5. Optics and Modern Physics

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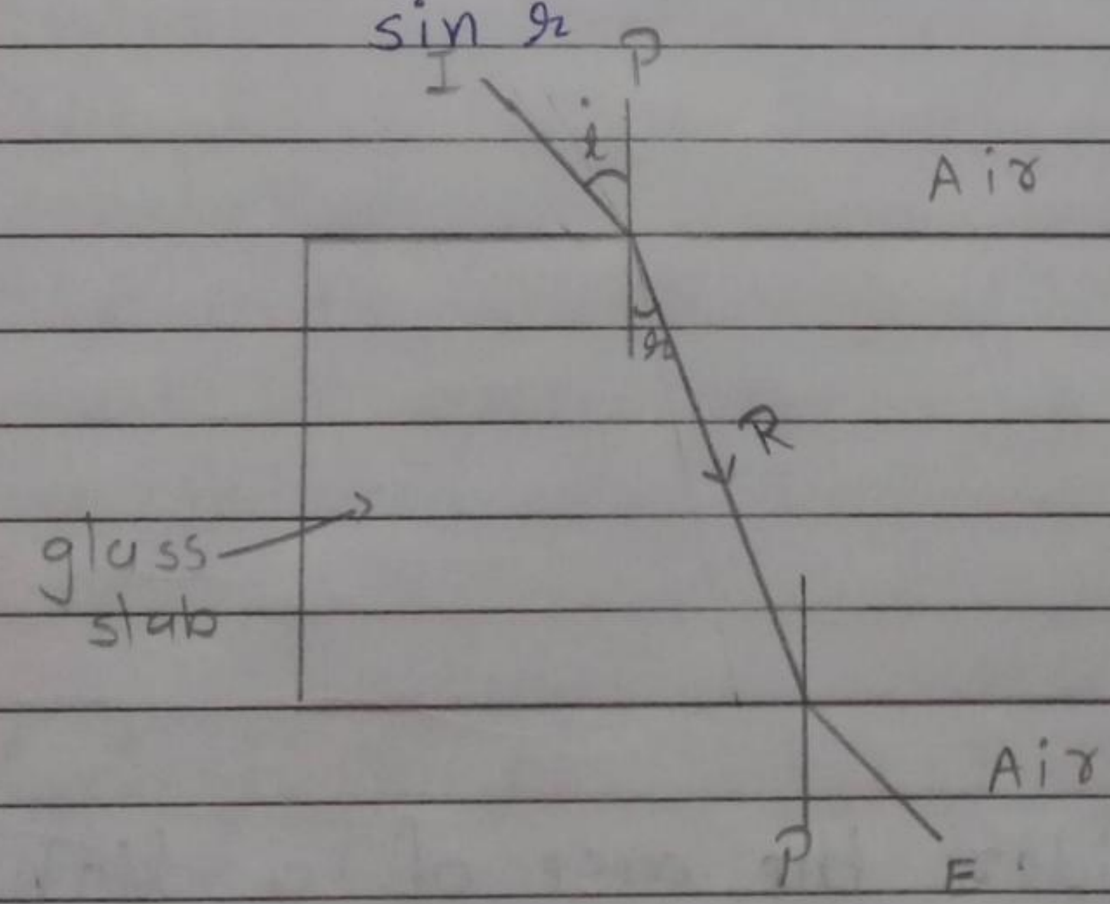
Laws of Refraction:-

Incident ray, normal and the refracted ray are in the same plane.

- Incident ray and refracted ray are in different media.
- Ratio of sine of angle of incidence to sine of the angle of refraction is constant for the given two media. It is termed as refractive index (μ).

$\therefore \mu = \frac{\sin i}{\sin r}$ - Snell's law



I = Incident ray
R = Refracted ray
E = Emergent ray
P = Normal to glass surface
$\angle i$ = Incident angle
$\angle r$ = Refracted angle

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☆ Snell's law:-

Ratio of sine of angle of incidence to sine of the angle of refraction is constant for the given two media. This is known as Snell's law.

$$\therefore \mu = \frac{\sin i}{\sin r}$$

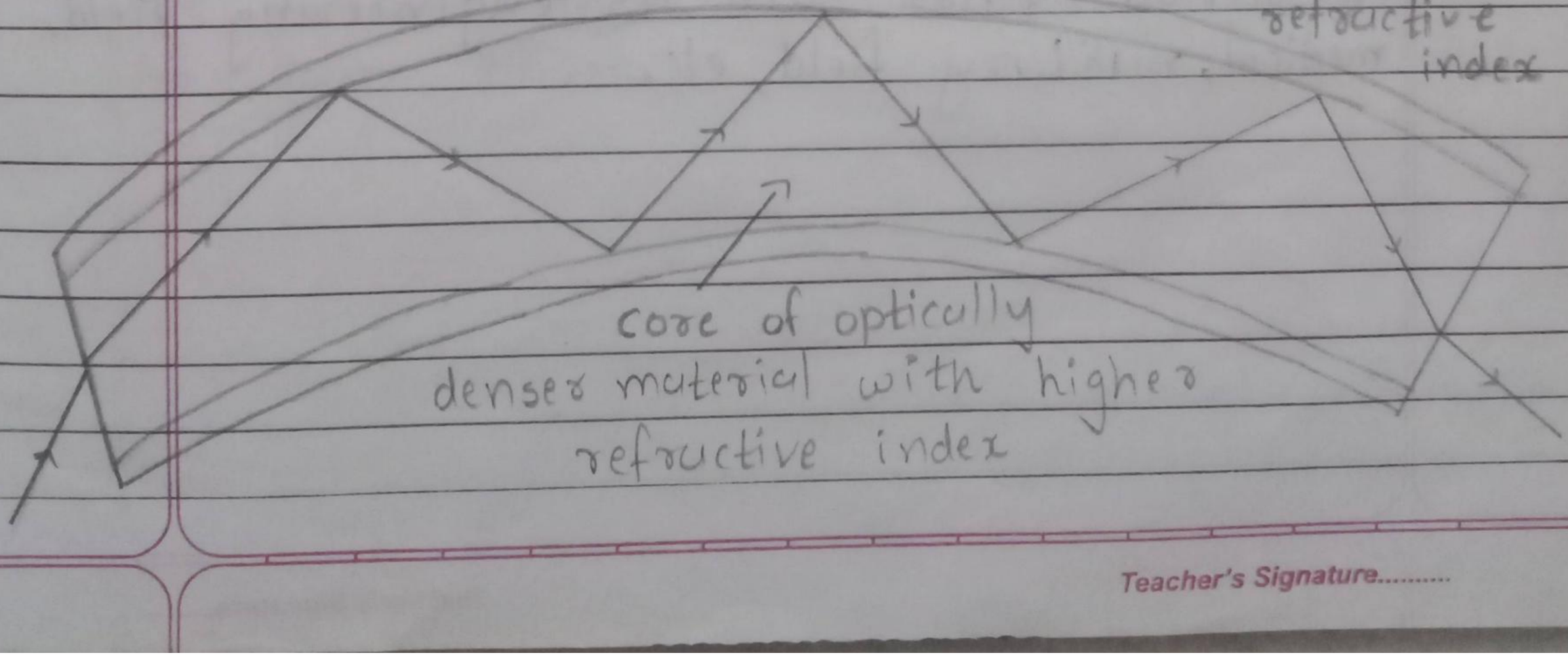
✯ Necessary Conditions for Total Internal Reflection:-

→ The two necessary conditions for the total internal reflection are:

(i) The light must travel from an optically denser medium to an optically rarer medium.

(ii) The angle of incidence in denser medium must be greater than the critical angle for the pair of media.

✯ Applications of Total Internal Reflection in Optical Fibers:-



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Optical fibres are now widely used to send audio or video signals over long distances. Optical fibres can transmit signals from one place to another using the phenomenon of total internal reflection. They are in the form of long and thin fibres of high-quality glass, quartz and plastic materials. Its diameter is about 0.0001 centimetres. The central-axial part of this fibre is called the core while the core is surrounded by the layer called cladding. In an optical fibre, the refractive index of the core is higher than that of cladding material.

As shown in the figure, when a light ray enters into one end of the optical fiber at a proper acceptance angle, it undergoes multiple total internal reflections and finally energoes out form the other end of the optical fiber. Even if the optical fiber is curved or twisted, the ray of light undergoes total internal reflection and passes through it.

Optical fiber is widely used in communication. In addition, it has various uses in various fields such as engineering field, medical, military field, etc.

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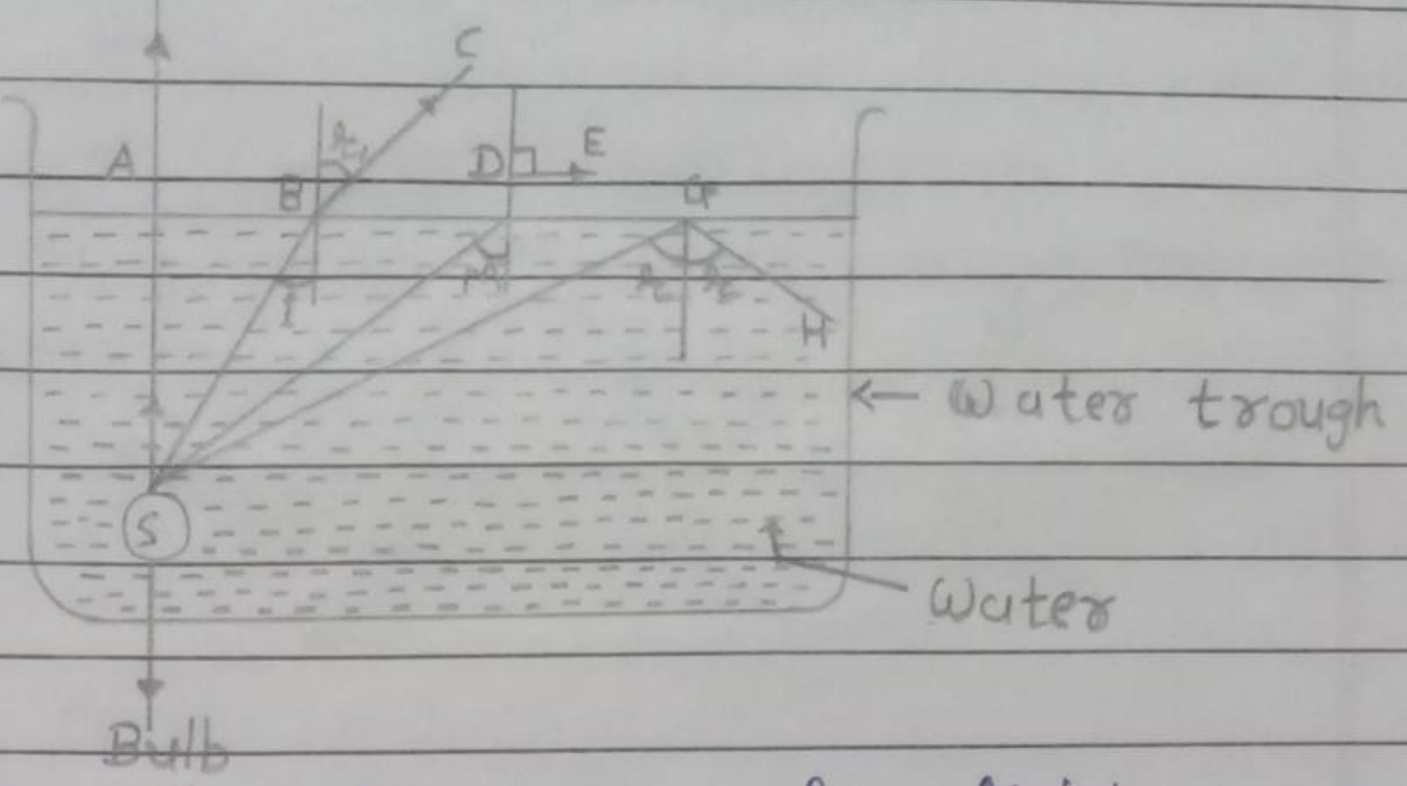
Total Internal Reflection of light:-



Consider the case of a light sources placed in a medium of higher refractive index say water and emitting light rays in all directions as shown in figure. We know that when a ray of light passes from an optically denser to a rarer medium, the refracted ray is bent away from the normal i.e. the angle of refraction is greater than the angle of incidence. First of all we consider a ray SB striking the interface at an angle i it is refracted at an angle r_1, Obviously $< r_1 > < i$, As the angle of incident increase the angle of refraction also increases till for a particular angle of incidence the refracted ray emerges along the surface of separation. This particular angle is known as critical angle.

Now next we consider the ray SD which is incident on critical angle and hence it is refracted along the boundry of seperation. If now any ray say SC is incident at an angle greater than critical angle $< M$, no refraction ocurs and

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the incident ray is reflected in the same medium, i.e. water. This phenomenon is called as total internal reflection.

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LASER:-

L - Light
A - Amplification
S - Stimulated
E - Emission
R - Radiation

"Light Amplification by stimulated Emission of Radiation."

Characteristics of Laser:-

1. A laser is an intense, powerful and coherent beam of light.
2. The laser light is highly directional.
3. In a laser beam, the rays are parallel to each other.
4. Laser is a strong, concentrated and highly focused beam.
5. Laser light is coherent.
6. A laser beam contains only monochromatic light.
7. All photons in a laser beam are in the same phase.

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★ Applications of Lasers in Engineering and Technology:-

1. Industrial welding and drilling:
Lasers are now widely used to make or weld metal tins. Lasers are also used to heat objects.

2. Civil engineering:
Lasers are used in surveying. Engineers use lasers to align long tunnels in a straight path.

3. Laser hardening is done to harden the material.

4. In electronics:
→ Laser is used in barcode guns/scanners.
→ Laser is used in laser printers, laser pointers
→ Laser is used in thermometers etc.

5. Communication:
The laser beam is used for long-distance continuous transmission through optical fibers.

6. Environment engineering:
Lasers are useful to measure and control air pollution as well as water pollution.

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7. Chemical industry:
In photo-chemistry, lasers are useful to monitor ultrafast chemical reactions.

8. Defence engineering:
Laser radar is used in the military. It can intercept the messages of the enemies and thus know the movements of the enemies.

9. Scientific research:
→ Lasers are used to test the physical and chemical properties of a substance.
→ Lasers are used for high-speed photography.
→ To find and study the hidden or unseen fingerprint in forensic science.
→ Laser is useful in the nuclear fusion process, as it can create extreme temperature.

Applications of Lasers in medical field:-

1. The structure and properties of micro-organisms can be studied using a laser.
2. In a cataract removal operation, a laser beam is used.
3. In an operation to remove the tumour, a laser beam is used.
4. Removal of kidney stones can be done by applying a laser beam.
5. In removing tooth decay, the laser is very useful.
6. A laser beam is used in cosmetic surgery.

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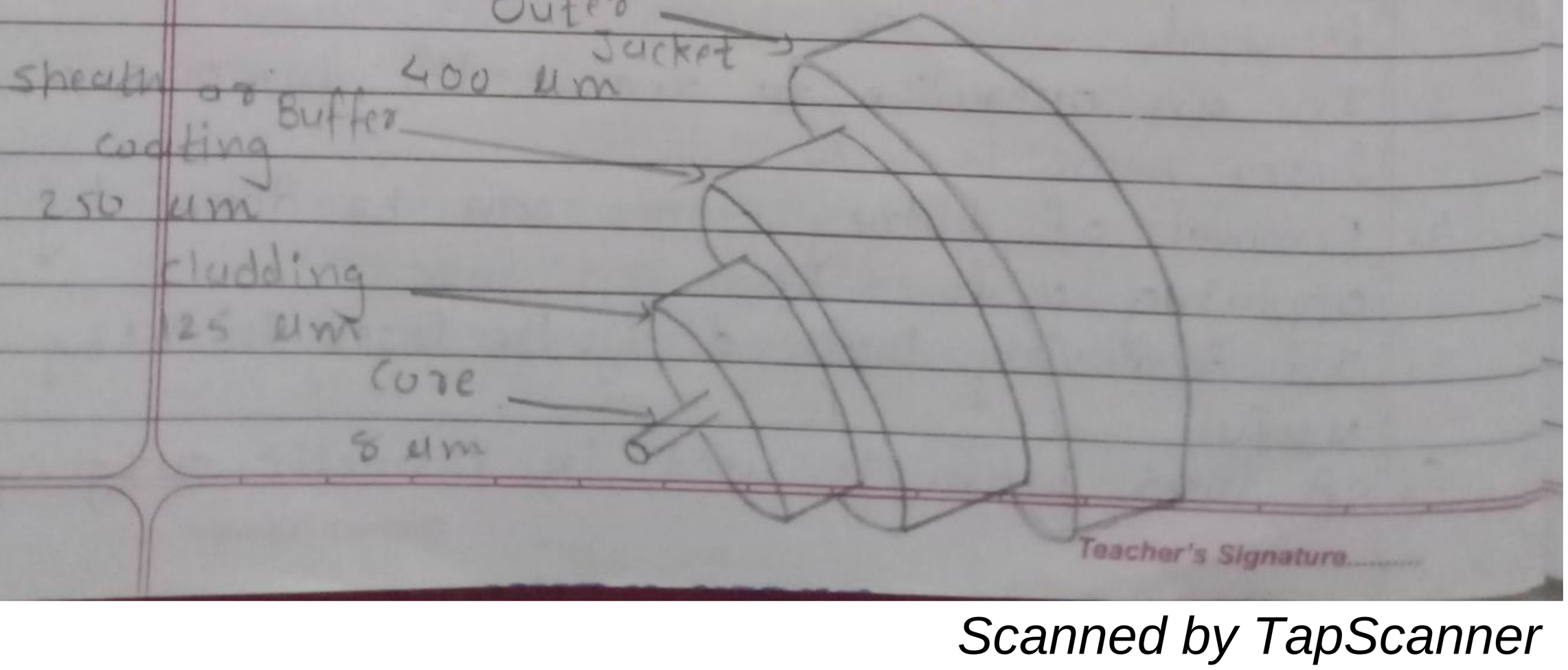
to beautify the skin.

7. Cholesterol levels can be determined by laser testing of blood passing through the blood vessels.

★ What is Optical fiber:-

An optical fiber is a cylindrical dielectric waveguide, as thick as human hair, made of glass and/or plastic. When a signal of information in the form of a light ray is inserted at one end, it exists at the other end, allowing the light waves to propagate along its length through the total internal reflections at its walls. During the continuous propagation within an optical fiber, the motion of a light ray follow the zig-zag path and a negligibly small portion of the light is likely to be dissipated through the sidewalls, but most of the light emerges at the other end.

★ Structure of Optical Fiber:-



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→ Core:

Core is the innermost cylindrical wire-like region. It is about 50 um(50×10^{-6} m) in diameter. The core is made up of dielectric material like glass or plastic. The Refractive index of the core is greater than that of cladding. The light ray propugates through the core region undergoing a zigzag path due to total internal reflection phenomenon.

→ Cladding:

It is the middle part. The core is surrounded by an outer coaxial cylindrical layer of cladding, which is made up of optical material like glass or plastic. The refractive index of the cladding is always smaller than that of the core ($n_{core} > n_{cladding}$). The thickness of the cladding is equal to or greater than the wavelength of the light to be passed through it. It directs back the light ray into the core, results in total internal reflection phenomenon. Cladding is the middle layer, which serves to confine the light to the core.

→ Sheath or Buffer coating:

It is the outermost protective part. It protects the core and cladding from damage due to moisture and wears by providing excellent mechanical strength. It is usually made up of opaque plastic material.

Optical fiber is formed as a single fiber or in the form of a flexible group of fibers

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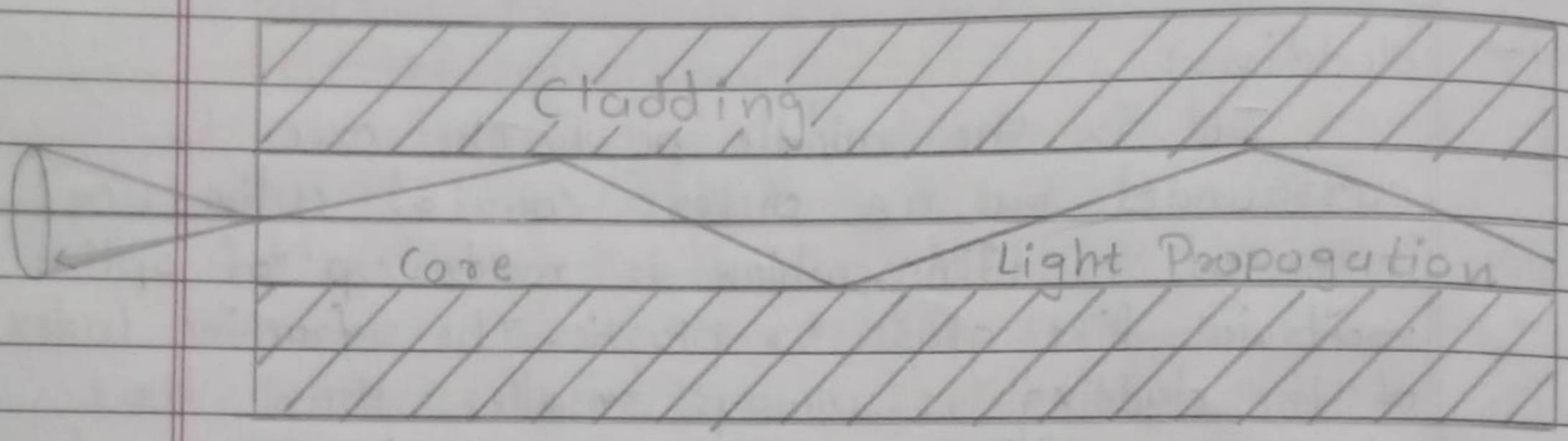
i.e. in the form of a cable. The number of fibers in a single jacket is called a Fiber Bundle. Each of these carries light independently. The entire structure is covered with a polyurethane or polythylene jacket.

Step index optical fiber:-



The core diameters of single-mode optical fibers are small i.e., about 8 μm to 10 μm, and they can carry only one mode. cladding ranges in diameter from 60 μm to 70 μm.

step index fiber is a fiber in which the core is of a large and uniform refractive index and there is a sharp decrease in the index of refraction at the cladding and this is the reason why it is called a step index fiber. Step index fiber is found in two types, that is mono mode fiber and multi-mode fiber.

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As shown in figure, the rays travel in the fiber as meridional rays and they cross the fiber axis for every reflection. Signal distortion is more in case of high-angle rays in multimode step index fiber. In single mode step index fiber, there is no distortion. The fiber has lower bandwidth. The bandwidth is about 50 MHz km for multimode step index fiber whereas it is more than 100 MHz km in case of single mode step index fiber. The diameter of the core is between 50-200 μm in the case of multimode fiber and 10 μm in the case of single mode fiber. Single mode fiber is used for short distance communication. Attenuation of light rays is more in multimode step index fibers but for single mode step index fibers, it is very less. Step index fibers are less expensive. Single mode step-index optical fiber has a low Numerical Aperture (NA) and low Acceptance, whereas NA of multimode step index fiber is more. 80% of the total optical fibers produced in the world is single-mode step-index optical fibers. Lasers are used as a source of light in these fibers. It is mainly used in submarine cable systems.

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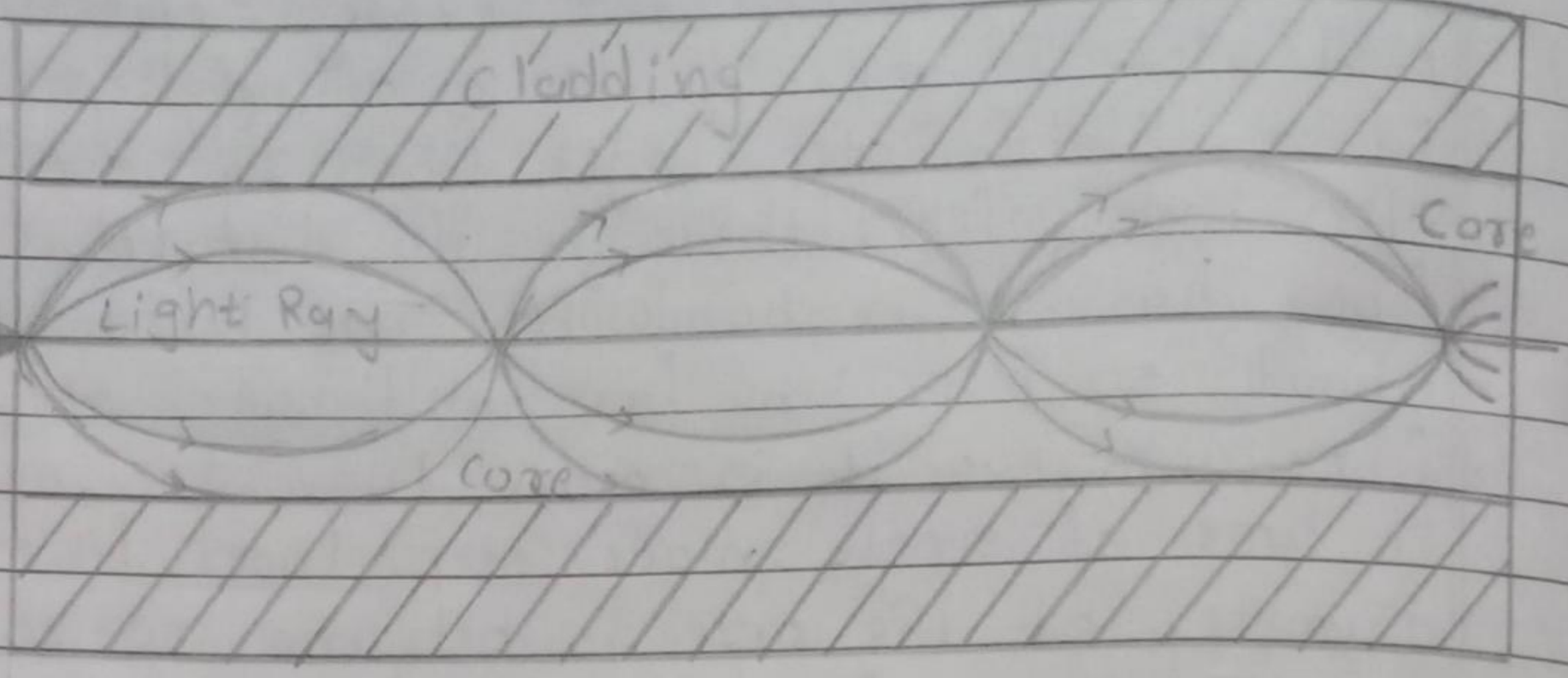
Graded index optical fiber:-



The Graded index optical fiber is a multimode type of optical fiber in which the core is made up of concentric layers with different refractive indices. So the refractive index of the core changes as we move away from the axis of optical fiber. The value of the refractive index in the center is higher and decreases gradually as moving away radially from the axis.

Graded index fiber is of only one type. that is, multi mode fiber. Index profiles is in the shape of a parabolic curve as shown in figure. The light rays propagate in the form of skew rays or helical rays. They will not cross the fiber axis. Signal distortion is very low even though the rays travel with different speeds inside the fiber. The fiber has higher bandwidth. For multimode Graded index fiber the diameter of the core is large and it is about 50-200 μm. Multimode fiber is

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used for long distance communication. Attenuation of light rays is less in grunded index fibers. Grunded-index optical fibers are Highly expensive. NA of graded index fiber is less. Laser or LED is used as the light source.

Advantages of optical fibers over Coaxial cables:-

1. Optical fiber is made from silica (SiO_2), which is found in abundance very cheaply.
2. Optical fiber is small in size, light in weight, flexible and has good mechanical strength.
3. If a normal conductor wire breaks accidentally, a short circuit sparks. Such accidents do not occur due to the insulating properties of optical fiber.
4. Electromagnetic radio frequency interference (EMI) and radio frequency interferences (RFI) do not affect optical fibers.
5. Optical fiber has low transmission loss per unit length and noise-free transmission.
6. In Optical fiber, light signals does not spread out much so signal safety is maintained.
7. Optical fiber is more efficient than electrical conducting wire, as it requires fewer repeaters and saves both maintenance and costs.
8. The tensile strength of the optical fiber is

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very high and it can be bend.

9. Optical fiber can be used for a long time. Optical fiber lasts for 20-30 years.
10. Optical fiber is temperature resistant.
11. Optical fiber transmits digital information through digital signals, which is especially useful in computers.

☆ Applications of Optical Fibers In Engineering Field:-

Optical fiber sensors:

1. Optical fibers are used in security alarm systems, electronic instrumentation systems, industrial automation controls, current, resistance and voltage sensors.
2. Optical fibers can be used as sensors to measure strain, temperature, pressure and other quantities by modifying a fiber.
3. Fibers have many uses in remote sensing.
4. Optical fiber interferometers are used for measurements of heat flux and unsteady temperature in turbo-machinery test rigs.

Applications in communication systems:

5. Engineers use optical fibers to detect damages and faults which are hard to reach places.
6. The industrial endoscopes are used for visual inspecting anything difficult to reach such as jet engine interiors.

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Applications in communicative systems:

7. The greatest impact of developments in fiber optics has been on telecommunication engineering and information technology.
8. many computers are networked by optical fiber through a common channel to transmit and process information.

Applications of Optical Fibers in the Medical Field:-

1. Optical fibers guided endoscope is used to inspect internal organs for diagnostic purposes.
2. It is used in Echo-Cardiogram.
3. In every laser surgery, optical fiber is used ~~to re-attach the detached~~ as a guiding medium.
4. It is used to detect tumours, stone, etc. in the body.
5. In ophthalmology, a laser beam guided by optical fiber is used to re-attach the detached retina.
6. They are used in the treatment of cancer by focusing rays direct to burn the cancer tumour.

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★ Give difference between Optical Fiber Cables and Coaxial Cables.

Optical Fiber Cables	Coaxial Cables
- Raw materials SiO_2 is low cost and easily available everywhere on the earth.	- Raw materials metals are costly and restrictively available from mines.
- Cheaper and economical production.	- Costly production.
- Smaller size and lighter in weight yet flexible and strong.	- The diameter is higher than optical fiber. Not lighter in weight. Not so flexible and strong.
- Less power loss. So, it requires low power to transmit the signals	- Power loss is considerably heavy for long-distance transmission.
- Optical fiber cables assure speedy transfer and good reception of data.	- The conventional metallic cable can transfer data speedy but reception quality is not satisfactory every time.
- The life span of optical fibers is 20 to 30 years.	- The life span of conventional metallic cables is 10 to 15 years.

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☆ Give difference between LASER and ordinary light.

Ordinary Light Beam	LASER Light Beam
- Spreads in all directions from the place of origin. (Divergent)	- Spreads in the same direction. (Non-divergent; Unidirectional)
- Intensity decreases gradually as it travels long distances and spread with the distance.	- Even travelling long distances rarely changes its cross-sectional.
- A convex lens or a concave mirror is needed to convert ordinary light into a parallel beam.	- Laser light is made up of parallel rays.
- Has low intensity and low ~~brit b~~ brightness.	- Has more intensity and has more brightness.
- Not coherent, that is, the phase of all photons is different.	- Coherent, meaning that all photons have the same phase.
- It Ordinary white light is a combination of many colours.	- A Laser beam is monochromatic as it is composed of a single colour (frequency).

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☆ Give difference between step index fiber and graded index fiber.

Ans.

Step Index Optical Fiber	Graded Index Optical Fiber
- Step index fiber is found in two ~~very~~ types, that is mono mode fiber and multi mode fiber.	- Graded index fiber is on of only one type, that is, multi mode fiber.
- Index profiles are in the shape of step.	- Index profiles is in the shape of a paraboli c curve.
- The light rays propagate in zig-zag manner inside the core.	- The light rays propagate in the form of skew rays or helical rays. They will not cross the fiber axis.
- Less expensive	- Highly expensive.
- Used ~~for~~ for short distance communication.	- Used for long distance communication.

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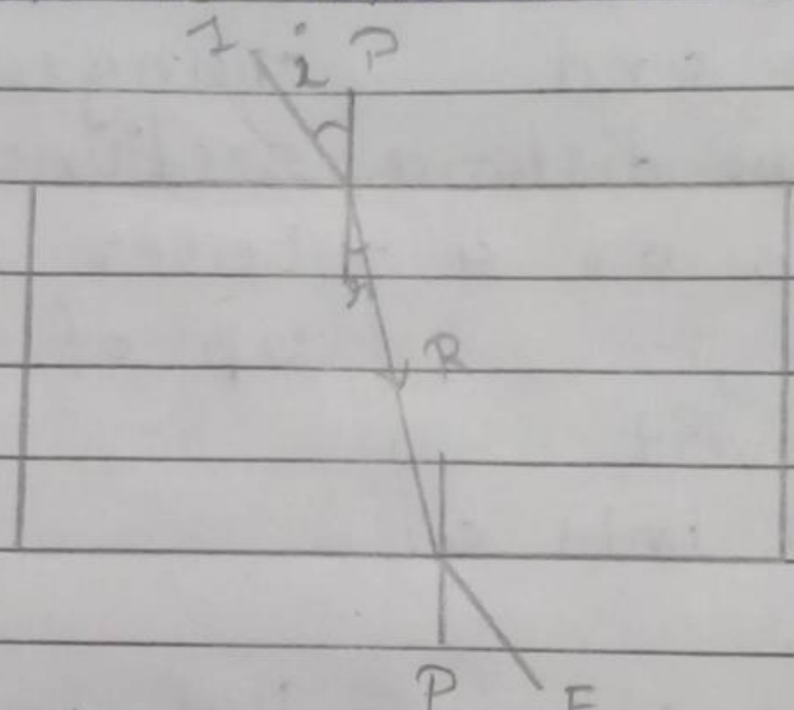
Definitions:-

1. Refruction:-

When a ray of light is travelling from one medium to another medium, it changes its direction of travelling at the contact surface of the two medium. This phenomenon is known as refruction.



I = Incident ray
R = Refracted ray
E = Emergent ray
P = Normal to gluss surface
∠i = Incident angle
∠r = Refracted angle

2. Refractive Index:-

The ratio of sine of angle of incidence to the sine of angle of refraction is constant for the two media. It is termed as refractive index.

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$$\mu = \eta = \frac{\sin i}{\sin r} = \text{constant}$$

or

The ratio of velocity/speed of light in a vacuum to the velocity/speed of light in a given media is known as refractive index of that medium.

$$\eta = \frac{c}{v}$$

where, c = speed of light in vacuum
v = speed of light in medium

3. Critical angle:-

The angle of incidence for which the angle of refraction becomes 90° is called the critical angle.

$$\theta_c = \sin^{-1} \frac{\eta_r}{\eta_i}$$

where, η_r = Refractive index for refractive medium
η_i = Refractive index for incidence medium

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4. Acceptance angle:-

The acceptance angle of an optical fiber is the maximum value of the angle at which the light ray travels through the fiber-core relative to the axis of the fiber.

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

5. Numerical Aperture:-

The sine value of the acceptance angle is known to be the numerical aperture.

$$NA = (n_1^2 - n_2^2)^{1/2}$$

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