

Engineering Optics

Lecture 39

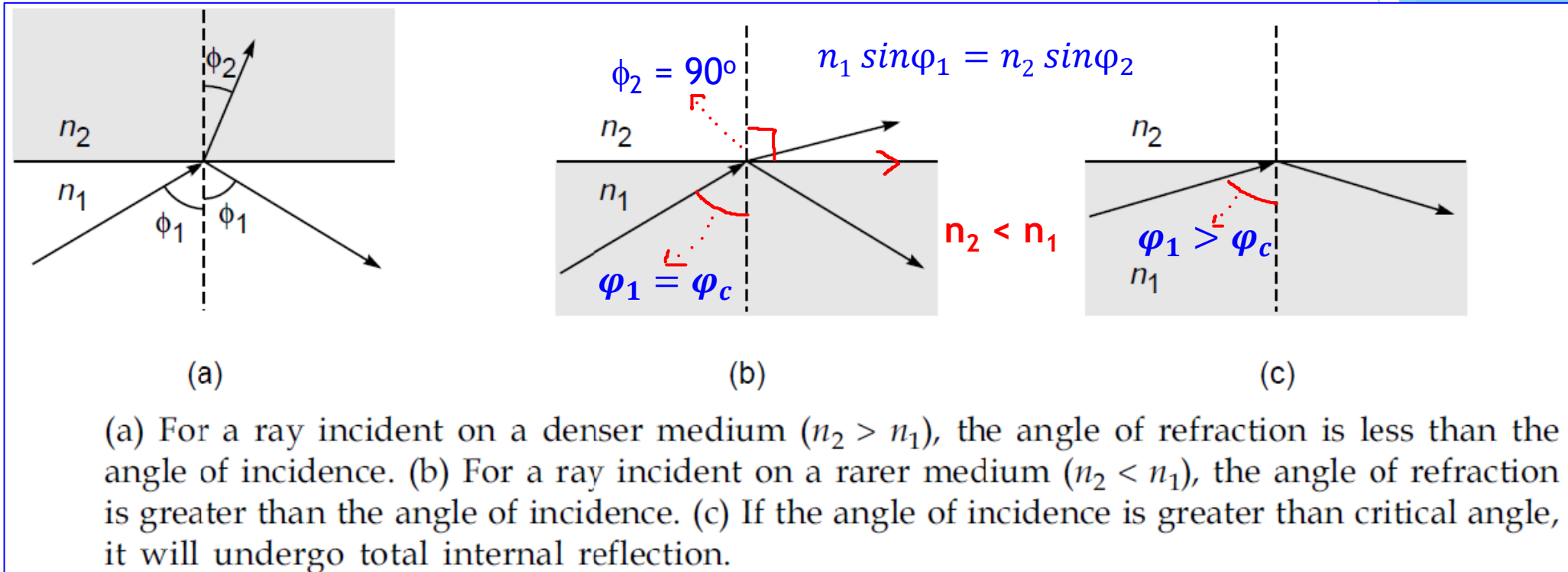
14/06/2023

by

Debolina Misra

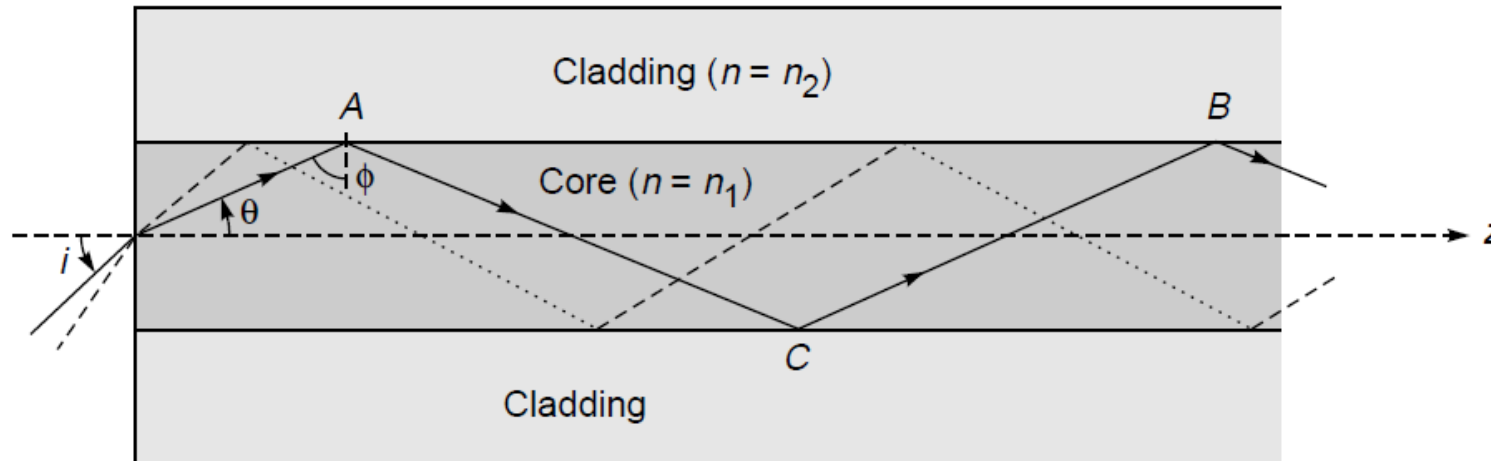
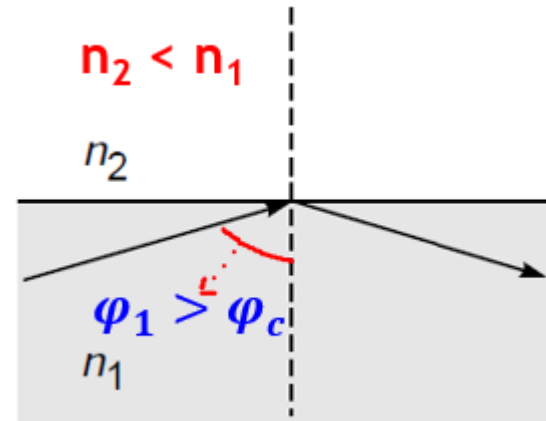
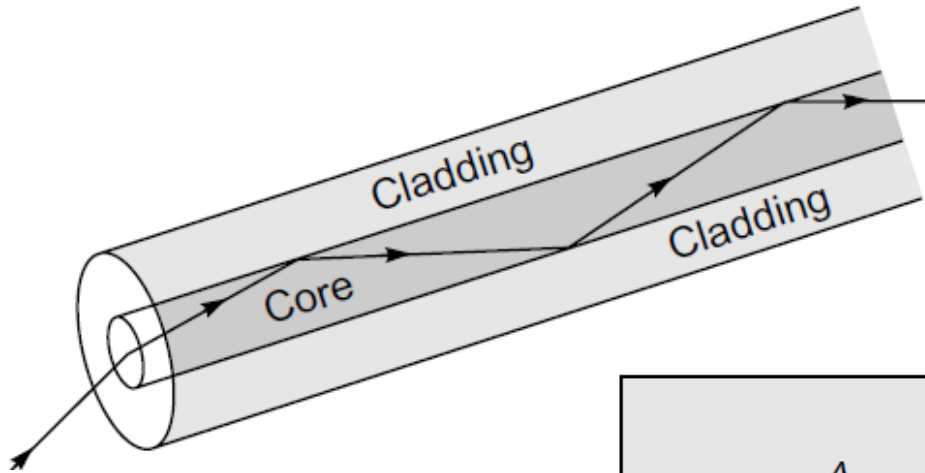
Assistant Professor in Physics
IIITDM Kancheepuram, Chennai, India

Total internal reflection



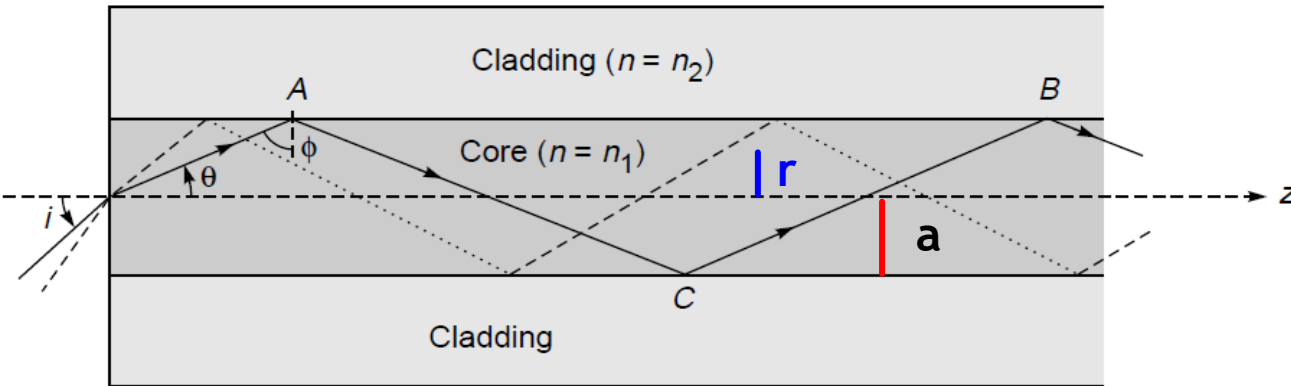
- ▶ if a ray is incident at the interface of a rarer medium ($n_2 < n_1$), then the ray will bend away from the normal
- ▶ The angle of incidence, for which the angle of refraction is 90° , is known as the critical angle and is denoted by ϕ_c .
- ▶ When $\phi_1 = \phi_c = \sin^{-1} \frac{n_2}{n_1} \rightarrow$ angle of refraction $\phi_2 = 90^\circ$
- ▶ If $\phi_1 > \phi_c$, there is no refracted ray and we have what is known as total internal reflection.

Optical fiber



- ▶ a cylindrical central dielectric core cladded by a material of slightly lower refractive index.

Optical fiber: refractive index



We define a parameter Δ

$$\Delta \equiv \frac{n_1^2 - n_2^2}{2n_1^2}$$

for most silica fibers, $\Delta \ll 1$
as $n_1 \approx n_2$

$$\Delta = \frac{n_1 - n_2}{n_1} \frac{n_1 + n_2}{2n_1} \approx \frac{n_1 - n_2}{n_2} \approx \frac{n_1 - n_2}{n_1}$$

- ▶ refractive index distribution in optical fiber (in the transverse direction) is given by

$$n = \begin{cases} n_1 & 0 < r < a \\ n_2 & r > a \end{cases}$$

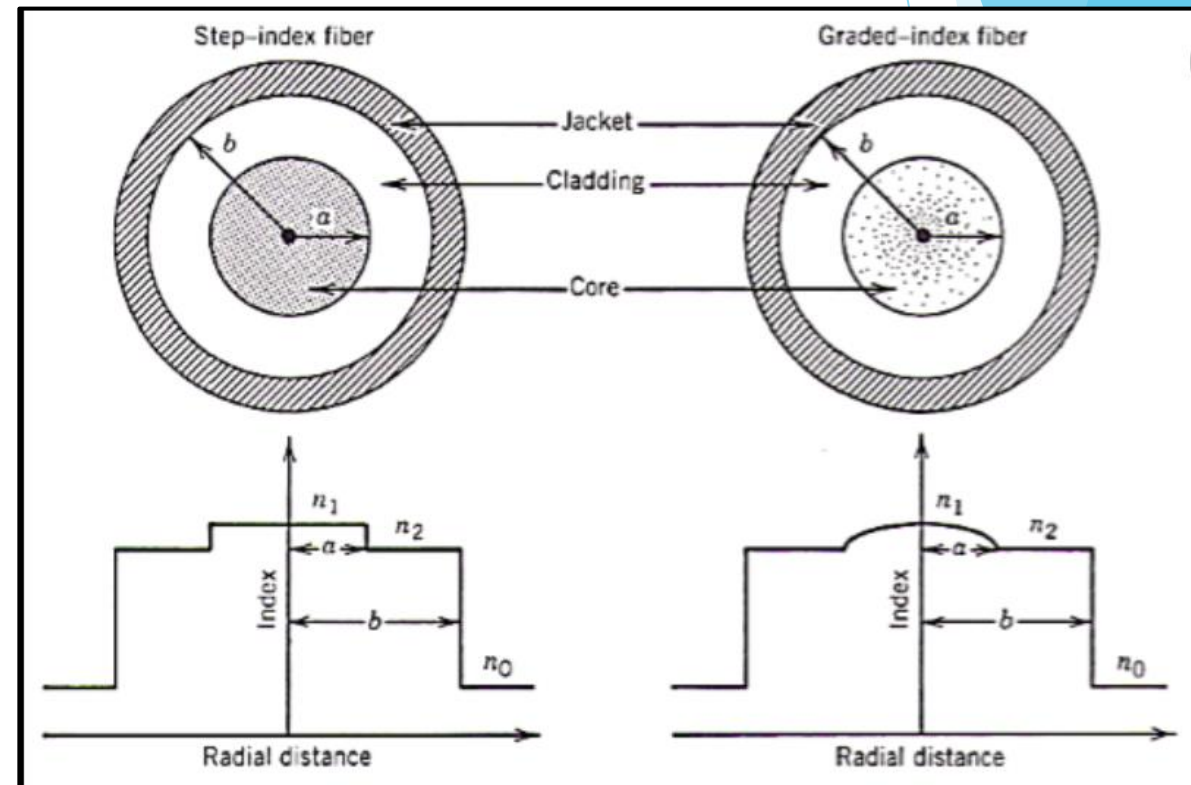
- ▶ where n_1 and n_2 ($< n_1$) \rightarrow r.i. of core and cladding and 'a' represents the radius of the core.

Optics, Ghatak

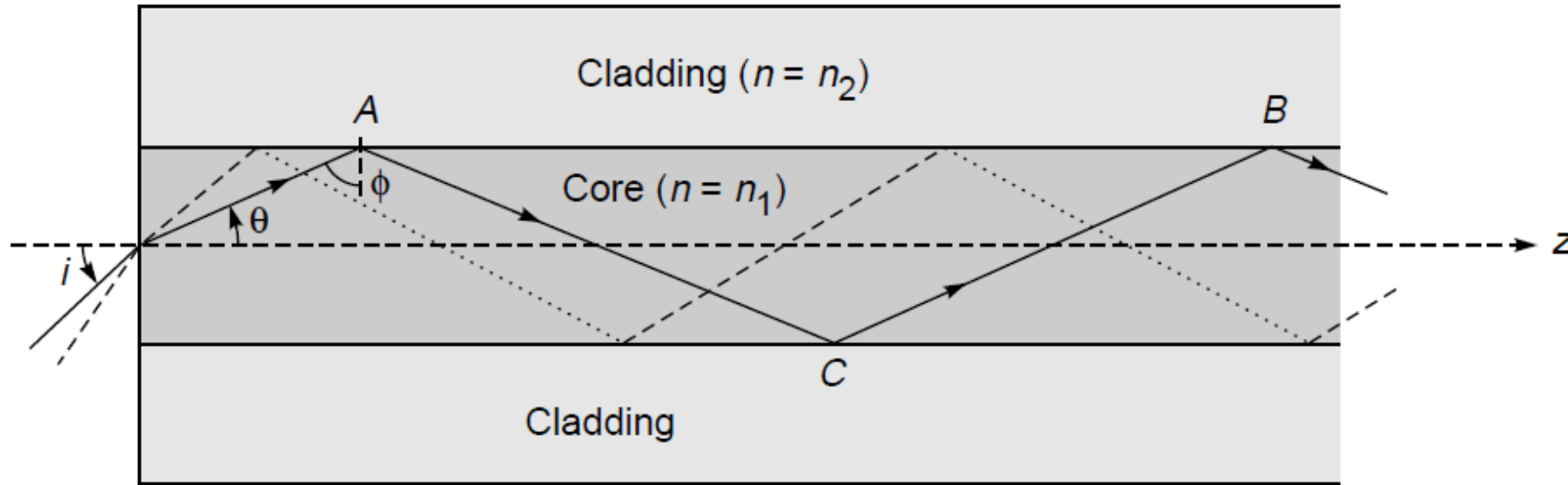
For a fiber, if 'a' $\approx 25 \mu\text{m}$,
Cladding \rightarrow pure silica with $n_2 \approx 1.45$
 $\Delta \approx 0.01$,
r.i. n_1 of the core = ?
core is usually silica doped with germanium;
doping by germanium increases refractive index.

Step indexed and graded indexed fibers

- ▶ Step index fiber → the core is of a uniform refractive index and there is a sharp decrease in the index of refraction at the cladding.
- ▶ Graded index fiber → refractive index of the core is maximum at the center core and then it decreases towards core-cladding interface.



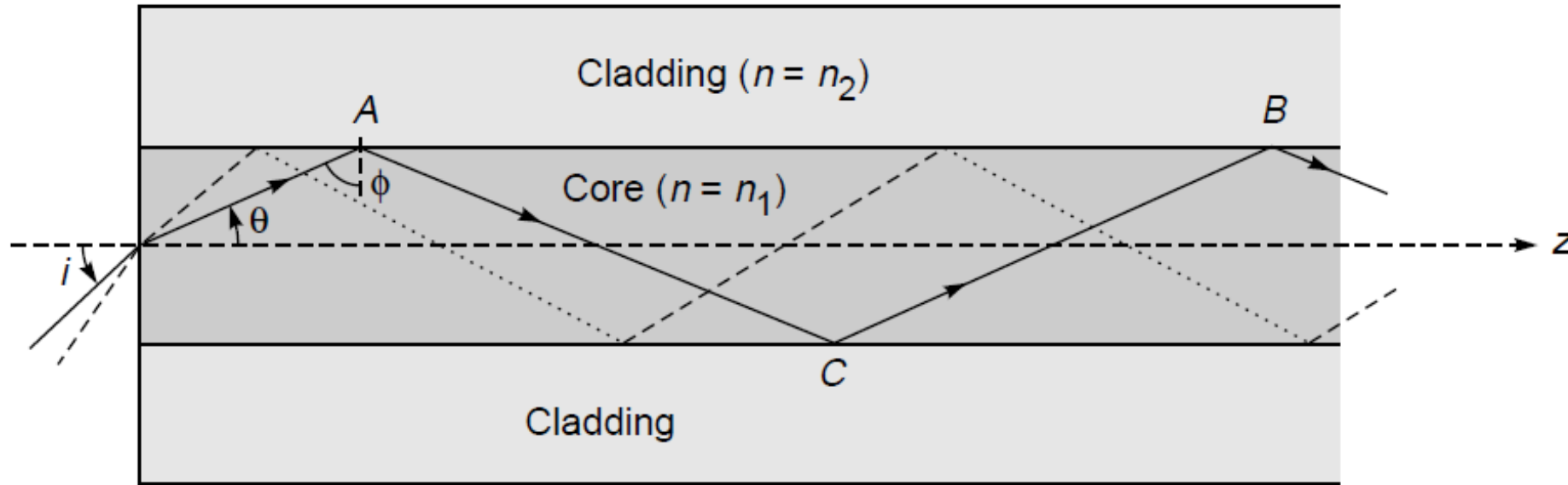
Optical fiber



- ▶ Now, for a ray entering the fiber, if the angle of incidence (at the core-cladding interface) is greater than the critical angle ϕ_c , then the ray will undergo TIR at that interface.
- ▶ Thus, for TIR to occur at the core-cladding interface

$$\phi > \phi_c = \sin^{-1} \left(\frac{n_2}{n_1} \right) \quad \text{What about } \theta ?$$

Optical fiber



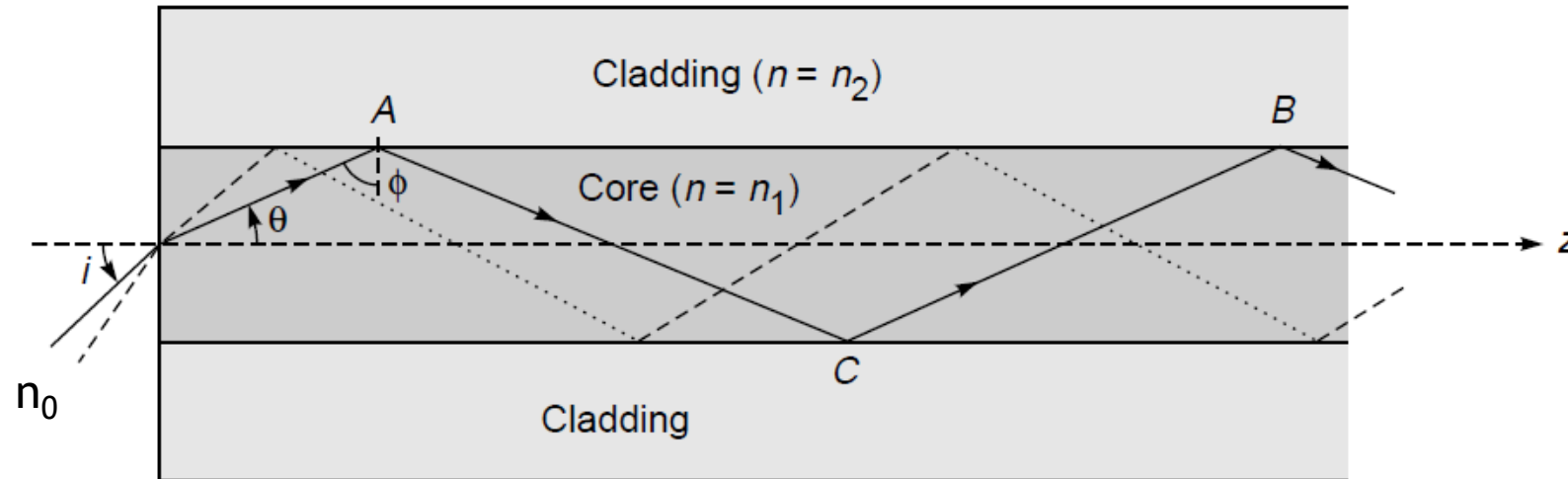
- ▶ Now, for a ray entering the fiber, if the angle of incidence (at the core-cladding interface) is greater than the critical angle ϕ_c , then the ray will undergo TIR at that interface.
- ▶ Thus, for TIR to occur at the core-cladding interface

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

or θ should be less than θ_c :

$$\theta < \theta_c = \cos^{-1} \left(\frac{n_2}{n_1} \right)$$

Find out the upper limit for i to guide a ray through a fiber

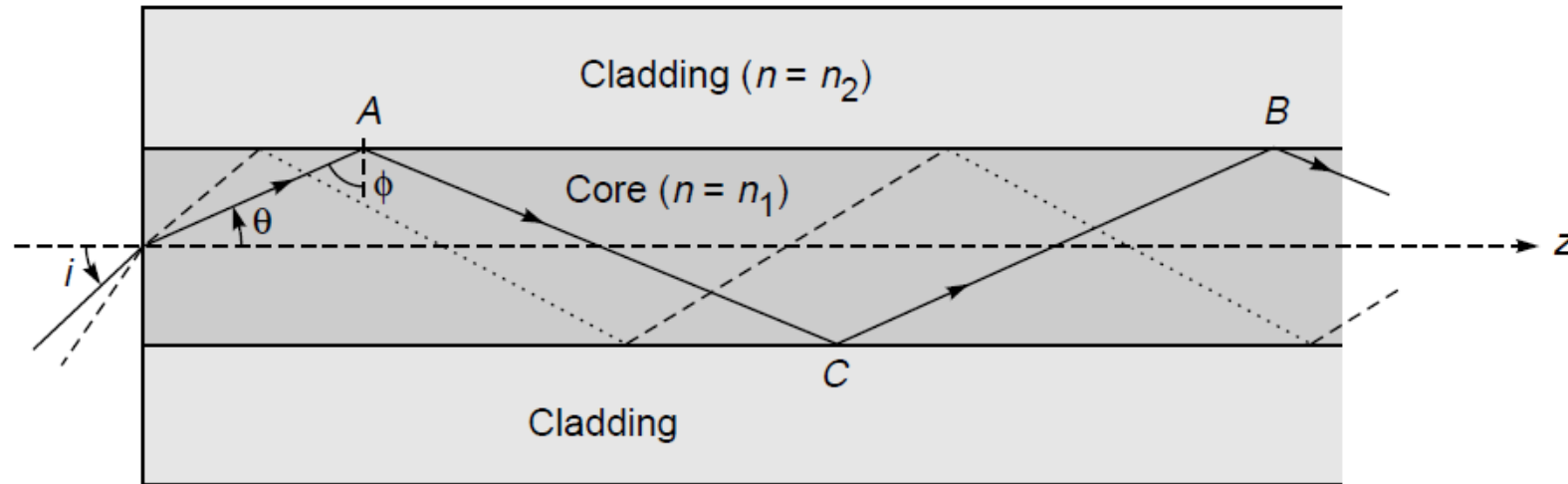


► For T.I.R, $\sin \phi (= \cos \theta) > \frac{n_2}{n_1}$

$\sin \theta$??

$\sin i$??

Solution



- For T.I.R, $\sin \phi (= \cos \theta) > \frac{n_2}{n_1}$

$$\sin \theta < \sqrt{1 - \left(\frac{n_2}{n_1}\right)^2}$$

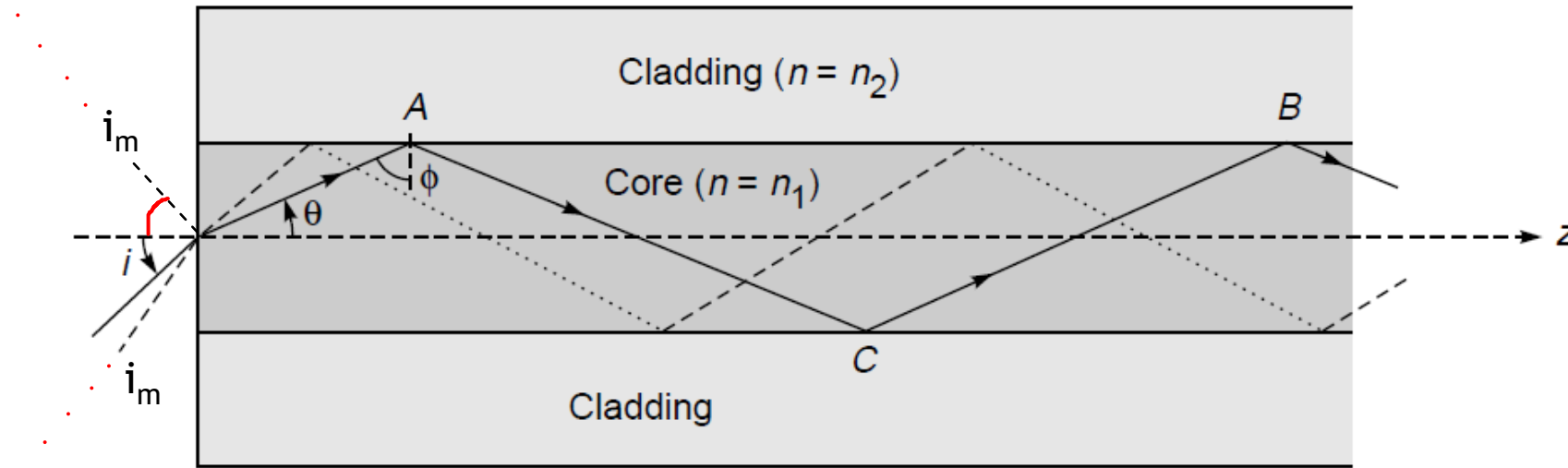
$$\sin i < \frac{n_1}{n_0} \sqrt{1 - \left(\frac{n_2}{n_1}\right)^2} = \sqrt{\frac{(n_1^2 - n_2^2)}{n_0^2}}$$

$$\frac{\sin i}{\sin \theta} = \frac{n_1}{n_0}$$

In most cases, the outside medium is air, i.e., $n_0 = 1$
maximum value of $\sin i$ for a ray to be guided

$$\sin i_m = \begin{cases} \sqrt{n_1^2 - n_2^2} & \text{if } n_1^2 < n_2^2 + 1 \\ 1 & \text{if } n_1^2 > n_2^2 + 1 \end{cases}$$

Numerical aperture



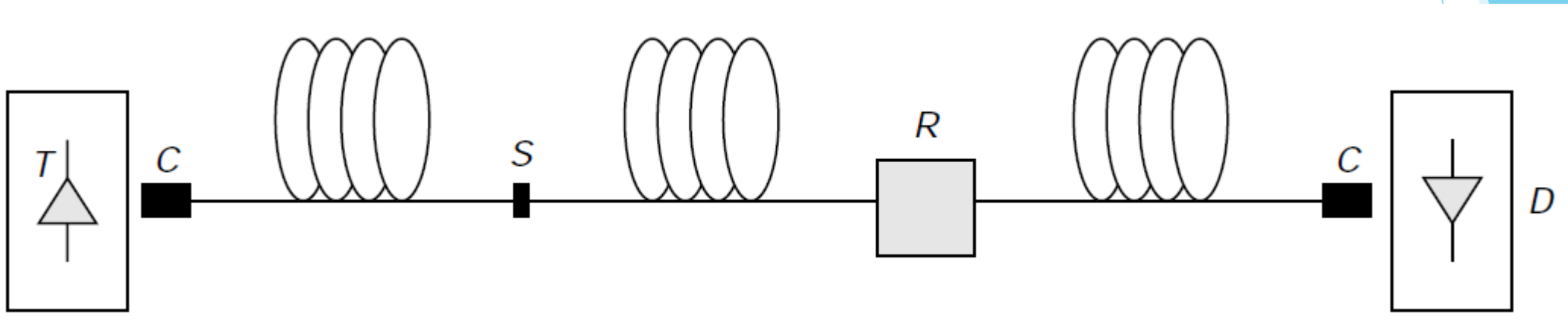
if light is incident on one end of the fiber, it will be guided through it provided $i < i_m$.

The quantity **$\sin i_m$** is known as the **numerical aperture (NA)** of the fiber and is a measure of the light-gathering power of the fiber.

In almost all practical situations, $n_1^2 < n_2^2 + 1$.

$$\text{NA} = \sqrt{n_1^2 - n_2^2}$$

A typical optical fiber communication system



- ▶ It consists of a transmitter (T) → LED/ laser diode → the light from which is coupled into an optical fiber through a connector C.
- ▶ Along the path of the optical fiber → splices (S: permanent joints) between sections of fibers
- ▶ Repeaters R : to boost the signal and correct any distortion that may have accumulated along the path of the fiber.
- ▶ At the end of the link, the light is detected by a photodetector and electronically processed to retrieve the signal.

Thank You