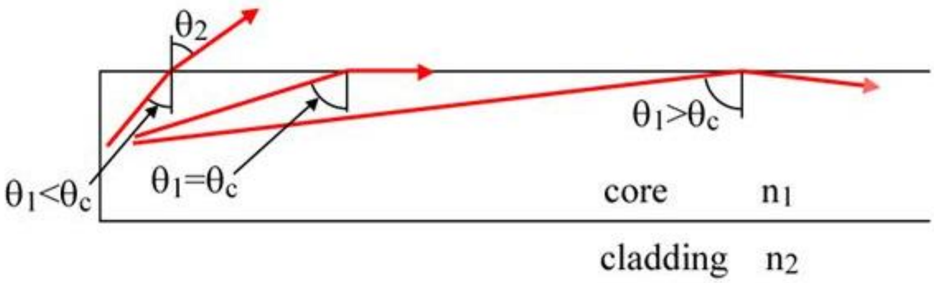
- The core is the inner part of the fibre.
- The refractive index of the core = n_1.
- The cladding surrounds the core completely.
- The refractive index of the cladding = n_2.

Light Guiding in Fibre:



- Ray bends at boundary between materials
  - Snell's law

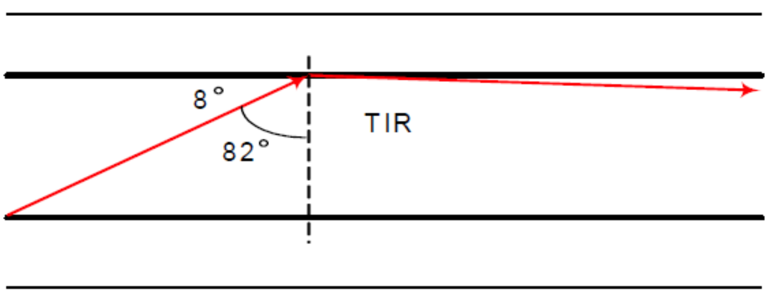
$$n_2 \sin\theta_2 = n_1 \sin\theta_1$$

$$\theta_2 = \sin^{-1}\left(\frac{n_2}{n_1} \sin\theta_1 \right)$$

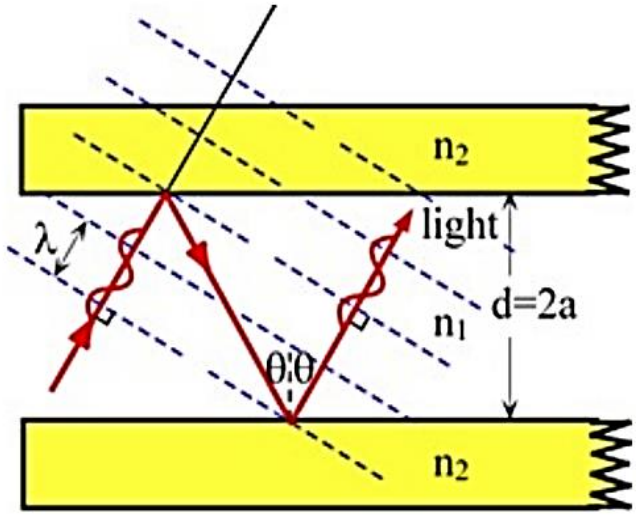
- Light confined to core if propagation angle is greater than the critical angle
  - Total internal reflection (TIR)

$$\theta_1 > \theta_c = \sin^{-1}\left(\frac{n_2}{n_1} \right)$$

- $n_1 > n_2$.
- Typical values of n_1= 1.5 and n_1= 1.485.
- Difference between the refractive indices of the core and cladding ~ 1%
- Hence the ratio works out to be 0.99 (n_2/n_1).
- Therefore the critical angle (θ_c) = 82°.



This could equally be expressed as the confinement angle ($\emptyset_{ca}$) = 8°.

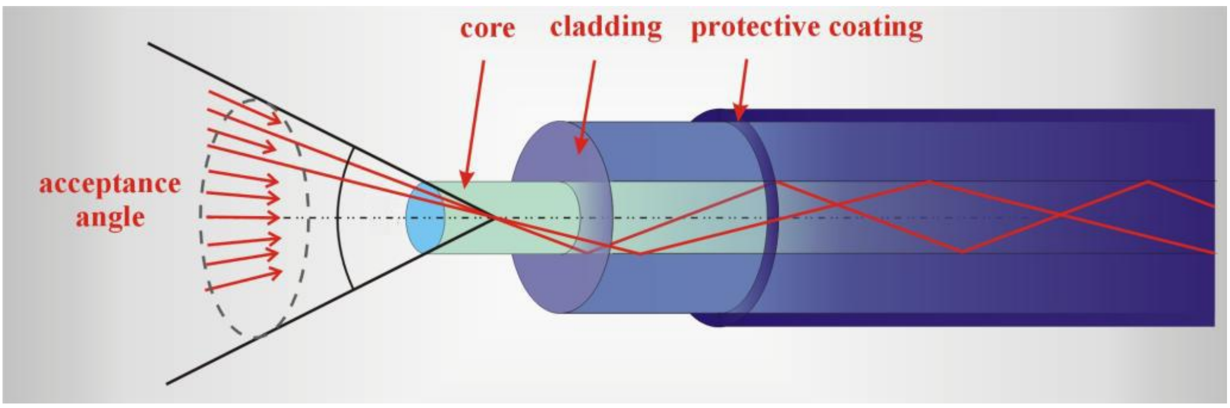


Propagation requires constructive interference

- Wave stays in phase after multiple reflections
- Only discrete angles greater than the critical angle are allowed to propagate

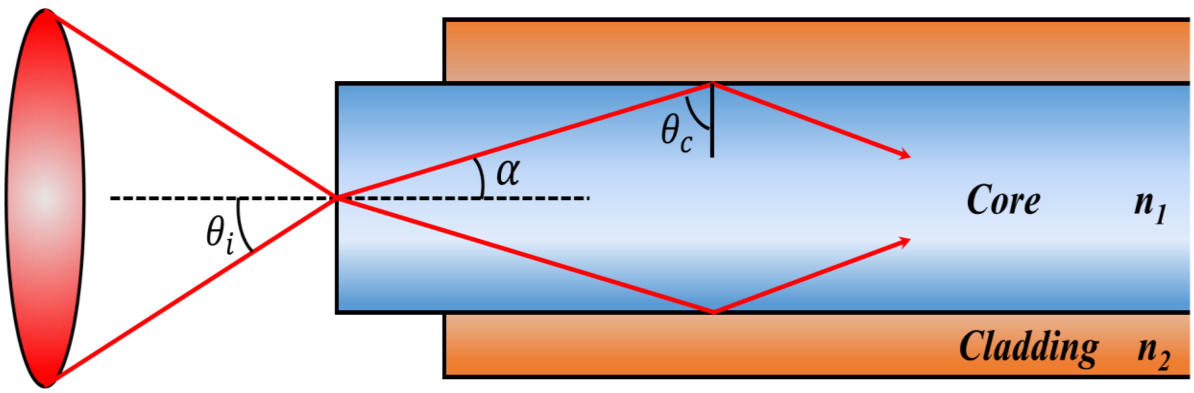
Numerical Aperture (NA):

Another way to look at light guiding in the fibre is to measure the fibre's acceptance angle. Since the acceptance angle is measured in air it is different from the confinement angle. The acceptance angle could also be represented in another form known as the Numerical Aperture (*NA*).
Numerical aperture *NA* defines of the maximum angle between the entering ray and the axis of the optical fiber, above which the phenomenon of the total internal reflection does not occur anymore and the ray cannot be propagated in the optical fiber. The angle is called the acceptance angle.



Numerical aperture *NA* is defined as the sinus of a half of the acceptance angle. The typical values are 0.1-0.4 which correspond to acceptance angle 11°- 460. Optical fiber transmits only the light entering the optical fiber under the angle equal or smaller than the acceptance angle. We will show, that the numerical aperture *NA* depends on the refraction index of the core and the cladding.

The acceptance angle for a fiber defines its Numerical Aperture (*NA*)



The *NA* is related to the critical angle θ_c of the waveguide and it's defined as:

$$NA = sin\,\alpha = \sqrt{{n_{co}}^2 - {n_{cl}}^2}$$

This equation suggests an optical fiber with a higher *NA* allows the launch of light with a larger launch angle, therefore enables the launch of higher power density into the core.

❖ Let's derive the formula for the numerical aperture *NA*.

From Snell's law we know that at the critical angle θ_c for the total internal reflection is expressed by the formula:

$$n_{co} sin\theta_c = n_{cl} \sin 90^o \qquad (a)$$

From the relationship of sum of angles in a triangle one gets:

$$n_{co} sin(90^o - \theta_c) = n_{cl} \qquad (b)$$

And

$$n_{co} cos\theta_c = n_{cl} \qquad (c)$$

From the reduction formulas one receives:

$$n_{co}\sqrt{1 - sin^2\theta_c} = n_{cl} \qquad (d)$$

After squaring both sides of the equation we obtain:

$$n_{co}{}^2(1 - sin^2\theta_c) = n_{cl}{}^2 \qquad (e)$$

And from this:

$$n_{co}{}^2 - n_{co}{}^2\, sin^2\theta_c = n_{cl}{}^2 \qquad (f)$$

Using the Snell's law once again for the core - air refraction for the light ray entering the optical fiber one gets:

$$n_{co}{}^2\, sin^2\theta_c = 1\, sin^2\alpha \qquad (g)$$

And substituting (g) to (f) one gets:

$$n_{co}{}^2 - sin^2\alpha = n_{cl}{}^2 \qquad (h)$$

Finally we obtain the formula for the numerical aperture *NA*:

$$NA = sin\,\alpha = \sqrt{n_{co}{}^2 - n_{cl}{}^2}$$

Telecommunications optical fiber $n_{co} \sim n_{cl}$:

$$NA = \sqrt{n_{co}{}^2 - n_{cl}{}^2} = \sqrt{(n_{co} - n_{cl})(n_{co} + n_{cl})} \cong \sqrt{2\, n_{co}{}^2\, \frac{n_{co} - n_{cl}}{n_{co}}}$$

$$NA \cong n_{co}\sqrt{2\Delta} \qquad , \qquad \Delta = \frac{n_{co} - n_{cl}}{n_{co}}$$

Properties of Optical Fibre - Signal Degradation

The optical net will operate properly, when we first select the proper optical fiber, apply the proper light transmitter that emits the light which is directed into the fiber, as well as the proper receiver that detects the light at the end of the fiber.

We distinguish the wide range of the Properties for Optical Fibre (Signal Degradation):

- Attenuation
- Dispersion
- Non-linearity

Optical Fiber Attenuation:

The extremely low attenuation or transmission loss of optical fibers is one of the most important factors in bringing its wide acceptance as a medium of transmission. Signal transmission within optical fibers, as with metallic conductors, is usually abbreviated as *dB*. The decibel (*dB*) is a convenient way of comparing two divergent power levels, say, P_{out} and P_{in}. This is defined as:

$$Loss\ in\ \mathrm{dB} = 10\log_{10}\left\{\frac{Input\ power\ (P_{out})}{Output\ power\ (P_{in})}\right\}$$

Optical fiber attenuation is the measurement of light loss between input and output. Total attenuation is the sum of all losses.

$$Loss_{dB} = 10\log_{10}\left(\frac{P_{out}}{P_{in}}\right)$$

Where P_{in} represented the power which is launched into the fiber, and P_{out} represented the power which is remaining after propagating along optical fiber.