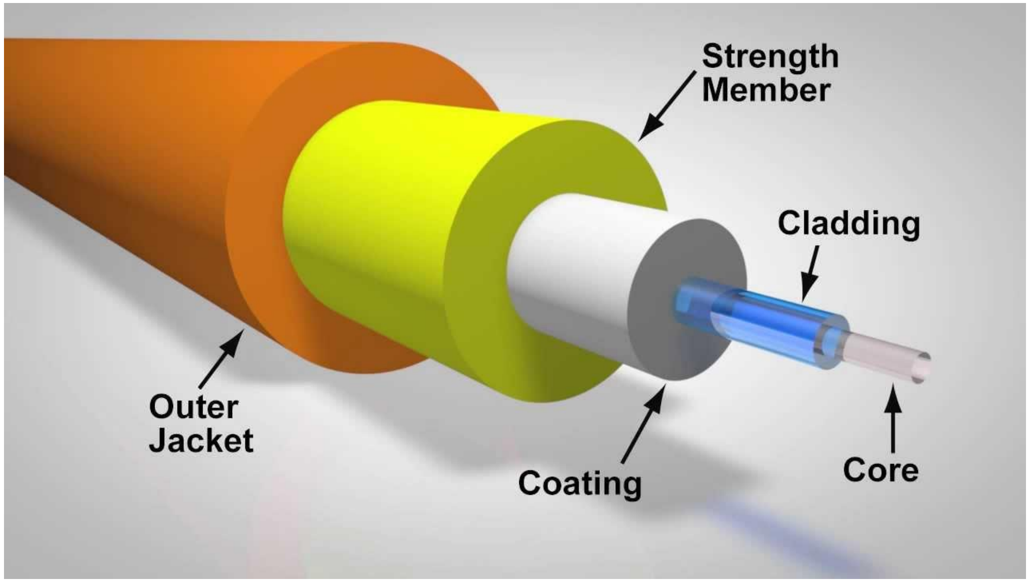
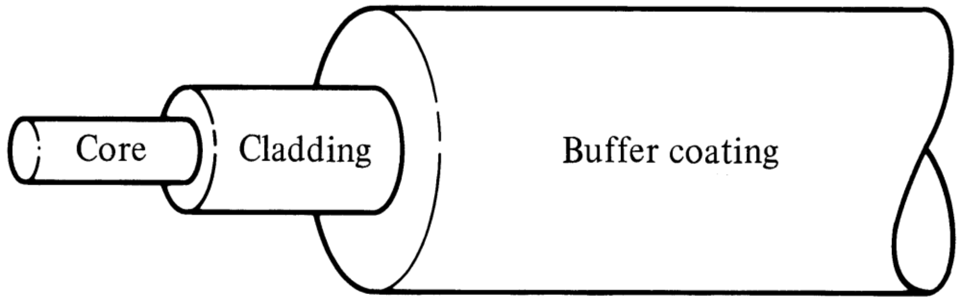
OPTICAL-FIBER
fundamentals



OPTICAL FIBER

- An optical fiber is a long cylindrical dielectric waveguide, usually of circular cross-section, transparent to the operating wavelength.

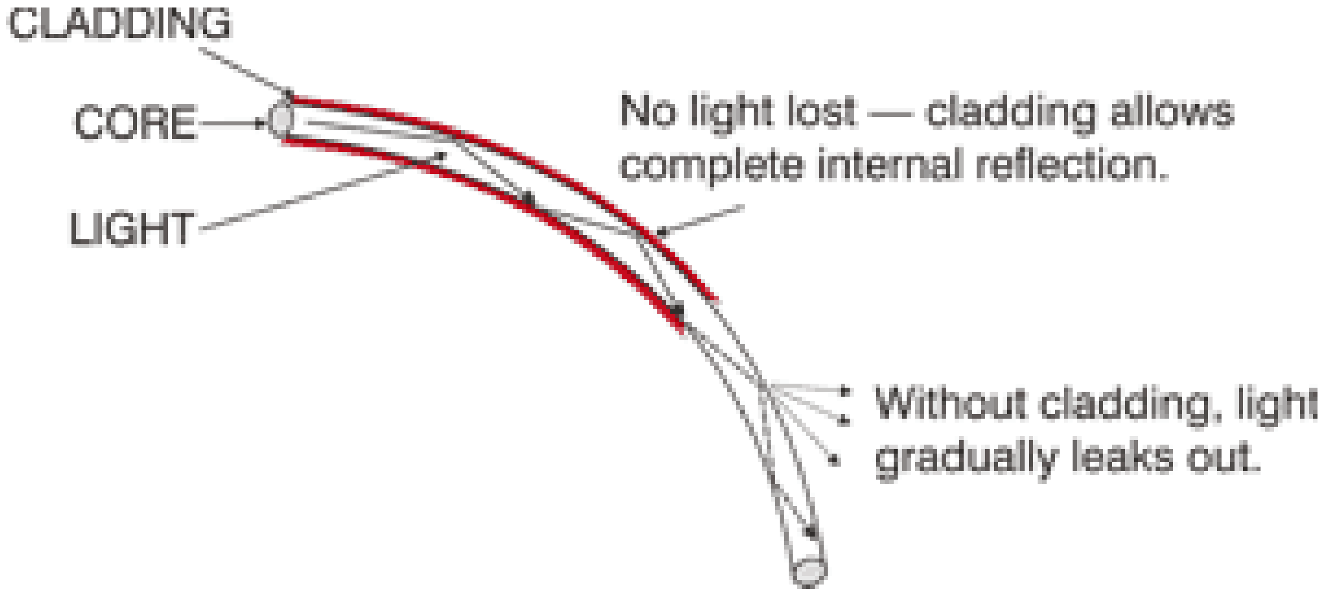
Fiber Structure



- A single solid dielectric of two concentric layers. The inner layer known as **Core** is of radius **'a'** and refractive index '$\mathbf{n_1}$'. The outer layer called **Cladding** has refractive index '$\mathbf{n_2}$'.

$$n_2 < n_1 \rightarrow \text{condition necessary is TIR}$$

Light Propagation through Optical Fiber



- **For light propagation through the fiber, the conditions for total internal reflection (TIR) should be met at the core-cladding interface**

CLASSIFICATION OF OPTICAL FIBERS

Classified on basis of

- **Core and Cladding materials**
- **Refractive index profile**
- **Modes of propagation**

Three Varieties:

a. Glass core and cladding (SCS: silca-clad silica)

- minimum attenuation & good propagation characteristics
- Least rugged – delicate to handle

b. Glass core with plastic cladding (PCS: plastic clad silica)

- More rugged than glass; attractive to military applications
- Medium attenuation and propagation characteristics

c. Plastic core and cladding

- More flexible and more rugged
- Easy to install, better withstand stress, less expensive, weigh 60% less than glass
- High attenuation- limited to short runs.

Refractive Index Profile: Two types

- **Step Index :** Refractive index makes abrupt change
- **Graded Index** : Refractive index is made to vary as a function of the radial distance from the centre of the fiber

Mode of propagations : Two types

- **Single mode :** Single path of light
- **Multimode :** Multiple paths

Optical Fiber Wave guiding

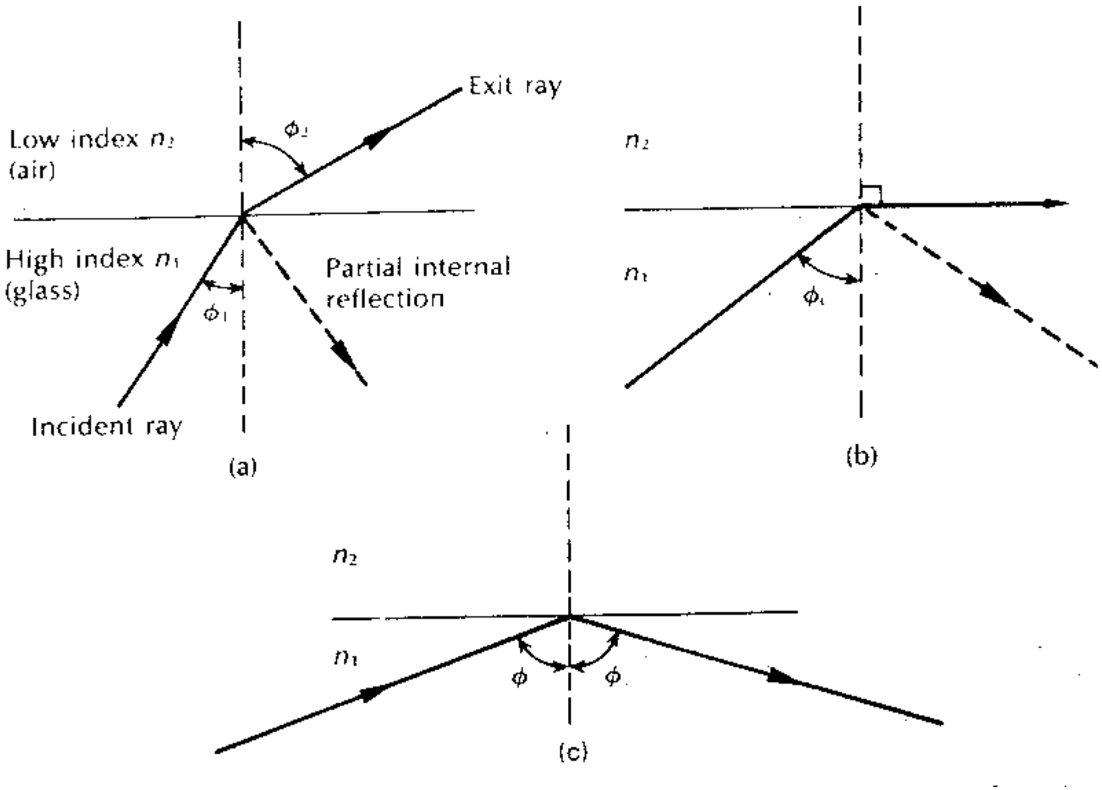
- To understand transmission mechanisms of optical fibers with dimensions approximating to those of a human hair;
  - Necessary to consider the optical waveguiding of a cylindrical glass fiber.

- Fiber acts as an open optical waveguide – may be analyzed using simple ray theory – **Geometric Optics**
  - Not sufficient when considering all types of optical fibers

- **Electromagnetic Mode Theory** for Complete Picture

Total Internal Reflection

- Light entering from glass-air interface ($n_1 > n_2$) - **Refraction**



Snell's Law:

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

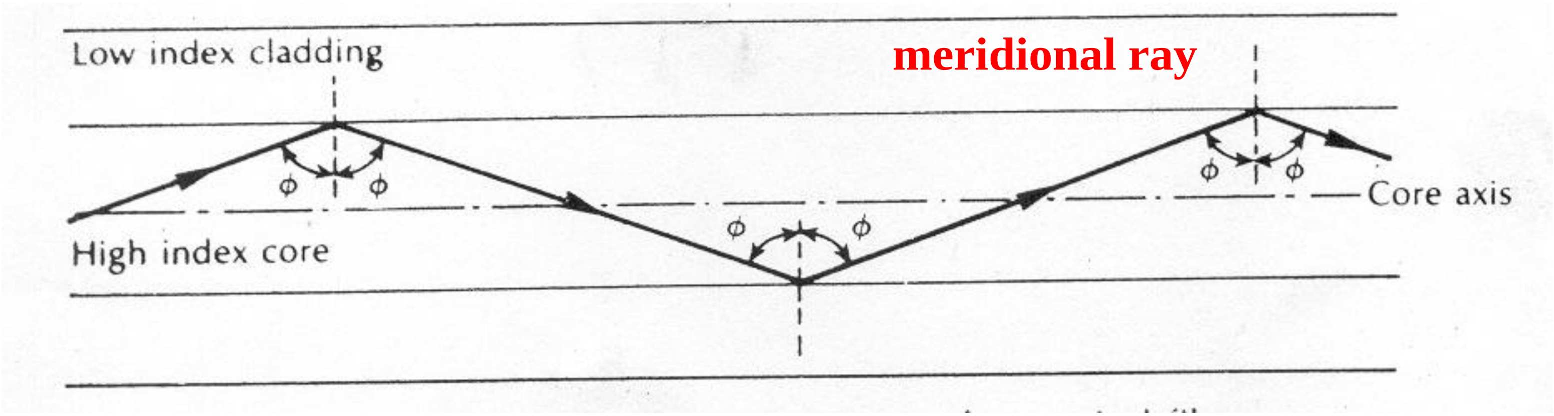
$$\Rightarrow \phi_2 > \phi_1$$

- At $\phi_2 = 90^o$, refracted ray moves parallel to interface between dielectrics and $\phi_1 < 90^o$ - **Limiting case of refraction**

Angle of incidence, $\phi_1 \rightarrow \phi_C$; **critical angle**

Total Internal Reflection

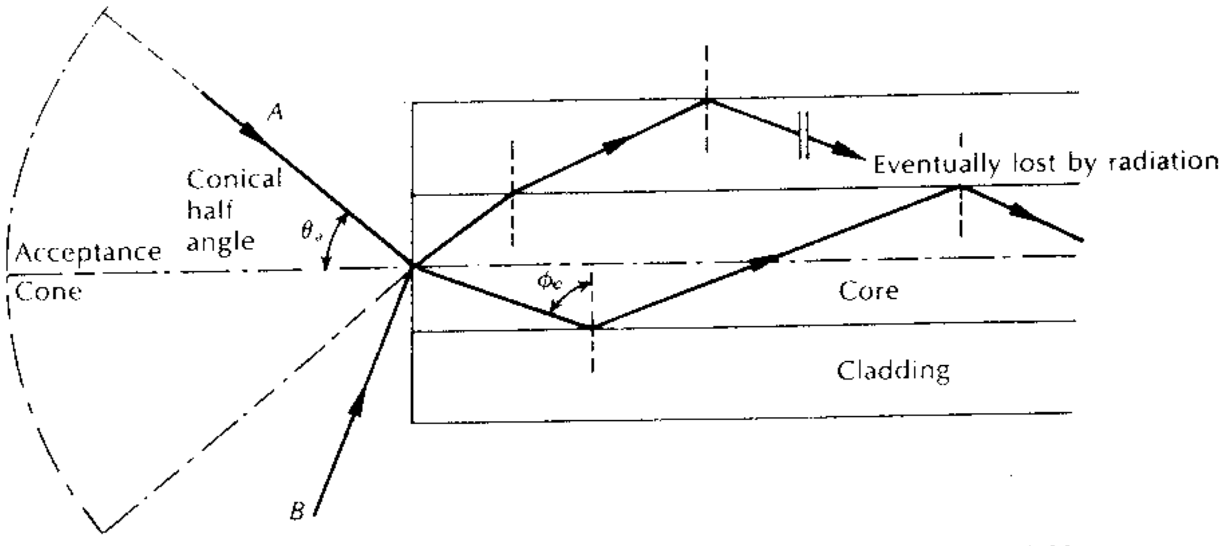
- Value of critical angle (ϕ_C); sin $\phi_C = n_2/n_1$
  - At angle of incidence greater than critical angle, the light is reflected back into the originating dielectric medium (TIR) with high efficiency (≈ 99.9%)



Transmission of light ray in a perfect optical fiber

ACCEPTANCE ANGLE

- Not all rays entering the fiber core will continue to be propagated down its length
- Only rays with sufficiently shallow grazing angle (i.e. angle to the normal > ϕ_C) at the core-cladding interface are transmitted by TIR.



➢ Any ray incident into fiber core at angle > θ_a will be transmitted to core-cladding interface at an angle < ϕ_C and will not follow TIR $\Rightarrow$ ***Lost***

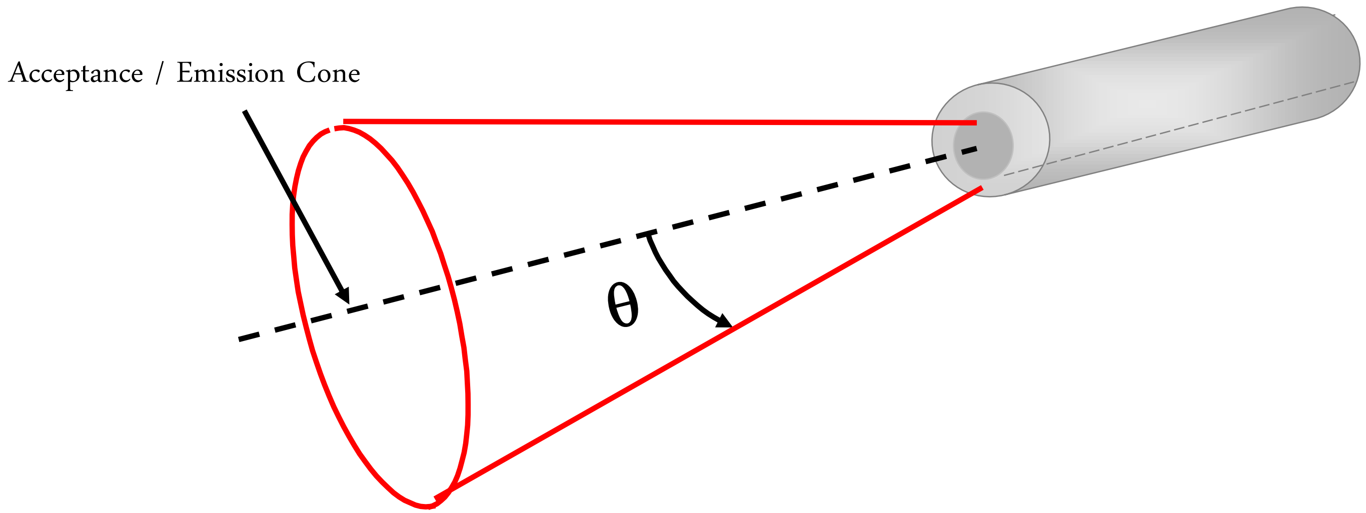
Acceptance Angle….

- For rays to be transmitted by TIR within the fiber core, they must be incident on the fiber core within an acceptance cone defined by the ***conical half angle*** "θ_a" .
  - *θ_a is the maximum angle to the axis at which light may enter the fiber in order to be propagated $\Rightarrow$* ***Acceptance angle*** *for the fiber*

- From symmetry considerations, **the output angle to the axis will be equal to the input angle for the ray,** assuming that the ray emerges into a medium of the same refractive index from which it was input.

Numerical Aperture (NA)

- **A Very useful parameter : measure of light collecting ability of fiber.**
  - Larger the magnitude of NA, greater the amount of light accepted by the fiber from the external source



$$NA = \sin\theta_a = \sqrt{n^2_{core} - n^2_{cladding}}$$

- **NA varies from 0.12- 0.20 for SMFs and 0.15- 0.50 for MMFs**

$$\theta' = (90 - \theta)$$

Where n_0 is refractive index of medium outside the fiber. For air n_0 =1.

$$n_0 \sin i = n_1 \sin\theta$$

Therefore,

$$n_1 \sin\theta'_c = n_2 \sin 90$$

$$Sin\,\theta'_c = \frac{n_2}{n_1}$$

$$NA = n_0 \sin i_m = n_1 \sin\theta$$

$$= n_1 \sin(90 - \theta_c)$$

$$Or\ NA = n_1\, Cos\,\theta'_c$$

$$= n_1 \sqrt{1 - Sin^2\theta'_c}$$

$$NA = n1\sqrt{1 - \frac{n_2^{\,2}}{n_1^2}} \qquad NA = \sqrt{n_1^{\,2} - n_2^{\,2}}$$

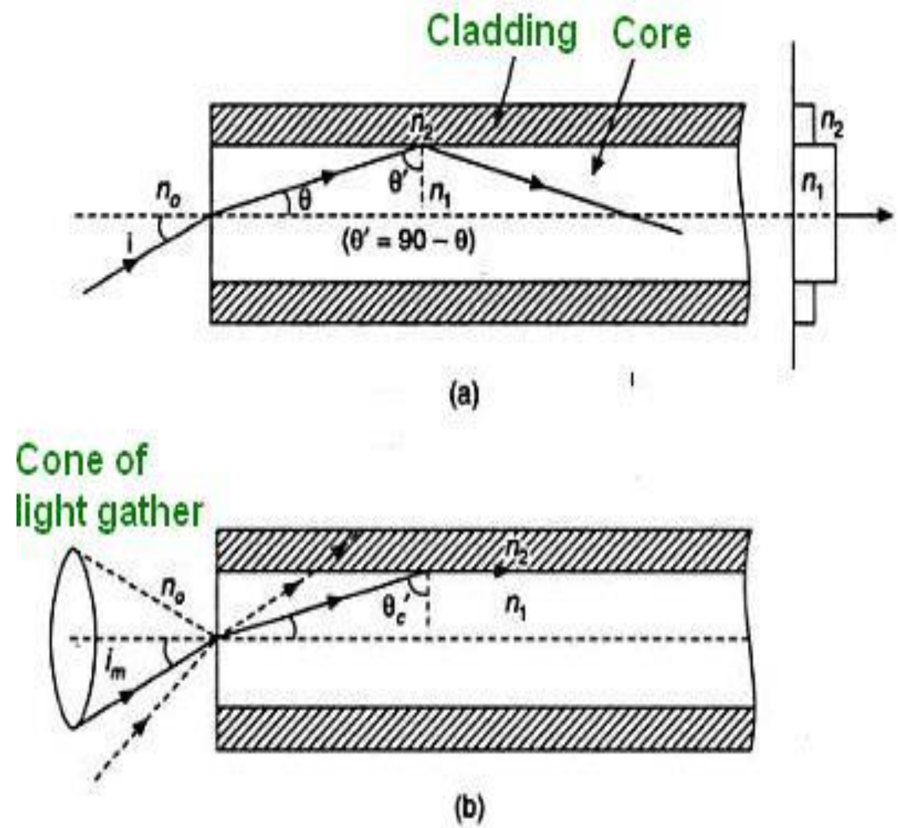
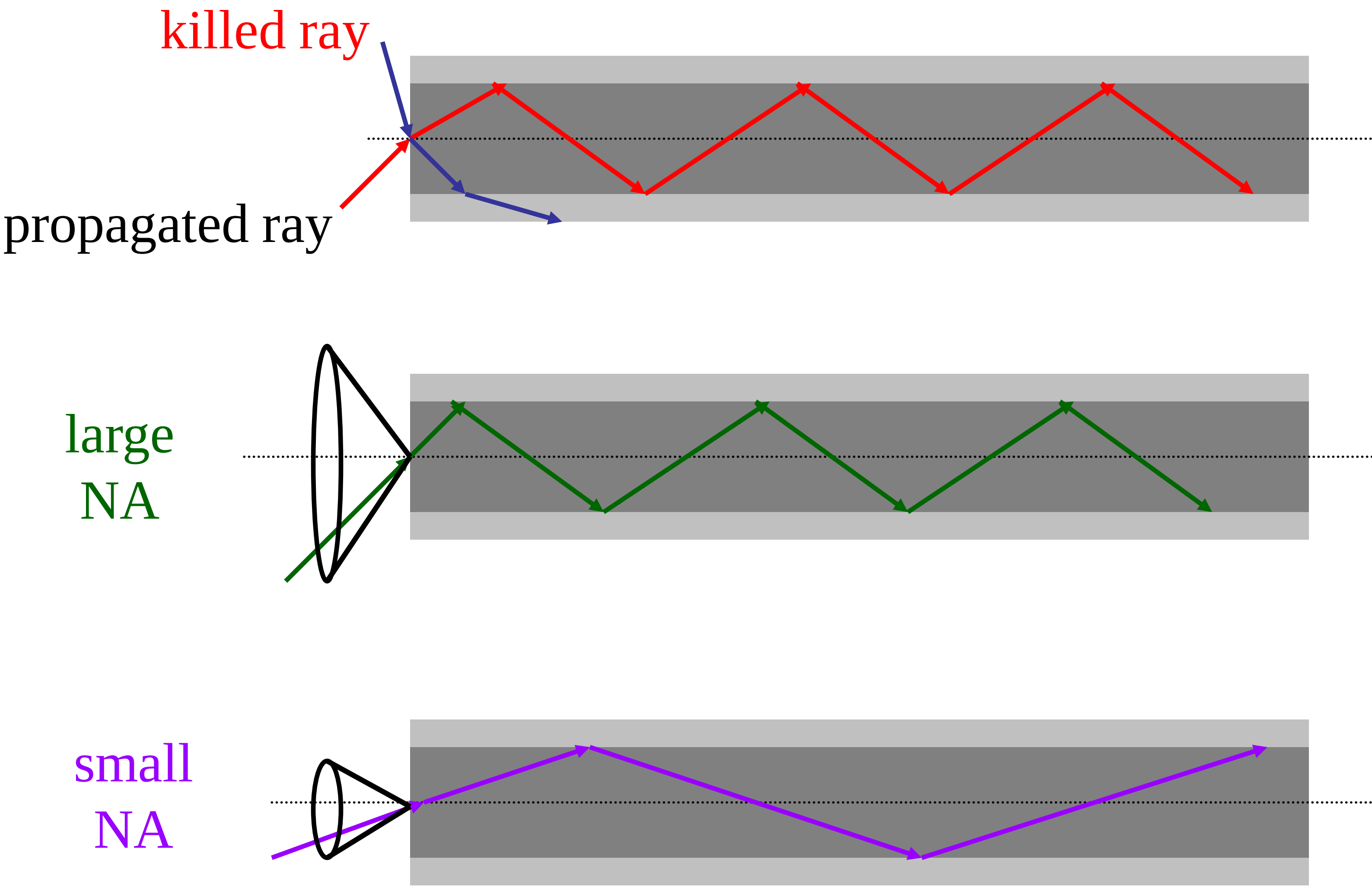


Figure 3

The significance of NA is that light entering in the cone of semi vertical angle im only propagate through the fibre. The higher the value of im or NA more is the light collected for propagation in the fibre. Numerical aperture is thus considered as a light gathering capacity of an optical fibre.

NA= Sin θ_a where θ_a, is called acceptance cone angle

NA and Number of Modes



NA and Δ (Relative R.I Difference)

- In terms of relative R.I. difference 'Δ' between core and cladding,

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2} \cong \frac{n_1 - n_2}{n_1} \quad (\text{for } \Delta << 1)$$

$$NA = n_1(2\,\Delta)^{1/2}$$

- NA ; independent of core and cladding diameters
- Holds for diameters as small as 8 μm

THANK YOU