frac{\partial \vec{B}}{\partial t}$?

• It relates the electric field vector $\vec{E}$ and magnetic induction vector $\vec{B}$.

• It is a time dependent or time varying equation.

• It explains the well known Faraday's laws and Lenz's law of electromagnetic induction.

• $\vec{E}$ is generated by the time variation of $\vec{B}$.

12. What are the characteristics of Maxwell's Fourth equation $\vec{\nabla} \times \vec{B} = \mu_o \left(\vec{J} + \frac{\partial \vec{B}}{\partial t} \right)$?

• It gives relation with the magnetic field vector $\vec{B}$ with displacement vector $\vec{D}$ and the current density $\vec{J}$.

• It is also a time dependent equation.

• It explains Ampere's circuital law.

• $\vec{B}$ can be produced by $\vec{J}$ and the time variation of $\vec{D}$

13. Write the general electromagnetic wave equation in terms of electric field vector $\vec{E}$ for free space.

$$\nabla^2 \vec{E} = \mu_o \varepsilon_o \frac{\partial^2 \vec{E}}{\partial t^2}$$

μ_0 - permeability in free space, ε_0 - permittivity in free space.

This is general electromagnetic wave equation in terms of electric field vector $\vec{E}$ for free space.

14. Write the general electromagnetic wave equation in terms of magnetic field vector $\vec{H}$ for free space.

$$\nabla^2 \vec{H} = \mu_o \varepsilon_o \frac{\partial^2 \vec{H}}{\partial t^2}$$

μ_0 – permeability is free space, ε_0 - permittivity is free space.

This general electromagnetic wave equation is in terms of $\vec{H}$ **for free space.**

15. Write the expression for velocity of em wave in free space.

$$c = \frac{1}{\sqrt{\mu_o \varepsilon_o}}$$

For vacuum or free space we have $\mu_0 = 4\pi \times 10^{-7}$ Hm^{-1} (henry per metre) and $\varepsilon_0 = 8.842 \times 10^{-12}$ Fm^{-1} (farad per metre).

16. Write the general solution of wave equation for plane polarised em wave.

$E_y = E_0 \cos(\omega t - kx)$ and $H_z = H_0 \cos(\omega t - kx)$ where, ω - angular frequency k - wave vector

17. Write the relation between the electric field vector $\vec{E}$ and magnetic field vector $\vec{H}$.

$$\therefore \quad \frac{\vec{E}}{\vec{H}} = \sqrt{\frac{\mu_o}{\varepsilon_o}}$$

This is the relation between the electric field vector and magnetic field vector. It is determined by the μ_0 and ε_0

18. What is intrinsic or characteristic impedance of free space?

The ratio of $\frac{\vec{E}}{\vec{H}}$ is having the unit of impedance (Resistance)

ie., ohm, Therefore, the quantity has the dimensions of impedance. $\sqrt{\frac{\mu_o}{\varepsilon_o}}$

It is known as **intrinsic or characteristic impedance of free space, denoted by Z_0**. It is a constant quantity for free space and having value = 377Ω.

19. What is poynting vector?

The cross product of electric field vector $\vec{E}$ and the magnetic field vector $\vec{H}$ is called poynting vector. It is denoted by $\vec{S} = \vec{E} \times \vec{H}$.

20. Write the general wave equation for the electric vector in an em wave in conducting medium.

$$\nabla^2 \vec{E} - \mu\varepsilon \frac{\partial^2 \vec{E}}{\partial t^2} - \mu\sigma \frac{\partial \vec{E}}{\partial t} = 0$$

$\vec{E}$ - electric field vector. μ– permeability of medium. ε - permittivity of medium.

This is the general wave equation for the electric vector in an electromagnetic wave propagating in conducting medium.

21. Write the general wave equation for the magnetic vector in an em wave in conducting medium.

In a similar way, by taking the curl of the eqn. (4) we obtain the general wave equation for the magnetic vector in a conducting medium as $\nabla^2 \vec{H} - \mu \varepsilon \frac{\partial^2 \vec{H}}{\partial t^2} - \mu \sigma \frac{\partial \vec{H}}{\partial t} = 0$

$\vec{H}$ - Magnetic field vector. μ – permeabity of medium. ε - permittivity of medium.

22. What is skin depth?

It is defined as the distance inside the conductor from the surface of the conductor at which the amplitude of the field vector is reduced to 1le times its value at the surface.

23. Define intensity of EM wave.

The magnitude of the average value of $\vec{S}$ at a point is called the intensity of radiation at that point. The S.I unit of intensity is W/m^2. It is given by $S_{av} = \frac{1}{2} \varepsilon_o c E_y^2$

ε_0 - permittivity of the medium. *c* - velocity of light.

24. Define radiation pressure.

The force per unit area on an object due to *EM* radiation is the radiation pressure P_r,

$P_r = \frac{I}{c}$, for total absorption of radiation

$P_r = \frac{2I}{c}$, for total reflection back along the path

25. Give the Properties of Electromagnetic Waves.

(i) Electromagnetic waves are produced by accelerated charges.

(ii) They do not require any material medium for propagation.

(iv) Variation of maxima and minima in both E and Boccur simultaneously (in phase).

(v) They travel in vacuum or free space with a speed 3×10^8 ms^{-1} given by the relation $c = \frac{1}{\sqrt{\mu_o \varepsilon_o}}$.

(μ_0 - permeability of free space and ε_0 - permittivity of free space)

Part - B - '16' Marks Questions

1. **Derive Maxwell's equations in differential and integral fo**

Differential equation-derivation-8mark

Integral equations-derivation-8mark

	Differential form	Integral form
I.	$\vec{\nabla}\cdot\vec{D} = \rho$	$\oiint_S \vec{D}\cdot\vec{ds} = \iiint_V \rho\, dV$
II.	$\vec{\nabla}\cdot\vec{B} = 0$	$\oiint_S \vec{B}\cdot\vec{ds} = 0$
III.	$\vec{\nabla}\times\vec{E} = -\frac{\partial\vec{B}}{\partial t}$	$\oint \vec{E}\cdot\vec{dl} = -\iint_S \frac{\partial\vec{B}}{\partial t}\cdot\vec{ds}$
IV.	$\vec{\nabla}\times\vec{H} = \vec{J} + \frac{\partial\vec{D}}{\partial t}$	$\oint \vec{H}\cdot\vec{dl} = \iint_S \left(\vec{J} + \frac{\partial\vec{D}}{\partial t}\right)\vec{ds}$

2 **Give an account of Maxwell's equation in free space. Apply the equations to deduce the electromagnetic wave equation and also determine the velocity in vacuum and conditions on the wave field.**

Maxwell's equation in free space – 8marks, deduction-4marks-the velocity in vacuum- 4marks

$$\nabla^2\vec{E} - \mu_o\varepsilon_o\frac{\partial^2\vec{E}}{\partial t^2} = 0 \quad \text{... (17)}$$

and

$$\nabla^2\vec{H} - \mu_o\varepsilon_o\frac{\partial^2\vec{H}}{\partial t^2} = 0 \quad \text{... (18)}$$

$$\frac{\partial^2 E_x}{\partial x^2} - \mu_o\varepsilon_o\frac{\partial^2 E_x}{\partial t^2} = 0 \quad \text{... (19)}$$

and

$$\frac{\partial^2 H_x}{\partial x^2} - \mu_o\varepsilon_o\frac{\partial^2 H_x}{\partial t^2} = 0 \quad \text{... (20)}$$

$$c = \frac{1}{\sqrt{\mu_o\varepsilon_o}} \quad \text{... (22)}$$

$$c = \frac{1}{\sqrt{4\pi\times10^{-7}\times 8.842\times10^{-12}}}$$

$$c = 2.998\times10^{8}\ \text{m s}^{-1}$$

3. **Derive wave equation for conducting medium using Maxwell's equations and also determine skin depth in a conducting medium.**

derivation for conducting medium-10mark, skin depth-definition & derivation-6mark

$$\nabla^2\vec{E} = \mu\frac{\partial}{\partial t}\left[\sigma\vec{E} + \frac{\partial}{\partial t}(\varepsilon\vec{E})\right]$$

or

$$\nabla^2\vec{E} = \mu\sigma\frac{\partial\vec{E}}{\partial t} + \mu\varepsilon\frac{\partial^2\vec{E}}{\partial t^2}$$

Thus,

$$\nabla^2\vec{E} - \mu\varepsilon\frac{\partial^2\vec{E}}{\partial t^2} - \mu\sigma\frac{\partial\vec{E}}{\partial t} = 0 \quad \text{... (12)}$$

$$\nabla^2\vec{H} - \mu\varepsilon\frac{\partial^2\vec{H}}{\partial t^2} - \mu\sigma\frac{\partial\vec{H}}{\partial t} = 0 \quad \text{... (13)}$$

$$E_{ox} = E_o e^{-kx} \quad \text{... (1)}$$

where $k = \sqrt{\frac{\mu\sigma\omega}{2}}$

4. **Discuss polarization in electromagnetic waves and also describe the production of EM waves**. Polarization – 4marks - producing electromagnetic waves-8marks – diagram-4marks

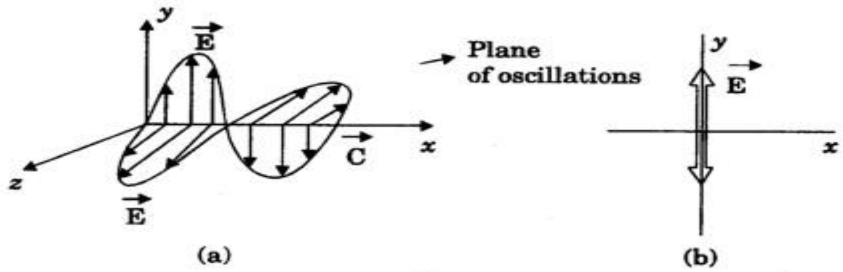


Fig. 2.8 (a) Plane of oscillations of a polarized EM wave
(b) Polarization representation of the electric field along 'y' axis

5. **Discuss the propagation of EM wave from vacuum to a non conducting medium.**

Propagation of EM from vaccum – derivation-16 marks,

$$\vec{\nabla} \times (\vec{\nabla} \times \vec{E}) = \vec{\nabla} \times \left(-\mu \frac{\partial \vec{H}}{\partial t} \right) \qquad n = \frac{c}{v} = \sqrt{\frac{\mu \varepsilon}{\mu_o \varepsilon_o}} = \sqrt{\mu_r \varepsilon_r}$$

$$\vec{\nabla}(\vec{\nabla} \cdot \vec{E}) - \nabla^2 \vec{E} = -\mu \frac{\partial}{\partial t} (\vec{\nabla} \times \vec{H})$$

Refractive index is

In a non-magnetic medium $\mu_r = 1$

$$\therefore \quad \boxed{n = \sqrt{\varepsilon_r}}$$

6. **Write a short note on i) Intensity of an EM waves. ii) Momentum and Radiation Pressure.**

Intensity of an EM waves – 8marks - Momentum and Radiation Pressure-8marks

The magnitude of the average value of $\vec{S}$ at a point is called the intensity of radiation at that point. The S.I unit of intensity is W/m^2.

$$I = \frac{\text{Power}}{\text{Area}} = \frac{P}{4\pi r^2}$$

$$\Delta P = \frac{\Delta u}{c} = \frac{I \cdot A \cdot \Delta t}{c} \qquad \text{... (4)}$$

and as

$$F = \frac{\Delta P}{\Delta t} = \frac{I \cdot A}{c} \qquad \text{... (5)}$$

As the electromagnetic waves carry momentum, they exert pressure when they are reflected or absorbed at the surface of a body. This is known as radiation pressure.

This is the relation for the total absorption of EM radiation.

$$\boxed{P_r = \frac{2I}{c},}$$

OSCILLATIONS-Part – 'A' '2' Marks Questions with answers

1. Define simple harmonic motion.

When the acceleration of particle is directly proportional to its displacement from its equilibrium position and it is always directed towards equilibrium position, then the motion of the particle is said to be **simple harmonic motion.**

2. What are the characteristics of simple harmonic motion?

• The motion must be periodic.

• The motion is oscillatory ie., to and fro along a straight line or along a curved path about a mean position.

• The body executing simple harmonic motion is acted upon by a restoring force whose magnitude is proportional to the displacement and its direction is towards the mean position.

• If there is no air resistance or friction, the motion once · started will continue indefinitely.

3. What are examples of simple harmonic motions?

• Vibrations of a tuning fork. • Vibrations of a sonometer wire.

• Vertical oscillations of the liquid column in a U-tube. • Angular oscillations of a torsion pendulum.

4. What are the types of oscillation?

1. Free oscillations 2. Damped oscillations 3. Forced oscillations

5. What is resonance?

The phenomenon of making a body vibrate with its natural frequency under the influence of another vibrating body with the same frequency is called resonance.

6. What is sharpness of resonance?

The rate of change (fall) of amplitude with the change of forcing frequency on each side of resonant frequency is known as sharpness of resonance.

7. Define progressive wave.

Progressive wave originating from a point source and propagating through an isotropic medium travel with equal velocity in all directions. At any instant, the wave front (locus of all particles vibrating with the same phase) will be spherical in nature.

8. What are the characteristics of progressive wave?

1. Each particle of the medium executes vibration about its mean position. The disturbance progresses onward from one particle to another

2. The particles of the medium vibrate with same amplitude about their mean positions.

3. Each successive particle of the medium performs a motion similar to that of its predecessor along the propagation of the wave, but later in time.

4. The phase of every particle changes from 0 to 2π.

9. Define standing waves.

When two progressive waves of same amplitude and wavelength travelling along a straight line in opposite directions superimpose on each other, stationary waves are formed.

10. What are the characteristics of standing waves?

1. The waveform remains stationary.

2. Nodes and antinodes are formed alternately.

3. The points where displacement is zero are called nodes and the points where the displacement is maximum are called antinodes.

4. Pressure changes are maximum at nodes and minimum at antinodes.

11. What are the differences between progressive waves and stationary waves?

S. No.	Progressive waves	Stationary waves
(i)	There is transfer of energy in the direction of propagation of wave.	There is no transfer of energy.
(ii)	No particle of the wave is permanently at rest.	The particles at nodes are permanently at rest.
(iii)	The particles of the medium vibrate with same amplitude about their mean	Amplitude of each particle is not same. It is maximum at antinodes and decreases gradually to zero at the nodes.
(iv)	The phase of vibration varies continuously.	Particles in the same segment vibrate in the same phase.

12. State Doppler effect.

The phenomenon of the apparent change in the frequency of the sound due to relative motion between the source of sound and the observer is called Doppler effect.

OPTICS - Part - A '2' Marks Question with Answers

1. State laws of reflection.

(i) Incident ray, normal and reflected ray lie in the same plane.

(ii) The angle of incidence is equal to the angle of reflection i.e. $\angle i = \angle r$

2. State laws of refraction.

(i) The incident ray, the refracted ray and the normal at a point of separation of two media lie in the same plane.

(ii) For any two medium, the ratio of sine of angle of incidence to sine of angle of refraction is constant. It is known as **Snell's law.** Therefore, $\sin i / \sin r$ = constant

3. Define refractive index of the medium.

The ratio of velocity of light in vacuum to velocity of light in medium, is called as refractive index.

$$\text{ie., Refractive index, } \mu = \frac{\text{Velocity of light in vacuum } (c)}{\text{Velocity of light in medium } (v)}$$

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

4. What is total internal reflection?

When a ray of light within a denser medium (e.g. water) approaches the surface at an angle of incidence greater than the critical angle, the ray of light is reflected back into the same medium (i.e. water). This phenomenon is known as total internal reflection.

5. Define critical angle.

The angle of incident at which the refracted ray just graze surface between denser and rarer media is called critical angle.

6. Give conditions of total internal reflection.

(a) The light should be incident from denser medium to rarer medium.

(b) The angle of incidence i in denser medium should be greater than critical angle θ_c.

7. Write expression for critical angle.

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

n_1 - refractive index of denser medium n_2 - refractive index of rarer medium

8. Mention a few applications of total internal reflection.

(i) Mirage. During the day time in the desert, it is seen that sand at some distance from the observer looks like a pond of water. This illusion is called mirage and it is caused due to total internal reflection of light. (Fig 4.6)

(ii) Optical fibre. An optical fibre is a transparent fibre used to conduct light through the phenomenon of total internal reflection.

9. What is interference?

This modification or change of intensity of light resulting from the superposition of two or more waves of light is called interference.

10. What is airwedge?

A wedge shaped (V-shaped) air film enclosed in between two glass plates is called air wedge.

11. What is the expression for the fringe width in air wedge experiment?

$$\text{Fringe width } \beta = \frac{\lambda}{2\theta}$$

λ - wavelenth of the light source, θ - Angle of wedge

12. What is the expression for the thickness of the wire in airwedge experiment?

$$d = \frac{\lambda l}{2\beta}$$

λ - wavelenth of the light source, l - Distance from the edge of contact, β - Fringe width

13. What is Michelson interferometer?

An interferometer is an instrument for measuring small changes in length. It is based on the principle of interference.

Michelson originally designed an interferometer which is used to find the wavelength of monochromatic light source and thickness of thin strips.

14. What are the applications of Michelson interferometer?

It is used to find

(i) the wavelength of a given light source. (ii) the refractive index and thickness of a transparent material (iii) the resolution of wavelengths (iv) the standardisation of metre

LASER-PART - A ‘2’ Marks Q & A

1. What is stimulated emission?

The process of induced emissions of photons caused by the incident photons is called stimulated emission. This process is a key factor for the operation of a laser.

2. What are the conditions necessary for stimulated emission of radiation?

(i) The atoms must be in the excited state.

(ii) The photon of light radiation must strike the atoms in the excited state.

3. Write the differences between spontaneous emission and stimulated emission

	Spontaneous emission	Stimulated emission
1.	Emission of light radiation is not triggered by external influence	Induced emissions of light radiations caused by incident photons
2.	Emitted photon travels in random direction	Emitted photon travels in particular direction
3.	Emitted photons cannot be controlled	Emitted photons can be controlled.
4.	This process is a key factor for ordinary light.	This process is a key factor for laser operation

4. What is meant by population inversion and how is it achieved?

The establishment of a situation in which the number of atoms in higher energy level is more than that in lower energy level is called population inversion. It is an essential requirement for producing a laser beam. It is achieved by pumping action.

5. Explain the need for population inversion in the production of laser?

Stimulated emission process is a key factor for the production of laser. For stimulated emission, more number of atoms must be in the excited state.

Establishing a situation in which number of atoms in higher energy state is more than that in lower energy state is called population inversion. Hence, population inversion is needed in the production of laser.

6. What is pumping action?

The process of creating a population inversion in the atomic states is known as pumping action. It is essential requirement for producing a laser beam.

7. What are the methods commonly used for pumping action?

(i) Optical pumping (excitation by photons)

(ii) Electrical discharge method (excitation by electrons)

(iii) Direct conversion (iv) Inelastic collision between atoms.

8. What is optical pumping?

When the atoms are exposed to light radiations (of energy hv), atoms in the lower energy state absorb these light radiations and go to excited state. This method of pumping is called optical pumping. It is used in solid state lasers like ruby laser and Nd - YAG laser.

9. What is meant by active material in laser?

A material in which population inversion can be achieved is called as active material.

10. What are the characteristics of the laser? (or) What are the properties of the laser beam?

• Laser light is highly coherent • It is highly powerful and intense. • It is directional and monochromatic.• It is capable of travelling over long distance without any energy loss.

• It is extremely bright.• Laser beam is not easily absorbed by the water.

11. Under which conditions a set of laser beams is said to be coherent?

A set of laser beams is said to be coherent if they have same frequency and constant phase difference among them with respect to space and time.

12. Compare the characteristics of laser with ordinary light.

	Ordinary light Source	Laser Source
1.	Light emitted is not monochromatic.	Light emitted is highly monochromatic.
2.	Light emitted does not have high degree of coherence	It has high degree of coherence.
3.	Emits light in all directions (not directional)	Emits light only in one direction (directional)
4.	Light is less intense and less bright	Laser light is much intense and bright.

13. What is optical resonant cavity?

It is a pair of mirrors with active material in between them. One of the mirrors of the resonant cavity is made partially reflecting to serve as an output element passing the light (laser) out of the resonator. The other mirror is a highly reflecting one.

14. What is the function of resonator cavity in laser?

Resonator cavity is made up of a pair of fully reflecting plate and a partially reflecting plate. Both of them are optically plane and accurately parallel. The active medium is placed between these mirrors.

The photons emitted along the axial direction during stimulated emission travel back and forth across the active medium and grow in strength. After enough strength is attained, laser beam emerges out from the partial reflector.

15. What is the principle of laser action?

Stimulated emission process is a key factor for the laser action. This can be multiplied through chain reaction. This multiplication of photons through stimulated emission leads to coherent, powerful, monochromatic, collimated beam of light-emission.

16. What are the three important components of any laser device?

(i) Active medium (ii) Pumping source (iii) Optical resonator

17. What are the conditions required for laser action?

• Population inversion should be achieved.

• Stimulated emission should be predominant over spontaneous emission.

18. What are Einstein's coefficients?

In Einstein's theory of spontaneous and stimulated emission, if N_1 and N_2 are the number of atoms in the lower energy state (E_1) and higher energy state (E_2), then the number of stimulated absorption transition is given by

$$\boxed{N_{ab} = B_{12} N_1 Q}$$

The number of spontaneous emission transition is given by

$$\boxed{N_{sp} = A_{21} N_2}$$

The number of stimulated emission transition is given by

$$\boxed{N_{st} = B_{21} N_2 Q}$$

Also $B_{12} = B_{21}$ and $\frac{A_{21}}{B_{21}} = \frac{8\pi h}{\lambda^3}$

where Q is the energy density of the incident radiation. A_{21}, B_{12} and B_{21} in the above three equations are called Einstein's Coefficients.

19. How lasers are classified? or Mention the various types of lasers.

(i) Solid state lasers (ii) Gas lasers (iii) Liquid lasers (iv) Dye lasers (v) Semiconductor lasers.

20. What is Nd - YAG laser?

Nd - YAG is a neodymium based laser. Nd - Neodymium (rare earth element Nd^{3+}).

YAG - Yittrium Aluminium Garnet ($Y_3Al_5O_{12}$). It is a four level solid state laser.

21. What are the applications of Nd-YAG laser ?

(i) It finds many applications in range finders and illuminators

(ii) It finds applications in resistor trimming, scribing, micro machining operations such as welding, drilling etc.

(iii) It finds applications in medical field like endoscopy, urology, neurosurgery, ENT, gynaecology, dermatology, dental surgery and general surgery.

22. What is CO_2 laser ?

It is a four level molecular gas laser. The active medium of this laser is CO_2 gas. Laser transition takes place between the vibrational energy states of the CO_2 molecules. It is a very useful and efficient laser.

23. What is the active medium in CO_2 laser ?

A gas mixture consisting of CO_2, nitrogen and helium is the active medium.

24. What are the applications of CO_2 laser ?

(i) High Power CO_2 lasers find applications in materials processing, welding, drilling, cutting, soldering etc., because of their very high output power.

(ii) It is used in laser remote sensing. (iii) It has found wide applications in neurosurgery and general surgery. (iv) It is used to perform micro-surgery and bloodless operations.

(iv) Heat treatment of metallic and non metallic (plastic, ceramic, glass) materials.

(v) Non - Destructive Testing (NDT): Testing the materials for flaws or defects without damaging them.

25. What is semiconductor laser?

Semiconductor diode laser is a specially fabricated *pn* junction device. It emits laser light when it is forward biased

26. What is homo-junction laser?

Homo-junction means that a pn junction is formed from a single crystalline material

Example: Gallium Arsenide (GaAs)

27. What are the drawbacks of homojunction laser diodes?

● The output beam has large divergence ● Coherence and stability are poor

● Optical confinement is very poor

28. What are the applications of semiconductor laser?

(i) It is mostly used in optical fiber communications.

(ii) It is used to heal the wounds by means of infrared radiation

(iii) It is used in computer laser printers and for writing and reading CD's

29. What is laser material processing?

Material processing involves cutting, welding, drilling and surface treatment using laser beams When the material is exposed to laser light, then light energy is converted into heat energy. Due to heating effect, the material is heated then melted and vapourised. Also a fine beam of laser acts like a machine tool to do cutting, welding etc.

30. Mention the applications of lasers in industry.

Nd:YAG and CO_2 lasers are very much used in industries for the following processes

31. What is laser welding ?

In this technique, a focused laser beam is incident on spot where the two parts are to be welded. The spot-contact points get welded due to heating affect of fine laser beams.

32. What are the advantages of laser welding ?

(i) Laser welding is contactless, therefore there is no possibility of introduction of harmful impurities.

(ii) Laser welding can be performed faster in atmospheric pressure unlike electron beam welding where vacuum is a must.

(iii) Dissimilar materials can be welded

33. What is heat treatment of laser ?

A powerful laser beam is incident on a metal surface. That portion at which laser light is incident gets heated. As the beam is moved away to other areas, the heated spot cools down rapidly. This procedure is used for heat treatment of metal surfaces which enhances the strength of the metal.

34. What are advantages of laser cutting ?

(i) Laser cutting is used for wide range of processed materials (paper, cloth, plywood, glass, ceramics, sheet metal);

(ii) This laser cutting introduces minimum mechanical distortion and minimum thermal damage in the material being cut

(iii) This cutting process has high chemical purity.

35. What is laser?

Laser stands for Light Amplification by Stimulated Emission of Radiation.

Laser is a light source. It produces a powerful, monochromatic, collimated beam of light in which the light waves are coherent.

36. What is stimulated absorption?

An atom in the ground state with energy E_1 absorbs a photon of energy *hv* and go to an excited state (higher state) with energy E_2 provided that the photon energy *hv* is equal to the energy difference (E_2 - E_1). This process is called **stimulated absorption or simply absorption.**

37. What is spontaneous emission?

The atom in the excited state E_2 returns to the ground state $E_1$by emitting a photon of energy *hv* without the action of an external agency. Such an emission of radiation which is not triggered by an external influence is called ***spontaneous emission***

38. What is gas laser?

Gas laser is a type of laser, in which gases such as CO_2, Nitrogen and He-Ne are used as active medium for laser operations. CO_2, Nitrogen and He-Ne are the important gas lasers.

Oscillations-Part - B '16' Marks Questions

1. Deduce the wave equation for progressive wave.

diagram -2mark-definition-2marks derivation-Differential equation of wave motion -12marks

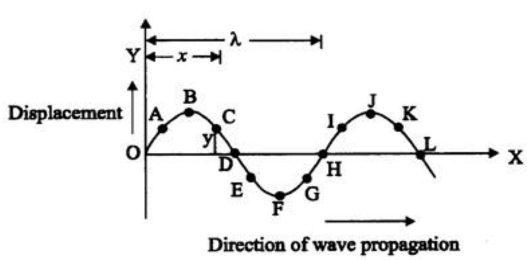


Fig. 3.16

$$\boxed{\frac{d^2y}{dt^2} = v^2\frac{d^2y}{dx^2}} \quad \ldots (13)$$

or

$$\boxed{\frac{d^2y}{dx^2} = \frac{1}{v^2}\frac{d^2y}{dt^2}}$$

2. Discuss analogy between electrical and mechanical oscillating system.

Mechanical system-6marks, electrical system-6marks, comparison-4marks

$$\boxed{f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}}$$

$$\omega = 2\pi f = \frac{2\pi}{T} = \sqrt{\frac{k}{m}}$$

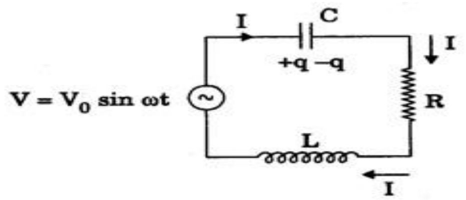


Fig. 3.12 Electrical System

$$\boxed{f = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}}$$

$$L\omega = \frac{1}{C\omega}$$

$$\omega^2 = \frac{1}{LC}$$

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

$$\boxed{f = \frac{1}{2\pi\sqrt{LC}}}$$

3. Discuss the energy transfer of a wave through the vibration of the string and also deduce the expression for the same.

Kinetic energy derivation– 4marks, Potential energy derivation-4marks, total enegy-6marks, energy transfer-2marks

$$dE = dU + dK = 2dK = m A^2 \omega^2 \sin^2(\omega t - kx) \quad \dots (9) \qquad dE = m(A\omega)^2 \sin^2(\omega t - kx)\, dz \quad \dots (10)$$

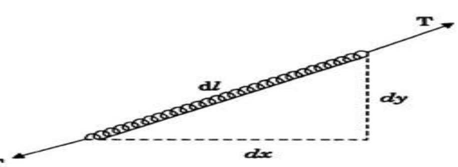


Fig. 3.18 An element of a string under the action of a wave.

$$dl = \sqrt{(dx)^2 + (dy)^2} = dx\sqrt{1 + \left(\frac{dy}{dx}\right)^2}$$

$$\approx dx\left(1 + \frac{1}{2}\left(\frac{dy}{dx}\right)^2\right) \quad \dots (2)$$

4. Explain the formation of interference fringes in an air-wedge shaped film. How is the thickness of the wire determined by this method?

Theory of air wedge-8marks, experiment-8marks

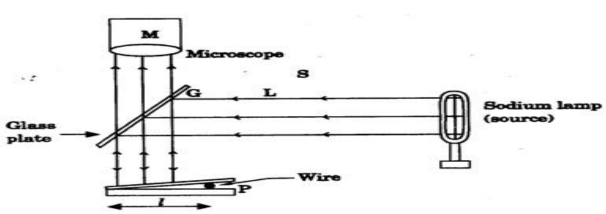


Fig. 4.14 Airwedge arrangement

$$\beta = \frac{\lambda}{\frac{2d}{l}} = \frac{\lambda l}{2d}$$

or

$$\boxed{d = \frac{\lambda l}{2\beta}}$$

5. Describe Michelson interferometer and explain how the fringes form in it. How can this are used for measuring the wavelength of monochromatic light. Derive the formula.

Principle-2marks, Construction-2marks, Working-4marks, Formation of fringes-2marks, Types of Fringes-2marks, Wavelength Determination-4marks

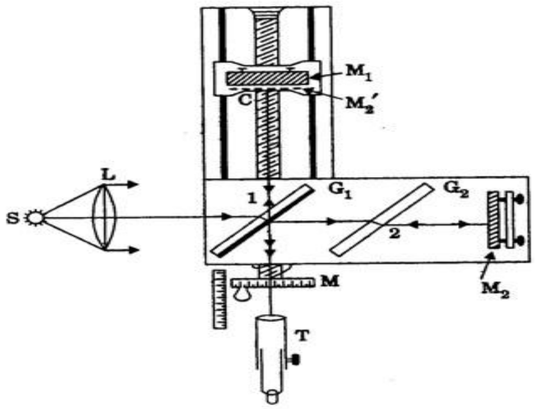


Fig. 4.16 Michelson interferometer

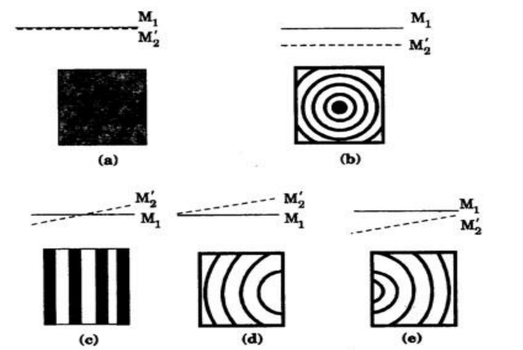


Fig. 4.18 Formation of different types of fringes by mirror M_1 and virtual image of mirror M_2.

6. For atomic transitions derive Einstein relations and hence deduce the expressions for the ratio of spontaneous emission rate to be stimulated emission rate.

Diagram-3marks, derivation-8marks, ratio of spontaneous emission rate to be stimulated emission-5marks

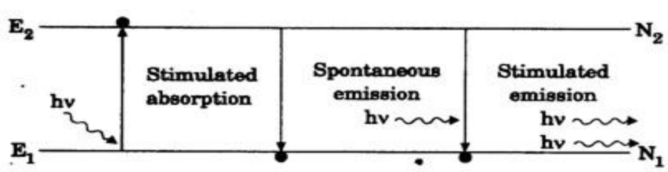


Fig. 5.4

$$N_{ab} = B_{12} N_1 Q \quad \text{... (1)}$$

$$N_{sp} = A_{21} N_2 \quad \text{... (2)}$$

$$N_{st} = B_{21} N_2 Q \quad \text{... (3)}$$

7. Explain the construction and working of Nd - YAG laser with neat diagram.

Principle-2mark, Diagram & Characteristics - 4marks, Construction-4marks Working-6marks,

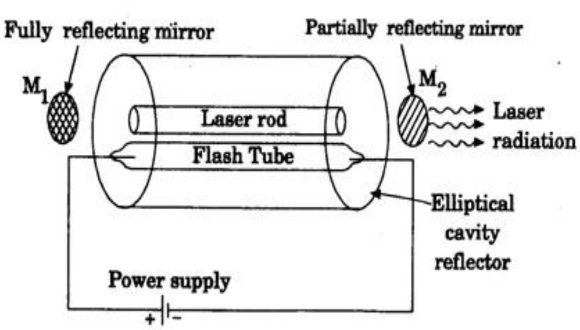


Fig. 5.17 Nd - YAG Laser

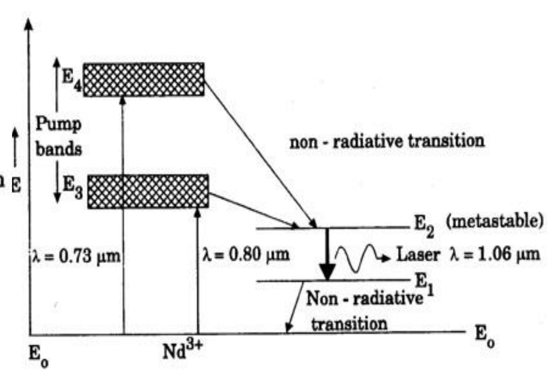


Fig. 5.18 Energy level of Nd^{3+} in Nd - YAG laser

8. Explain the modes of vibrations of CO_2, molecule. Describe the construction and working of CO_2 laser with necessary diagrams.

Energy states of CO_2 molecules with diagram-6marks, construction and working-10 marks

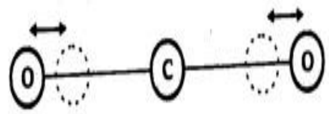


Fig. 5.19 Symmetric stretching mode

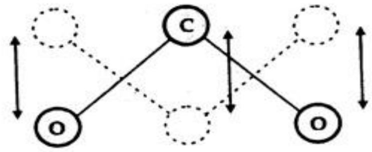


Fig 5.20 Bending mode

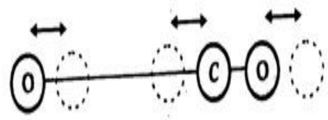


Fig. 5.21 Asymmetric stretching mode

$$N_2 + e^* \rightarrow N_2^* + e$$

$$N_2^* + CO_2 \rightarrow CO_2^* + N_2$$

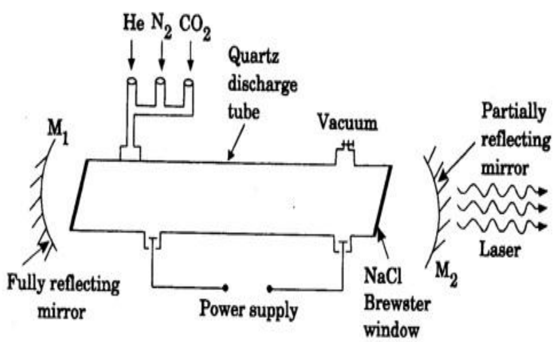


Fig. 5.22 CO_2 laser

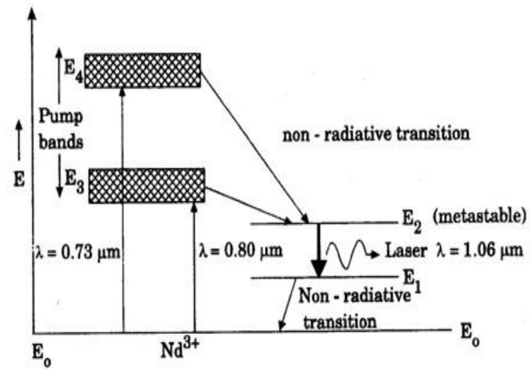


Fig. 5.18 Energy level of Nd^{3+} in Nd - YAG laser

9. Explain the principle, construction and working of a semiconductor diode laser with necessary diagrams.

Principle-2mark, Diagram & Characteristics - 4marks, Construction-4marks Working-6marks

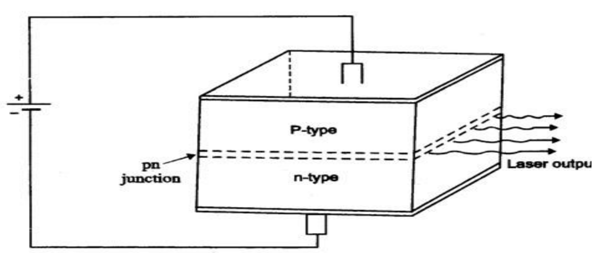


Fig. 5.25 Semiconductor diode laser (Homojunction)

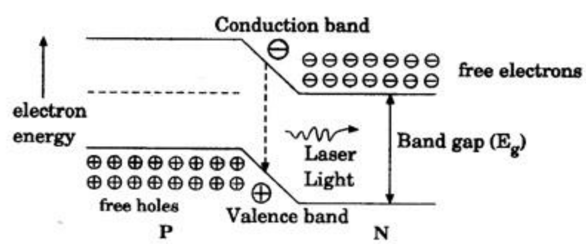


Fig. 5.26 Energy level diagram of a semiconductor laser

10. Discuss the applications of Lasers in industry.

Material processing, Laser welding Laser cutting (or) Drilling Laser Soldering Process, Holography Laser in Communication – any four- 4*4=16marks.

ENGINEERING PHYSICS - UNIT: IV-BASIC QUANTUM MECHANICS

PART – A - '2' MARKS Q&A

1. State compton effect.

When a beam of X- rays is scattered by a substance of low atomic number, the scattered radiation consists of two components. One has the same wavelength λ as the incident ray and the other has a slightly longer wavelength λ′. This phenomenon of change in wavelength of scattered X -rays is known as **compton effect.**

2. What is Compton wavelength?

The change in wavelength corresponding to scattering angle of 90° obtained in Compton effect is called Compton wavelength.

Mathematically, $\Delta\lambda = \frac{h}{m_o c}(1 - \cos\theta)$

m_o - rest mass of electron $= 9.11 \times 10^{-31}$ kg

When $\theta = 90°$, $\Delta\lambda = \frac{h}{m_o c}(1 - \cos 90°)$

$$= \frac{h}{m_o c}(1 - 0)$$

$$\frac{h}{m_o c} = 0.0243 \text{ Å}$$

This is known as Compton wavelength of electron.

3. What are matter waves?

The waves associated with moving particles of matter (e.g., electrons, photons, etc) are known as matter waves or de-Broglie waves.

4. How De-Broglie justified his concept?

• Our universe is fully composed of light and matter.

• Nature loves symmetry. If radiation like light can act like wave and particle, then material particles (e.g., electron, neutron etc.) should also act as particle and wave.

• Every moving particle has always associated with a wave.

5. Write an expression for the wavelength of matter waves? (or) What is de - Broglie's wave equation?

Wavelength for matter waves is $\lambda = \frac{h}{mv} = \frac{h}{p}$

where h → planck's constant, m → mass of the particle

v → velocity of the particle with which the wave is associated. p → momentum of the particle.

6. Write an expression for the de - Broglie wavelength associated with electrons.

De-Broglie wave length associated with electrons accelerated by the potential *V*.

$$\lambda = \frac{h}{\sqrt{2 m_o e V}}$$

$h \rightarrow$ planck's constant, $e \rightarrow$ charge of the electron, $m \rightarrow$ mass of the electron V$\rightarrow$ voltage

7. State the properties of the matter waves.

(i) Lighter is the particle, greater is the wavelength ... associated with it.

(ii) Smaller is the velocity of the particle, greater is wavelength associated with it.

(iii) These waves are not electromagnetic waves.

(iv) The velocity of de Broglie wave is equal to the velocity of the material particle.

8. Write down Schroedinger time independent and dependent wave equations.

Schroedinger time independent wave equation is

$$\nabla^2 \psi + \frac{2m}{\hbar^2}(E - V)\psi = 0$$

Schroedinger time dependent wave equation

$$\left(-\frac{\hbar^2}{2m}\nabla^2 + V\right)\psi = i\hbar\frac{\partial\psi}{\partial t}$$

where $\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$ is Laplacian operator.

Ψ - Wave function, *m* - Mass of the particle, *E* - Total energy of the particle. , V - Potential energy. and $\hbar = \frac{h}{2\pi}$

9. Mention some of the physical significances of the wave function.

(i) The wave function (Ψ) relates the particle and wave nature of matter statistically.

(ii) It is a complex quantity and hence we cannot measure it.

(iii) If the particle is certainly to be found somewhere in a space of dimensions *dx*, *dy*, *dz*, then the probability value is equal to one. i.e., $P = \int\int\int_V |\psi|^2 \, dx\, dy\, dz = 1$

10. What are eigen values and eigen function?

Energy of a particle moving in one dimensional box of width a is given by

$$E_n = \frac{n^2 h^2}{8ma^2}$$

For each value of n, there is an energy level. Each value of E, is called an eigen value.

For every quantum state (i.e., for different 'n' values), there is a corresponding wave function Ψ_n.

This corresponding wave function is called eigen function.

Eigen function associated with dimensional box is given by

$$\psi_n = \sqrt{\frac{2}{a}} \sin\left(\frac{n\pi x}{a}\right)$$

11. What is Schrodinger wave equation?

The equation that describes the wave nature of a particle in mathematical form is known as Schrodinger wave equation.

12. What is a wave function?

A variable quantity which characterises de - Broglie wave is known as wave function and it is denoted by the symbol Ψ.

13. Define correspondence principle.

Any new theory in Physics must reduce to well-established corresponding classical theory when the new theory is applied to the special situation in which the less general theory is known to be valid.

UNIT – IV

BASIC QUANTUM MECHANICS

1. Derive an expression for the change in wavelength suffered by an X-ray photon when it collides with an electron. (or) Derive an expression for compton shift and show that it is independent of the wavelength of the incident photons. (Jan 2005, Jan. 2010)
2. (i) What is Compton effect?

   (ii) Give the theory of Compton effect and show that the Compton shift $\Delta\lambda = \frac{h}{m_0 c}(1-\cos\theta)$ (May 2005, Jan. 2010)
3. Explain Compton effect and derive an expression for the wavelength of scattered photon, Also briefly explain its experimental verification. (Jan 2006, Jan. 2009)

Compton Shift

When a photon of energy 'h γ' collide with an electron of a scattered at rest, The photon gives its energy to the electron. Therefore the scattered photon will have lesser energy or lower frequency or higher wavelength compared to the wavelength of incident photon. Since the electron gains energy, it recoils with the velocity 'v'. This effect is called Compton effect and the shift in wavelength is called **Compton Shift.** **………. 1 Marks**

Total Energy before collision = Total Energy after collision

$$h\nu + m_0 c^2 = h\nu' + m_0 c^2$$ **................ 2 Marks**

Total* X–component *Momentum before collision=Total* X–component *Momentum after collision

$$\frac{h\nu}{c} = \frac{h\nu'}{c}\cos\theta + m v \cos\phi$$ **................ 2 Marks**

Total* X–component *Momentum before collision=Total* X–component *Momentum after collision

$$0 = \frac{h\nu'}{c}\sin\theta - m v \sin\phi$$ **................ 2 Marks**

$$h^2\nu^2 + h^2\nu'^2\cos^2\theta - 2h^2\nu\nu'\cos\theta = m^2c^2v^2\cos^2\phi$$ **................ 2 Marks**

$$h^2\nu^2 + h^2\nu'^2 - 2h^2\nu\nu'\cos\theta = m^2c^2v^2$$

$$h^2\nu^2 + h^2\nu'^2 - 2h^2\nu\nu' + m_0^2c^4 + 2h(\nu - \nu')m_0c^2 = m_0^2c^4$$ **................ 2 Marks**

$$2h(\nu - \nu')m_0c^2 - 2h^2\nu\nu'(1 - \cos\theta) + m_0^2c^4 = m_0^2c^2(c^2 - v^2)$$ **................ 2 Marks**

$$2h(\nu - \nu')m_0c^2 - 2h^2\nu\nu'(1 - \cos\theta) + m^2c^2(c^2 - v^2) = m_0^2c^2(c^2 - v^2)$$

Change in wavelength $\Delta\lambda = \frac{h}{m_0 c}(1 - \cos\theta)$ **................ 2 Marks**

Case : I when $\theta = 0$; $\cos 0 = 1$

Compton Shift $\Delta\lambda = \frac{h}{m_0 c}(1 - \cos\theta)$

$\Delta\lambda = 0$

Case : II when θ= 90º ; cos 90 º = 0

Compton Shift $\Delta\lambda = \frac{h}{m_0 c}(1 - \cos\theta)$

$\Delta\lambda = 0.02424\ A^o$

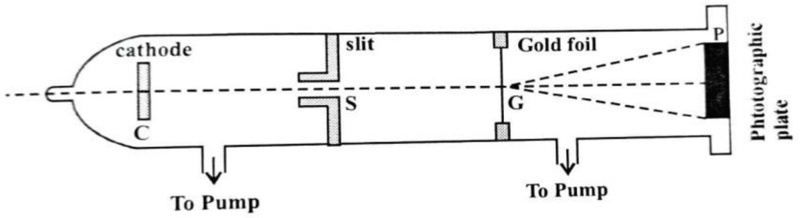
Case : III when θ= 180º ; cos 180º = - 1

Compton Shift $\Delta\lambda = \frac{h}{m_0 c}(1 - \cos\theta)$

$\Delta\lambda = 0.04848\ A^o$

Thus for θ = 180º the ***shift in wavelength*** is found to be ***maximum.*** ***................*** **1 Marks**

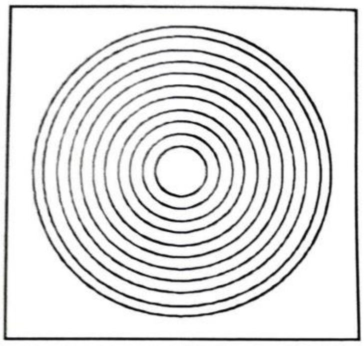
4. Briefly explain its experimental verification and also explain - G.P. Thomson's experiment . (Jan 2006, Jan. 2009)



.... **1 Marks**

Experimental arrangement ***................*** **3Marks**

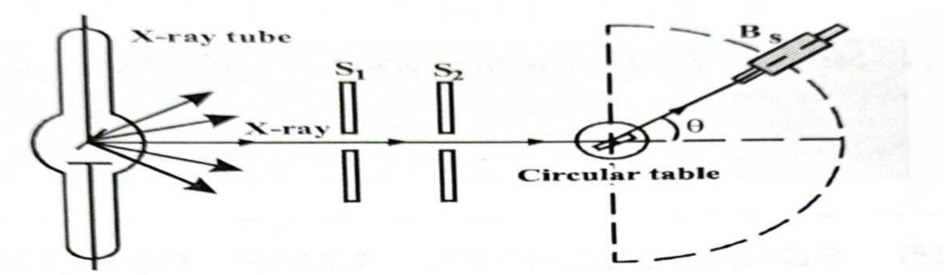
Working ***................*** **3Marks**



.... **1 Marks**

EXPERIMENTAL VERIFICATION OF COMPTON EFFECT

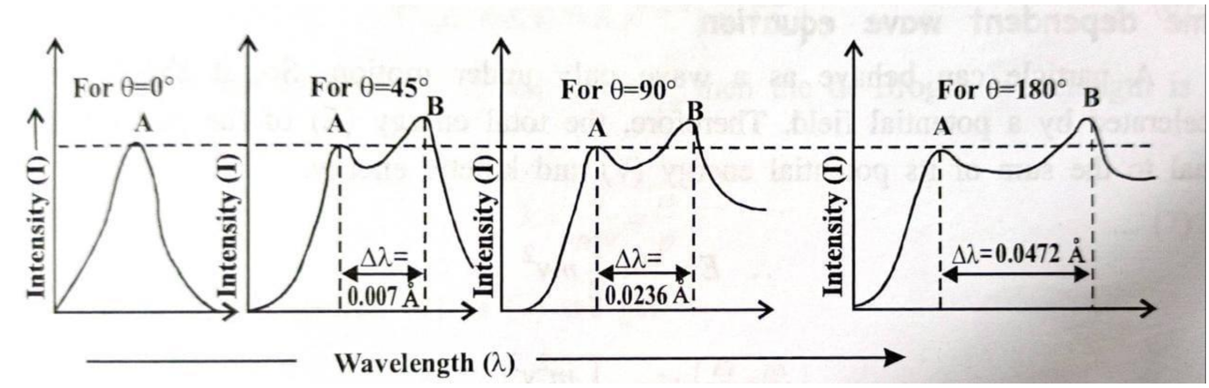
Principle ***................*** **1 Marks**



.... 1Marks

Experimental arrangement **................ 2 Marks**

Working **................ 3Marks**



.... 1Marks

5. Arrive at the time independent Schrodinger's wave equation and explain the significance of the wave function ψ

TIME INDEPENDENT WAVE EQUATION

$$\nabla^2 \psi = \frac{1}{u^2} \frac{d^2 \psi}{dt^2}$$ **................ 1Marks**

$$\frac{d^2 \psi}{d t^2} = -\omega^2 \psi$$ **................ 1Marks**

$$\nabla^2 \psi = \frac{-\omega^2 \psi}{u^2}$$ **................ 1Marks**

$$\frac{\omega^2}{u^2} = \frac{4 \pi^2}{\lambda^2} ...$$ **............. 1Marks**

$$\frac{\omega^2}{u^2} = \frac{4 \pi^2 m^2 v^2}{h^2} ...$$ **............. 1Marks**

$$\nabla^2 \psi + \frac{4\pi^2 m^2 v^2}{h^2} \psi = 0$$ **................ 1Marks**

$$2m(E - V) = m^2 v^2$$

$$\nabla^2 \psi + \frac{8\pi^2 m}{h^2}(E - V)\psi = 0$$ **................ 1Marks**

$$\nabla^2 \psi + \frac{2m}{\hbar^2}(E - V)\psi = 0$$ **................ 1Marks**

6. Derive in time dependent Schrodinger wave equation and hence deduce the time independent Schrodinger wave equation. (May 2005, Jan. 2009, Jan. 2011)

TIME DEPENDENT WAVE EQUATION

$$\nabla^2 \psi = \frac{1}{u^2} \frac{d^2 \psi}{dt^2}$$ **................ 1Marks**

$$\frac{d\psi}{dt} = -i\, 2\pi \frac{E}{h} \psi$$ **................ 1Marks**

$$E\psi = i\hbar \frac{d\psi}{dt} \qquad \hbar = \frac{h}{2\pi}$$ **................ 1Marks**

$$\nabla^2 \psi + \frac{2m(E - V)}{\hbar^2} \psi = 0$$ **................ 1Marks**

$$\frac{-\hbar^2}{8m} \nabla^2 \psi = E\psi - V\psi$$ **................ 1Marks**

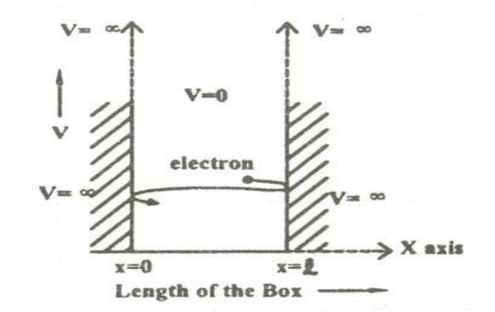
$$\left\{V - \frac{\hbar^2}{8m} \nabla^2\right\}\psi = i\hbar \frac{d\psi}{dt}$$ **................ 1Marks**

$$H\psi = E\psi$$ **................ 2Marks**

6. Solve Schrodinger wave equation for a particle in a box (one dimensional) and obtain the energy eigen values. (May 2005, Jan. 2009, Jan. 2011)

Application of Schrodinger wave equation to a particle (electron) enclosed in a one dimensional (1 D) infinite potential well (or) Box

Diagram & Explanation 1Marks



$$\nabla^2 \psi + \frac{8 \pi^2 m}{h^2}(E - V)\psi = 0$$ **................ 1Marks**

out side the well, the potential energy V of the electron is α

$$\frac{d^2 \psi}{dx^2} + \frac{8 \pi^2 m}{h^2}[E - \alpha]\psi = 0$$

Inside the well, the potential energy V of the electron is 0

$$\frac{d^2 \psi}{dx^2} + \frac{8 \pi^2 m}{h^2}[E - 0]\psi = 0$$ **................ 1Marks**

$$\frac{d^2 \psi}{dx^2} + k^2 \psi = 0$$ **................ 1Marks**

i. Initial Condition $x = 0$ $\psi = 0$ $B = 0$ **................ 1Marks**

ii. Boundary Condition $x = l$ $\psi = 0$ $k = \frac{n \pi}{l}$ **................ 1Marks**

Energy of the Particle (electron) $E = \frac{n^2 h^2}{8 m E l^2}$ **................ 2Marks**

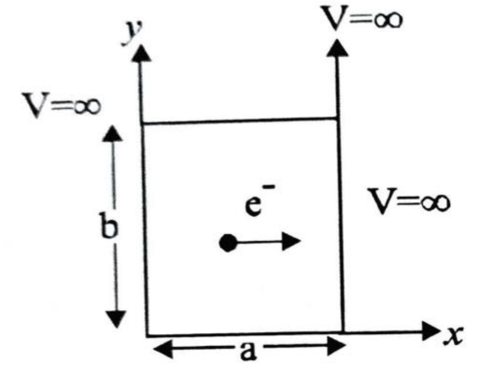
$$P = \int |\psi|^2 \, dx = 1$$ **................ 4Marks**

$$\psi = \sqrt{\frac{2}{l}} \sin (n \pi x / l)$$ **................ 1Marks**

7. Solve Schrodinger wave equation for a particle in a box (one dimensional) and obtain the energy eigen values. (May 2005, Jan. 2009, Jan. 2011)

particle in a two dimensional (2 D) potential Box

Diagram & Explanation 1Marks



$$\frac{d^2 \psi}{d x^2} + \frac{d^2 \psi}{d y^2} + \frac{8 \pi^2 m}{h^2} E \psi = 0$$ **................ 1Marks**

Solution of this equation $\psi (x, y) = X (x) Y (y)$ **................ 1Marks**

$$Y \frac{d^2 X}{d x^2} + X \frac{d^2 Y}{d y^2} + \frac{8 \pi^2 m}{h^2} E X Y = 0$$ **................ 1Marks**

$$\frac{1}{X} \cdot \frac{d^2 X}{d x^2} + \frac{1}{Y} \frac{d^2 Y}{d y^2} = - [K_x^2 + K_y^2]$$ **................ 1Marks**

$$\frac{d^2 X}{d x^2} + K_x^2 X = 0 \qquad \frac{d^2 Y}{d y^2} + K_y^2 Y = 0$$ **................ 2Marks**

i. **When** $x = 0, X = 0$ $\quad B_x = 0$ **................ 1Marks**

ii. **When** $x = a, X = 0$ $\quad K_x = \frac{n_x \pi}{a}$ **................ 1Marks**

$X (x) = A_x \sin \frac{n_x \pi x}{a}$ **This equation is called normalised wave equation. 1Marks**

$P = \int |X(x)|^2 \, dx = 1$ **................ 1Marks**

$X (x) = \sqrt{\frac{2}{a}} \sin \frac{n_x \pi x}{a}$ **................ 1Marks**

These equation is called Eigen function

$Y (y) = \sqrt{\frac{2}{b}} \sin \frac{n_y \pi y}{b}$ **................ 1Marks**

$\psi (x, y) = \sqrt{\frac{2}{a b}} \sin n_x \pi x . \sin n_y \pi y$ **................ 1Marks**

Eigen function for an electron in 2 dimensional box

$$E = \frac{h^2}{8m} \cdot \left[\frac{n_x^2}{a^2} + \frac{n_y^2}{b^2} \right]$$ 1Marks

Energy Eigen value for a particle in 2 dimensional box.

$$\psi_{n_x, n_y} = \frac{2}{a} \sin \frac{n_x \pi x}{a} \cdot \sin \frac{n_y \pi y}{a}$$ 1Marks

8. Solve Schrodinger wave equation for a particle in a box (one dimensional) and obtain the energy eigen values. (May 2005, Jan. 2009, Jan. 2011)

Particle in a two dimensional (3 D) potential Box

Diagram & Explanation 1Marks

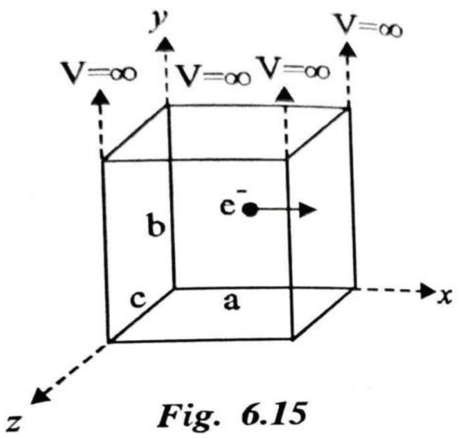


Fig. 6.15

$$\frac{d^2\psi}{dx^2} + \frac{d^2\psi}{dy^2} + \frac{d^2\psi}{dz^2} + \frac{8\pi^2 m E}{h^2}\psi = 0$$ 1Marks

Solution of equation 2 is $\psi(x, y, z) = X(x)\, Y(y)\, Z(z)$ 1Marks

$$\psi = X Y Z$$

$$Y Z \frac{d^2 X}{dx^2} + X Z \frac{d^2 Y}{dy^2} + X Y \frac{d^2 Z}{dz^2} + \frac{8\pi^2 m E}{h^2} X Y Z = 0$$ 1Marks

$$\frac{1}{X} \cdot \frac{d^2 X}{dx^2} + \frac{1}{Y} \frac{d^2 Y}{dy^2} + \frac{1}{Z} \frac{d^2 Z}{dz^2} = -\left[K_x^2 + K_y^2 + K_z^2 \right]$$ 1Marks

$$\frac{d^2 X}{dx^2} + K_x^2 X = 0 \qquad \frac{d^2 Y}{dy^2} + K_y^2 Y = 0 \qquad \frac{d^2 Z}{dz^2} + K_y^2 Z = 0$$ 2Marks

$$X(x) = A_x \operatorname{Sin} K_x X + B_x \operatorname{Cos} K_x X$$ 1Marks

When $x = 0, X = 0 \quad B_x = 0$ 1Marks

When x = a, X = 0

$X(x) = Ax \sin \frac{n_x \pi x}{a}$ This equation is called normalised wave equation. 1Marks

$P = \int |X(x)|^2 dx = 1$ 1Marks

$A_x = \sqrt{\frac{2}{a}}$ 1Marks

$X(x) = \sqrt{\frac{2}{a}} \sin \frac{n_x \pi x}{a}$

These equation is called Eigen function

$Y(y) = \sqrt{\frac{2}{b}} \sin \frac{n_y \pi y}{b}$

$Z(z) = \sqrt{\frac{2}{c}} \sin \frac{n_y \pi y}{c}$ 1Marks

$\psi(x, y, z) = \frac{2\sqrt{2}}{\sqrt{abc}} \sin n_x \pi x \cdot \sin n_y \pi y \cdot \sin n_z \pi z$ 1Marks

The above equation is called Eigen function for an electron in 3 dimensional box .

$E = \frac{h^2}{8m} \cdot \left[\frac{n_x^2}{a^2} + \frac{n_y^2}{b^2} + \frac{n_z^2}{c^2} \right]$ 1Marks

Energy Eigen value for a particle in 3 dimensional box.

ENGINEERING PHYSICS - UNIT: V-APPLIED QUANTUM MECHANICS

Part 'A' '2' Marks Questions with answers

1. What is a harmonic oscillator?

A particle undergoing simple harmonic motion is called a harmonic oscillator.

2. Give examples for harmonic oscillator.

Familiar examples are; a simple pendulum, an object floating in a liquid, a diatomic molecule and an atom in a crystal lattice.

3. What is the significance of zero point energy in a harmonic oscillator?

For lowest (ground) state, $n = 0$

$$\boxed{E_o = \frac{1}{2} h\nu}$$

This is the lowest value of energy, called **zero point energy**. Even it the temperature reduces to absolute zero, the oscillator would still have an amount of energy 1/2 $h\nu$. In old quantum mechanics, the energy of n^{th} level. $En = nh\nu$

whereas in wave mechanics

$$E_n = \left(n + \frac{1}{2}\right) h\nu$$

4. Define barrier penetration.

The transmission of electrons through the barrier is known as **barrier penetration.** The phenomena is also termed as the **tunnel effect.** The phenomena of barrier penetration is entirely due to the wave nature of matter.

5. What is quantum tunneling?

The phenomenon of transmission of a particle through a potential barrier of finite width and height, even when its energy is less that the barrier height is called quantum tunneling.

6. What are the significance of tunneling effect?

1. Tunneling is a very important physical phenomena which occurs in certain semiconductor diodes. In such diodes electrons pass through potential barriers even though their kinetic energies are smaller than the barrier heights.

2. The tunneling effect also occurs in the case of the alpha particles. The kinetic energy of alpha particle is only a few MeV but it is able to escape from a nucleus whose potential wall is perhaps 25 MeV high.

3. The ability of electrons to tunnel through a potential barrier is used in the Scanning Tunneling Microscope (STM) to study surfaces on an atomic scale of size.

7. What is an electron microscope?

It is a microscope which uses electron beam to illuminate a specimen and it produces an enlarged image of the specimen. It has very high magnification power and resolving power when compared to optical microscope.

8. What are the types of electron microscopes?

There are four types of electron microscopes. They are

1. Transmission Electron Microscope (TEM)
2. Scanning Electron Microscope (SEM)
3. Scanning Transmission Electron Microscope (STEM)
4. Scanning Tunneling Microscope (STM).

9. What is scanning tunneling microscope?

It is an instrument used for imaging surfaces at the atomic level.

In STM, good resolution is considered to be 0.1 nm lateral resolution and 0.01 nm (10 pm) depth resolution. With this resolution, individual atoms within materials are routinely imaged and manipulated.

10. What is the principle behind scanning tunnelling microscope.

STM is based on the concept of quantum barrier tunneling. When a conducting tip is brought very near to the surface to be examined, a bias (voltage difference) is applied between the two can allow electrons to tunnel through the vacuum between them. Information is acquired by monitoring the current as the tip's position scans across the surface, and it is usually displayed in image form.

11. Mention few applications of STM.

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

2. Uses of STM to study metals and semiconductors surface can provide non-trivial real space information.

3. One innovative applications of STM recently found is manipulation of atoms.

4. To analyze the electronic structures of the active sites at catalyst surfaces.

5. STM is used in the study of structure, growth, morphology, electronic structure of surface, thin flims and nano structures.

12. State the disadvantages of STM.

- A small vibration even a sound can disturb the tip and the sample together.
- A single dust particle can damage the needle.

13. What is resonant diode?

A resonant tunneling diode (RTD) is a diode with resonant tunneling structure. The electrons can tunnel through some resonant states at certain energy levels.

14. Define resonant tunneling.

The transmission probability of the double symmetric barrier is maximum. The tunneling current reaches peak value when energy of electron wave is equal to quantised energy state of the well. This phenomenon is known as resonance tunneling.

15. State Block Theorem.

If an electron in a linear lattice of lattice constant '*a*' characterised by potential function $V(x) = V(x + a)$ satisfies the Schoredinger equation

$$\frac{d^2 \psi(x)}{dx^2} + \frac{2m}{\hbar^2}[E - V(x)]\psi(x) = 0$$

then the wave functions $\Psi(x)$ *of electron (with energy E) obtained as a solution of Schrodinger equation are of the form*

$$\psi(x) = u_k(x)\, e^{\pm ika}$$

$$\text{with} \quad u_k(x) = u_k(x + a)$$

16. What is an energy band?

A set of closely spaced energy levels is called an energy band.

17. What is valence band?

The electrons in the outermost shell are called valence electrons. The band formed by a series of energy level containing the valence electrons is known as Valence Band.

18. What is conduction band?

The band formed by a series of energy level containing the conduction electrons is known as conduction band. The energy levels occupying this band is defined as the **lowest unfilled energy band.** This band may be empty or partially filled. In conduction band, the electrons can move freely.

19. What is forbidden gap?

Both conduction band and valence band are separated by a region or gap is known as forbidden band or gap.

Part - B - '16' Marks Questions

1. Obtain an expression for the energy levels of the harmonic oscillator for applying Schrodinger wave equation.

definition-2marks, schrodinger equation and its simplification -4marks, eigen values-4marks, wavefunctions-4marks, significance of zero point energy-2marks

Definition

A particle undergoing simple harmonic motion is called a harmonic oscillator.

$$\frac{d^2\psi}{dx^2} + \left(\frac{2mE}{\hbar^2} - \frac{m^2\omega^2}{\hbar^2}x^2\right)\psi = 0 \qquad ...(6)$$

$$E_n = \left(n + \frac{1}{2}\right)h\nu$$

Schrodinger wave equation for the oscillator.

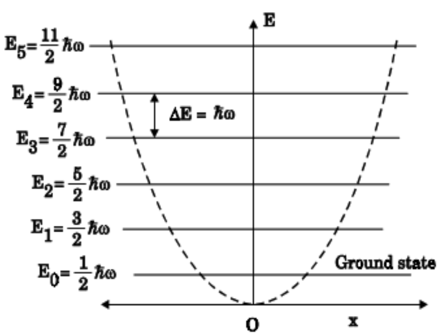


Fig. 7.2 Energy levels allowed for a harmonic oscillator. Note that the oscillator cannot have zero energy

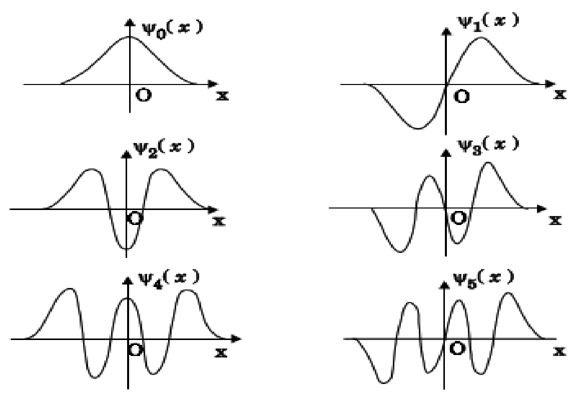


Fig. 7.3 Wave functions for Harmonic Oscillator

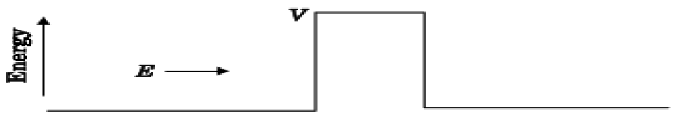
2. Discuss barrier penetration and quantum tunneling.

Diagram -2marks, Quantum tunneling-2marks, expression for transmission probability-8mark

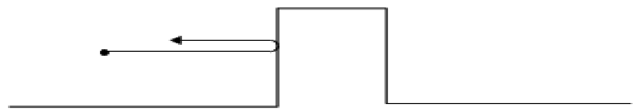
Significance of barrier penetration-4marks

$$T = T_o e^{-2ka}$$

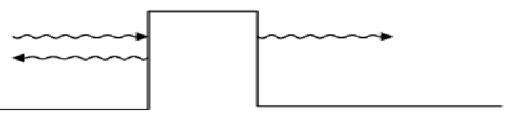
Quantum mechanics leads to an entirely new result. It shows that there is a finite chance for the electron to leak to the other side of the barrier.



(a) A particle with energy E < V approaching a potential barrier.



(b) From classical mechanics, the particle must be reflected by the barrier.



(c) In quantum mechanics, the de Broglie waves that represent the particle are partly flected and partly transmitted, I.e., the particle has finite probability of penetrating the barring

Fig. 7.4

3. What is the principle of scanning tunneling microscope? Explain the construction and working of scanning tunneling microscope with a suitable diagram.

Principle-2marks, diagram with explanation-4marks, working & scanning-6marks, application-2marks & advantages & disadvantages-2marks

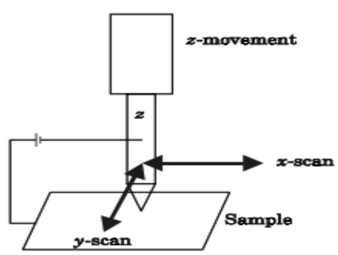


Fig. 7.7 Sketch of STM

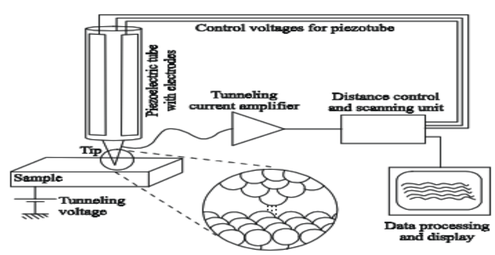


Fig. 7.8 Scanning Tunneling Microscope

4. Explain the construction and working of resonant diode.

Principle-2marks, structure diagram with explanation-4marks, working without & with bias-4marks, current-energy characteristics-4marks, application& advantages-2marks

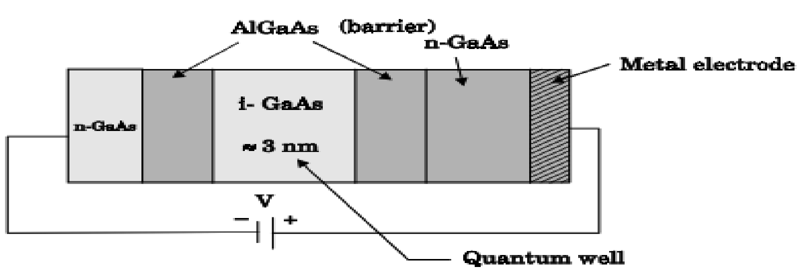
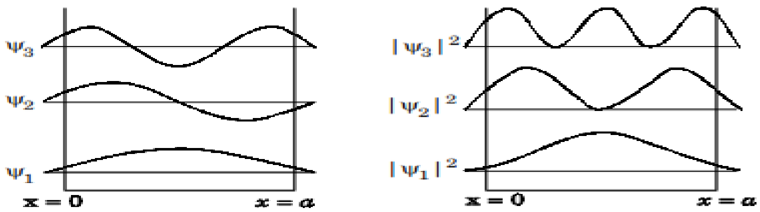


Fig. 7.14 Structure of Resonant Tunnel Diode (RTD)

5. Discuss a particle in a finite potential well starting from Schrodinger wave equation.

3-Regions potential limit-3marks, Schrodinger equation-6marks, solution obtained -6marks, diagram-1marks



(a) Wave functions

(b) Probability densities inside non - rigid box

Fig. 7.18

- The eigen functions are similar in appearance to those of infinite well except that they extend a little outside the box.
- Even though the particle energy E is less than the P.E. V_0, there is a definite probability that the particle is found outside the box.
- The particle energy is not enough to break through the walls of the box but it can penetrate the walls and leak out.

6. Explain Bloch's theorem for particles in a periodic potential.

Theorem-3marks, statement-3marks, derivation-10marks

Bloch Theorem

It is a mathematical statement regarding the form of one electron wave function for a perfectly periodic potential.

Statement

If an electron in a linear lattice of lattice constant 'a' characterised by potential function $V(x) = V(x + a)$ *satisfies the Schrodinger equation*

$$\frac{d^2 \psi(x)}{dx^2} + \frac{2m}{\hbar^2} [E - V(x)] \psi(x) = 0 \qquad \dots (1)$$

then the wave functions $\psi(x)$ *of electron (with energy E) is obtained as a solution of Schrodinger equation are of the form*

7. Discuss Kraning penney model.

Diagram-3marks, basics of model-6marks, E-K curve-6marks, conclusion-1marks

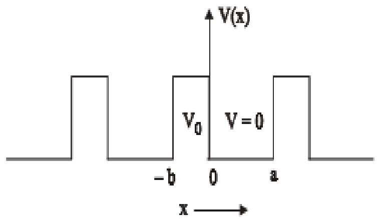


Fig. 7.21 One dimensional periodic potential (Kronig and Penny model)

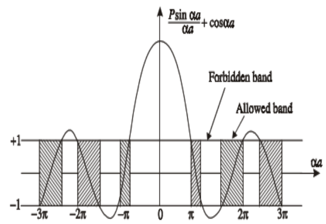


Fig. 7.22 A plot of αa versus $\left(\frac{P \sin \alpha a}{\alpha a} + \cos \alpha a\right)$

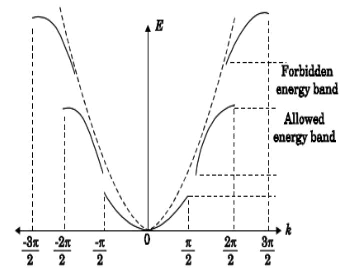


Fig. 7.23 Plot of energy Vs. wave vector in one dimensional lattice

8. Describe origin of energy bands in solid.

3diagrams – 3marks, energy band definition-1marks three types of explanation – 12 marks,

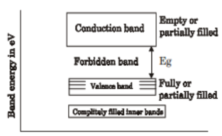


Fig. 7.25 Energy bands in solids

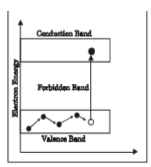


Fig. 7.26 Valence band, conduction band and forbidden gap

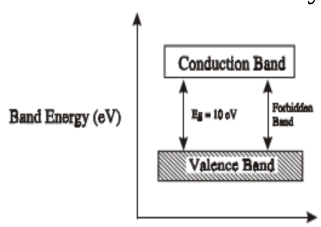


Fig. 7.27 Energy band for insulator

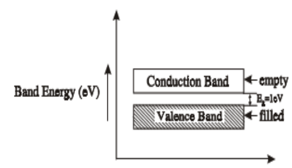


Fig. 7.28 Energy band for semiconductors