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Total No. of Questions : 09

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B.Tech. (AI & DS/ AI & ML / Block Chain / CE / CSE / (AI & ML) (Cyber Security)/(DS) / CS & D / EE / ECE / EEE / ETE / FT / IT / ME / R & AI / CSE (Internet of Things and Cyber Security including Block Chain Technology)) (Sem-1,2)

ENGINEERING PHYSICS

Subject Code : BTPH101/23

M.Code : 93794

Date of Examination : 24-05-2024

Time : 3 Hrs.

Max. Marks : 60

INSTRUCTIONS TO CANDIDATES :

1. SECTION-A is COMPULSORY consisting of TEN questions carrying TWO marks each.
2. SECTION - B & C have FOUR questions each.
3. Attempt any FIVE questions from SECTION-B & C carrying EIGHT marks each.
4. Select atleast TWO questions from SECTION - B & C.

SECTION-A

1. *Write short notes on :*

a) Define unit cell.

b) Show that at 0 K, the probability of finding an electron in an energy level below the fermi level is 1.

c) What destroys the superconducting state of a current carrying wire?

d) Why paramagnetic behavior decreases with increase in temperature?

e) What is atomic polarizability?

f) Solve the gradient of 1/r, where $\vec{r} = x\hat{i} + y\hat{j} + z\hat{k}$.

g) What information can be obtained from Wave function?

h) Write a note on three level laser.

i) What is total internal reflection?

j) An electron has a speed of 500 m/s, correct upto 0.01%, with what minimum accuracy, can you locate the electron?

SECTION-B

2. Explain the measurement of wavelength of X-ray using Bragg's spectrometer. Calculate the minimum wavelength of continuous X-rays emitted from an X-ray tube whose operating voltage is 40 kV.

3. What is Tunnel diode? Why it is called so? Discuss the VI characteristics of Tunnel diode.

4. a) What is Hysteresis loop?

   b) What are ferromagnetic materials? Explain ferromagnetism using domain theory.

5. Solve the electromagnetic wave equation for isotropic homogeneous medium and show that a wave propagate through a non-conducting medium with constant amplitude.

SECTION-C

6. Explain the construction and working of He-Ne laser with the help of energy level diagram. What is the role of He in He-Ne laser?

7. Derive the expression for group velocity and show that group velocity is equal to particle velocity.

8. What are different modes of propagation of signal in optical fibre? Derive the expression for total number of reflections in a fibre of length L.

9. What are Carbon nanotubes? What are the different types of Carbon nanotubes? Discuss top-down method of synthesis of nano particles.

NOTE : Disclosure of Identity by writing Mobile No. or Marking of passing request on any paper of Answer Sheet will lead to UMC against the Student.

SECTION : A

ANS a. A unit cell in a crystal is the smallest repeating unit that has the full symmetry of the crystal structure. It is defined as a parallelepiped, which provides six lattice parameters: the lengths of the cell edges (a, b, c) and the angles between them (α, β, γ)1. The unit cell is the simplest repeating unit in the crystal, and opposite faces of a unit cell are parallel2.

There are different types of unit cells, including:

Primitive Unit Cells: Constituent particles occupy only the corner positions.

Centred Unit Cells: Constituent particles occupy other positions in addition to those at corners. These include:

Body-Centred Unit Cell: A particle at the center of the body.

Face-Centred Unit Cell: A particle at the center of each face.

End-Centred Unit Cell: A particle at the center of two opposite faces.

ANS b. At absolute zero temperature (0 K), the probability of finding an electron in an energy level below the Fermi level is indeed 1. This can be shown using the Fermi-Dirac distribution function, which describes the probability of an electron occupying a particular energy state at a given temperature.

The Fermi-Dirac distribution function is given by:

$F(E)=e(E-EF)/kT+11$

Where:

(f(E)) is the probability of an electron occupying the energy state (E),

(E_F) is the Fermi energy,

(k) is the Boltzmann constant,

(T) is the absolute temperature.

At (T = 0) K, the distribution function simplifies because the exponential term (e^{(E – E_F) / kT}) becomes either 0 or infinity, depending on whether (E) is less than or greater than (E_F):

For (E < E_F):

E(E−EF)/kT→0

Thus,

F(E)=0+11=1

For (E > E_F):

E(E−EF)/kT→∞

Thus,

F(E)=∞+11=0

Therefore, at 0 K, the probability of finding an electron in an energy level below the Fermi level ((E < E_F)) is 1, and the probability of finding an electron in an energy level above the Fermi level ((E > E_F)) is 0. This means that all energy states below the Fermi level are fully occupied by electrons, while all energy states above the Fermi level are empty.

ANS c. The superconducting state of a current-carrying wire can be destroyed by several factors:

1)Critical Temperature: If the temperature of the superconducting material rises above its critical temperature ((T_c)), it will lose its superconducting properties and revert to a normal resistive state.

2.)Critical Magnetic Field: Superconductors can only maintain their superconducting state up to a certain magnetic field strength, known as the critical magnetic field ((H_c)). If the external magnetic field exceeds this critical value, the superconducting state is destroyed.

3)Critical Current: Superconducting wires can carry very high electrical currents without resistance, but there is a limit known as the critical current ((I_c)). If the current exceeds this critical value, the electron pairs that form the superconducting state (Cooper pairs) break up, and the material loses its superconductivity.

ANS d. Paramagnetic behavior decreases with an increase in temperature due to the relationship between magnetic susceptibility and temperature, as described by Curie's Law. According to Curie's Law, the magnetic susceptibility (χ

) of a paramagnetic material is inversely proportional to its absolute temperature (T

):

$\chi=T/C$

where C

is the Curie constant. This means that as the temperature increases, the magnetic susceptibility decreases.

The reason behind this behavior is that paramagnetic materials have unpaired electrons that align with an external magnetic field, causing the material to be attracted to the field. However, as the temperature increases, the thermal energy also increases, causing more random motion of the electrons. This random motion disrupts the alignment of the magnetic moments with the external magnetic field, leading to a decrease in the overall magnetic susceptibility1.

In summary, the increase in temperature causes increased thermal agitation, which disrupts the alignment of magnetic moments in paramagnetic materials, resulting in a decrease in paramagnetic behavior.

ANS e. Atomic polarizability refers to the tendency of an atom or molecule to acquire an electric dipole moment when subjected to an external electric field. This property is a measure of how easily the electron cloud around an atom or molecule can be distorted by the electric field.

When an electric field is applied, the negatively charged electrons and positively charged atomic nuclei experience opposite forces, leading to a separation of charges and the creation of an induced dipole moment. The polarizability (α

) of an atom or molecule is defined as the ratio of the induced dipole moment (μind

) to the local electric field (E

):

$\mu ind=\alpha E$

The polarizability is influenced by factors such as the number of electrons, the size of the electron cloud, and the atomic or molecular structure. Larger atoms or molecules with more diffuse electron clouds tend to have higher polarizability because their electrons are less tightly bound to the nucleus and can be more easily distorted by an external electric field12.

In summary, atomic polarizability is a measure of how easily an atom or molecule's electron cloud can be distorted by an external electric field, leading to the formation of an induced dipole moment.

ANS g. In quantum mechanics, a wave function (denoted as $$\psi$$ or $$\Psi$$) is a mathematical description of the quantum state of a particle or system of particles. The wave function contains all the information about the system and can be used to determine various physical properties. Here are some key pieces of information that can be obtained from a wave function:

1. *Probability Density*: The square of the absolute value of the wave function, $$|\psi|^2$$, represents the probability density of finding a particle at a given position in space. This is known as the Born rule.

2. *Expectation Values*: By applying quantum operators to the wave function, one can calculate the expectation values of physical observables such as position, momentum, and energy. The expectation value of an observable $$\hat{Q}$$ is given by:

$$

\langle Q \rangle = \int \psi^* \hat{Q} \psi \, d\tau

$$

where $$\psi^*$$ is the complex conjugate of the wave function and $$d\tau$$ represents the volume element in the integral.

3. *Energy Levels*: The wave function can be used to solve the Schrödinger equation, which provides the allowed energy levels of a quantum system. The time-independent Schrödinger equation is:

$$

\hat{H} \psi = E \psi

$$

where $$\hat{H}$$ is the Hamiltonian operator and $$E$$ is the energy eigenvalue.

4. *Momentum Distribution*: The wave function in momentum space can be obtained by performing a Fourier transform of the wave function in position space. This provides information about the momentum distribution of the particle.

5. *Spin and Other Quantum Numbers*: For particles with intrinsic properties such as spin, the wave function includes these degrees of freedom. The wave function can provide information about the spin state and other quantum numbers of the particle.

In summary, the wave function is a fundamental concept in quantum mechanics that encapsulates all the information about a quantum system, allowing us to determine probabilities, expectation values, energy levels, and other physical properties.

ANS h. A three-level laser is a type of laser system that involves three distinct energy levels for the lasing process. Here is a brief note on the three-level laser:

Three-Level Laser

Energy Levels:

In a three-level laser, the material is first excited to a short-lived high-energy state.

This high-energy state spontaneously drops to a somewhat lower-energy state with an unusually long lifetime, called a metastable state1.

Population Inversion:

The metastable state is crucial because it traps and holds the excitation energy, building up a population inversion.

Population inversion is a condition where more atoms are in the excited state than in the ground state, which is necessary for laser action1.

Laser Transition:

The laser transition occurs between the metastable state and the ground state.

An example of a three-level laser medium is ruby ($Cr^{3+}:Al_2O_3$), which was used by Maiman for the first laser2.

Pumping Mechanism:

The gain medium must be pumped with enough energy to achieve population inversion.

The threshold pump power is relatively high because more than half of the ions or atoms need to be pumped into the upper laser level2.

Applications:

Three-level lasers are used in various applications, including scientific research and medical procedures.

In summary, a three-level laser system relies on a metastable state to achieve population inversion and produce laser light. The ruby laser is a classic example of this type of laser.

ANS i. Total internal reflection is an optical phenomenon that occurs when a light ray traveling from a medium with a higher refractive index to a medium with a lower refractive index is completely reflected back at the interface, instead of being refracted. This phenomenon is governed by the principles of Snell's law and the critical angle.

Conditions for Total Internal Reflection

Medium Transition: The light ray must travel from a more optically dense medium (higher refractive index) to a less optically dense medium (lower refractive index).

Angle of Incidence: The angle of incidence must be greater than the critical angle for the given pair of media.

ANS j. Speed of the electron, (v = 500 {m/s})

Uncertainty in speed, (Delta v = 0.05% \times 500 ,{m/s} = 0.0005 \times 500 , {m/s} = 0.25 , {m/s})

Uncertainty in Momentum: The momentum (p) of an electron is given by (p = mv), where (m) is the mass of the electron.

Mass of the electron, (m = 9.11 \times 10^{-31} {kg})

Uncertainty in momentum, (\Delta p = m \Delta v)

Therefore, (\Delta p = 9.11 \times 10^{-31} , {kg} \times 0.25 , {m/s} = 2.2775 \times 10^{-31} , {kg} \cdot {m/s})

Conclusion:

The minimum uncertainty in the momentum of the electron is (2.2775 \times 10^{-31} , \text{kg} \cdot \text{m/s}).

SECTION : B

ANS 2. To measure the wavelength of X-rays using Bragg's spectrometer, we apply *Bragg's Law*, which is a fundamental equation that relates the wavelength of electromagnetic radiation to the diffraction pattern produced when it is scattered by a crystal. The law is given by the equation:

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

Here:

- \(n \) is the order of the reflected wave, typically taken as 1 for the first-order reflection.

- \(\lambda \) is the wavelength of the X-ray.

- \(d \) is the distance between the planes in the crystal lattice.

- \(\theta \) is the angle of incidence at which the X-ray beam is directed onto the crystal surface.

When X-rays are incident upon a crystal, the atoms in the crystal cause the X-rays to be scattered. If the scattered waves interfere constructively, they will enhance each other and produce a detectable signal. This occurs at specific angles that satisfy Bragg's Law, allowing us to calculate the wavelength of the X-rays.

For the calculation of the minimum wavelength (\(\lambda_{min} \)) of continuous X-rays emitted from an X-ray tube operating at 40 kV, we use the formula derived from the energy of the photon and the voltage applied:

$$ \lambda_{min} = \frac{hc}{eV} $$

Where:

- \(h \) is Planck's constant (\(6.626 \times 10^{-34} \) J·s).
- \(c \) is the speed of light (\(3 \times 10^8 \) m/s).
- \(e \) is the elementary charge (\(1.602 \times 10^{-19} \) C).
- \(V \) is the voltage (40 kV or \(40 \times 10^3 \) V).

Plugging in the values, we get:

$$ \lambda_{min} = \frac{(6.626 \times 10^{-34} \text{ J·s})(3 \times 10^8 \text{ m/s})}{(1.602 \times 10^{-19} \text{ C})(40 \times 10^3 \text{ V})} $$

After calculating, the minimum wavelength \(\lambda_{min} \) comes out to be approximately *0.031 nm*[1].

Please note that the actual measurement process would involve using a Bragg spectrometer to observe the diffraction pattern and applying the Bragg's Law equation to determine the wavelength from the observed angles. The calculation provided here is a theoretical estimation based on the given voltage. In a real-world scenario, the precision of the measurement would depend on the accuracy of the spectrometer and the quality of the crystal used.

ANS 3. Tunnel Diode: Overview

A tunnel diode is a type of semiconductor diode that has a heavily doped p-n junction. This heavy doping results in a very thin depletion region, allowing for quantum mechanical tunneling to occur at certain voltage levels. Due to this tunneling effect, the tunnel diode exhibits negative resistance in a portion of its voltage-current (V-I) characteristics.

Why is it Called a Tunnel Diode?

The name "tunnel diode" comes from the quantum mechanical tunneling effect that dominates its operation. In quantum mechanics, tunneling refers to the phenomenon where particles pass through a barrier that they classically shouldn't be able to pass. In the case of a tunnel diode, electrons are able to "tunnel" through the thin depletion region at certain voltage levels, leading to the unique characteristics of the diode.

V-I Characteristics of Tunnel Diode

The V-I characteristics of a tunnel diode can be divided into several regions:

1. **Ohmic Region (Zero Bias):**
    - At zero bias (no external voltage applied), the tunnel diode behaves like a normal diode with a small current due to the thermal generation of carriers.
2. **Forward Bias Region:**
    - **Peak Current (I_peak):** As the forward voltage increases, electrons tunnel through the thin depletion region, leading to a rapid increase in current. The current reaches a maximum at a certain voltage called the peak voltage (V_peak).
    - **Negative Resistance Region:** Beyond the peak voltage, further increase in voltage reduces the tunneling probability, causing a decrease in current. This region, where an increase in voltage leads to a decrease in current, is known as the negative resistance region.
    - **Valley Current (I_valley):** The current decreases until it reaches a minimum at a voltage called the valley voltage (V_valley).
    - **Positive Resistance Region:** Beyond the valley voltage, the diode starts behaving like a normal forward-biased diode, and the current increases with voltage.
3. **Reverse Bias Region:**
    - In reverse bias, the tunnel diode initially allows a small leakage current. With increasing reverse voltage, the current increases slightly due to tunneling until it eventually reaches a saturation point where it behaves similarly to a normal diode.

Key Points in the V-I Curve:

- **V_peak (Peak Voltage):** The voltage at which the current reaches its maximum value (I_peak).
- **I_peak (Peak Current):** The maximum current in the forward bias before the negative resistance region starts.
- **V_valley (Valley Voltage):** The voltage at which the current reaches its minimum value (I_valley).
- **I_valley (Valley Current):** The minimum current in the forward bias after the negative resistance region.

V-I Characteristics Graph

Here's a typical V-I characteristics curve for a tunnel diode:

```
| I
|        /\
|       /  \
|      /    \
|     /      \
|____/        \______
|              |
|<---- Negative Resistance ---->
|              |
|              V
|              |
|            Reverse Bias
|________________________ V
```

In the above graph:

- The initial sharp rise to the peak represents the tunneling current.
- The subsequent drop represents the negative resistance region.
- The rise after the valley represents normal diode behavior.
- In reverse bias, a small current flows initially, increasing slightly due to tunneling.

Tunnel diodes are used in high-frequency oscillators, amplifiers, and fast switching circuits due to their unique negative resistance property.

ANS 4. A. A hysteresis loop is a graphical representation that describes the relationship between two physical quantities where the system shows dependence on its history. It is most commonly discussed in the context of magnetic materials, but it can also apply to other systems such as elastic materials and ferroelectrics.

In the context of magnetism, the hysteresis loop shows the relationship between the magnetic flux density (B) and the magnetic field strength (H). The key characteristics of a magnetic hysteresis loop are:

1. **Coercivity (Hc):** The magnetic field strength required to reduce the magnetization of the material to zero after it has been magnetized.
2. **Remanence (Br):** The residual magnetic flux density that remains when the external magnetic field is reduced to zero.
3. **Saturation:** The maximum level of magnetization that a material can achieve, where further increases in magnetic field strength do not result in significant increases in magnetization.

4. **Area of the loop:** The area enclosed by the hysteresis loop represents the energy loss per cycle of magnetization, often due to heat dissipation and other losses.

- **Initial Magnetization Curve (O to A)**:
    - Starting from an unmagnetized state (point O), as the external magnetic field (H) is increased, the magnetization (B) also increases until it reaches saturation (point A).
- **Remanence (Br)**:
    - After reaching saturation and then reducing the external magnetic field to zero, the material retains some magnetization (point B), known as remanence or residual magnetization (Br).
- **Caoercivity (Hc)**:
    - To demagnetize the material, a reverse magnetic field must be applied. The magnitude of this field is called coercivity (point C).
- **Negative Saturation (D)**:
    - Further increasing the reverse magnetic field drives the material to negative saturation (point D).
- **Symmetry and Return Path**:
    - Reducing the reverse magnetic field to zero again leaves a negative remanent magnetization (point E). Applying a forward magnetic field returns the material to positive saturation, completing the loop.

ANS 4.B Ferromagnetic Materials

Ferromagnetic materials are those materials that exhibit strong magnetic properties due to the alignment of magnetic moments within the material. These materials can retain magnetization even after the external magnetic field is removed, making them suitable for permanent magnets and various magnetic applications.

Examples of Ferromagnetic Materials:

1. **Iron (Fe)**
2. **Nickel (Ni)**

3. **Cobalt (Co)**
4. **Certain alloys like Alnico (aluminum, nickel, cobalt) and Permalloy (nickel-iron alloy)**

Ferromagnetism: Domain Theory

Ferromagnetism can be explained using the concept of magnetic domains. The domain theory was proposed to describe how ferromagnetic materials become magnetized and retain their magnetization.

Key Concepts of Domain Theory:

1. **Magnetic Domains:**
   - A ferromagnetic material consists of small regions called magnetic domains. Within each domain, the magnetic moments of atoms are aligned in the same direction, resulting in a net magnetic moment for the domain.
2. **Random Orientation:**
   - In an unmagnetized ferromagnetic material, these domains are randomly oriented. As a result, the net magnetization of the material is zero because the magnetic moments of the domains cancel each other out.
3. **Domain Alignment:**
   - When an external magnetic field is applied, the magnetic moments of the domains start to align with the direction of the applied field. This alignment increases the net magnetization of the material.
4. **Growth of Aligned Domains:**
   - Domains that are aligned with the external magnetic field grow at the expense of the domains that are not aligned. This growth occurs by the movement of domain walls (the boundaries between different domains).
5. **Saturation Magnetization:**
   - When all the domains are aligned with the external field, the material reaches its saturation magnetization. At this point, further increase in the external magnetic field does not increase the magnetization.
6. **Retentivity and Coercivity:**
   - After the external magnetic field is removed, the material retains some magnetization, known as retentivity or remanent magnetization.
   - To demagnetize the material, a reverse magnetic field needs to be applied. The strength of this field is called the coercive field or coercivity.

Visualization of Domain Theory:

1. **Unmagnetized State:**
   - In the unmagnetized state, domains are oriented randomly:

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     plaintext
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     ← → ← →
     ```

```
↓ ↑ ↓ ↑
```

2. **Application of External Magnetic Field:**
   - Upon applying an external magnetic field, domains align with the field:

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3. **Saturation:**
   - At saturation, all domains are fully aligned with the external field:

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     ```
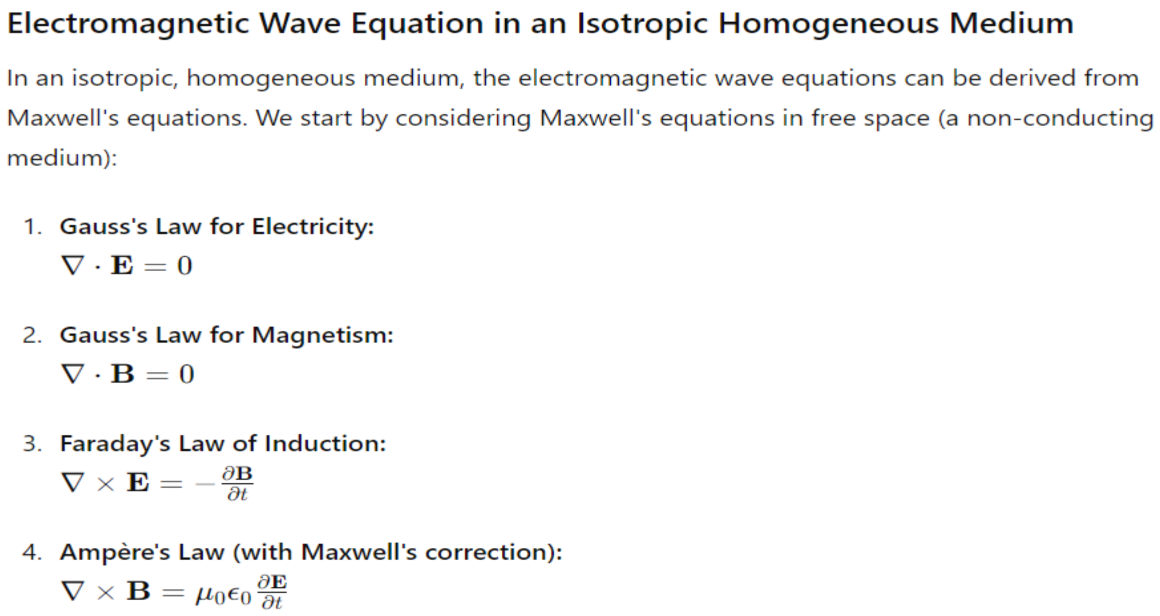

Energy Considerations:

- **Exchange Energy:** The energy associated with the interaction between neighbouring atomic spins. It favours parallel alignment of spins within a domain.
- **Magnetostatic Energy:** The energy due to the external magnetic field. It influences the alignment of the domains with the external field.
- **Anisotropy Energy:** The energy related to the directional dependence of the material's magnetic properties. Certain crystallographic directions are energetically favorable for magnetization.

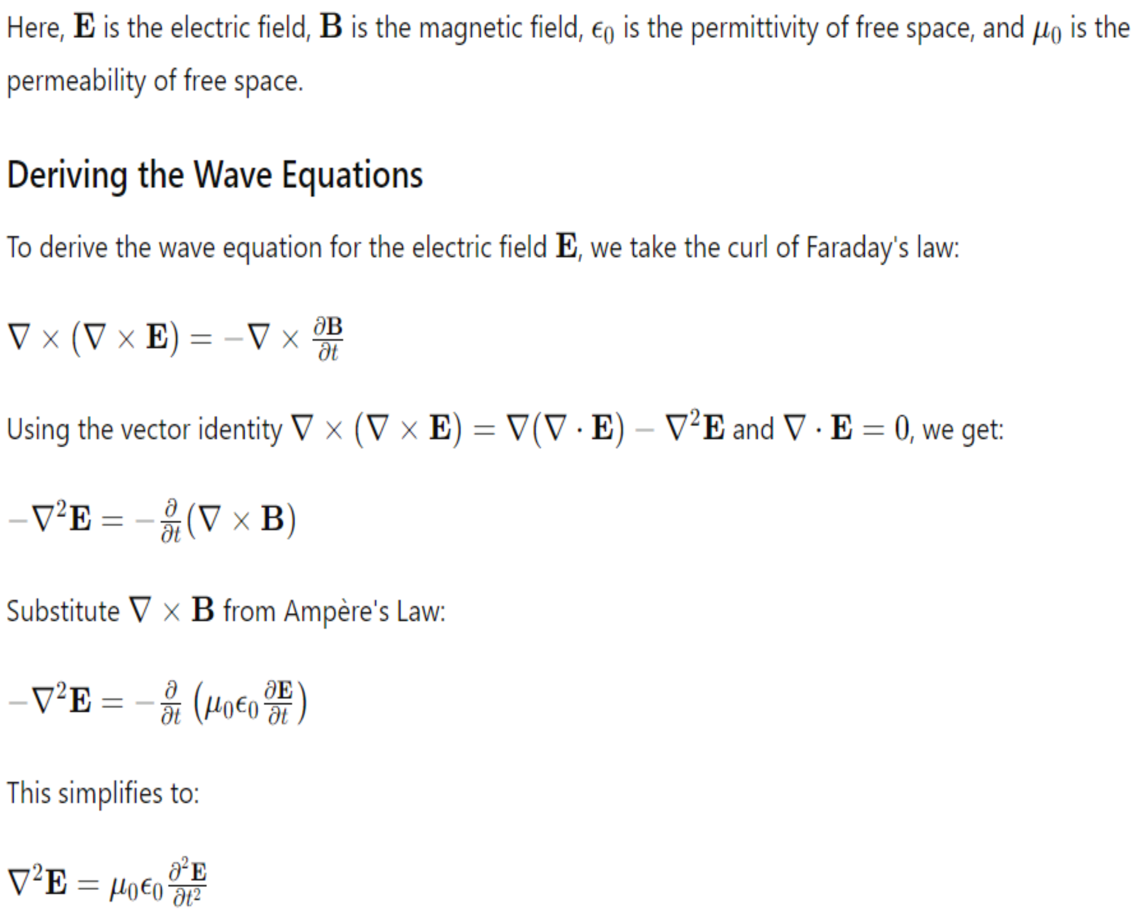
ANS 5.



Electromagnetic Wave Equation in an Isotropic Homogeneous Medium

In an isotropic, homogeneous medium, the electromagnetic wave equations can be derived from Maxwell's equations. We start by considering Maxwell's equations in free space (a non-conducting medium):

1. **Gauss's Law for Electricity:**
   $\nabla \cdot \mathbf{E} = 0$
2. **Gauss's Law for Magnetism:**
   $\nabla \cdot \mathbf{B} = 0$
3. **Faraday's Law of Induction:**
   $\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$
4. **Ampère's Law (with Maxwell's correction):**
   $\nabla \times \mathbf{B} = \mu_0 \epsilon_0 \frac{\partial \mathbf{E}}{\partial t}$



Here, $\mathbf{E}$ is the electric field, $\mathbf{B}$ is the magnetic field, ϵ_0 is the permittivity of free space, and μ_0 is the permeability of free space.

Deriving the Wave Equations

To derive the wave equation for the electric field $\mathbf{E}$, we take the curl of Faraday's law:

$$\nabla \times (\nabla \times \mathbf{E}) = -\nabla \times \frac{\partial \mathbf{B}}{\partial t}$$

Using the vector identity $\nabla \times (\nabla \times \mathbf{E}) = \nabla(\nabla \cdot \mathbf{E}) - \nabla^2 \mathbf{E}$ and $\nabla \cdot \mathbf{E} = 0$, we get:

$$-\nabla^2 \mathbf{E} = -\frac{\partial}{\partial t}(\nabla \times \mathbf{B})$$

Substitute $\nabla \times \mathbf{B}$ from Ampère's Law:

$$-\nabla^2 \mathbf{E} = -\frac{\partial}{\partial t}\left(\mu_0 \epsilon_0 \frac{\partial \mathbf{E}}{\partial t}\right)$$

This simplifies to:

$$\nabla^2 \mathbf{E} = \mu_0 \epsilon_0 \frac{\partial^2 \mathbf{E}}{\partial t^2}$$

These are the standard wave equations for the electric and magnetic fields in an isotropic homogeneous medium.

Solution to the Wave Equation

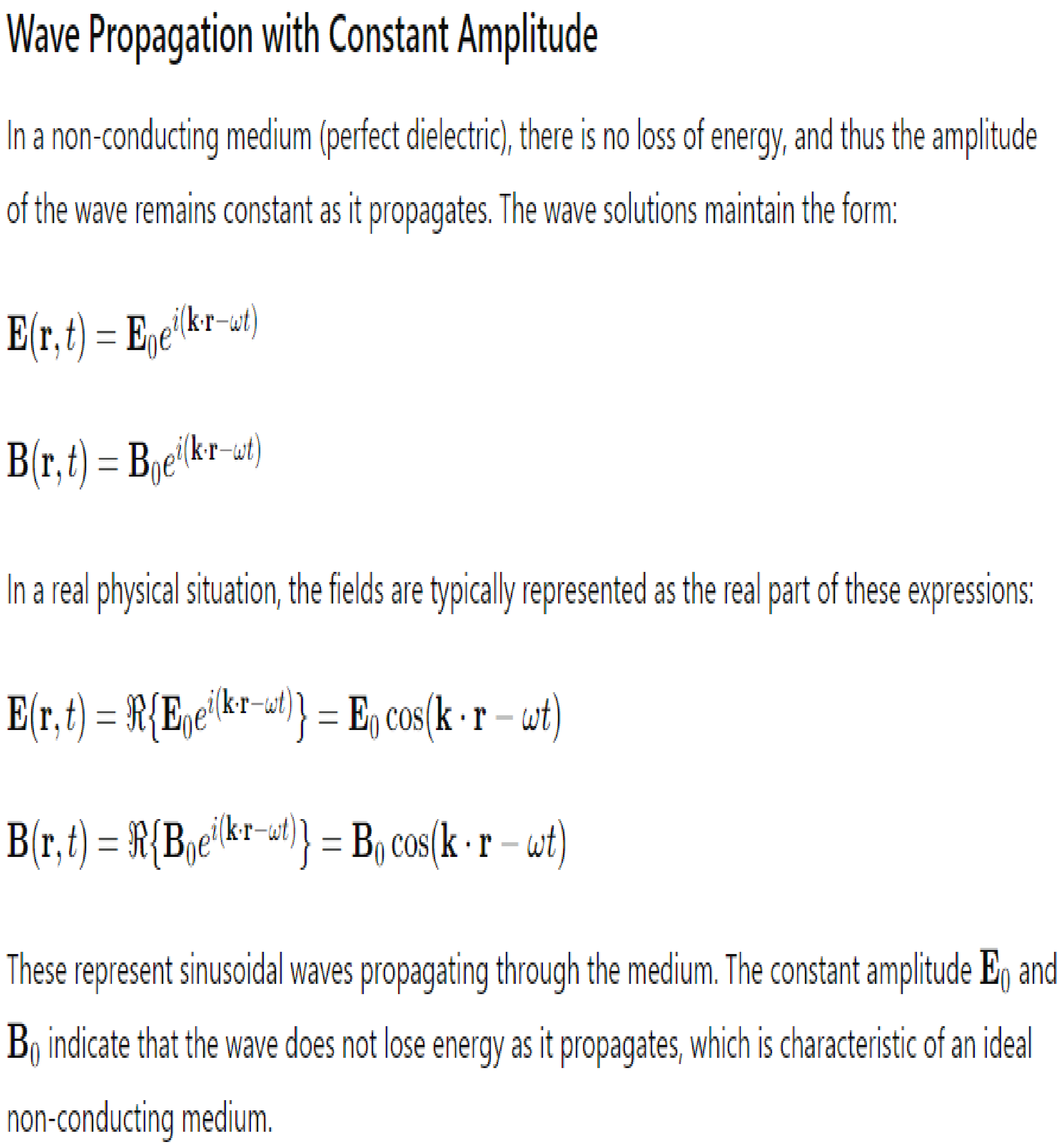
The general solution to the wave equation in three dimensions is:

$$\mathbf{E}(\mathbf{r}, t) = \mathbf{E}_0 e^{i(\mathbf{k} \cdot \mathbf{r} - \omega t)}$$

$$\mathbf{B}(\mathbf{r}, t) = \mathbf{B}_0 e^{i(\mathbf{k} \cdot \mathbf{r} - \omega t)}$$

where:

- $\mathbf{k}$ is the wave vector.
- ω is the angular frequency.
- $\mathbf{E}_0$ and $\mathbf{B}_0$ are the amplitudes of the electric and magnetic fields, respectively.



Wave Propagation with Constant Amplitude

In a non-conducting medium (perfect dielectric), there is no loss of energy, and thus the amplitude of the wave remains constant as it propagates. The wave solutions maintain the form:

$$\mathbf{E}(\mathbf{r}, t) = \mathbf{E}_0 e^{i(\mathbf{k}\cdot\mathbf{r} - \omega t)}$$

$$\mathbf{B}(\mathbf{r}, t) = \mathbf{B}_0 e^{i(\mathbf{k}\cdot\mathbf{r} - \omega t)}$$

In a real physical situation, the fields are typically represented as the real part of these expressions:

$$\mathbf{E}(\mathbf{r}, t) = \Re\{\mathbf{E}_0 e^{i(\mathbf{k}\cdot\mathbf{r} - \omega t)}\} = \mathbf{E}_0 \cos(\mathbf{k}\cdot\mathbf{r} - \omega t)$$

$$\mathbf{B}(\mathbf{r}, t) = \Re\{\mathbf{B}_0 e^{i(\mathbf{k}\cdot\mathbf{r} - \omega t)}\} = \mathbf{B}_0 \cos(\mathbf{k}\cdot\mathbf{r} - \omega t)$$

These represent sinusoidal waves propagating through the medium. The constant amplitude $\mathbf{E}_0$ and $\mathbf{B}_0$ indicate that the wave does not lose energy as it propagates, which is characteristic of an ideal non-conducting medium.

SECTION:C

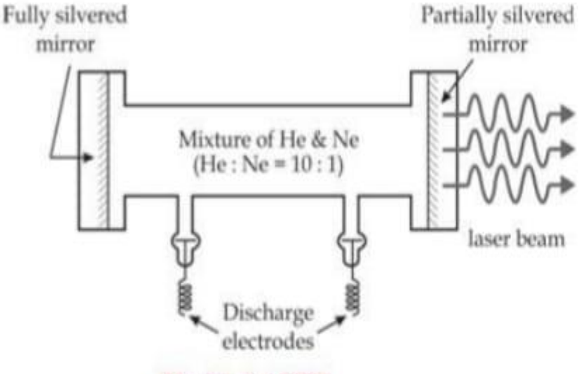
ANS 6:

Helium -Neon (He-Ne) Laser

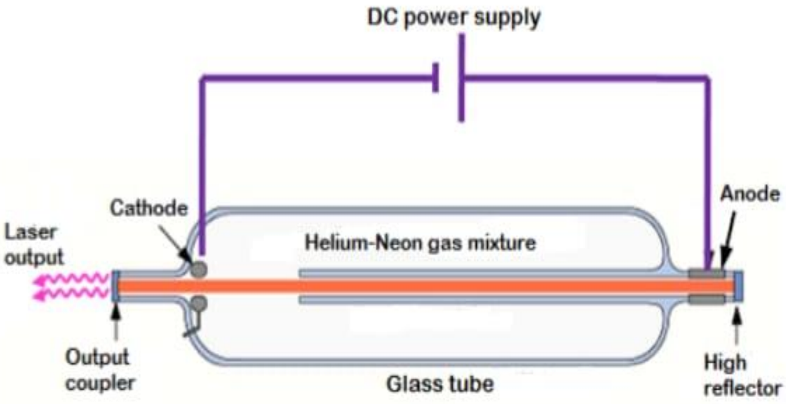
Construction:

(i) Active medium:

It is a gas laser, which consists of a narrow quartz tube filled with a mixture of helium and neon gases in the ratio 10:1 respectively, at low pressure (~0.1 mm of Hg). Ne atoms act as active centres and responsible for the laser action, while He atoms are used to help in the excitation process. The length of the quartz tube is about 50 cm and the diameter is about 1 cm.



He-Ne LASER

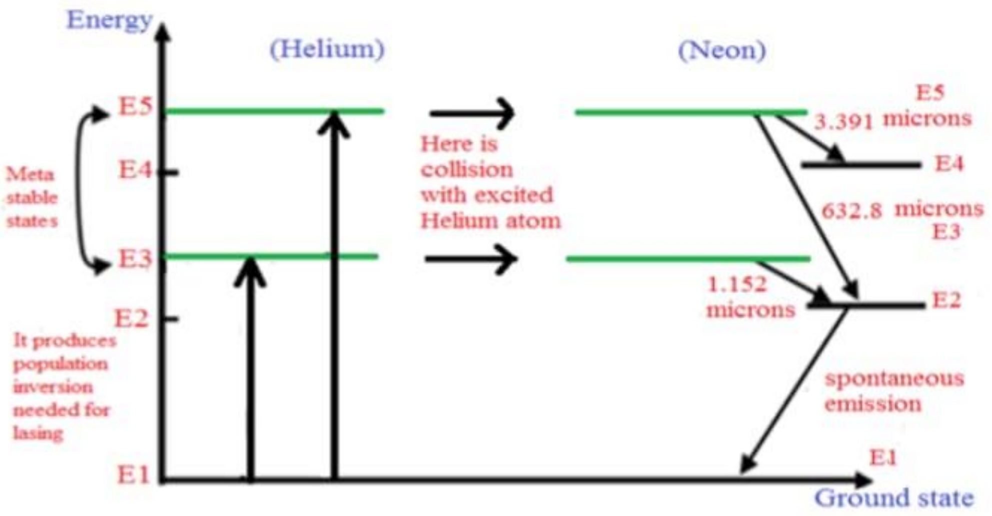


ii) Optical resonator:

To construct the optical resonator cavity, two parallel mirrors are placed at the ends of the quartz tube one of them is partly transparent while the other is fully reflecting. The spacing between the mirrors is adjusted such that it should be equal to the integral multiple of half-wavelengths of the laser light.

(iii) Pumping system:

The pumping is done through electrical discharge by using electrodes that are connected to a high frequency alternating current source.



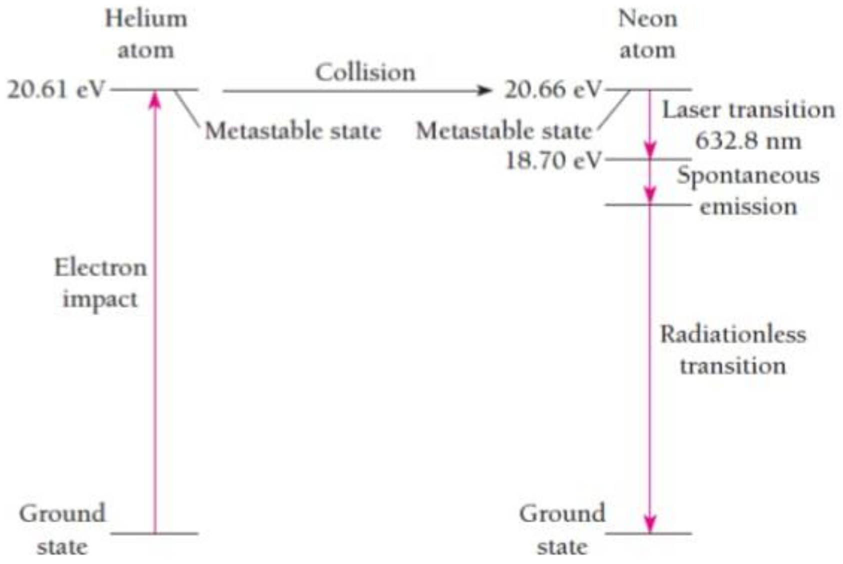


Figure: The helium-neon laser. In a four-level laser such as this, continuous operation is possible. Helium-neon lasers are commonly used to read bar codes.

The common helium-neon gas laser achieves a population inversion in a different way. A mixture of about 10 parts of helium and 1 part of neon at a low pressure (1 torr) is placed in a glass tube that has parallel mirrors, one of them partly transparent, at both ends. The spacing of the mirrors is again (as in all lasers) equal to an integral number of half-wavelengths of the laser light. An electric discharge is produced in the gas by means of electrodes outside the tube connected to a source of high-frequency alternating current, and collisions with electrons from the discharge excite He and Ne atoms to metastable states respectively 20.61 and 20.66 eV above their ground states. Some of the excited He atoms transfer their energy to ground-state Ne atoms in collisions, with the 0.05 eV of additional energy being provided by the kinetic energy of the atoms. The purpose of the He atoms is thus to help achieve a population inversion in the Ne atoms.

The laser transition in Ne is from the metastable state at 20.66 eV to an excited state at 18.70 eV, with the emission of a 632.8-nm photon. Then another photon is spontaneously emitted in a transition to a lower metastable state; this transition yields only incoherent light. The remaining excitation energy is lost in collisions with the tube walls. Because the electron impacts that excite the He and Ne atoms occur all the time, unlike the pulsed excitation from the xenon flash lamp in a ruby laser, a He-Ne laser operates continuously. This is the laser whose narrow red beam is used in supermarkets to read bar codes. In a He-Ne laser, only a tiny fraction (one in millions) of the atoms present participates in the laser process at any moment.

Characteristics of He-Ne Laser

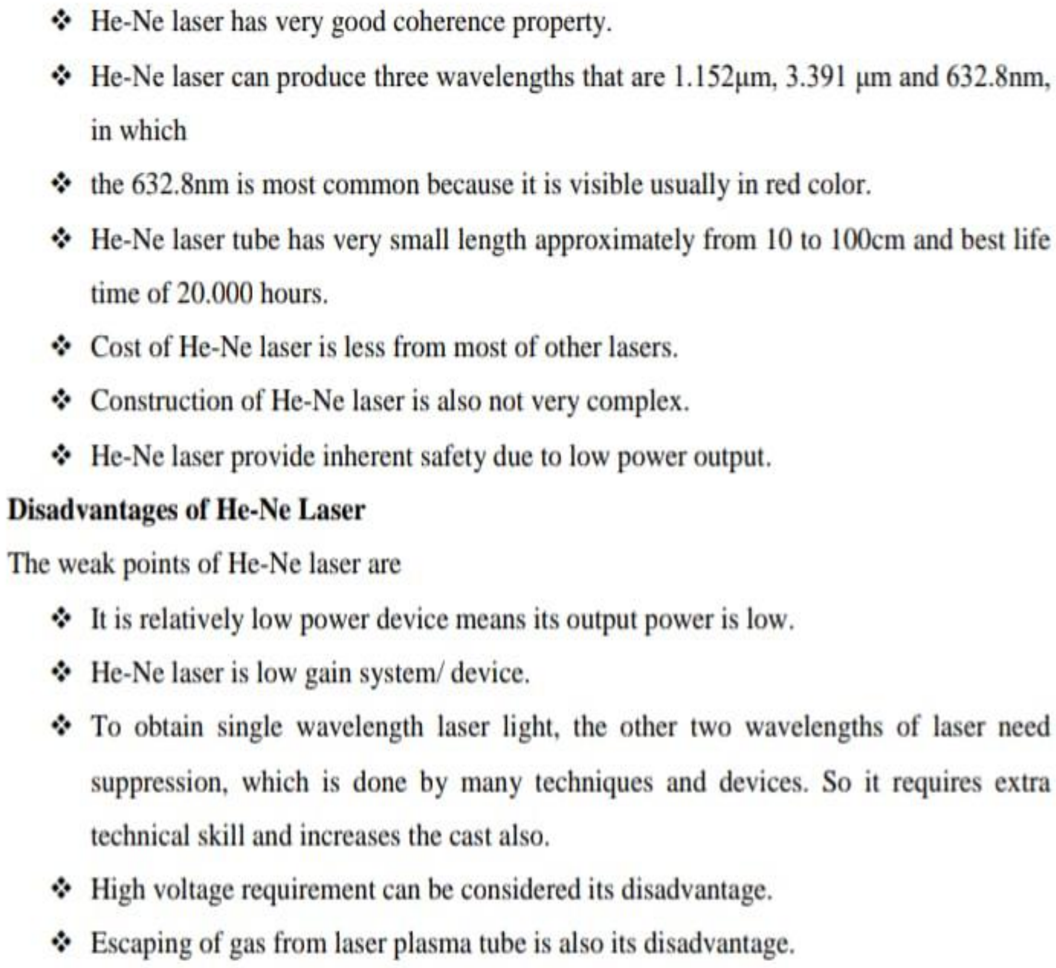
The He-Ne laser is a relatively low power device with an output in the visible red portion of the spectrum. The most common wavelength produced by He-Ne lasers is 632.8nm, although two lower power (1.152μm and 3.391μm) infrared wavelengths can be produced if desired. Majority of He-Ne lasers generate less than 10m watt of power, but some can be obtained commercially with up to 50m watts of power. For He-Ne lasers the typical laser tube is from 10 to 100 cm in length and the life time of such a tube can be as high as 20,000 hours.

Applications / Uses of He-Ne Laser

The Helium-Neon gas laser is one of the most commonly used laser today because of the following applications.

- He-Ne lasers are produced in large quantities from many years.
- Many schools / colleges / universities use this type of laser in their science programs and experiments.
- He-Ne lasers also used in super market checkout counters to read bar codes and QR codes.
- The He-Ne lasers also used by newspapers for reproducing transmitted photographs.
- He-Ne lasers can be use as an alignment tool.
- It is also used in Guns for targeting.

Advantages of He-Ne Laser



- He-Ne laser has very good coherence property.
- He-Ne laser can produce three wavelengths that are 1.152μm, 3.391 μm and 632.8nm, in which
- the 632.8nm is most common because it is visible usually in red color.
- He-Ne laser tube has very small length approximately from 10 to 100cm and best life time of 20.000 hours.
- Cost of He-Ne laser is less from most of other lasers.
- Construction of He-Ne laser is also not very complex.
- He-Ne laser provide inherent safety due to low power output.

Disadvantages of He-Ne Laser

The weak points of He-Ne laser are

- It is relatively low power device means its output power is low.
- He-Ne laser is low gain system/ device.
- To obtain single wavelength laser light, the other two wavelengths of laser need suppression, which is done by many techniques and devices. So it requires extra technical skill and increases the cast also.
- High voltage requirement can be considered its disadvantage.
- Escaping of gas from laser plasma tube is also its disadvantage.

ANS 7: To derive the expression for group velocity and show that it is equal to particle velocity, we need to consider the context of wave packets in quantum mechanics. A wave packet is a superposition of waves with slightly different wavelengths and frequencies. The group velocity is the speed at which the envelope of the wave packet (which represents the particle) travels

We know that group velocity

$$V_g = \frac{d\omega}{dk}$$

$$V_g = \frac{d(2\pi\nu)}{d(\frac{2\pi}{\lambda})} \qquad \left(k = \frac{2\pi}{\lambda}\right)$$

$$V_g = \frac{d\nu}{d(\frac{1}{\lambda})}$$

$$\frac{1}{V_g} = \frac{d(\frac{1}{\lambda})}{d\nu} \qquad (1)$$

We know that the total energy of the particle is equal to the sum of kinetic energy and potential energy. i.e

$$E = K + V$$

Where

K – kinetic energy
V – Potential energy

$$E = \frac{1}{2}mv^2 + V$$

$$E = \frac{1}{2}mv^2 + V$$

$$E - V = \frac{1}{2}\frac{(mv)^2}{m}$$

$$E - V = \frac{1}{2m}(mv)^2$$

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

$$mv = \sqrt{2m(E - V)}$$

According to de-Broglie wavelength-

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

$$\lambda = \frac{h}{\sqrt{2m(E-V)}}$$

$$\frac{1}{\lambda} = \frac{\sqrt{2m(E-V)}}{h} \qquad (3)$$

Now put the value of $\frac{1}{\lambda}$ in equation(1)

$$\frac{1}{V_g} = \frac{d}{dv}[\frac{2m(E-V)^{\frac{1}{2}}}{h}]$$

$$\frac{1}{V_g} = \frac{d}{dv}[\frac{2m(h\nu-V)^{\frac{1}{2}}}{h}]$$

$$\frac{1}{V_g} = \frac{d}{dv}[\frac{2m(E-V)^{\frac{1}{2}}}{h}]$$

$$\frac{1}{V_g} = \frac{d}{dv}[\frac{2m(h\nu-V)^{\frac{1}{2}}}{h}]$$

$$\frac{1}{V_g} = \frac{1}{2h}[2m(h\nu - V)]^{\frac{-1}{2}} 2m.h$$

$$\frac{1}{V_g} = \frac{1}{2h}[2m(E - V)]^{\frac{-1}{2}} 2m.h \qquad (\because E = h\nu)$$

$$\frac{1}{V_g} = \frac{m}{mv} \qquad \{\text{from equation (2)}\}$$

$$V_g = V$$

Thus, the above equation shows that group velocity is equal to particle velocity.

ANS 8: Optical fibres propagate light signals using different modes, which refer to the ways light waves travel through the fibre. The primary modes of propagation in optical fibers are:

1. Single-Mode Propagation

- **Description**: Single-mode fibres (SMF) have a small core diameter (around 8-10 micrometers) that allows only one mode of light to propagate.

- **Characteristics**:
    - **Low Dispersion**: Minimal spreading of the light pulse over long distances.
    - **Long-Distance Communication**: Ideal for long-haul communication systems.
    - **Higher Bandwidth**: Supports higher data rates due to reduced modal dispersion.

2. Multi-Mode Propagation

- **Description**: Multi-mode fibres (MMF) have a larger core diameter (50 or 62.5 micrometres) that allows multiple modes or paths of light to propagate.
- **Characteristics**:
    - **Modal Dispersion**: Different modes travel at different speeds, causing pulse broadening and limiting the bandwidth and distance.
    - **Short-Distance Communication**: Suitable for shorter distances such as within buildings or campuses.
    - **Lower Cost**: Easier to manufacture and connect than single-mode fibers.

Types of Multi-Mode Propagation:

Step-Index Multi-Mode Fiber

- **Core Structure**: The core has a uniform refractive index with a sudden change (step) at the cladding boundary.
- **Characteristics**:
    - **High Modal Dispersion**: Significant pulse spreading due to different path lengths of the modes.
    - **Simple Design**: Easier and cheaper to manufacture.

Graded-Index Multi-Mode Fiber

- **Core Structure**: The core has a varying refractive index that gradually decreases from the centre outward.
- **Characteristics**:
    - **Reduced Modal Dispersion**: Light rays traveling in different modes are continually refracted, reducing path differences and thus dispersion.
    - **Better Performance**: Higher bandwidth and longer transmission distances compared to step-index MMF.

ANS 9: Carbon nanotubes (CNTs) are cylindrical molecules made up of rolled-up sheets of single-layer carbon atoms (graphene). They possess extraordinary mechanical, electrical, thermal, and optical properties, making them highly attractive for a wide range of applications, including nanotechnology, electronics, optics, and materials science.

Types of Carbon Nanotubes

Carbon nanotubes can be categorized based on their structure and number of walls:

1. **Single-Walled Carbon Nanotubes (SWCNTs):**
    - **Structure:** Consist of a single layer of graphene rolled into a cylindrical shape.
    - **Properties:** Exhibit high electrical conductivity, flexibility, and strength.
    - **Applications:** Used in electronics, sensors, and as additives to improve mechanical properties of composites.
2. **Multi-Walled Carbon Nanotubes (MWCNTs):**
    - **Structure:** Comprised of multiple concentric layers of graphene, resembling a set of nested tubes.
    - **Properties:** Generally have greater tensile strength and thermal stability compared to SWCNTs but lower electrical conductivity.
    - **Applications:** Used in composite materials, thermal management, and as conductive fillers in polymers.
3. **Double-Walled Carbon Nanotubes (DWCNTs):**
    - **Structure:** Consist of exactly two concentric graphene cylinders.
    - **Properties:** Combine properties of both SWCNTs and MWCNTs, offering a balance of high strength, flexibility, and conductivity.
    - **Applications:** Used in applications requiring both high strength and conductivity, such as in advanced nanocomposites.

Structural Variations

Carbon nanotubes also vary in terms of their chirality, which refers to the specific orientation of the carbon atoms in the nanotube. This can significantly affect their properties.

- **Armchair (n, n):** Metallic properties and very high electrical conductivity.
- **Zigzag (n, 0):** Can be either metallic or semiconducting depending on their diameter.
- **Chiral (n, m):** Always semiconducting with varied electronic properties.

Methods of synthesis of nanoparticles:

Ball Milling Method for Synthesis of Nanomaterials

Ball milling is a mechanical process and thus all the structural and chemical changes are produced by mechanical energy. The technique is widely used in various industries and academic research for the synthesis of nanomaterials. It involves the grinding of materials to a fine powder in a rotating vessel containing steel or ceramic balls. Here's an overview of the process and its applications:

Process

1. **Preparation:**
    - **Materials:** The raw materials (e.g., metal oxides, carbon, etc.) are chosen based on the desired nanomaterial properties.
    - **Ball Mill:** A cylindrical device containing balls (steel, ceramic, or tungsten carbide) of varying sizes.
2. **Milling:**
    - **Loading:** The raw materials and the balls are loaded into the ball mill.
    - **Rotation:** The ball mill is rotated at a certain speed (usually between 200-500 rpm).
    - **Impact and Friction:** As the vessel rotates, the balls are lifted and then drop onto the material, causing impact and friction, which breaks down the particles into finer sizes.
3. **Mechanisms:**
    - **Mechanical Activation:** The repeated impact and friction lead to plastic deformation, fracturing, and cold welding, resulting in the formation of nanoscale particles.
    - **Homogeneity:** Continuous milling ensures a uniform size distribution of nanoparticles.
4. **Duration:**
    - **Time:** The milling time can vary from a few hours to several days, depending on the material and desired properties.

Advantages

- **Scalability:** Suitable for both small-scale and large-scale production.
- **Versatility:** Can be used for a wide range of materials (metals, ceramics, polymers).
- **Simple Setup:** Requires relatively simple and inexpensive equipment.

Disadvantages

- **Contamination:** Potential contamination from the balls and vessel material.
- **Energy Intensive:** Requires significant energy to achieve desired particle sizes.
- **Non-uniformity:** May result in a broad particle size distribution if not properly controlled.

Sol-Gel Method

The sol-gel method is a versatile and widely used technique for the synthesis of various nanomaterials, including ceramics, glasses, and thin films. This process involves the transition of a system from a liquid "sol" (a colloidal suspension of particles) to a solid "gel" phase. Here’s an overview of the process, advantages, disadvantages, and applications of the sol-gel method:

Process

1. **Preparation of Sol:**
   - **Precursors:** Metal alkoxides or metal chlorides are commonly used as precursors.
   - **Sol Formation:** The precursors are dissolved in a suitable solvent (often alcohol), and hydrolysis and polymerization reactions are initiated by adding water and an acid or base catalyst. This forms a colloidal suspension or "sol."
2. **Gelation:**
   - **Polymerization:** As the reactions proceed, the sol undergoes further polymerization, leading to the formation of a three-dimensional network. This results in a viscous "gel."
   - **Aging:** The gel is allowed to age, during which it undergoes syneresis (expulsion of solvent) and further polycondensation, enhancing the network structure.
3. **Drying:**
   - **Evaporation:** The solvent is evaporated from the gel, leaving behind a porous solid network.
   - **Types of Drying:** Different drying methods can be employed:
     - **Ambient Drying:** Produces xerogels, which are often brittle and porous.
     - **Supercritical Drying:** Produces aerogels with low density and high surface area.
4. **Thermal Treatment:**
   - **Calcination or Sintering:** The dried gel is subjected to heat treatment to remove residual organic components and to crystallize the material, resulting in the final product.

Advantages

- **Versatility:** Can produce a wide range of materials, including oxides, non-oxides, and composites.
- **Purity:** High purity of the final product due to the controlled chemical reactions.
- **Homogeneity:** Uniform distribution of components at the molecular level.
- **Low Temperature:** Synthesis can be carried out at relatively low temperatures compared to conventional methods.
- **Shape Control:** Ability to produce materials in various forms, such as powders, thin films, fibers, and monoliths.

Disadvantages

- **Time-Consuming:** The process can be slow, particularly during gelation and drying stages.
- **Shrinkage and Cracking:** Significant shrinkage and potential cracking during drying.
- **Solvent Use:** Involves the use of solvents, which may be environmentally hazardous and require proper disposal.