UNIT- IV
Fiber Optical Communication

Basic Optical Communication System

Basic optical fiber Communication System is similar to a general communication system.

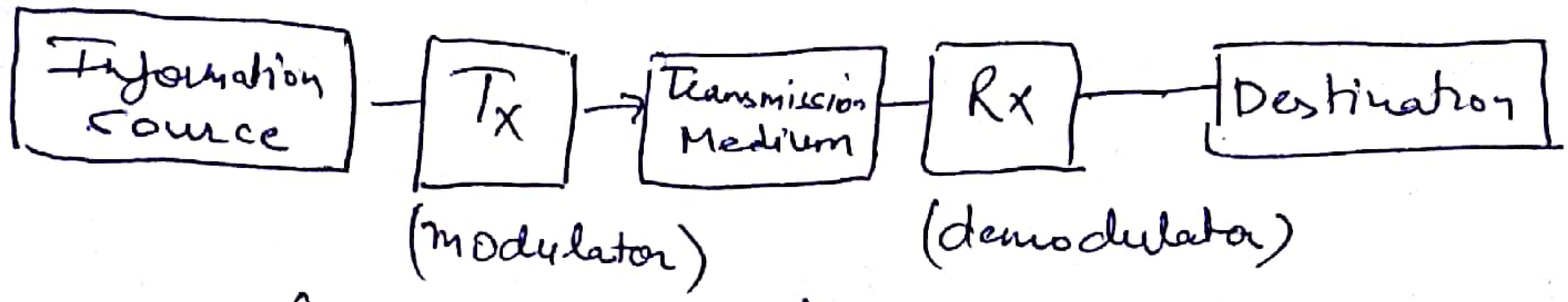


Fig. 1: General communication system

In optical fiber Communication system, basic blocks are similar in function as of Fig. 1 with some additional circuitary. Fig 2 shows the general optical fiber communication system.

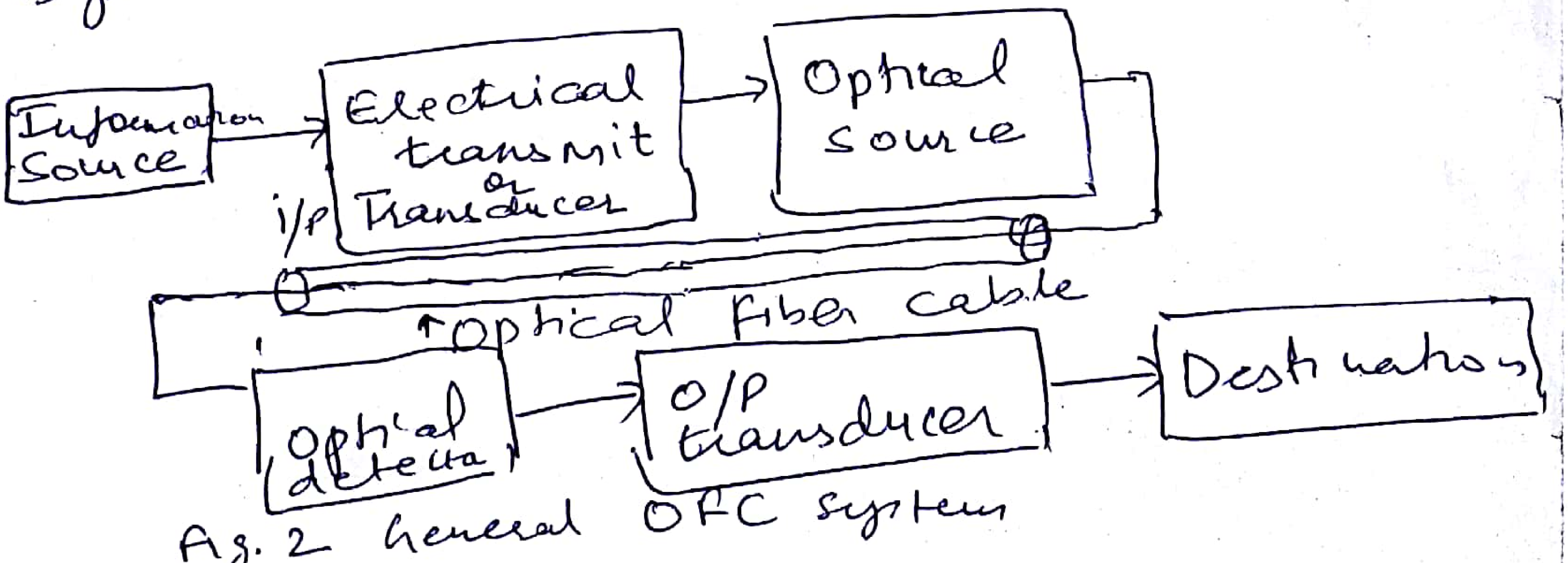


Fig. 2 General OFC system

① **Information source**

This is similar as general communication system. This is any type message signal/ baseband signal/ Data bits/ fax / audio.

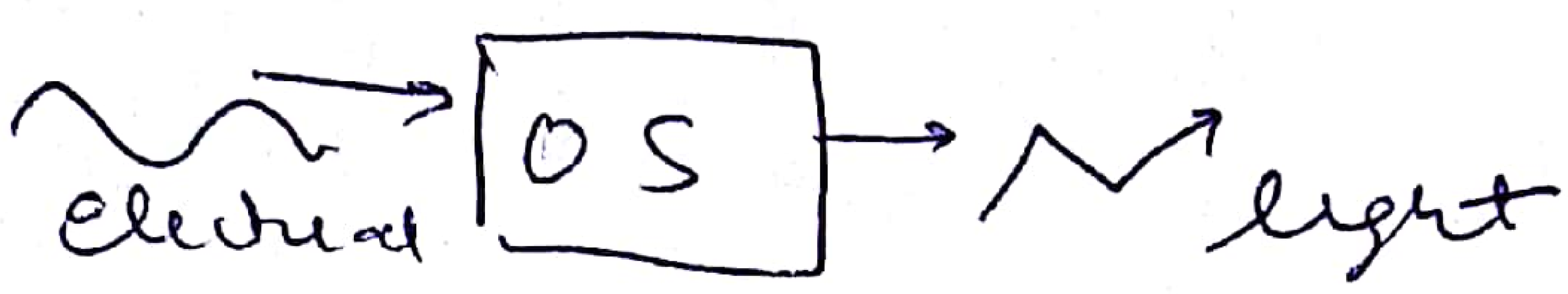
This source may be digital or analog in nature. And this can be non-electric as well

② I/P Transducer

This is used to convert non-electric s/g to electric compatible form.

③ Optical Source

Optical Source provides the electrical to optical signal conversion.



This can also be used for modulation of light wave carrier. Hence O/P light is modulated light wave that ~~are~~ inhibits the advantages of modulation.

EX LED, Laser lights.

④ Optical fiber cable

Optical FC provides the optical medium to light (signal)

optical fiber are highly Noise robust and provide efficient transmission.

⑤ Optical detector, O/P transducer and Destination

This sub block provide light to electrical conversion (eg PN, P-i-n detectors) then O/P transducer provides electrical to non-electrical form and then to destination.

Advantages of optical fiber communication

(1) **Increase the range of Bandwidth**

optical carrier freq Range – 10^{13} to 10^{16} Hz
metallic cables Range – 50Hz –
coaxial cable Range – 10^{6} Hz

Higher the Range of BW, higher will be the information carrying capacity

(2) **Small size and weight**

optical fiber have very small diameter which is often lower than diameter of human hair. weight is also very less as compared to metallic cables and coaxial cables. even after several protective coatings.

(3) **Electrical isolation**

These are made of glass or plastic polymers.
Hence they are spark proof, no arcing no short circuits, no earthing, no environment hazards.

(4) **They are highly immune to interference and cross talks.**

High degree of Signal security

Can not be hacked easily.

(6) Low transmission losses.

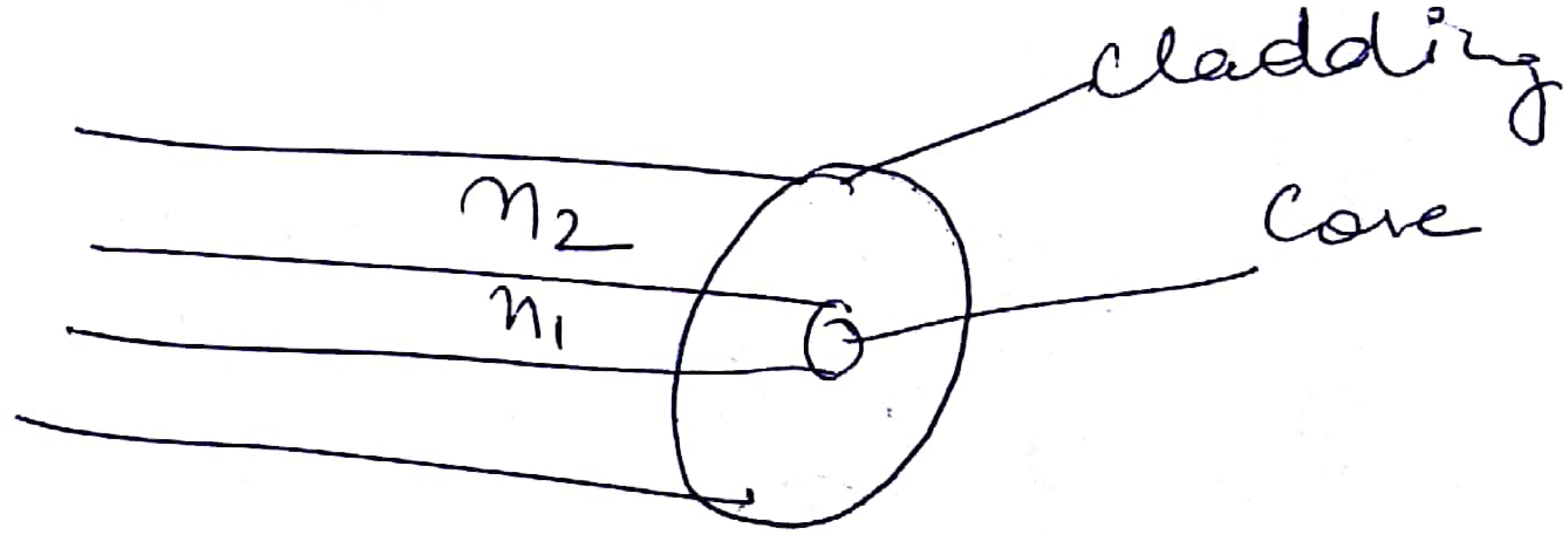
Fibers are fabricated with losses as low as 0.15 dB/Km

(7) Ruggedness and flexibility

(8) System Reliability and ease of maintenance

(9) Potential low cost

Optical fiber



core refractive index n_1.

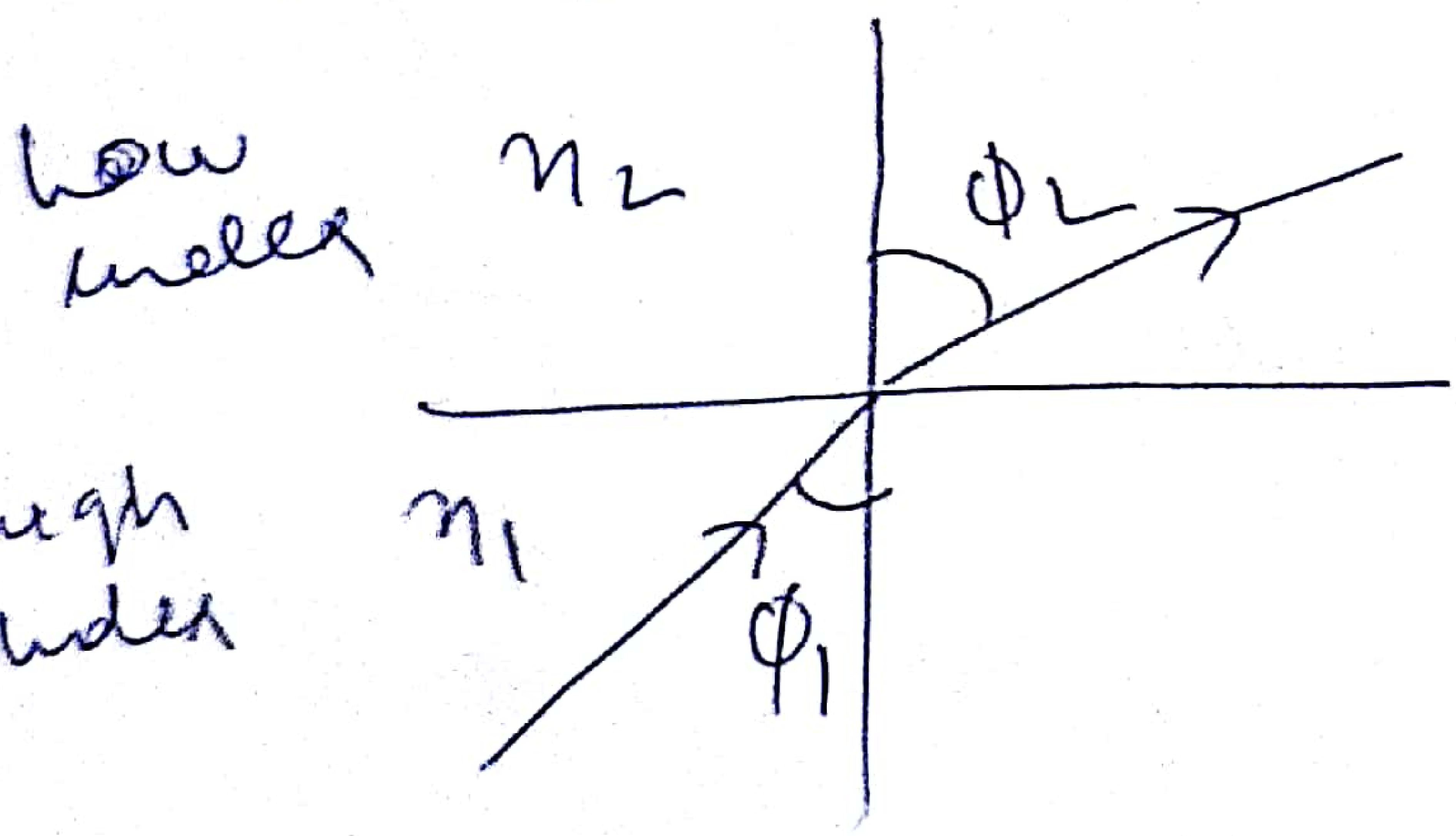
cladding refractive index n_2

$n_1 > n_2$ must

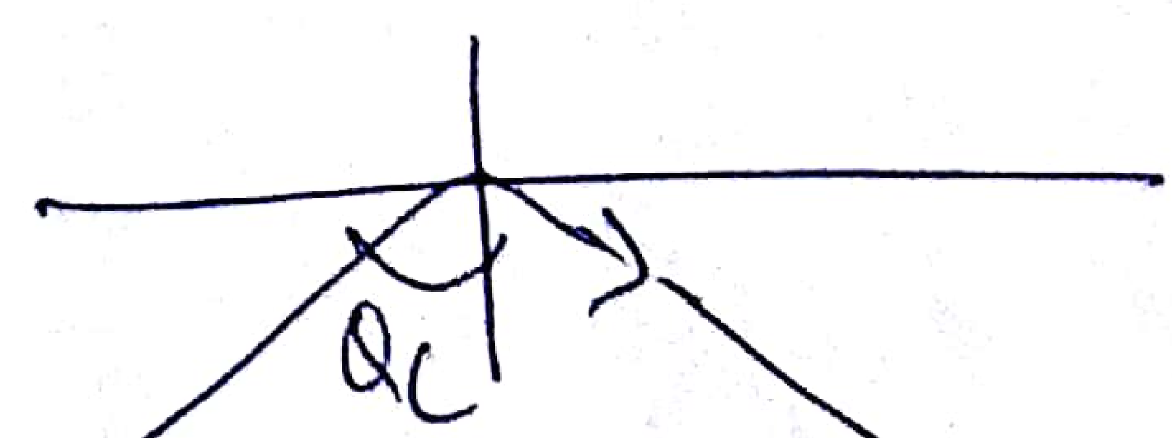
Light propagation through optical light

in an optical fiber, light propagate in fiber using ray theory of transmission a ray of light travels more slowly in an optically dense medium than in one that is less dense and refractive index is the parameter of high and low density.

using the phenomenon of refraction, when a light ray is incident on the interface between two dielectric of differing refractive indices, refraction occurs



if $n_1 >> n_2$



Snell's law states

$$\frac{\sin\phi_1}{\sin\phi_2} = \frac{n_2}{n_1}$$

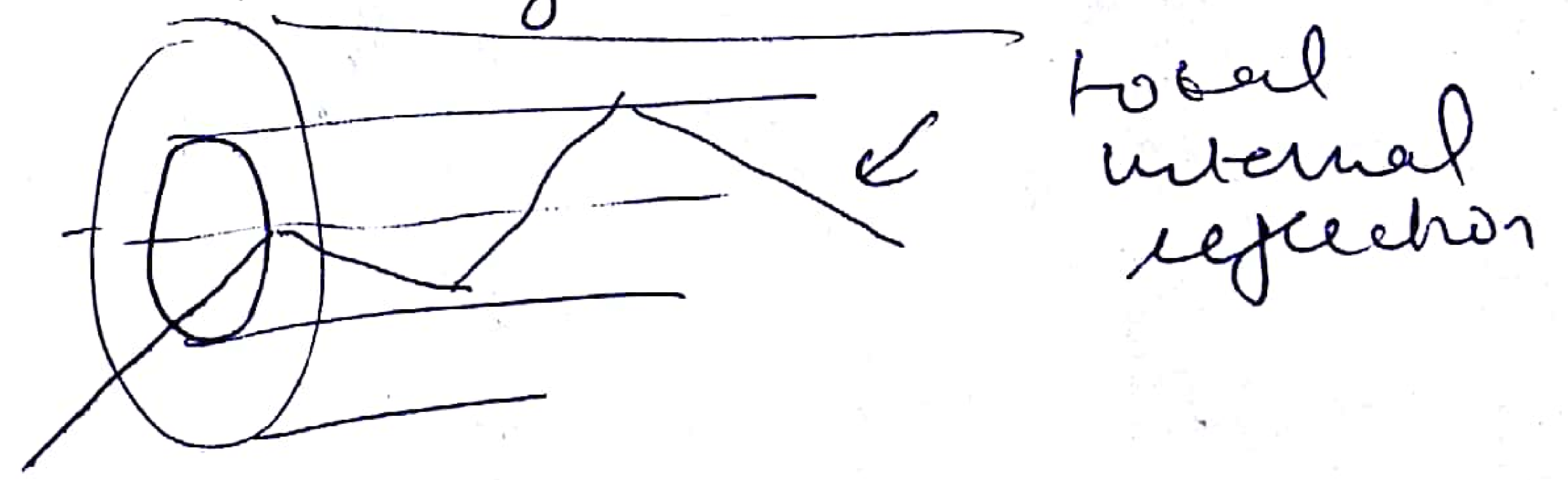
$$\phi_1 \propto \frac{1}{n_1} \qquad \phi_2 \propto \frac{1}{n_2}$$

if $n_1 > n_2$ $\quad \phi_2 >> \phi_1$

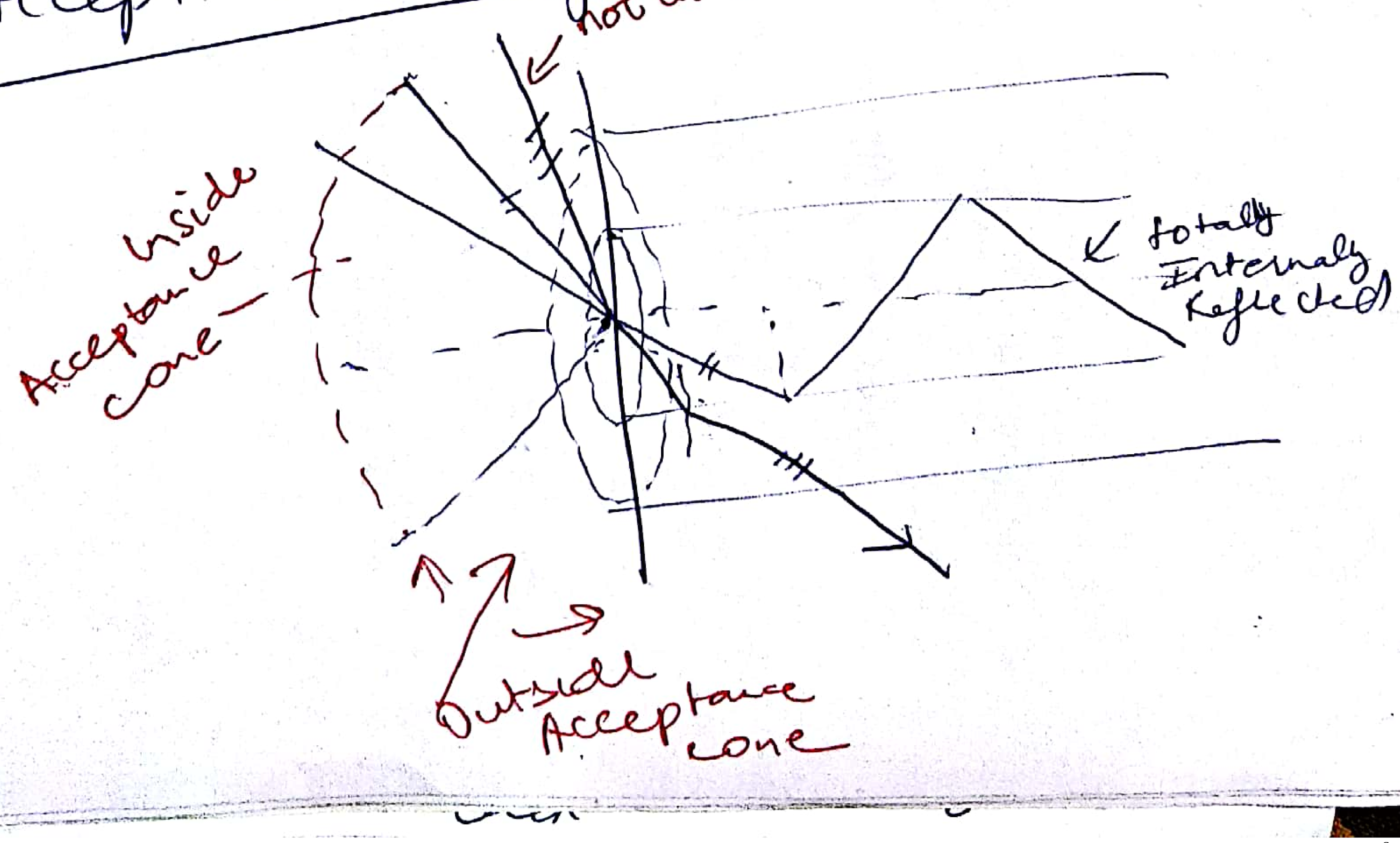
As n_1 is greater than n_2, angle of refraction is always greater than angle of incidence.

$$\frac{\sin \phi_c}{\sin 90} = \frac{n_2}{n_1}$$

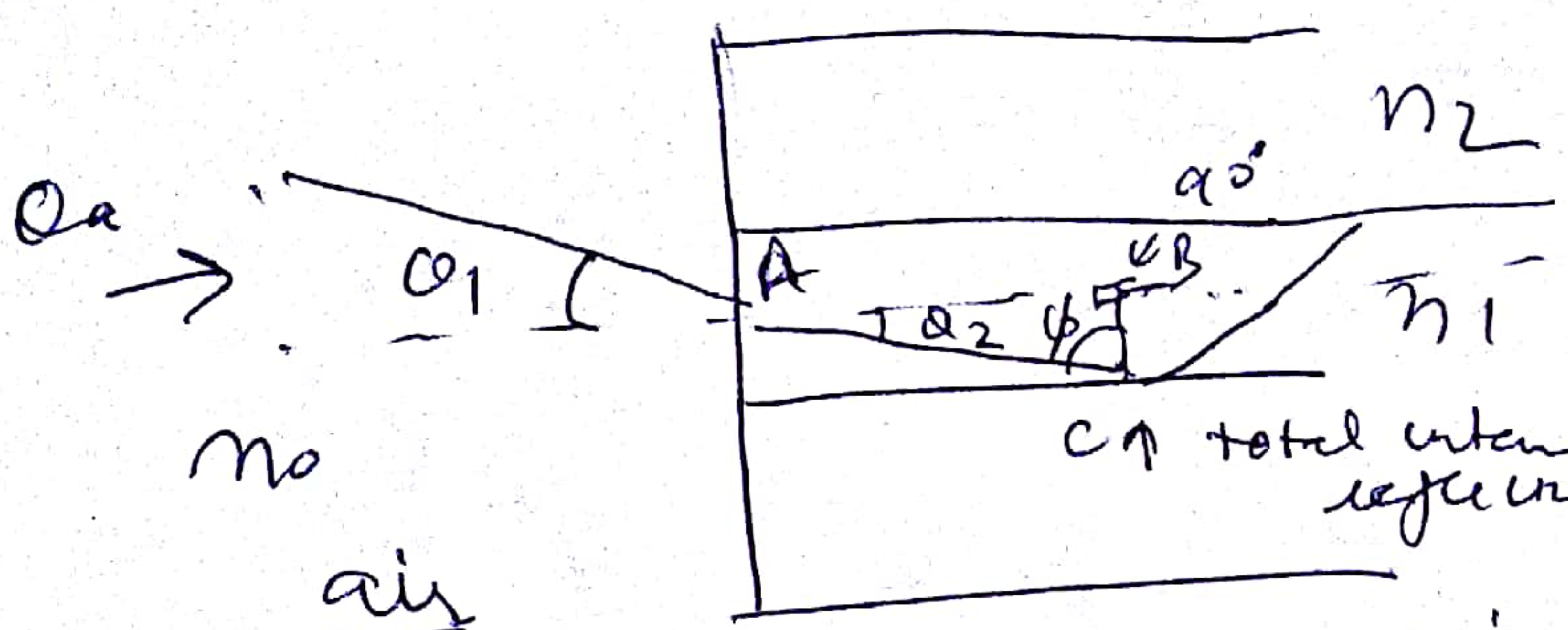
If light rays are incident at greater angle that critical angle then light rays will totally refracted inside the same medium. hence This phenomena is known as TOTAL internal reflection.



Acceptance angle



Numerical Aperture



numerical aperture combines both acceptance angle and its sufficient condition for Total internal Reflection

at air

Snells law

$$n_o \sin \theta_1 = n_1 \sin \theta_2$$

θ_1 varies from 0 to θ_a (acceptance angle)

so for maximum acceptance angle

$$n_o \sin \theta_a = n_1 \sin \theta_2$$

in ΔABC

$$\sin \theta_2 = \cos \phi \qquad \boxed{\phi = \frac{\pi}{2} - \theta_2}$$

So maximum critical angle θ_c

$$n_o \sin \theta_a = n_1 (1 - \sin^2 \phi)^{1/2}$$

$$\boxed{n_1 \sin \phi_c = n_2} \quad \text{TIR} \quad \text{mea}$$

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

$$n_0 \sin\theta_a = (n_1^2 - n_2^2)^{1/2}$$

$$NA = n_0 \sin\theta_a = (n_1^2 - n_2^2)^{1/2}$$

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2}$$ fractional index difference

$$\boxed{NA = n_0 \sin\theta_a = n_1 (2\Delta)^{1/2}}$$

Fiber Configurations

Basic three types of optical fiber Configurations are

① Step index multimodal fiber

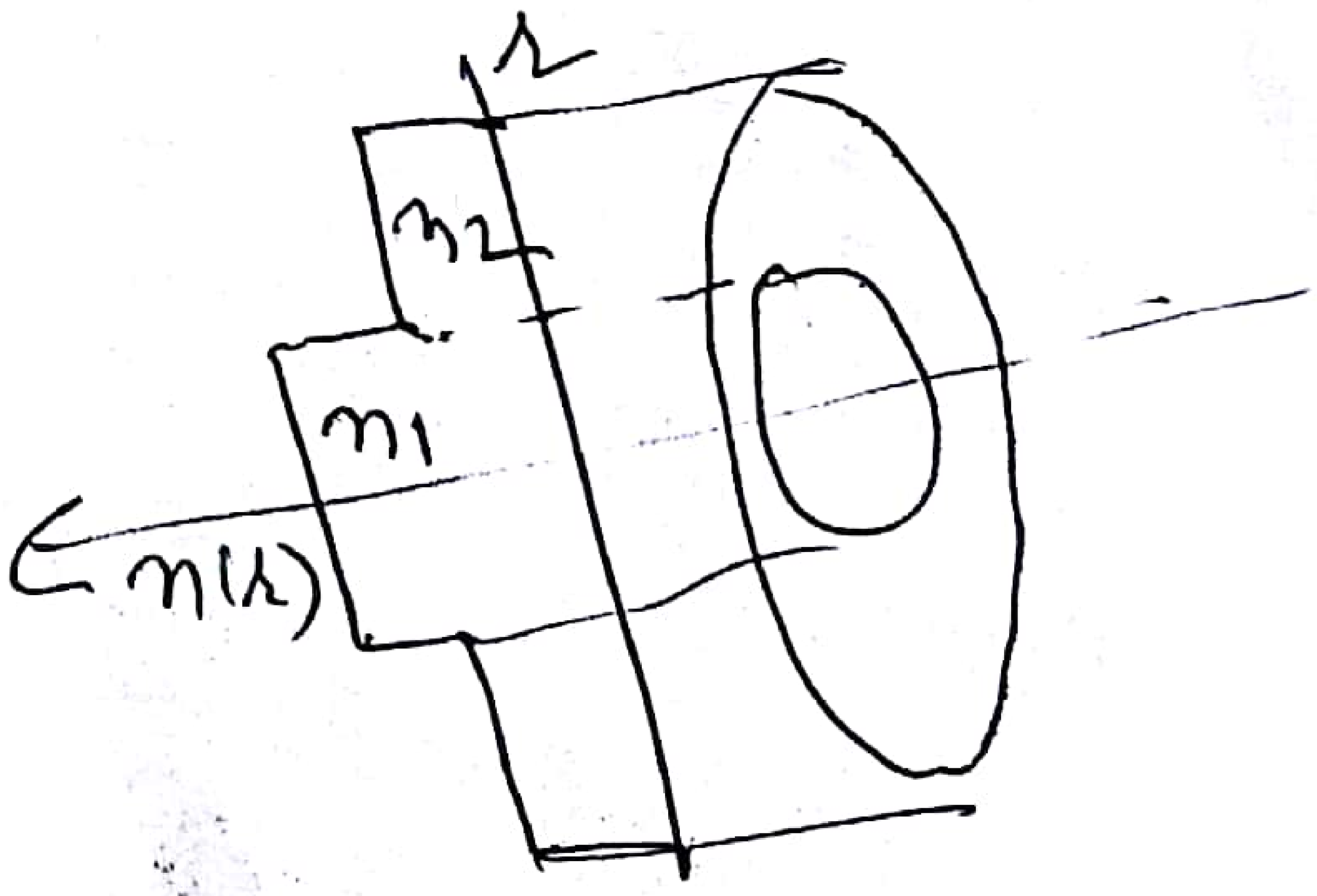
② Step index single mode fiber

③ graded-index fiber.

⇒ Step index fiber

whenever in any optical fiber, if refractive index of core and cladding has a step change that is cladding has a constant lower refractive index then core These fiber are step index fiber

$$n(r) = \begin{cases} n_1 & r < a \\ n_2 & r \geq a \end{cases}$$



$n_1 > n_2$

(a) <u>Single mode step index fiber</u>

→ They allow only one transverse electromagnetic mode.

→ core diameter is of order 2 to 10 μm

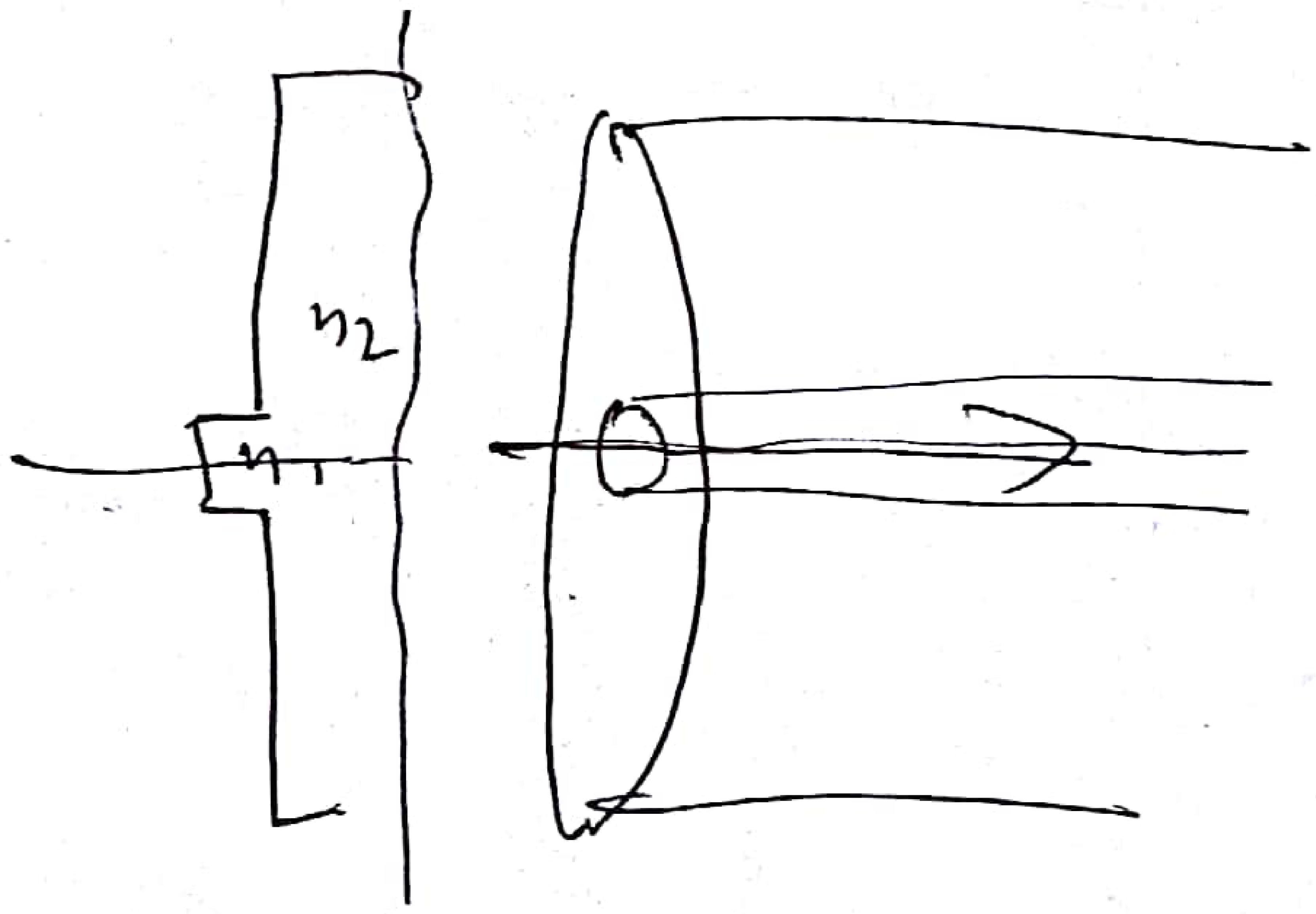
→ Small NA

→ Coupling more difficult

→ No modal dispersion (low intermodal dispersion)

→ High data rates } transmission

→ long distance }



(b) Multimodal step index fiber

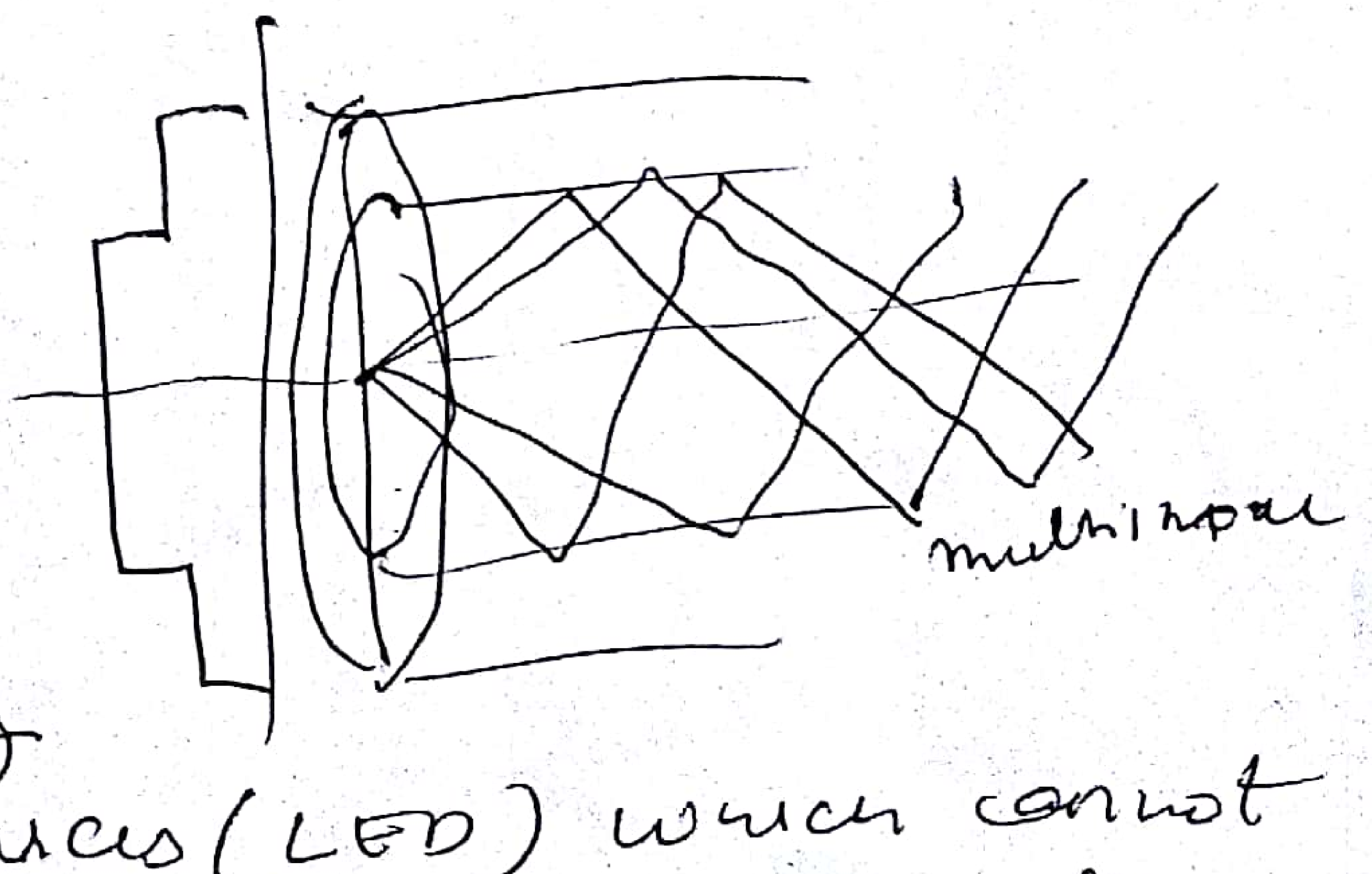
(1) Large NA

(2) Easy coupling

(3) Intermodal dispersion exists.

(4) low data rate

(5) shorter distance.



(6) The use of spatially incoherent optical sources (LED) which cannot be efficiently coupled to single-mode fiber

Total number of modes that can propagate through multimode fiber

$$M_n = \frac{V^2}{2}$$

V is normalised freq.

$$V = \frac{2\pi}{\lambda} \underbrace{a}_{\text{core radius}} (NA)$$

λ → operating wavelength

Q a multimode SIF with core diameter = 80μm and relative index difference $\Delta = 1.5\%$ operating at wavelength of 0.85μm. If core refractive index is 1.48

Find V and M_n

$$V = \frac{2\pi}{\lambda} a n_1 (2\Delta)^{1/2}$$

$$= \frac{2\pi \times 40\times10^{-6} \times 1.48 \; (2\times 0.015)^{1/2}}{0.85 \times 10^{-6}}$$

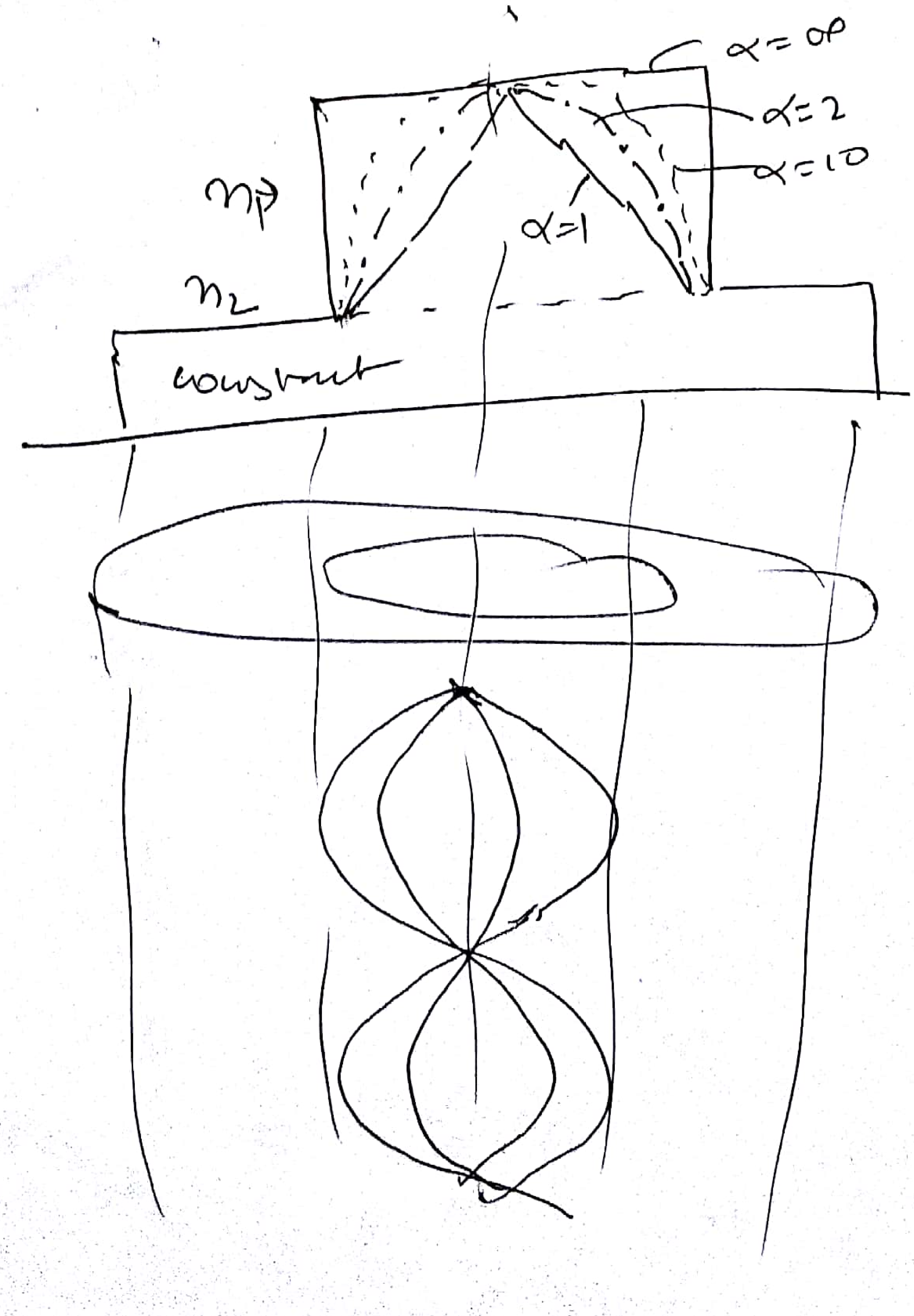
$$= 75.8$$

$$M_n = \frac{V^2}{2} = 2873$$

Graded index fiber

GIF do not have constant refractive index in the core but a decreasing core index $n(r)$ toward cladding

$$n(r) = \begin{cases} n_1\left(1-2\Delta\left(\frac{r}{a}\right)^{\alpha}\right)^{1/2} & r<a \text{ (core)} \\ n_1(1-2\Delta)^{1/2} = n_2 & r \geq a \text{ (cladding)} \end{cases}$$



... will be non-existence as well

Losses in optical fiber

In optical fiber communications, the signal attenuation is usually expressed in decibels per unit length (i.e. dB/km)

$$\alpha_{dB} L = 10 \log_{10} \frac{P_i}{P_o}$$

signal attenuation / unit length or fiber loss parameter

L — length of fiber

P_i — input power
P_o — output power

There are number of mechanisms responsible for signal attenuation
→ Material composition
→ preparation
→ purification techniques
→ waveguide structure

· Material composition causes

Intrinsic absorption
→ due to basic silica structure
→ at higher energy excitation due to stimulation of electron transitions

Extrinsic absorption
→ external impurities
→ Cr^{3+}, C^{2+}, Cu^{2+}, Fe^{2+} (metallic impurities)

→ Material Scattering

Linear Scattering losses
- → Rayleigh scattering
- → Mie scattering

Non-Scattering losses
- → Stimulated Brillouin Scattering
- → Stimulated Raman scattering.

Linear Scattering losses are caused when some or all the power is transfered linearly from one mode to other mode. But this transfer radiates out of the fiber. This is due to the non-ideal physical properties of the manufactored fiber which are difficult to eradicate at present

→ Rayleigh scattering

Causes due to the refractive index fluctuations, density fluctuation, compositional variations which are frozen into the glass lattice on cooling.

$$\gamma_R \propto \frac{1}{\lambda^4}$$

λ → optical wavelength

γ_R → Rayleigh scattering coefficient

$$\gamma_R = \frac{8\pi^3}{3\lambda^4} n^8 p^2 \beta_c K T_f$$

T_f → fictive temp

K → Boltzman Const

β_c → Isothermal compressibility

p → photo elastic coef.

n → refractive index.

Total losses

$$\boxed{\mathcal{L}_r = \exp(-\gamma_R L)}$$

→ Mie Scattering

These losses occur when inhomogeneities are comparable in size with the guided wavelength

→ Occurs due to

① non-perfect cylindrical structure of waveguide

② irregularities in the core-cladding interface

③ core-cladding refractive index difference along fiber length

④ diameter fluctuations

⑤ strains and bubbles.

Non-linear scattering losses

These losses occur due to the non-linear characteristics of optical fiber at high optical power density.

→ they shift frequency.

① Stimulated Brillouin Scattering.

→ causes due to the modulation of light through molecular vibrations within the fiber.

→ SBS is a backward freq. shift process

→ it produces ① a phonon of acoustic freq.

② Scattered photon

(2) Stimulated Raman Scattering

- it produce a high freq phonon rather than an acoustic phonon
- SRS also occur in both forward and backward direction

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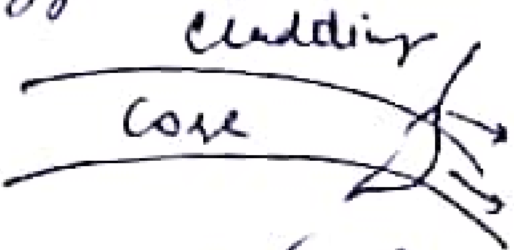
fiber bend Losses

optical fibers suffer radiation losses at bends or curves on their paths. This is due to the energy in the evanescent field at the bend exceeding the velocity of the light energy to be radiated from the fiber



The loss can generally be represented by a radiation attenuation coeff.

$$\alpha_r = C_1 \exp(-C_2 R)$$

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