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F. Y. B. TECH. (COMMON) (SEMESTER - I)
COURSE NAME: ENGINEERING PHYSICS
COURSE CODE: ES10175A
(2017 PATTERN)
ESE Solution

Q.1. a) Explain with the help of neat diagrams construction and working of CO_2 laser. **[6]**

Ans.: **Construction diagram- 1M, Energy level diagram- 1M, Construction- 2M, working-2M.**

Carbon dioxide Laser: It is a four level molecular laser operating at 10.6 μm in the far IR region.

Construction: The schematic of a typical CO_2 is shown in below. It consists of a discharge tube having a bore of diameter 1.5 m and length of 25 cm. The discharge tube is filled with a mixture of carbon dioxide, nitrogen and helium gases in the ratio 1:2:3 respectively. Water vapour is also added as an additional component. CO_2 molecules are the active centers lasing on the transitions between the vibrational levels of the electronic ground state. A high dc voltage causes an electric discharge to pass through the tube. This breaks down CO_2 molecules to form oxygen and carbon monoxide. Therefore, a small amount of water vapour is added to the gaseous mixture which regenerates CO_2.

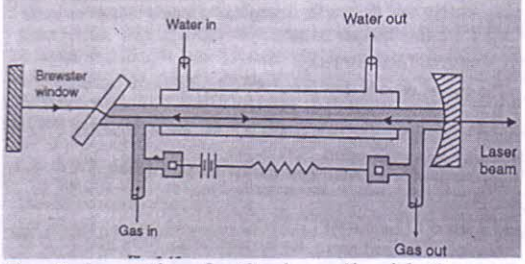


Fig. Schematic of a Carbon dioxide Laser

Working: Fig. below shows the lowest vibrational levels of the ground electron energy state of CO_2 molecule and N_2 molecule. The excited state of an N_2 molecule is metastable and is identical in energy to (001) vibrational level of CO_2 molecule, shown as E_5 in the figure.

On passing current through the mixture of gases, the N_2 molecules get excited to the metastable state. These N_2 molecules return to ground state through inelastic collisions with ground state CO_2 molecules. The CO_2 molecules are then excited to E_5 level. Some of the CO_2 molecules are also excited to the upper level E_5 through collisions with electrons. The E_5 level is the upper laser level while the E_3 and E_4 levels act as the lower laser levels. As the population of CO_2 molecule builds up at the E_5 level, population inversion is achieved between E_5 level and the levels at E_4 and E_3.

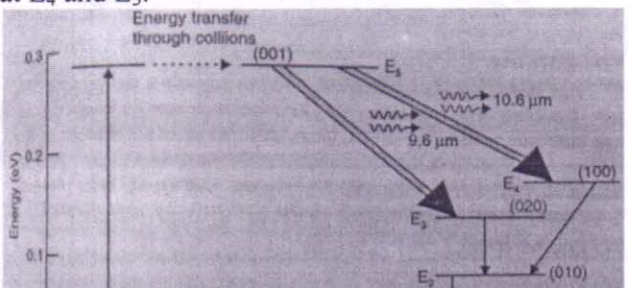


Fig. Energy levels of nitrogen and carbon dioxide molecules showing transition between the levels

The laser transition between E_5 and E_4 levels produces far IR radiation with a wavelength of 10.6 μm. The lasing transition between E_5 and E_3 levels produces far IR radiation with a 9.6 μm wavelength. E_3 and E_4 levels are also metastable states. CO_2 molecules at these levels fall to lower level E_2 through inelastic collisions with normal, unexcited CO_2 molecules. This tends to accumulation of population at E_2 level. In addition, as the gaseous mixture gets heated, E_2 level being close to the ground state E_1, tends to get populated due to thermal excitations. Therefore, E_2 level needs to be depopulated or else it will inhibit laser excitation. The presence of helium, in the gas mixture, along with CO_2 helps to decrease the population density of E_2 level by de-exciting CO_2 molecules through inelastic collisions. It also helps in cooling the gaseous mixture through heat conduction. CO_2 laser operates in CW (continuous wave) mode and is capable of generating high powers of the order of several kilowatts (for CW 10^4 W and for pulsed 10^7 W) at a high efficiency of ~ 40%.

Q. 1. b) Derive an expression for Numerical aperture (NA) of an optical fibre. **[6]**

Ans.: **Diagram- 2M, Derivation- 4M.**

An optical fibre has three co-axial regions. The innermost region is the region guiding the light, known as the core. It is surrounded by a coaxial middle region known as the cladding. The outermost region is known as a sheath. The cladding has a refractive index that is always lower than that of the core. Its purpose is to confine light to the core. Light entering the core and striking the core-cladding interface at an angle greater than the critical angle will be reflected back into the core. The reflected light will continue to rebound and propagate through the fibre. The function of the sheath is to protect both core and cladding from abrasions, contamination and moisture. It also increases the mechanical strength of the fibre.

The main function of an optical fibre is to accept and transmit as much light from the source as possible. The light gathering ability of a fibre is decided by two factors, core size and the numerical aperture (NA). NA, in turn, is determined by the acceptance angle and the fractional refractive index change.

Consider an optical fibre into which light is launched. The end of the fibre at which light is launched is called as the 'launching end'. Let n_1 be the refractive index of the core and n_2 be that of the cladding which is less than n_1. Let n_o be the refractive index of the medium from which light is launched into the fibre.

Fig. below shows a light ray entering the fibre at an angle θ_i to the axis of the fibre. The ray refracts at an angle θ_r and strikes the core-cladding interface at an angle φ. As $n_1>n_2$, if the refracted ray strikes the core-cladding interface at an angle greater than the critical angle ($\varphi>\varphi_c$), the ray undergoes total internal reflection at the interface. As long as $\varphi>\varphi_c$, the light will stay within the fibre.

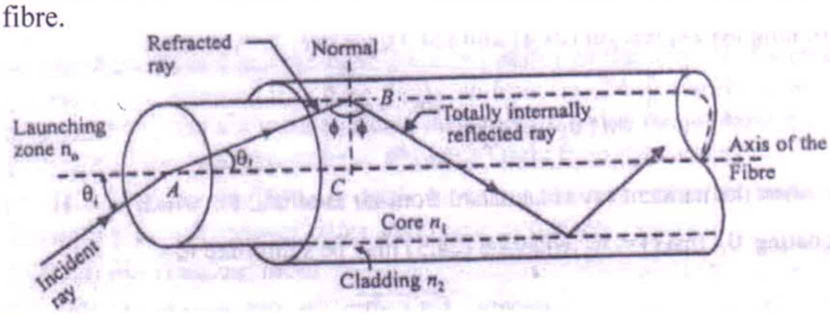


Fig. Illustration of the path of a light ray incident on the end of an optical fibre at an angle θ_i to the axis

To find the angle of incidence θ_i for which $\varphi \geq \varphi_c$ such that light rebounds within the fibre, using Snell's law at the launching face of the fibre,

$$\frac{\sin\theta_i}{\sin\theta_r} = \frac{n_1}{n_o} \qquad (1)$$

If θ_i is increased beyond a limit, ϕ will drop below a critical value ϕ_c and the ray will escape from the side walls of the fibre. θ_i has the largest value when $\phi = \phi_c$.

From ΔABC

$$\sin\theta_r = \sin(90 - \phi) = \cos\phi \qquad (2)$$

Substituting (2) in (1), and designating angle of incidence as θ_0 for maximum angle of incidence which is accepted by the optical fibre for which there is total internal reflection, i.e., $\emptyset = \emptyset_c$, we have

$$\sin\theta_0 = \frac{n_1}{n_o}\cos\phi_c \tag{3}$$

But $\sin\phi_c = \frac{n_2}{n_1}$

$$\therefore \cos\phi_c = \frac{\sqrt{n_1^2 - n_2^2}}{n_1} \tag{4}$$

Substituting (4) in (3)

$$\sin\theta_i(\max) = \frac{n_1}{n_o}\,\frac{\sqrt{n_1^2 - n_2^2}}{n_1}$$

$$= \frac{\sqrt{n_1^2 - n_2^2}}{n_o} \tag{5}$$

When the incident ray is launched from air, $n_o = 1$.

$$\sin\theta_o = \sqrt{n_1^2 - n_2^2} \tag{6}$$

$$\therefore \theta_o = \sin^{-1}\sqrt{n_1^2 - n_2^2} \tag{7}$$

Angle θ_o is called acceptance angle of the fibre.

Acceptance angle is defined as the maximum angle that a light ray can make with the axis of the fibre and propagate along with it.

The light rays contained within the cone having a full angle $2\theta_o$ are accepted and transmitted along the fibre. This cone is called the acceptance cone. The larger the diameter of the core, the larger is the acceptance angle. Light incident beyond the angle θ_o refracts through the cladding and the corresponding optical energy is lost.

Fractional refractive index change:

The fractional index (Δ) between the refractive indices of the core and the cladding is known as fractional refractive index. It is expressed as

$$\Delta = \frac{n_1 - n_2}{n_1} \tag{8}$$

As n_1 must be larger than n_2 for total internal reflection to occur, Δ is always positive. In order to guide light rays effectively through a fibre, Δ<<1 and is typically of the order of 0.01.

Numerical Aperture (NA): Numerical aperture is defined as the sine of the acceptance angle.

$$\therefore NA = \sin\theta_o$$

$$= \sqrt{n_1^2 - n_2^2} \tag{9}$$

$$n_1^2 - n_2^2 = (n_1 + n_2)(n_1 - n_2)$$

$$= \frac{(n_1 + n_2)}{2}\cdot\frac{(n_1 - n_2)}{n_1}\cdot 2n_1$$

Approximating $\frac{n_1 + n_2}{2} \approx n_1$, we have

$$n_1^2 - n_2^2 = 2n_1^2\cdot\Delta$$

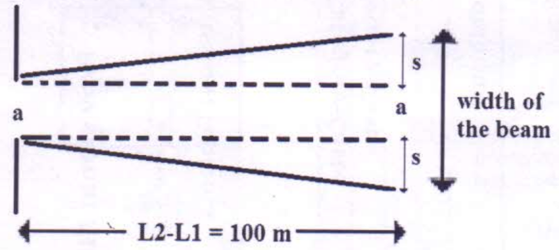
$$\therefore NA = n_1\sqrt{2\Delta} \tag{10}$$

Q. 1. c) Laser beam comes out of a diode laser ($\lambda = 8732$ Å) through a rectangular slit with width 1 mm. Calculate the width of the beam at a distance of 100 m from the source. **[4]**

Ans.: Formula: $a \sin\theta = n\lambda$. $\therefore \theta = \sin^{-1}(\lambda/a) = 0.05$ and

$\tan \theta = s/(100\times10^3)$ gives $s = 87$ mm.

Width = a+2s = 1 + 2(87) = **175 mm**.



Q. 2. A) Describe with the help of neat diagrams, construction and working of Single Hetero-junction diode laser. **[6]**

Ans.: **Construction diagram- 1M, Energy level diagram- 1M, Construction- 2M, working-2M.**

Hetero-junction/structure Diode Laser: Semiconductor lasers are of two types, (i) Homo-junction laser and (ii) Hetero-junction laser.

Principle: Charge carriers are confined to a narrow region so that population inversion is achieved at lower current (diode current in forward bias). This results in laser action beginning at lower threshold current and the laser can be operated continuously at room temperature.

Construction: A SH laser is fabricated by growing a layer of GaAlAs on GaAs. A thin ($\approx$0.1-0.2 μm) region of p-type GaAs is sandwiched between n-GaAs and p-GaAlAs. GaAlAs has a larger band gap of 2.15 (and lower refractive index) than GaAs with a bandgap of 1.424.

For forming the optical resonator cavity, external mirrors are not required in a diode laser. A pair of parallel planes are cleaved at the two ends of the hetero-junction structure. This provides the required reflection of light to form the resonant cavity. The two remaining sides of the structure are roughened. This eliminates lasing occurring in directions other than the main axis of the structure. Such a structure is called as Fabry-Perot cavity. The top and bottom faces are metalized and ohmic contacts are provided to pass current through the SH structure.

Working: In a normal pn junction, the electrons that are injected by the n region diffuse into the p material and population inversion occurs for only a part of the electrons near the junction. In the SH laser, the narrow p-GaAs layer becomes the active region. When a positive bias is applied to the device, electrons are injected from the n-GaAs into the active p-GaAs. An equal density of holes are injected by the p-GaAlAs. The electrons that are injected into the active region (p-GaAs) by the n-GaAs layer are prevented from diffusing into p-GaAlAs, i.e., are confined to a narrow region, by means of the potential barrier (ΔE due to the difference between energy gaps of GaAs and GaAlAs) provided by the larger band gap p-GaAlAs layer. The change of refractive index at the hetero-junction also helps in confining light in this region. If the thickness of the active region is made small, a smaller forward bias current can lead to population inversion and lasing action.

Fig. below gives the schematic of a SH laser and its action in confining the charge carriers and light in the active region (region 2). In this region, electrons are present in the conduction band and there are empty states or holes in the valence band which leads to population inversion when current is injected in the forward bias. Spontaneously emitted photons lead to stimulated emission due to this population inversion. This leads to a large gain in region 2. In region 1, the states at the bottom of the conduction band and top of the valence band are filled and hence there cannot be any transition and hence no production of light. In region 3, the corresponding states are empty hence no production of light. Therefore there is loss in regions 1 and 3.

An optical cavity is formed by preparing two surfaces parallel to each other and perpendicular to the depletion layer. This is done by cleaving (breaking) the crystal. No mirrors are required here because the reflectivity of these surfaces is high due to large difference in the refractive index of GaAs (3.66) and air (1).

Reflectivity

$$R = \left(\frac{\mu_1 - \mu_2}{\mu_1 + \mu_2}\right)^2 = \left(\frac{3.66 - 1}{3.66 + 1}\right)^2 = 0.33$$

i.e. 33%.

The remaining 4 surfaces are roughened so that light is scattered and lost.

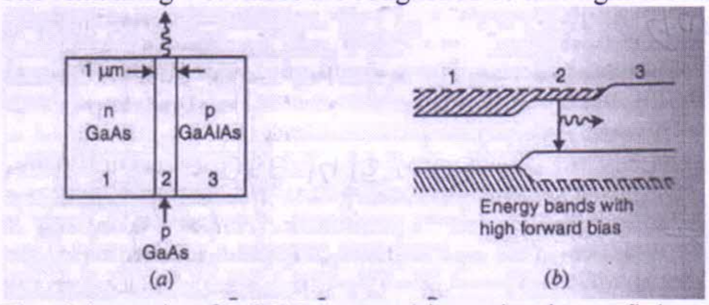


Fig. Schematic of a SH Laser and its action in confining the charge carriers and light in the active region

The refractive index p-GaAs (region 2) is larger than that for n-GaAs (region 1) by 1% and by 5% than that for p-GaAlAs (region 3). This leads to confinement of the photons in region 2 where there is a large gain due to stimulated emission.

Q. 2. b) Explain, with the help of neat diagrams, the role of optical cavity in directionality, monochromaticity and coherence of a laser. **[6]**

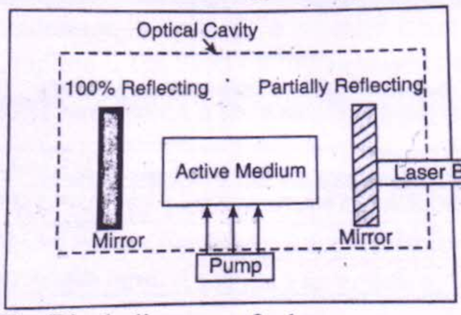
Ans.: **Diagram- 1.5M, Directionality- 1.5M, Monochromaticity with formula- 1.5M, Coherence- 1.5M.**

Optical cavity: An optical cavity is formed by two parallel mirrors containing the active medium. One of the mirrors is perfectly reflecting and the other is partially reflecting.

Directionality: Only those photons which are travelling perpendicular to the mirrors traverse the active medium repeatedly and produce their replicas through stimulated emission. This makes the laser beam highly directional and has very less divergence. Photons travelling in all other directions are eventually lost from the sides of the active medium.

Coherence: The laser beam comes out of the mirror with partial reflectivity. Since all the photons have almost the same original photon, they have the same initial phase and hence the laser has high degree of coherence.

Monochromaticity: Apart from confining selected photons, the optical cavity also selects photons with particular wavelength. The length of the optical cavity, can be fine tuned so that the it accommodates integral multiple of half of the desired wavelength $\lambda_m = \frac{2\mu L}{m}$, where m is the mode number, L is the length of the cavity, μ is the refractive index of the medium. The laser beam therefore has much higher degree of monochromaticity than normal sources.



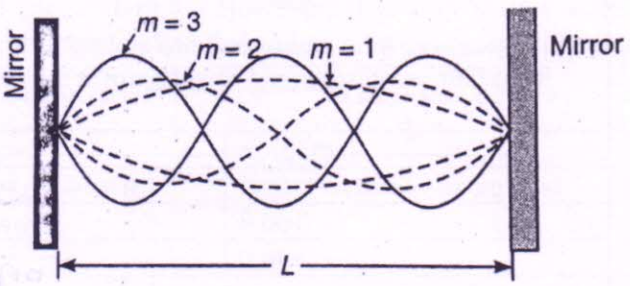


Fig. Block diagram of a laser

Q. 2. c) Population inversion is obtained in a CO_2 laser. The ratio of number of molecules in the higher energy state to that in the lowest energy state (N2/N1) is 1.5. Calculate the equivalent temperature for laser wavelength λ = 9.6 µm. Given, k = 1.38 × 10^{-23} J/K. **[4]**

Ans.: $E_2 - E_1 = \frac{1.24}{9.6\ \mu m} = 0.1292$ eV

$$\frac{N_2}{N_1} = e^{\frac{-(E_2-E_1)}{KT}} \qquad T = \frac{-(E2-E1)}{k\ln(\frac{N2}{N1})} = \mathbf{-3705\ K}$$

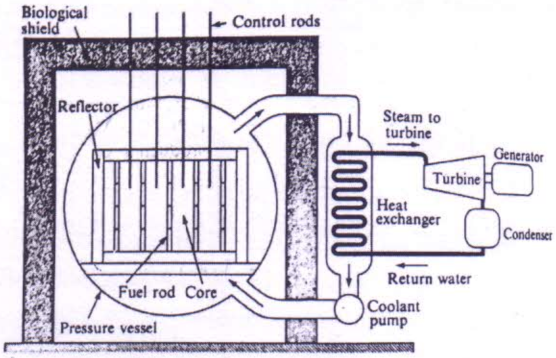
Q. 3. A) Draw a neat diagram of a nuclear fission reactor and explain its construction and working.

[6]

Ans.: **Diagram- 2M, Construction and working- 4M.**

Nuclear reactor: Nuclear reactor uses natural uranium as the fuel. Natural Uranium has only 0.72% of U^{235} which is fissionable by slow neutrons with cross section for fission ~ 579 barns. U^{238} constitutes 99.2745% of the natural Uranium but has very low fission cross section ~ 2.7×10^{-6} barns. Nuclear reactor consists of following blocks.

Fuel rods: Core of the reactor contains the fuels rods made of natural Uranium. Since Uranium undergoes corrosion very easily it is usually encapsulated by Zr or Ti protective layer.



Moderator: The neutrons generated due to fission are fast neutrons with energy ~ 1-2 MeV. The cross section for fission of U^{235} by fast neutrons is extremely small (~ 10^{-6} barns). On the other hand, cross section for fission of U^{235} by slow neutrons (energy less than few eV) is 579 barns, which is almost eight orders of magnitude higher than that for fast neutrons. The fast neutrons therefore have to be slowed down. This is achieved by inelastic scattering from nuclei of a moderator. A good moderator should not only have a high cross section of inelastic scattering but also a small cross section for absorption as absorption will lead to decrease in the number of neutrons which is not desirable.

Water has the largest cross section for inelastic scattering because it contains proton (nucleus of hydrogen). The neutron transfers its energy efficiently to proton through resonance transfer due to comparable masses. However, it has a large cross section for absorption. Heavy water (Deuterium oxide-D_2O) has a very small cross section for absorption and hence is suitable moderator in spite of a smaller cross section for scattering. However, it is exorbitantly costly. Graphite is the third option and used as a moderator quite often due to low cost and reasonably good scattering and low absorption coefficients. Graphite is mixed with Uranium in the fuel rods.

Material	σ_s (barns)	σ_a (barns)
H_2O	49.2	0.66
D_2O	10.6	0.001
Graphite	4.7	0.0045

Control rods: Nuclear reaction a reactor is self sustained due to chain reaction. A random fission gives the first few neutrons which lead to initial fissions. Each fission gives rises to 2-3 neutrons. These neutrons increase in geometric progression. If uncontrolled, this could lead to explosion. Control rods, made of materials that have large cross section for absorption of neutrons, are therefore used.

Material	Neutron absorption cross section σ_a (barns)	Natural Abundance	Mechanical property	Rod formation
B^{10}	3835	20%	Brittle	B or B_4C stuffed in hollow metal rods
Cd^{113}	20600	12%	Not malleable	Alloyed with In and Ag
Hf^{174}	561	0.2%	Good	Rods of pure Hf

Core enclosure: The core of the reactor containing fuel rods, moderator and control rods is enclosed by wall made of Ni or Th which are good reflectors of neutrons. This ensures minimum leakage of neutrons.

Pressure vessel and heat exchanger: The core is placed in a pressure vessel. The energy generated in the nuclear reaction is converted to heat in the core and this heat is harnessed by the coolant in the pressure vessel. Typical coolants are H_2O, D_2O or liquid metal, etc. Heat carried away by the coolant is then transferred to water through a heat exchanger. The water turns into steam and runs a turbine. A generator connected to the turbine then generates electricity. The steam is condensed and re-circulated through the heat exchanger.

Biological Shield: The complete reactor is enclosed by 2m thick cement concrete wall called biological shield. It shields the outside world from radiation emanating out of the reactor.

Q. 3. b) With the help of a potential energy diagram, explain fission on the basis of liquid drop model. **[4]**

Ans.: **Labelled diagram- 2M, Explanation- 2M.**

A nucleus can be thought to be similar to a liquid drop. A nucleon deep inside the nucleus is surrounded by nucleons from all the sides. However, a nucleon at the surface is pulled towards the centre as there are no nucleons above the surface. This gives rise to surface energy. For a large nucleus like U^{235}, the surface energy term and electrostatic terms together leads to a potential energy curve near the barrier as shown in Fig.

When a slow neutron interacts with U^{235}, it gives rise to a compound nucleus U^{236} and an energy equivalent of neutron binding energy is given out due to mass defect. This generated energy could be given out a γ-ray photon by radiative transition or it could excite the compound nucleus U^{236} into its vibrational mode. The excited compound nucleus is the represented as $(U^{236})^*$ with an excited energy equal to the neutron binding energy BE shown in Fig. below. The neutron binding energy U^{235} which is equal to the excitation energy of $(U^{236})^*$ is larger than the activation energy to overcome the coulomb barrier and hence the compound nucleus breaks up into fragment nuclei accompanied by emission of two to three fast neutrons. The cross-section for fission σ_f = 579 barns. Cross section in Nuclear Physics is proportional to probability of occurrence of that event. 1 barn = 1 b = 10^{-24} cm^2.

There are several combinations of fragment nuclei that could be produced in this fission reaction. One of them is shown below.

$$n^1 + U^{235} \rightarrow (U^{236})^* \rightarrow La^{147} + Br^{87} + 2n^1$$

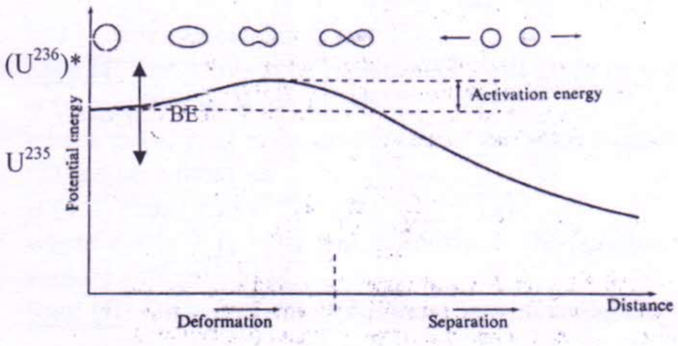


Fig. Potential energy for a liquid drop model

For U^{238} with neutron binding energy less than activation energy and hence the fission cross section is eight orders of magnitude smaller than that for U^{235}. U^{235} is therefore fissile material whereas U^{238} is not.

Q. 3. C) Calculate the energy of the ground state of a neutron trapped in a infinite potential well of width L= 10^{-14} m. Given mass of neutron = 1.67×10^{-27} kg, h = 6.63×10^{-34} J-sec. **[4]**

Ans.: $E = \frac{n^2h^2}{8mL^2}$ = **3.29×10^{-13} J = 2.05 MeV**.

Q. 4. a) Derive Schrodinger time independent equation. **[6]**

Ans.: **Introduction- 1M, Derivation- 5M.**

Schrodinger time independent equation: A wave, in general, is represented by a differential equation of the type

$$\frac{\partial^2 y}{\partial t^2} = v^2 \frac{\partial^2 y}{\partial x^2}$$

The solution of this equation is

$$y = Ae^{-i(\omega t - kx)}$$

Where, A is the amplitude, y is the displacement, $\omega = 2\pi v$ is the angular frequency and $k = \frac{2\pi}{\lambda}$.

- Starting with De-Broglie's idea of matter waves, Schrodinger in 1926 developed it into a mathematical theory known as wave mechanics.
- Consider a particle of mass m moving with velocity v. Let (x, y, z) be the co-ordinates representing the position of the particle at time t.
- According to De Broglie's hypothesis, this particle is associated with a wave system having wave length.

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

Where, p = mv = momentum of particle.

Step I: Let ψ be the wave variable associated with the matter waves. ψ is a function of x, y, z and t. In analogy with the equation $\frac{\partial^2 y}{\partial t^2} = v^2 \frac{\partial^2 y}{\partial x^2}$, we can write the differential equation for the matter waves in (3 dimensions) with wave velocity u as

$$\frac{\partial^2 \psi}{\partial t^2} = u^2 \left[\frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} + \frac{\partial^2 \psi}{\partial z^2} \right]$$

$$\text{or} \quad \frac{\partial^2 \psi}{\partial t^2} = u^2 \cdot \nabla^2 \psi \qquad \ldots(1)$$

$$\text{Where } \nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$$

and is called Laplacian operator.

Step II: The solution of Equation (1) will gives us ψ as a function of space and time. Let it be,

$\psi(x, y, z, t) = \psi_0(x, y, z) \cdot e^{-i\omega t}$ ...(2)

where $\psi_0(x, y, z)$ is the amplitude of the wave at point (x, y, z) and is a function of x, y, z. Equation (2) can be written as,

$\psi(r, t) = \psi_0(r) \cdot e^{-i\omega t}$ ...(3)

where $\mathbf{r} = \mathbf{i}x + \mathbf{j}y + \mathbf{k}z$ and is known as the position vector of the point (x, y,z) and **i, j, k** are unit vectors along the axes.

Step III: Differentiating Equation (3) with respect to t, we have,

$$\frac{\partial \psi}{\partial t} = -i\omega\psi_0 \cdot e^{-i\omega t}$$

$$\therefore \quad \frac{\partial^2 \psi}{\partial t^2} = i^2\omega^2\psi_0 e^{-i\omega t}$$

$$\text{or} \quad \frac{\partial^2 \psi}{\partial t^2} = -\omega^2\psi \quad ...(4) \quad \left(\text{Since } i^2 = -1 \text{ and } \psi_0 \cdot e^{-i\omega t} = \psi\right).$$

$\therefore$ From Equations (1) and (4) we have

$$u^2 \cdot \nabla^2\psi = -\omega^2\psi$$

$$\text{or} \quad \nabla^2\psi + \frac{\omega^2}{u^2} \cdot \psi = 0 \qquad ...(5)$$

Step IV:

$$\text{Now,} \quad \omega = 2\pi\upsilon \text{ and } u = \upsilon \cdot \lambda$$

$$\text{Where,} \quad \upsilon = \text{frequency of waves}$$

$$\therefore \frac{\omega}{u} = \frac{2\pi\upsilon}{\upsilon\lambda} = \frac{2\pi}{\lambda} \qquad ...(6)$$

Hence Equation (5) becomes.

$$\nabla^2\psi + \frac{4\pi^2}{\lambda^2} \cdot \psi = 0 \qquad ...(7)$$

The De Broglie wavelength of the particle is given by,

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

Hence Equation (7) can be written as,

$$\nabla^2\psi + \frac{4\pi^2 \cdot p^2}{h^2} \cdot \psi = 0 \qquad ...(8)$$

Step V: The total energy E of the particle is the sum of kinetic and potential energies.

$$\therefore \quad E = \frac{1}{2} mv^2 + V \; (V = P.E) = \frac{1}{2m} \cdot m^2v^2 + V$$

$$E = \frac{p^2}{2m} + V$$

$$\therefore \quad P^2 = 2m(E - V) \qquad ...(9)$$

Step VI: Putting this value of in Equation (8) we have,

$$\nabla^2 \psi + \frac{4\pi^2}{h^2} \cdot 2m (E - V) \psi = 0$$

Putting $\frac{h}{2\pi} = \hbar$ we have

$$\nabla^2 \psi + \frac{2m}{\hbar^2} \cdot (E - V) \psi = 0 \quad ...(10)$$

Equation (10) is known as Schrodinger's time independent equation in three dimensions. Schrodinger's time independent equation in one dimensions is

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

Q. 4. b) Parameters of three moderator are tabulated below: **[4]**

Material	σ_s (barns)	σ_a (barns)	Cost
H_2O	49.2	0.66	Low
D_2O	10.6	0.001	High
Graphite	4.7	0.0045	Moderate

Where, σ_s is scattering cross-section and σ_a is absorption cross-section. On the basis of this information, discuss merits and demerits of these moderator materials.

Ans.: **In totality- 4M.**

The neutrons generated due to fission are fast neutrons. The cross section for fission of U^{235} by fast neutrons is extremely small. On the other hand, cross section for fission of U^{235} by slow neutrons is higher. The fast neutrons therefore have to be slowed down. This is achieved by inelastic scattering from nuclei of a moderator.

A good moderator should not only have a high cross section of inelastic scattering but also a small cross section for absorption as absorption will lead to decrease in the number of neutrons which is not desirable.

Water has the largest cross section for inelastic scattering because it contains proton (nucleus of hydrogen). The neutron transfers its energy efficiently to proton through resonance transfer due to comparable masses and also cost wise it is effective. But, it has a large cross section for absorption which decreases the number of neutrons in the reactor.

Heavy water (Deuterium oxide-D_2O) has a very small cross section for absorption and hence is suitable moderator in spite of a smaller cross section for scattering. However, it is exorbitantly costly.

Graphite is the third option and used as a moderator quite often due to low cost and reasonably good scattering and low absorption coefficients. Graphite is mixed with Uranium in the fuel rods.

Q. 4. c) Calculate the binding energy per nucleon for $_{92}U^{235}$. Given, mass of U^{235}, proton and neutron as 235.0439299 amu, 1.007276 amu and 1.008665 amu respectively. **[4]**

Ans.: $\Delta m = [(92\times1.007276)+(143\times1.008665)] - 235.0439299 = 1.8645571$ amu

BE = 1.8645571 amu × 931.5 MeV/amu = 1743.36 MeV

BE/A = (1743.36 MeV / 23) = **7.4 MeV**

Q. 5. MCQs **(1 × 20 = 20 Marks)**

a) Sound waves with frequency > 20 kHz is called **(iii) ultrasound**.

b) Variation of Loudness of sound with its intensity is **(iv) logarithm to the base 10.**

c) Ultrasound with high frequency is used in ultrasonic non-destructive testing because smaller wavelength gives **(iv) all of the above.**

d) Thickness of a quartz crystal generating ultrasound determines its **(i) frequency.**

e) Reverberation time of an auditorium will decrease if **(i) chairs in the auditorium are made softer.**

f) A film is said to be thin if its thickness is smaller than **(ii) coherence length of light.**

g) If μ_1, μ, μ_2 are the refractive indices of air, anti-reflection coating (ARC) and glass, respectively, then the ARC has maximum efficiency if μ = **(iii)** $(\mu_1\mu_2)^{1/2}$.

h) When monochromatic light with wavelength λ is incident on a slit with width a, maximum diffraction occurs when **(i)** $a < \lambda$.

i) Keeping all other parameters same, if the value of grating element is decreased then grating's **(ii) dispersion increases.**

j) Light from sodium vapour lamp is diffracted using diffraction grating. Two prominent lines have wavelengths 5890 Å and 5896 Å. If the angle of diffraction in the first order is θ(5890) and θ(5896) then **(iii)** $\theta(5890) < \theta(5896)$.

k) In an unbiased p-n junction diode **(i) intrinsic Fermi energy E_{Fi} is higher on the p-side than that on the n-side.**

l) The barrier potential V_{bi} in a p-n junction diode depends on **(iv) all of the above.**

m) In an n-type semiconductor, the value of $E_F - E_{Fi}$ increases with **(ii) increase in doping concentration of pentavalent impurity.**

n) For two samples A and B of n-type semiconductor, the doping concentration of donor impurities is 1×10^{20} m^{-3} and 3×10^{20} m^{-3}, respectively. If the hole concentration in sample A is 9×10^{12} m^{-3}, then the hole concentration in sample B is **(i)** 3×10^{12} **m^{-3}.**

o) In an intrinsic semiconductor, the Fermi energy lies at the centre of **(iii) forbidden band.**

p) Sun light is converted to electrical energy by **(i) photovoltaic effect.**

q) For a solar PV cell current is equal to I_{sc} when the load resistance is **(iii) zero.**

r) A solar PV panel is kept at a latitude such that the sun is overhead at 12 noon. Sun beam will go through air mass AM1.2 at an angle of **(ii)** 33.6^0 w.r.t. vertical.

s) Texturing of the surface of solar PV cell is done to **(ii) increase light refracted into solar cell.**

t) If the band gap of the solar cell material is 1.44 then it will not absorb light of wavelength **(iv) 9000 Å.**