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SCHEME FOR PHYSICS Internal Assessment Test 1 – November 2024

Sub:	Physics for CSE stream					Sub Code:	BPHYS102	Branch:	ISE/AIDS/AIML/CSE-AIML
Date:	20/11/2024	Duration:	90 mins	Max Marks:	50	Sem/Sec:	II Sem / A, B, C, D, E, F, G, H		OBE

Answer any FIVE FULL Questions

Given: $c = 3 \times 10^{8}$ m/s; $h = 6.625 \times 10^{-34}$Js; $k = 1.38 \times 10^{-23}$ J/K; $m_e = 9.1 \times 10^{-31}$kg; $e = 1.6 \times 10^{-19}$C

Q		Question / Scheme	MARKS	CO	RBT
1	(a)	Explain the principle of a semiconductor diode laser and hence describe its construction and working. Principle : 1 mark Diagram: 2 mark Construction -2 mark Working - 2mark	[07]	CO1	L2
	(b)	The width of a spectral line of wavelength 6328Å is 10^{-4}Å. Evaluate the minimum time spent by the electron in the upper energy state between the excitation and de-excitation processes. Formula - 1Mark Calculation -1 Mark Accurate result - 1 mark	[03]	CO1	L3
2	(a)	Derive time independent Schrodinger wave equation for a particle moving in one dimension. Formulae for K, lamda, : 2 mark Differentiation and simplification : 4 mark Final result : 1 mark	[07]	CO1	L2
	(b)	The ratio of population of two energy levels is 1.563 X 10^{-25}. Find the wavelength of the light emitted at 27°C. Formula - 1Mark Calculation -1 Mark Accurate result - 1 mark	[03]	CO1	L3
3	(a)	State and explain Heisenberg's uncertainty principle and show that electrons cannot exist in the nucleus of an atom. Explanation of Principle : 2mark Logical deduction: 4 mark Conclusion: 1mark	[07]	CO1	L2
	(b)	Calculate the de Broglie wavelength of an electron of mass 0.65 MeV/c^2 moving with a kinetic energy of 200eV.	[03]	CO1	L3

Formula - 1Mark
Calculation -1 Mark
Accurate result - 1 mark

Q		Question / Scheme	MARKS	CO	RBT
4	(a)	Explain the various interaction of radiation with matter and hence obtain the expression for energy density using Einstein's A and B coefficients. Also draw inference on the condition $B_{12}=B_{21}$. Explanation : 3 mark Logical deduction: 3 mark Conclusion: 1mark	[7]	CO1	L2
	(b)	Write about any two attenuation mechanisms in an optical fiber. Mechanism 1 : 1.5 mark	[3]	CO1	L2

	Mechanism 1 : 1.5 mark			
5 (a)	Define numerical aperture. Derive an expression for numerical aperture and arrive at the condition for propagation of light. Definition: 1 mark Diadram & explanation: 2 mark Derivation : 3 mark Final condition : 1 mark	[7]	CO1	L2
(b)	Calculate the probability of finding an electron in a one dimensional potential well of width 'L' between x= L/4 and x=3L/4 in its first excited state. Formula - 1Mark Calculation -1 Mark Accurate result - 1 mark	[3]	CO3	L3
6 (a)	Find the eigen function and energy eigen values for a particle in a one-dimensional potential well of infinite height. Derivation of Eigen function: 3 mark Derivation of Eigen value : 3 Mark Diagram: 1Mark	[7]	CO3	L2
(b)	The attenuation of light in an optical fiber is 0.812 dB/Km. What fraction of its initial intensity remains after 800m. Formula - 1Mark Calculation -1 Mark Accurate result - 1 mark	[3]	CO1	L3
7 (a)	What are modes and refractive index profile? Discuss the different types of optical fibers with relevant figures. Definition of Mode -1 mark Definition of Profile - 1 mark Explanation of 3 types - 5 mark	[7]	CO1	L2
(b)	A LASER pulse with an output power of 5mW lasts for a duration of 8 ns. Calculate the wavelength of LASER if the number of photons emitted per pulse is 5.61×10^8. Formula - 1Mark Calculation -1 Mark Accurate result - 1 mark	[3]	CO1	L3
8 (a)	With the help of a block diagram discuss point to point communication system using an optical fiber. Mention its advantages and disadvantages. Block diagram: 2mark Explanation of Parameters : 3 mark Advantages & Disadvantages : 2 mark	[7]	CO1	L2
8 (b)	Determine the energy of an proton having a de Broglie wavelenth of 1.5×10^{-14}m. Also calculate the group velocity if the mass of a proton is 1.67×10^{-27} Kg.	[3]	CO1	L3

Formula - 1Mark
Calculation -1 Mark
Accurate result - 1 mark

IAT -1 PHYSICS SOLUTION

1A

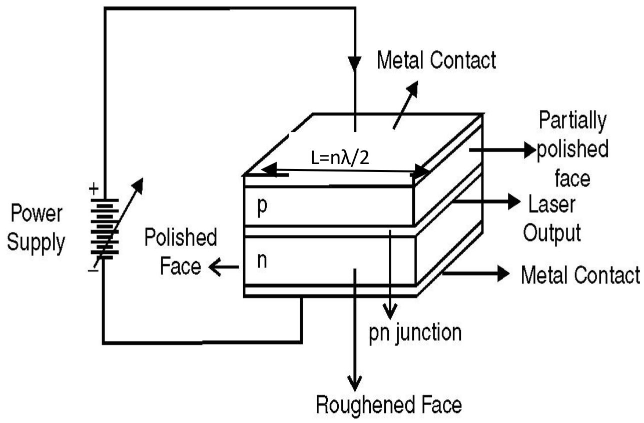
Gallium – Arsenide Semiconductor laser :

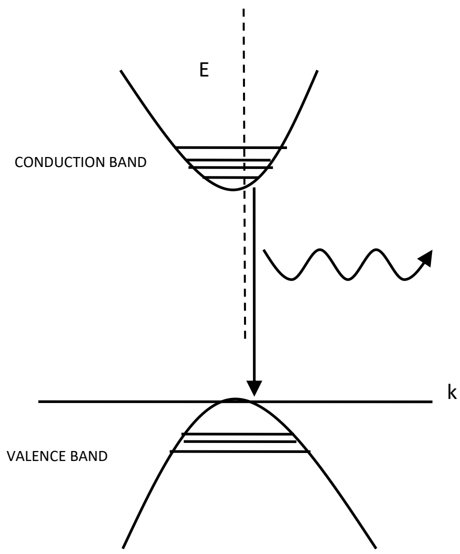
It is the only device which can be used for amplification in the infrared and optical ranges.

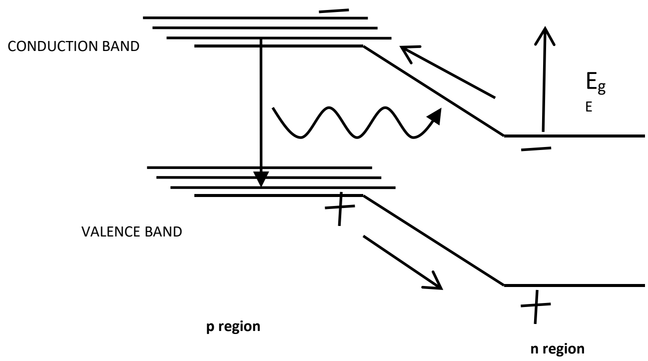
CONSTRUCTION

Gallium Arsenide is heavily doped with Tellurium (n side) and Zinc (P side) to a concentration of 10^{19} atoms /cm^3. Resonant cavity is formed by polishing the end faces of Junction diode.

Amplification is possible if the population of the valence and conduction bands could be inverted as shown in the diagram.







WORKING

The first laser action was observed in a GaAs junction(8400Å) which is a direct gap semiconductor.

When a heavily doped junction is forward biased, electrons from n side are injected into p side causing population inversion. They combine with holes on the P side releasing photons. The junction region is the active region .The optical cavity is formed by the faces of the crystal itself which are taken on the cleavage plane and are then polished. The wavelength of the radiation depends on temperature. The wavelength of laser increases as the energy gap decreases. The frequency can be increased to the optical region by alloying with phosphor according to the relation $Ga(As)_{1-x}P_x$.

If E_g is the energy gap, then $E_g = eV_{forward} = \frac{hc}{\lambda}$

1B

$$\Delta E \times \Delta t = \frac{h}{4\pi}$$

$$lifetime\ \Delta t = \frac{h}{4\pi.\Delta E}$$

$$E = \frac{hc}{\lambda}$$

$$\Delta E = -\frac{hc}{\lambda^2}\Delta\lambda = \frac{6.62x10^{-34}x3x10^8}{(6328x10^{-10})^2}x10^{-14}$$

$$\Delta t = 1.06x10^{-8}s$$

2A

Time independent Schrödinger equation

A matter wave can be represented in complex form as

$$\Psi = A\sin kx(\cos wt + i\sin wt)$$

$$\Psi = A\sin kxe^{iwt}$$

Differentiating wrt x

$$\frac{d\Psi}{dx} = kA\cos kxe^{iwt}$$

$$\frac{d^2\Psi}{dx^2} = -k^2A\sin kxe^{iwt} = -k^2\Psi \text{ .... (1)}$$

From Debroglie's relation

$$\frac{1}{\lambda} = \frac{h}{mv} = \frac{h}{p}$$

$$k = \frac{2\pi}{\lambda} = \frac{2\Pi p}{h}$$

$$k^2 = 4\Pi^2 \frac{p^2}{h^2} \quad \ldots\ldots\ldots\ldots\ldots. (2)$$

Total energy of a particle

E = Kinetic energy + Potential Energy

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

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

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

Substituting in (2)

$$k^2 = \frac{4\Pi^2 (E - V)2m}{h^2}$$

$\therefore$ From (1)

$$\frac{d^2\Psi}{dx^2} + \frac{8\Pi^2 m(E - V)\Psi}{h^2} = 0$$

For 3D

$$\frac{d^2\Psi}{dx^2} + \frac{d^2\psi}{dy^2} + \frac{d^2\psi}{dx^2} + \frac{8\Pi^2 m(E - V)\Psi}{h^2} = 0$$

2B

$$\frac{N_g}{N_e} = e^{\frac{hc}{\lambda kT}}$$

$$T = 300K$$

$$\frac{N_e}{N_g} = 1.56x10^{-25} = e^{-\frac{hc}{\lambda kT}}$$

$$\ln\left(\frac{N_e}{N_g}\right) = -\frac{hc}{\lambda kT}\ln_e e$$

$$\lambda = -\frac{hc}{kT\ln\left(\frac{N_e}{N_g}\right)} = 841nm$$

3A

HEISENBERG'S UNCERTAINTY PRINCIPLE:

The position and momentum of a particle cannot be determined accurately and simultaneously. The product of uncertainty in the measurement of position (Δx) and momentum is always greater than or equal to $\frac{h}{2\Pi}$.

(1 mark)

$$(\Delta x).(\Delta p) \geq \frac{h}{4\Pi}$$

TO SHOW THAT ELECTRON DOES NOT EXIST INSIDE THE NUCLEUS:

We know that the diameter of the nucleus is of the order of 10^{-15}m.If the electron is to exist inside the nucleus, then the uncertainty in its position Δx cannot exceed the size of the nucleus

$$\Delta x = 5x10^{-15}m$$

Now the uncertainty in momentum is

$$\Delta x = 5x10^{-15}m$$

$$\Delta P = \frac{h}{4\pi x\Delta x} = 0.1x10^{-19}kg.m/s$$

Then the momentum of the electron can atleast be equal to the uncertainty in momentum.

$$P \approx \Delta P = 0.1x10^{-19}kg.m/s$$

Now the energy of the electron with this momentum supposed to be present in the nucleus is given by (for small velocities -non-relativistic-case)

$$E = \frac{p^2}{2m} = 5.5x10^{-11}J = 343MeV$$

The beta decay experiments have shown that the kinetic energy of the beta particles (electrons) is only a fraction of this energy. This indicates that electrons do not exist within the nucleus. They are produced at the instant of decay of nucleus ($n \rightarrow p + e + \bar{\nu}$ / $p \rightarrow n + \overset{+}{e} + \nu$).

3B

Mass m = 0.65 MeV/C^2 =0.65x10^{6}x1.6x10^{-19} / (3x10^8)^2
E = 200x1.6x10^{-19} J

$$\lambda = \frac{h}{\sqrt{2mE}} = 7.69x10^{-11} m$$

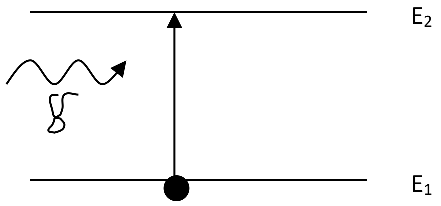
4A

Expression for energy density:

Induced absorption:

It is a process in which an atom at a lower level absorbs a photon to get excited to the higher level.

Let E_1 and E_2 be the energy levels in an atom and N1 and N_2 be the number density in these levels respectively. Let U_γ be the energy density of the radiation incident..



$$\gamma = \frac{E_2 - E_1}{h}$$

Rate of absorption is proportional to the number of atoms in lower state and also on the energy density U_γ.

Rate of absorption = B_{12} N_1U_γ

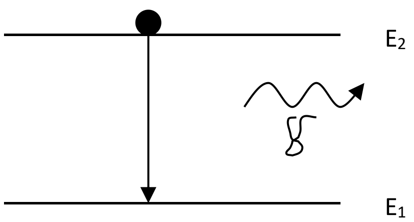
Here B_{12} is a constant known as Einsteins coefficient of spontaneous absorption.

Spontaneous emission:

It is a process in which ,atoms at the higher level voluntarily get excited emitting a photon. The rate of spontaneous emission representing the number of such deexcitations is proportional to number of atoms in the excited state.

Rate of spontaneous emission = A_{21} N_2

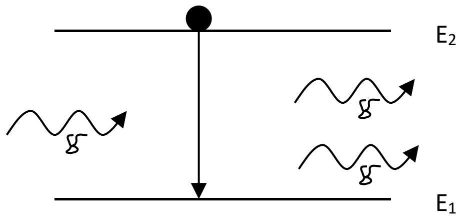
Here B_{12} is a constant known as Einsteins coefficient of spontaneous emission.



$$\gamma = \frac{E_2 - E_1}{h}$$

Stimulated emission:

In this process, an atom at the excited state gets deexcited in the presence of a photon of same energy as that of difference between the two states.



$$\gamma = \frac{E_2 - E_1}{h}$$

The number of stimulated emissions is proportional to the number of atoms in higher state and also on the energy density U_γ.

Rate of stimulated emission = $B_{21}\ N_2U_\gamma$

Here B_{21} is the constant known as Einsteins coefficient of stimulated emission.

At thermal equilibrium,

Rate of absorption = Rate of spontaneous emission + Rate of stimulated emission

$$B_{12}\ N_1U_\gamma = A_{21}\ N_2 + B_{21}\ N_2\ U_\gamma$$

$$U_\gamma = \frac{A_{21}N_2}{B_{12}N_1 - B_{21}N_2}$$

Rearranging this, we get

$$U_\gamma = \frac{A_{21}}{B_{21}}\left[\frac{1}{\frac{B_{12}N_1}{B_{21}N_2} - 1}\right]$$

From Boltzmann's law , $\frac{N_1}{N_2} = e^{\frac{h\gamma}{kT}}$

Hence

$$U_\gamma = \frac{A_{21}}{B_{21}}\left[\frac{1}{\frac{B_{12}}{B_{21}}e^{\frac{h\gamma}{kT}} - 1}\right]$$

From Planck's radiation law,

$$U_\gamma = \frac{8\pi h\gamma^3}{c^3}\left[\frac{1}{e^{\left[\frac{h\gamma}{kT}\right]} - 1}\right]$$

Comparing these expressions, we get

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\gamma^3}{c^3} \text{ and } \frac{B_{12}}{B_{21}} = 1$$

Conclusions

1.Rate of stimulated emission is directly proportional to wavelength

2. Rate of Induced absorption is equal to rate of Stimulated emission

4B

Different loss mechanisms:

1. Absorption losses:

In this case, the loss of signal power occurs due to absorption of photons by the impurities and defects present in glass .Impurities such as Ge- 0 , B-O, absorb in the range of 1-2 µm, chromium and copper ions absorb at 0.6µm.,Fe ions absorb at 1.1µm. Hydoxy ions absorb at 1.38µm. Better techniques of making glass with reduced water content can minimize these losses.Tominimise the absorption loss, impurity content has to be less than 1 part in 10^9.

2. Scattering losses:

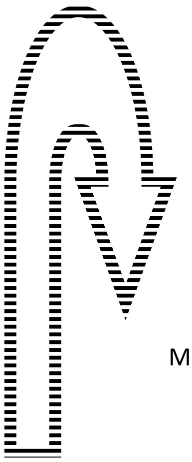
This occurs due to the Rayleigh scattering of the signal caused by variations in refractive index of the glass due to changes in composition, defects, presence of air bubbles, strains etc. The scattered light moves in random direction and escapes from the fiber reducing the intensity. These losses decrease at higher wavelengths.Hence, this loss is minimized by operating at high wavelengths.

$$\text{Scattered Intensity}\,\alpha\,\frac{1}{\lambda^4}$$

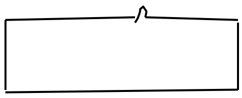
3. Radiation losses:

Radiative losses occur due to bending of fiber.

Macroscopic Bends:This refers to the bends having radii that are large compared to the fibre diameter.These losses are reduced by using lower wavelength and lower numerical aperture. This loss is high at 1550nm.



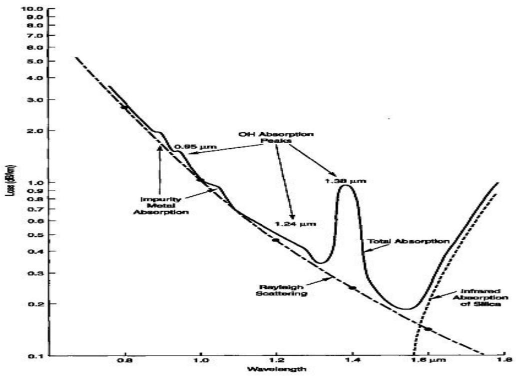
Macro bend



Micro bend

Microscopic bends:

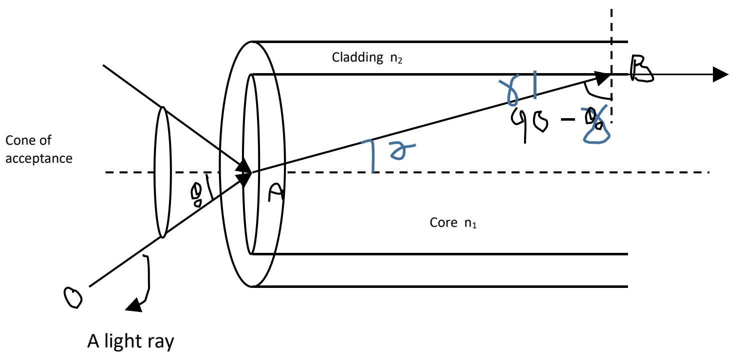
These are repetitive small scale fluctuations in the linearity of the fibre axis.



5A

Sine of angle of acceptance is known as Numerical aperture.

<u>Expression for condition for propagation :</u>



Consider a light ray falling in to the optical fibre at an angle of incidence θ_o equal to acceptance angle. Let n_0 be the refractive index of the surrounding medium .

Let n_1 be the refractive index of the core.

Let n_2 be the refractive index of the cladding.

From Snell's Law:

For the ray OA $n_0 \sin\theta_0 = n_1 \sin r = n_1\left(\sqrt{1-\cos^2 r}\right)$............ (1)

For the ray AB
$$n_1 \sin(90-r) = n_2 \sin 90$$
$$n_1 \cos r = n_2$$
$$\cos r = \frac{n_2}{n_1}$$

[here the angle of incidence is (90 - θ_1) for which angle of refraction is 90^0].

Substituting for cosr in equation (1)

$$n_0 \sin\theta_0 = n_1 \sqrt{1-\frac{n_2^2}{n_1^2}}$$

$$\sin\theta_0 = Sin\theta \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$

If the medium surrounding the fiber is air then $n_0 = 1$,

Numerical aperture = $\sin\theta_0 = \sqrt{n_1^2 - n_2^2}$

The total internal reflection will take place only if the angle of incidence $\theta_i < \theta_0$

$$\therefore \sin\theta_i < \sin\theta_0$$

$\sin\theta_i < \sqrt{n_1^2 - n_2^2}$

This is the condition for propagation.

5B

$n = 2$

$$\Pr obability = \int_{L/4}^{3L/4} |\psi^2| dx = \int \frac{2}{L}\sin^2\frac{2\pi}{L}x.dx = \frac{2}{L}\int (\frac{1-\cos 4\pi x/L}{2})dx$$

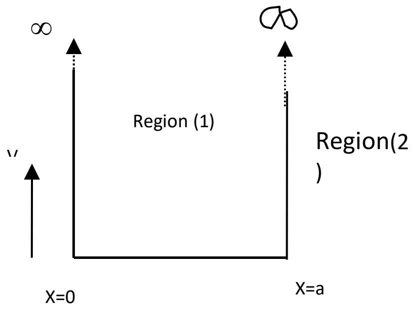
$$= \frac{2}{L}\int_{L/4}^{3L/4}\frac{1}{2}dx - \frac{2}{2L}\int\frac{\cos 4\pi x/L}{L}dx = \frac{1}{L}[L/2] - \frac{1}{L}\left[\frac{\sin 4\pi x/L}{4\pi/L}\right]_{L/4}^{3L/4}$$

$$= 0.5 - 0 = 0.5$$

6A

Particle in an infinite potential well problem:

Consider a particle of mass m moving along X-axis in the region from X= 0 to X = a in a one dimensional potential well as shown in the diagram. The potential energy is assumed to be zero inside the region and infinite outside the region.



Applying, Schrodingers equation for region (1) as particle is supposed to be present in region (1)

$$\frac{d^2\Psi}{dx^2} + \frac{8\Pi^2 mE\psi}{h^2} = 0 \,\Theta\, V = 0$$ for region (1)

But $k^2 = \frac{8\Pi^2 mE}{h^2}$

$$\therefore \frac{d^2\Psi}{dx^2} + k^2\Psi = 0$$

Auxiliary equation is $\left(D^2 + k^2\right)x = 0$

Roots are D = +ik and D = -ik

The general solution is

$$x = Ae^{ikx} + Be^{-ikx}$$
$$= A(\cos kx + i\sin kx) + B(\cos kx - i\sin kx)$$
$$= (A+B)\cos kx + i(A-B)\sin kx$$
$$= C\cos kx + D\sin kx$$

The boundary conditions are

1. At x=0, $\Psi = 0 \therefore C = 0$

2. At x=a, $\Psi = 0$

D sin ka = 0 $\Rightarrow$ ka = nΠ ....(2)

where n = 1, 2 3…

$$\therefore \Psi = D\sin\left(n\frac{\Pi}{a}\right)x$$

From (1) and (2) E = $\frac{n^2h^2}{8ma^2}$

To evaluate the constant D:

Normalisation: For one dimension

$$\int_0^a \Psi^2 dx = 1$$

$$\int_0^a D^2 \sin^2(\frac{n\Pi}{a})x dx = 1$$

But $\cos 2\theta = 1 - 2\sin^2\theta$

$$\int_0^a D^2 \frac{1}{2}(1 - \cos 2(\frac{n\Pi}{a})x)dx = 1$$

$$\int_0^a \frac{D^2}{2} dx - \int_0^a \frac{1}{2}\cos 2(\frac{n\Pi}{a})x)dx = 1$$

$$\frac{D^2 a}{2} - \quad [\sin 2\left(\frac{n\Pi}{a}\right)\frac{x}{2}]_0^a = 1$$

$$D^2 \frac{a}{2} - 0 = 1$$

D = $\sqrt{\frac{2}{a}}$

$$\therefore \Psi_n = \sqrt{\frac{2}{a}} \sin\left(n\frac{\Pi}{a}\right)x$$

6B

$$\alpha = \frac{10}{L}\log_{10}\left(\frac{P_{in}}{P_{Out}}\right)$$

$$\left(\frac{P_{in}}{P_{out}}\right) = 10^{\frac{\alpha L}{10}} = 1.16$$

$$P_{out} = \frac{P_{in}}{1.16} = 0.86 P_{in}$$

7A

Mode: It represents a specific electric field and magnetic field pattern propagating along specific path. Only a certain discrete number of modes are capable of propagating along the fiber. These are the electromagnetic waves that satisfy the homogeneous wave equation and the boundary conditions.

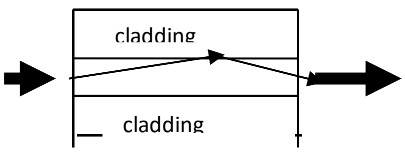
Refractive Index profile

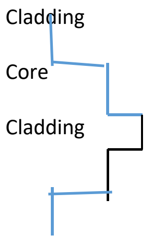
It is a plot of representing variation of refractive index inside the core and cladding.

<u>Types:</u>

1. Single mode fiber:

Core diameter is around 5-10 µm. The core is narrow and hence it can guide just a single mode.



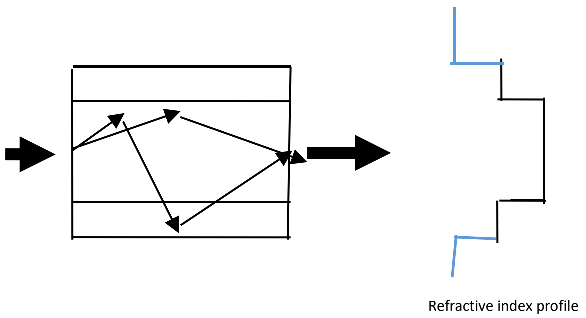


Refractive index profile

- No modal dispersion
- Difference between n_1& n_2 is less.Critical angle is high. Low numerical aperture.
- Low Attenuation -0.35db/km
- Bandwidth -100GHz
- Preferred for short range

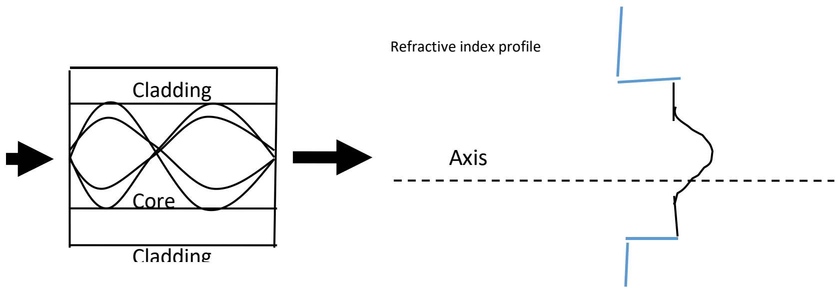
Step index multimode fibre :

- Here the diameter of core is larger so that large number of rays can propagate. Core diameter is around 50. µm.
- High modal dispersion
- Difference between n_1& n_2 is high. Low Critical angle. Large numerical aperture.
- Losses high
- Bandwidth -500MHz
- Allows several modes to propagate
- Preferred for Long range



Graded index multimode fiber:

In this type, the refractive index decreases in the radially outward direction from the axis and becomes equal to that of the cladding at the interface. Modes travelling close to the axis move slower where as the modes close to the cladding move faster.As a result the delay between the modes is reduced. This reduces modal dispersion.



- Low modal dispersion
- High data carrying capacity.
- High cost
- Many modes propagate
- Bandwidth -10GHz

7B

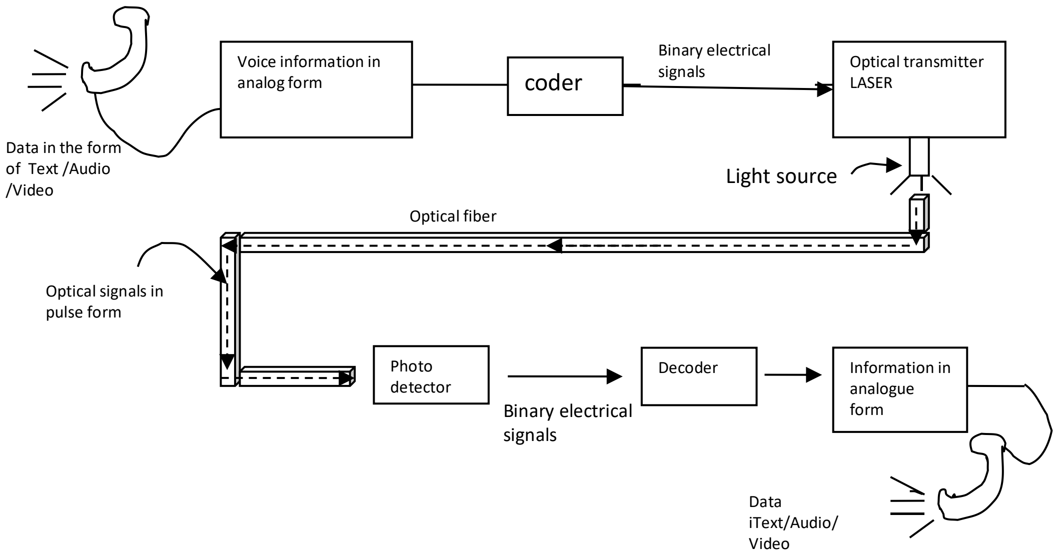
$$P=\frac{E}{t}=\frac{nhc}{\lambda t}$$

$$\lambda=\frac{nhc}{Pt}=\frac{5.61x10^{8}x6.62x10^{-34}x3x10^{8}}{0.005x8x10^{-9}}=2.78x10^{-6}m$$

8A

Point to point communication system using optical fibers

This system is represented through a block diagram as follows.



The information in the form of voice/ picture/text is converted to electrical signals through the transducers such as microphone/video camera. The analog signal is converted in to binary data with the help of coder. The binary data in the form of electrical pulses are converted in to pulses of optical power using Semiconductor Laser. This optical power is fed to the optical fiber. Only those modes within the angle of acceptance cone will be sustained for propagation by means of total internal reflection. At the receiving end of the fiber, the optical signal is fed in to a photo detector where the signal is converted to pulses of current by a photo diode. Decoder converts the sequence of binary data stream in to an analog signal . Loudspeaker/CRT screen provide information such as voice/ picture.

Merits and Demerits of optical fiber communication

Merits –

Large bandwidth (1000GHz)
Data security
No Electrical Interference (No cross talk)
Low loss (0.01dB/km)
Portable
Cheaper

Demerits

Repair costs high
Light emitting sources are limited to low power
The distance between the transmitter and eceiver should keep short or repeaters are needed to boost the signal.

8B

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

$$E = \frac{h^2}{2m\lambda^2} = 5.84x10^{-13} J$$

$$V_g = \frac{h}{m\lambda} = 2.6x10^{7} m/s$$