Engineering Optics

Lecture 33

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by

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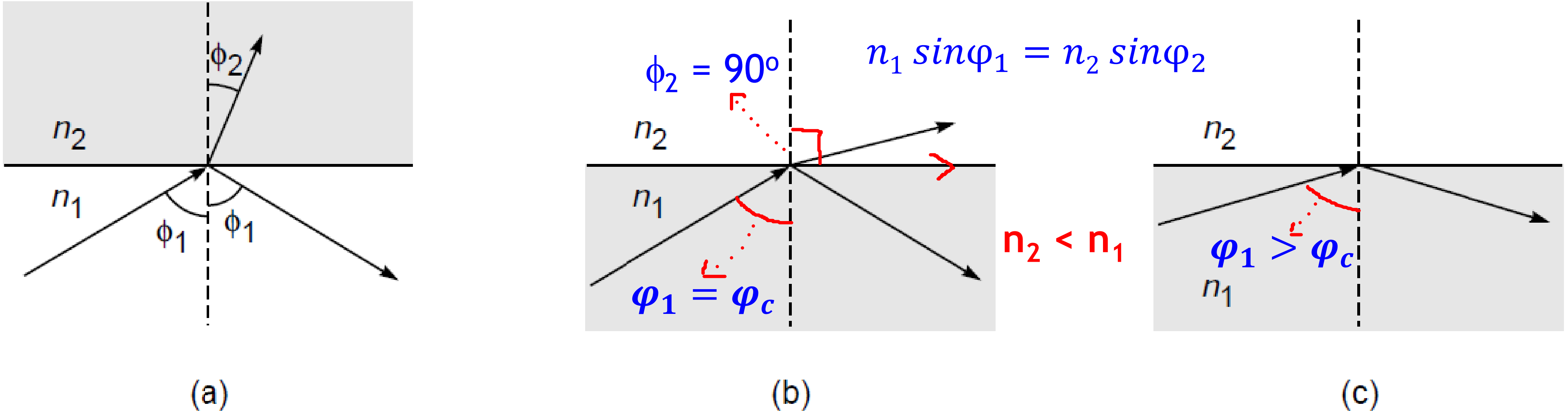
Total internal reflection



(a) For a ray incident on a denser medium ($n_2 > n_1$), the angle of refraction is less than the angle of incidence. (b) For a ray incident on a rarer medium ($n_2 < n_1$), the angle of refraction is greater than the angle of incidence. (c) If the angle of incidence is greater than critical angle, it will undergo 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 90º, is known as the critical angle and is denoted by ϕ_c.
- When $\varphi_1 = \varphi_c = \sin^{-1}\frac{n_2}{n_1}$ → angle of refraction ϕ_2 = 90º
- If $\phi_1 > \phi_c$, there is no refracted ray and we have what is known as total internal reflection.

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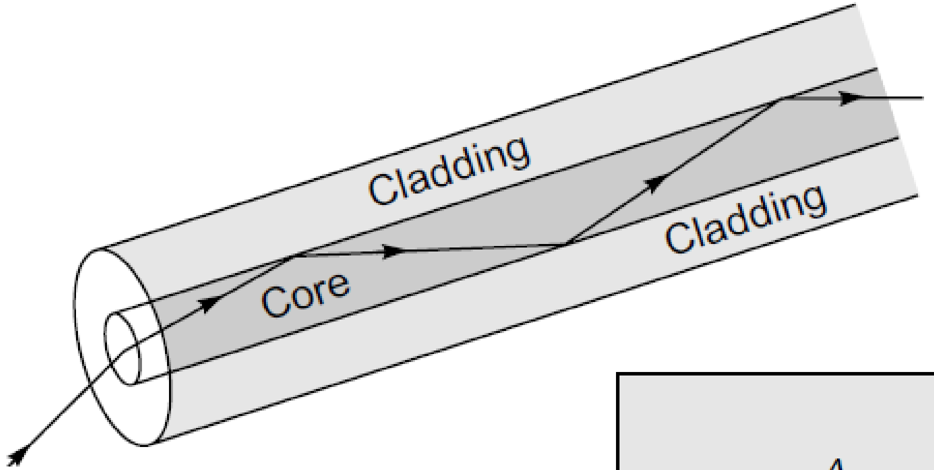
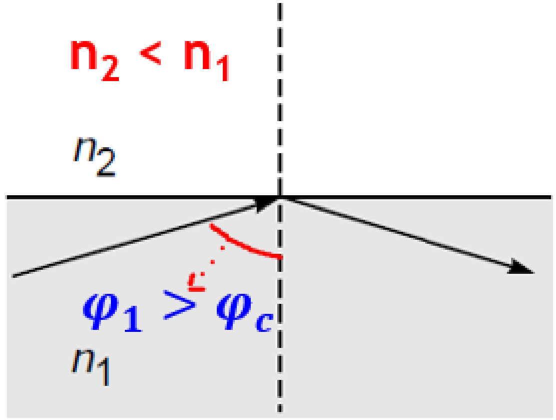
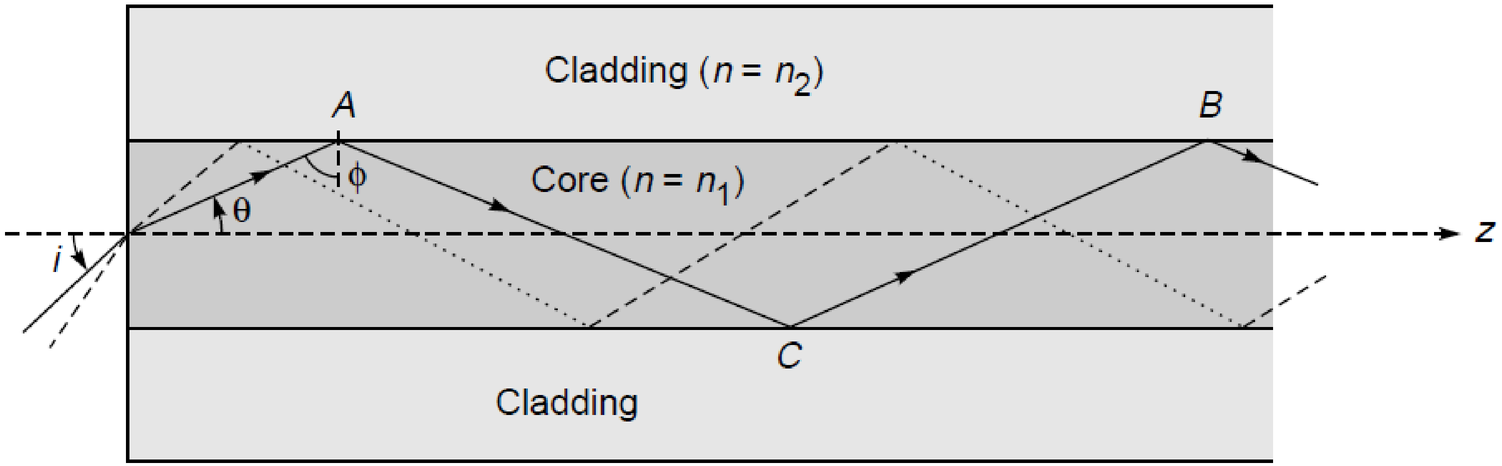
Optical fiber







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

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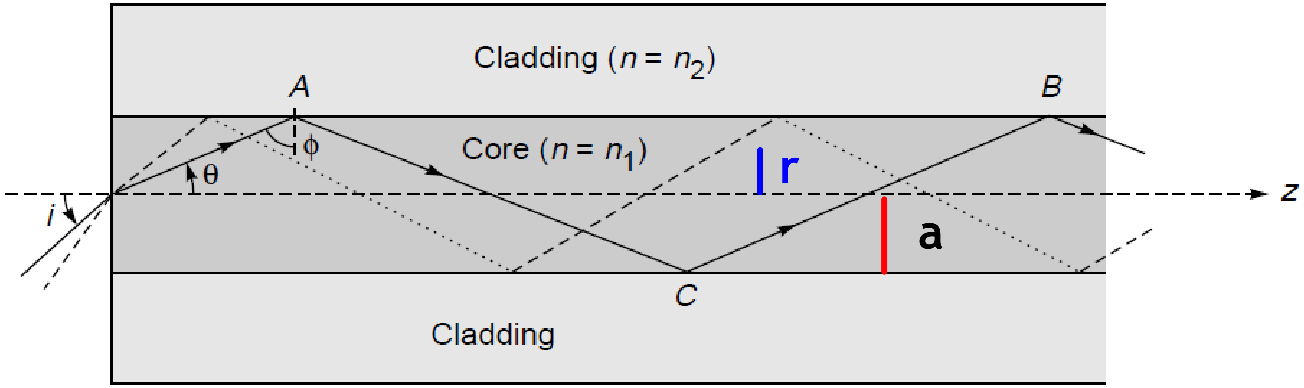
Optical fiber: refractive index



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

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

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

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We define a parameter Δ

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

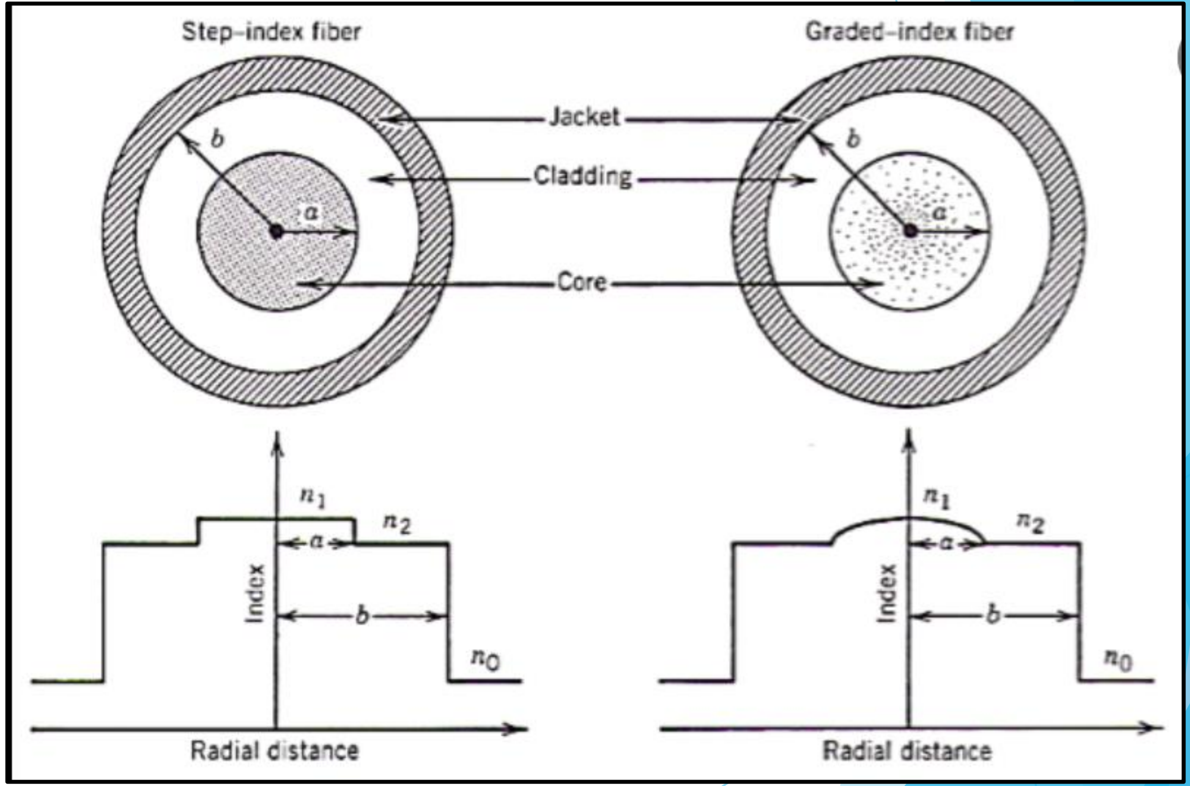
for most silica fibers, Δ <<1
as $n_1 \approx n_2$

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

For a fiber, if 'a' ≈25 μm,
Cladding → pure silica with n_2 ≈1.45
Δ ≈ 0.01,
r.i. n_1 of the core = ?
core is usually silica doped with germanium;
doping by germanium increases refractive index.

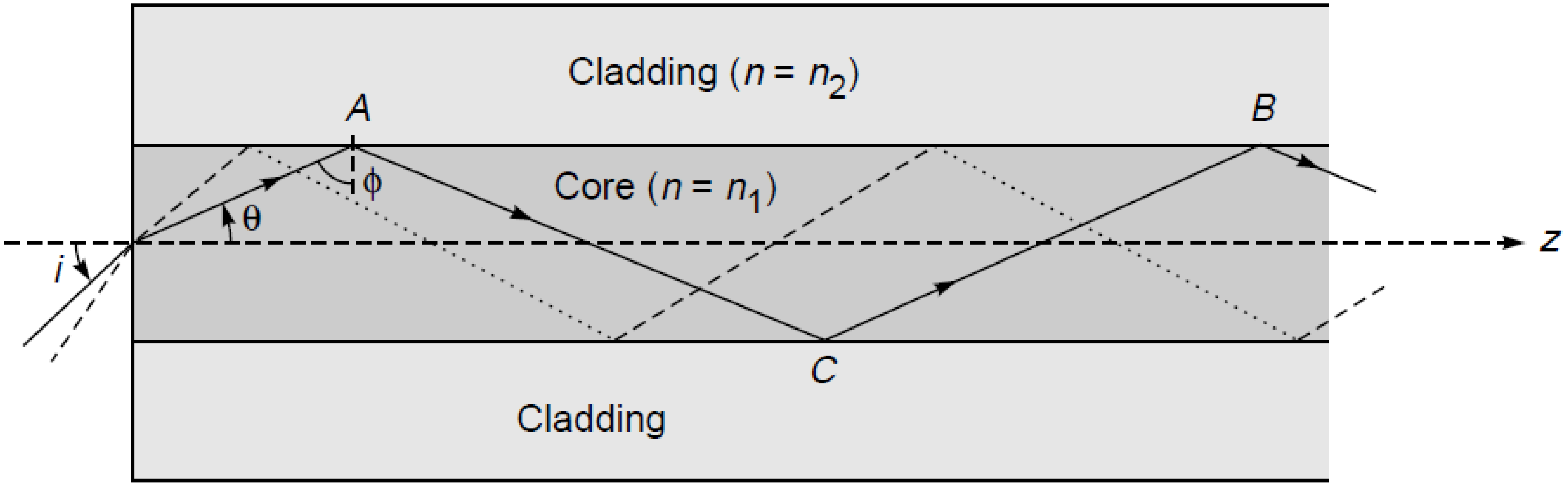
Step indexed and graded indexed fibers

- 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.



https://www.fiberoptics4sale.com/blogs/wave-optics/step-index-optical-fibers

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

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

What about θ ?

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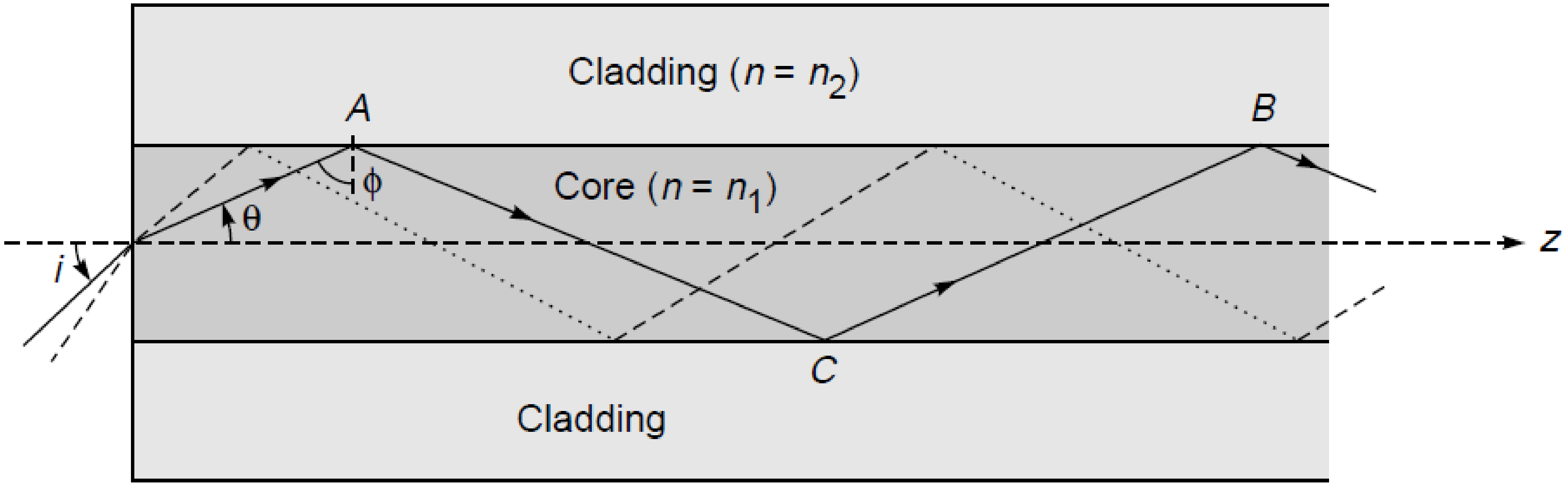
Optical fiber



- 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:

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

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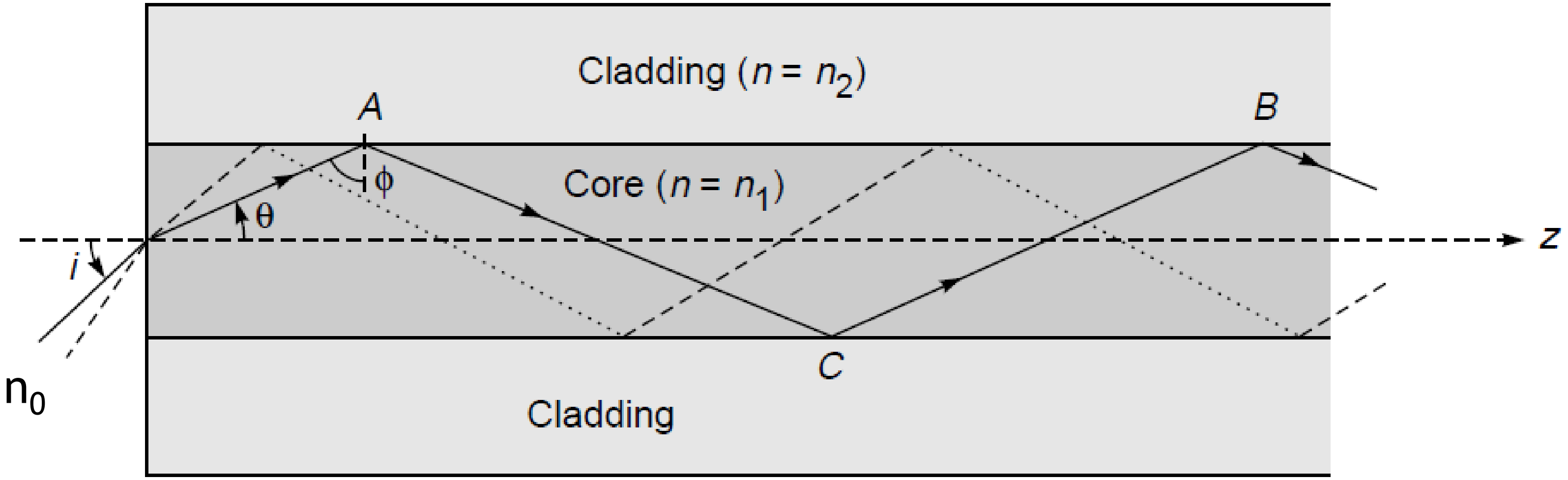
Find out the upper limit for *i* to guide a ray through a fiber



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

Sinθ ??

Sin*i* ??

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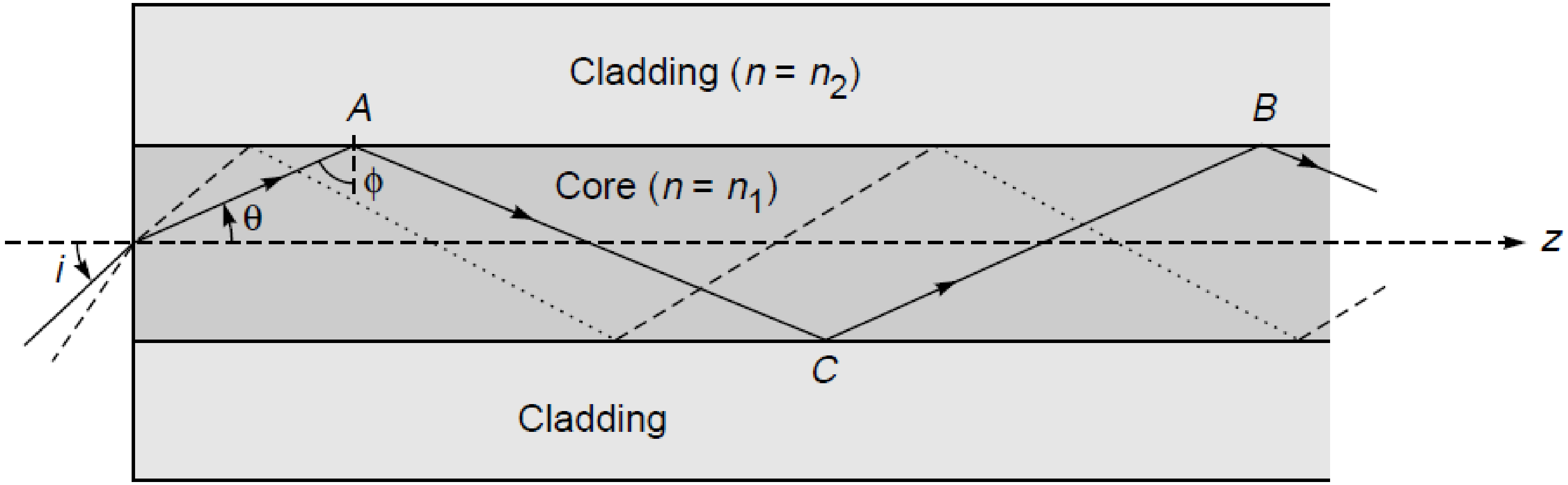
Solution



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

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

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

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

In most cases, the outside medium is air, i.e., $n_0 = 1$

maximum value of *sin i* for a ray to be guided

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

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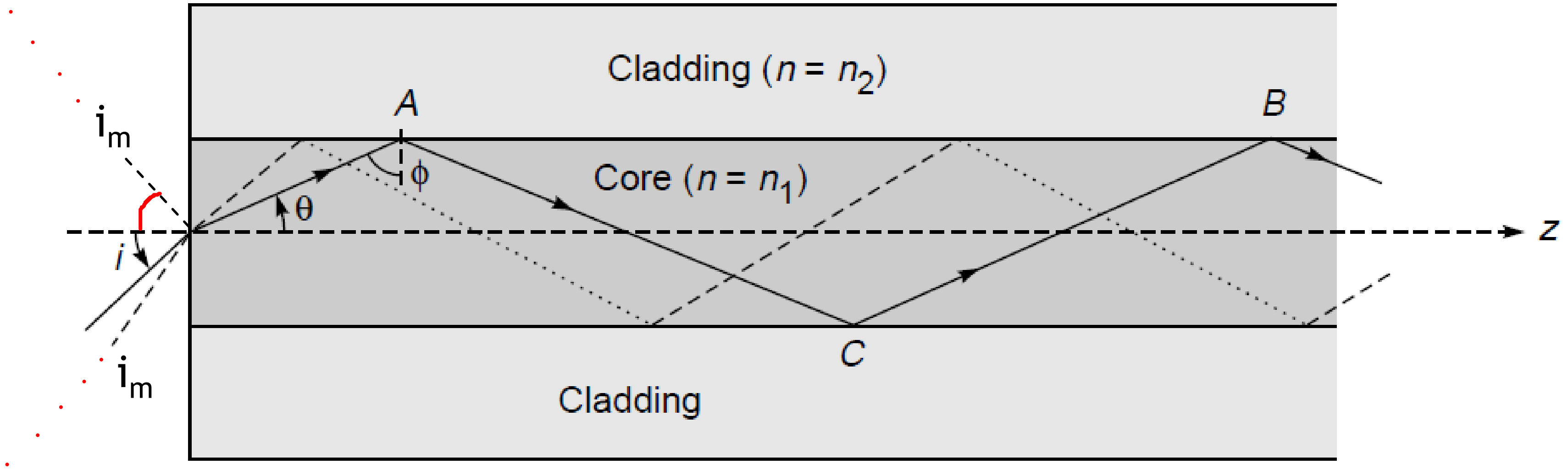
Numerical aperture



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

The quantity **sini_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, $n_1^2 < n_2^2 + 1$

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

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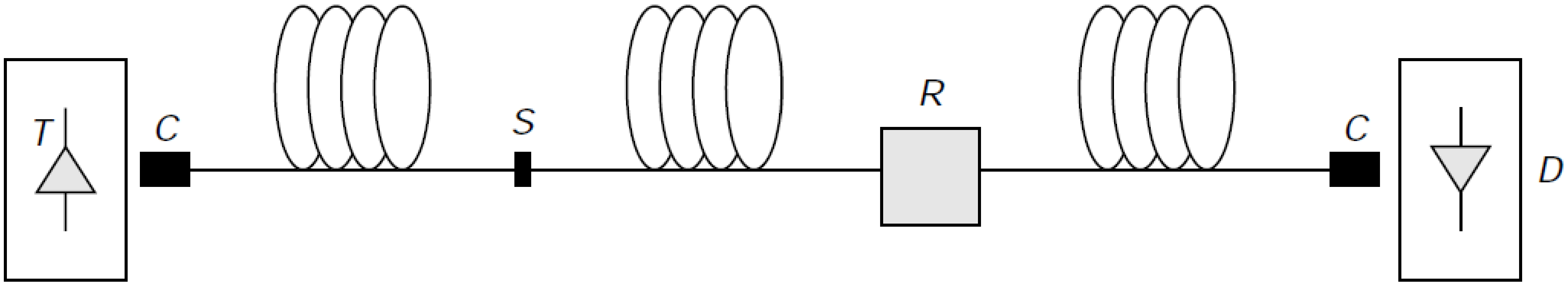
A typical optical fiber communication system



- 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