Optical Fiber Communications

— Chapter 2 —

— Optical fiber waveguides —

Optical fiber waveguides

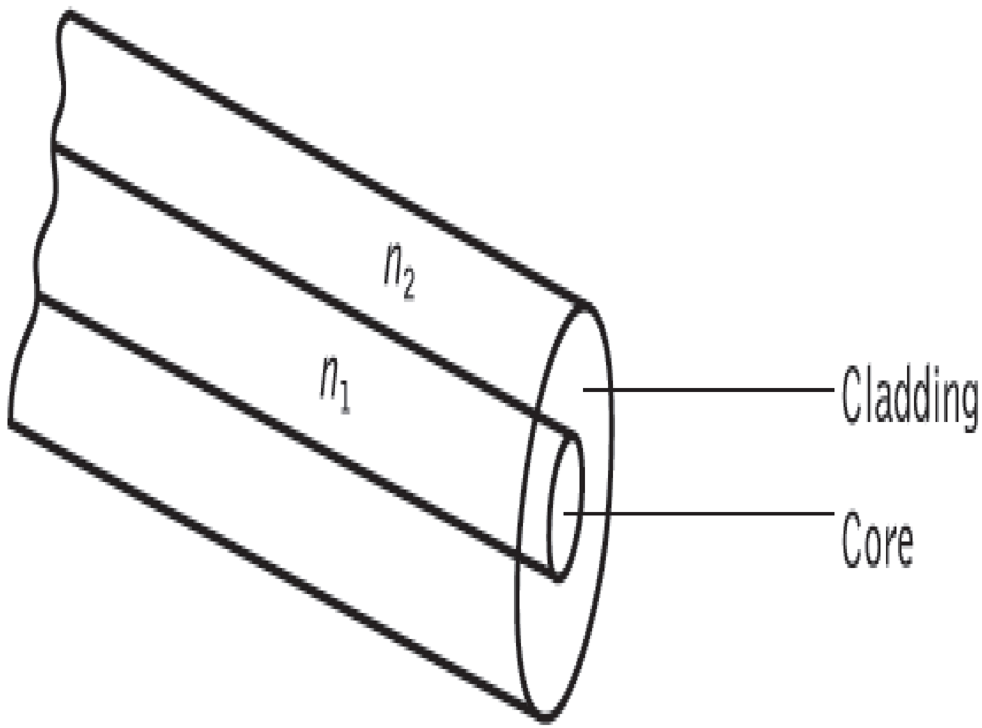


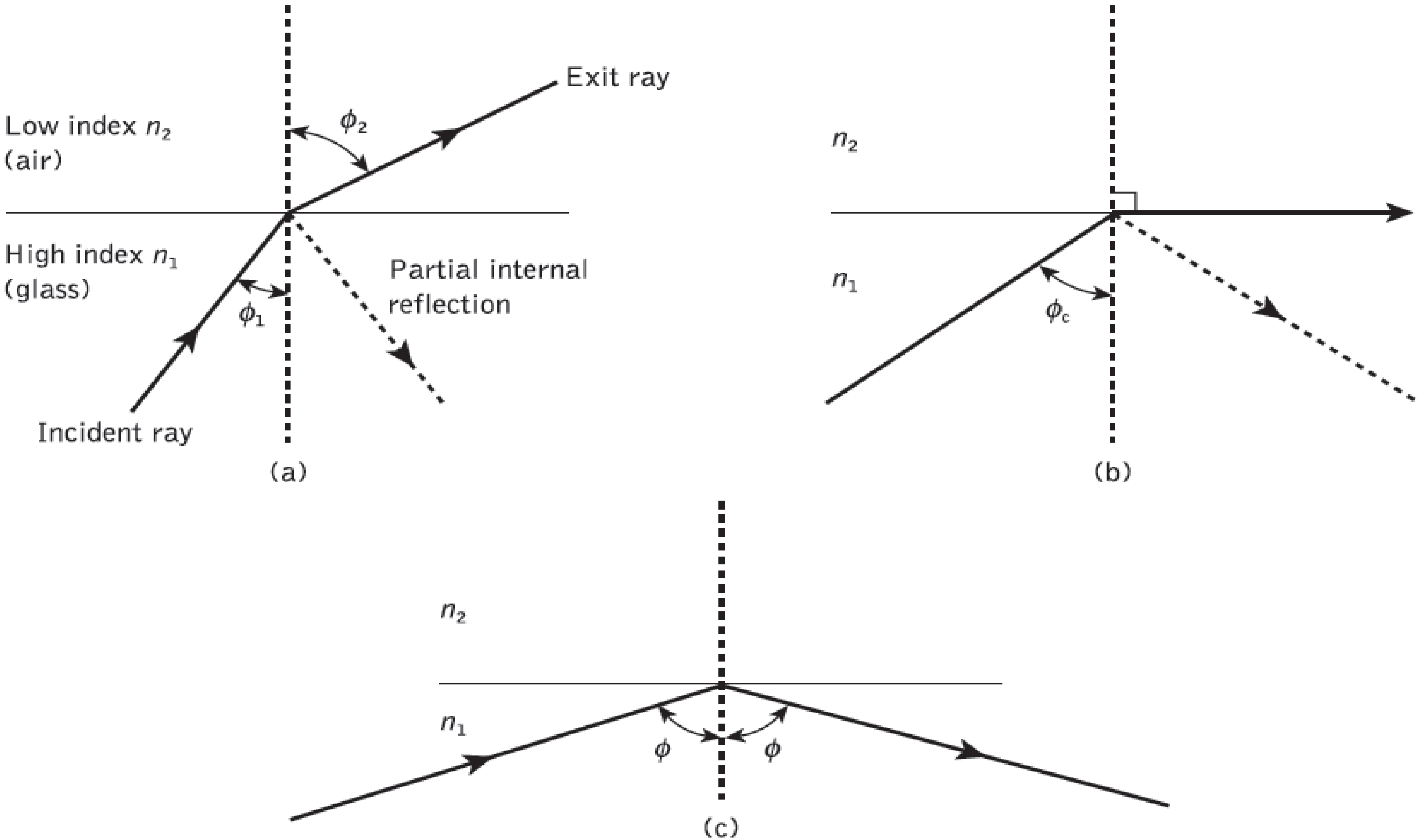
Figure 2.1 Optical fiber waveguide showing the core of refractive index n_1, surrounded by the cladding of slightly lower refractive index n_2

Total internal reflection

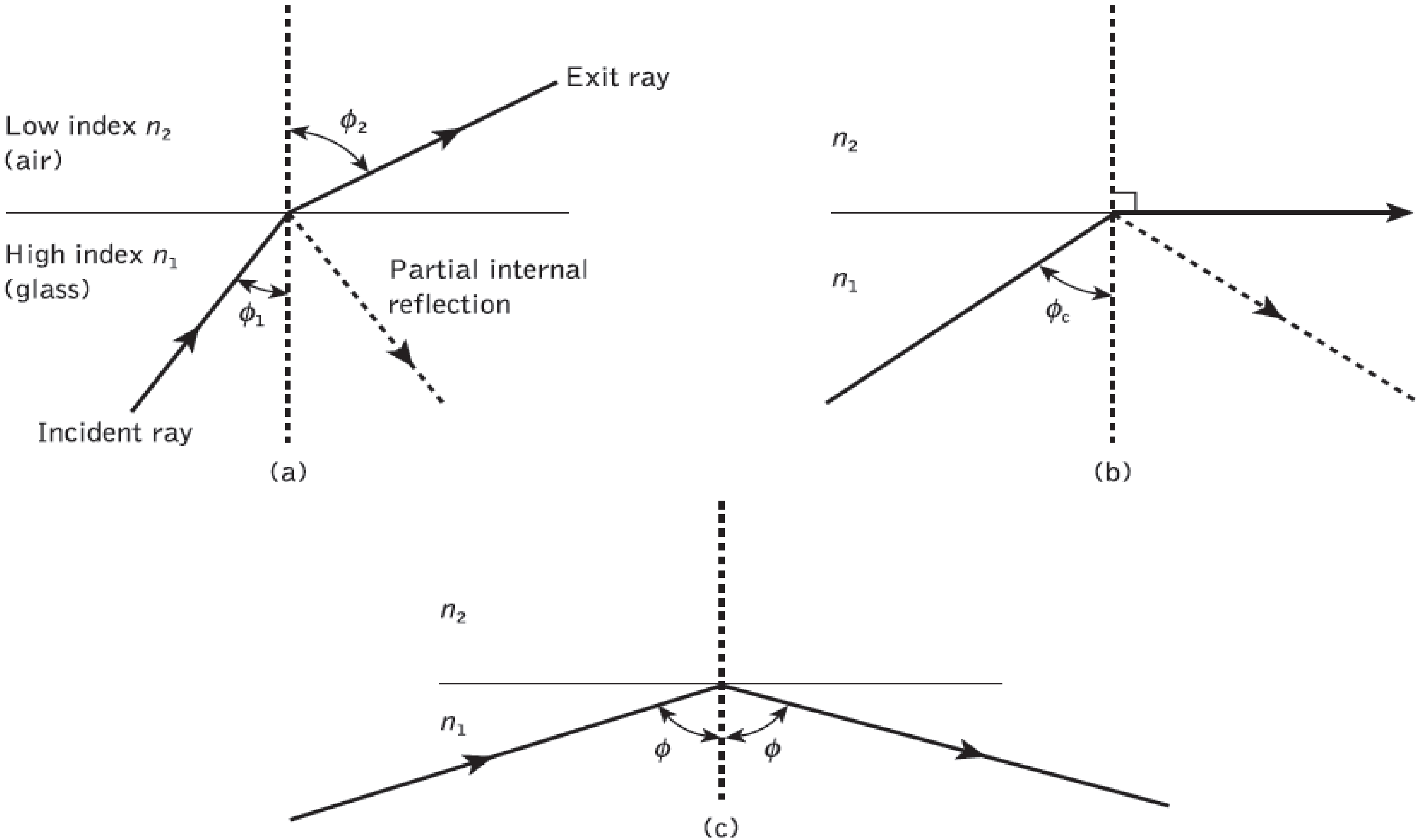
- The angles of incidence $\varphi 1$ and refraction $\varphi 2$ are related to each other and to the refractive indices of the dielectrics by Snell's law of refraction which states that
  - $n1 \sin \varphi 1 = n2 \sin \varphi 2$
  - *Or*

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

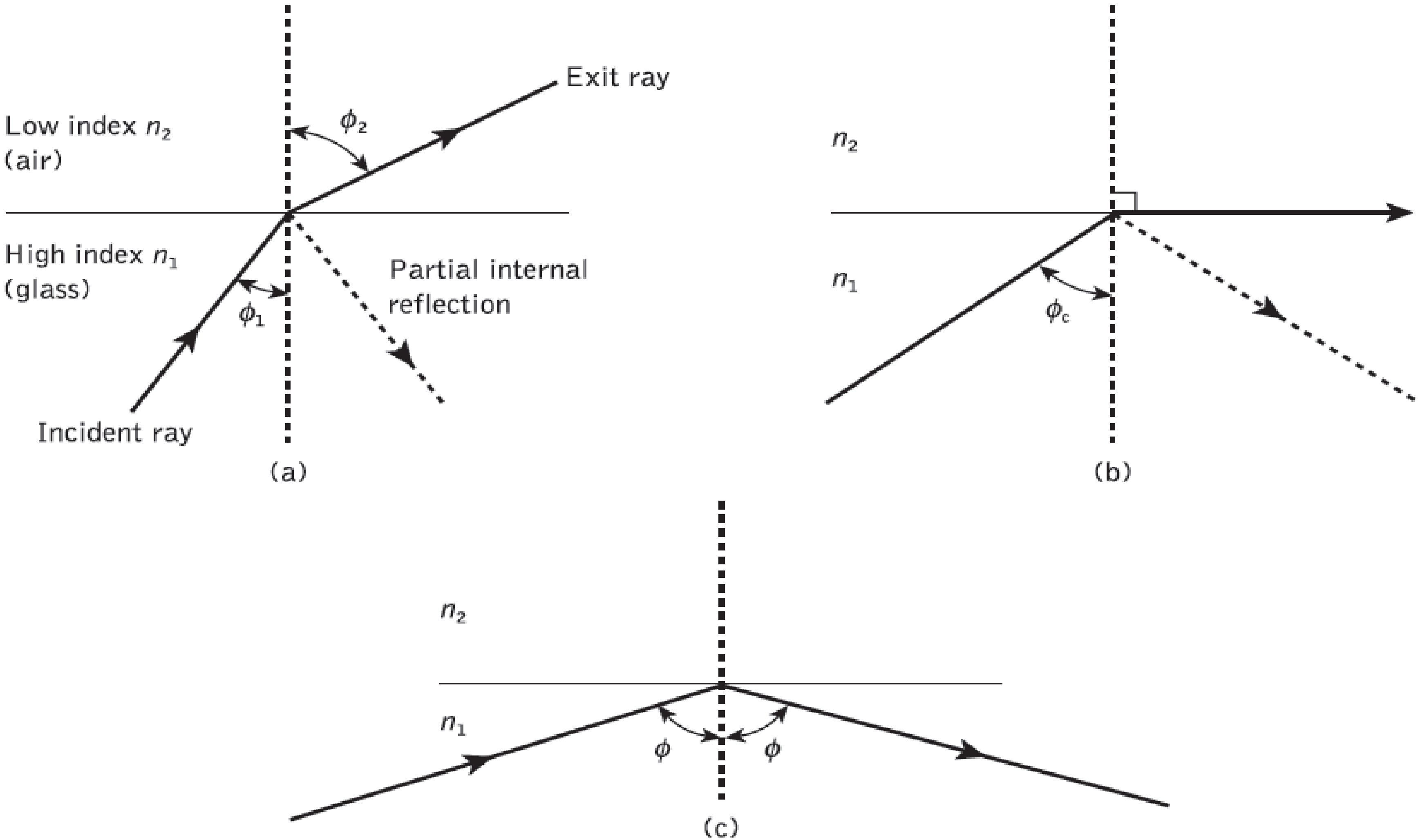
Light rays incident on a high to low refractive index interface (e.g. glass–air): (a) refraction



Light rays incident on a high to low refractive index interface (e.g. glass–air): (b) the limiting case of refraction showing the critical ray at an angle φc



Light rays incident on a high to low refractive index interface (e.g. glass–air): (c) total internal reflection where φ > φc

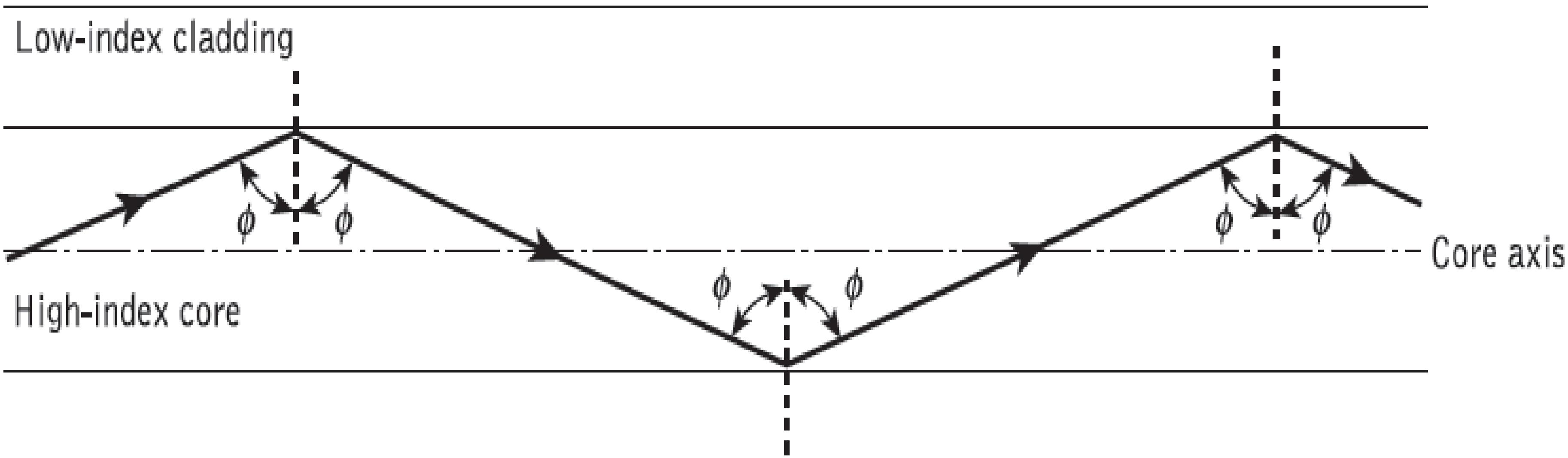


Total internal reflection

- The value of the critical angle is given by

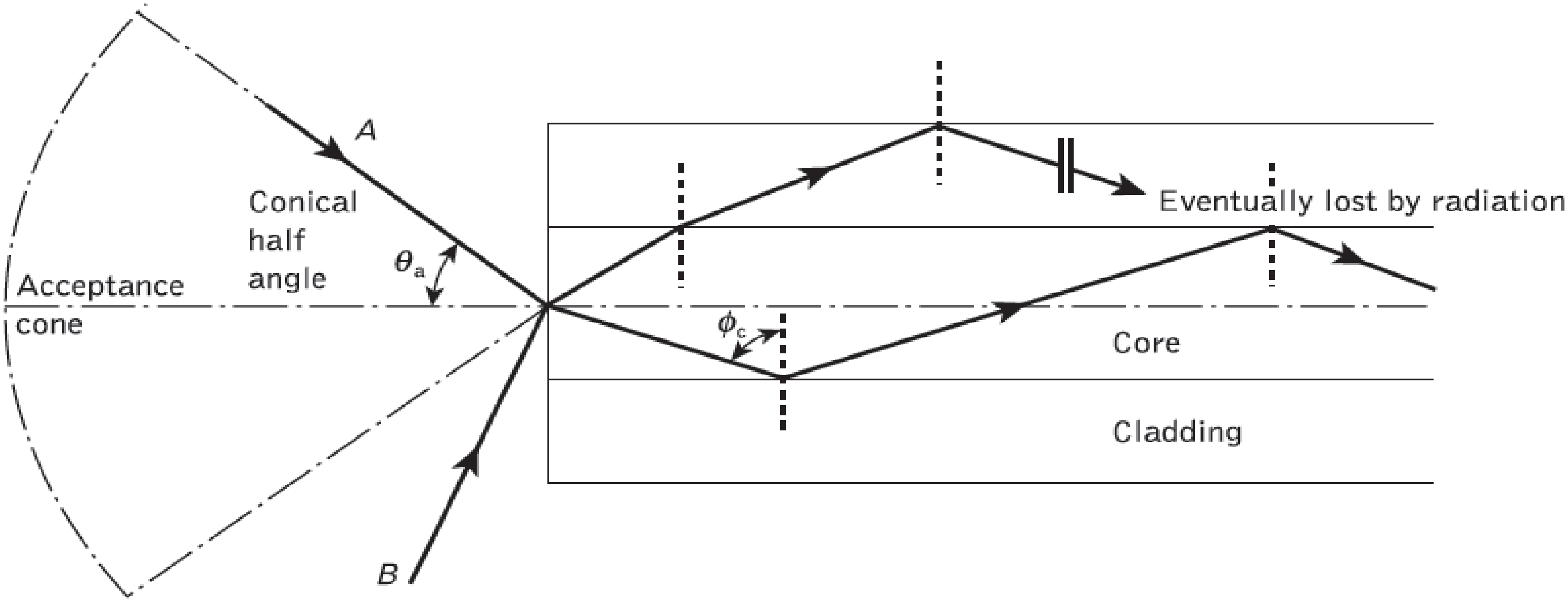
$$\sin \phi_c = \frac{n_2}{n_1}$$

The transmission of a light ray in a perfect optical fiber



At angles of incidence greater than the critical angle the light is reflected back into the originating dielectric medium (total internal reflection) with high efficiency (around 99.9%).

The acceptance angle θa when launching light into an optical fiber



Any rays which are incident into the fiber core at an angle greater than θa will be transmitted to the core–cladding interface at an angle less than φc, and will not be totally internally reflected.

θa is sometimes referred to as the maximum or total acceptance angle

meridional rays vs Skew rays

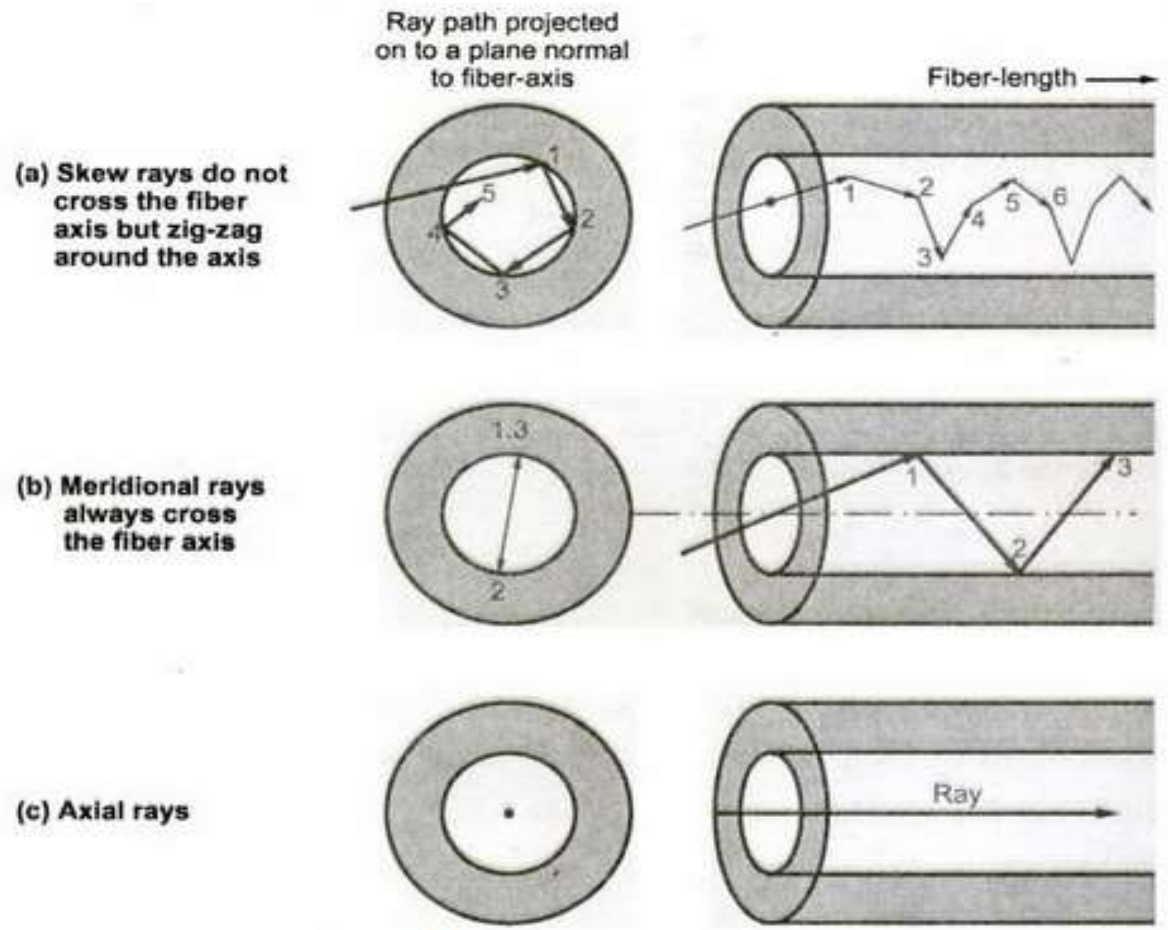


Fig. 11 Different ray propagation

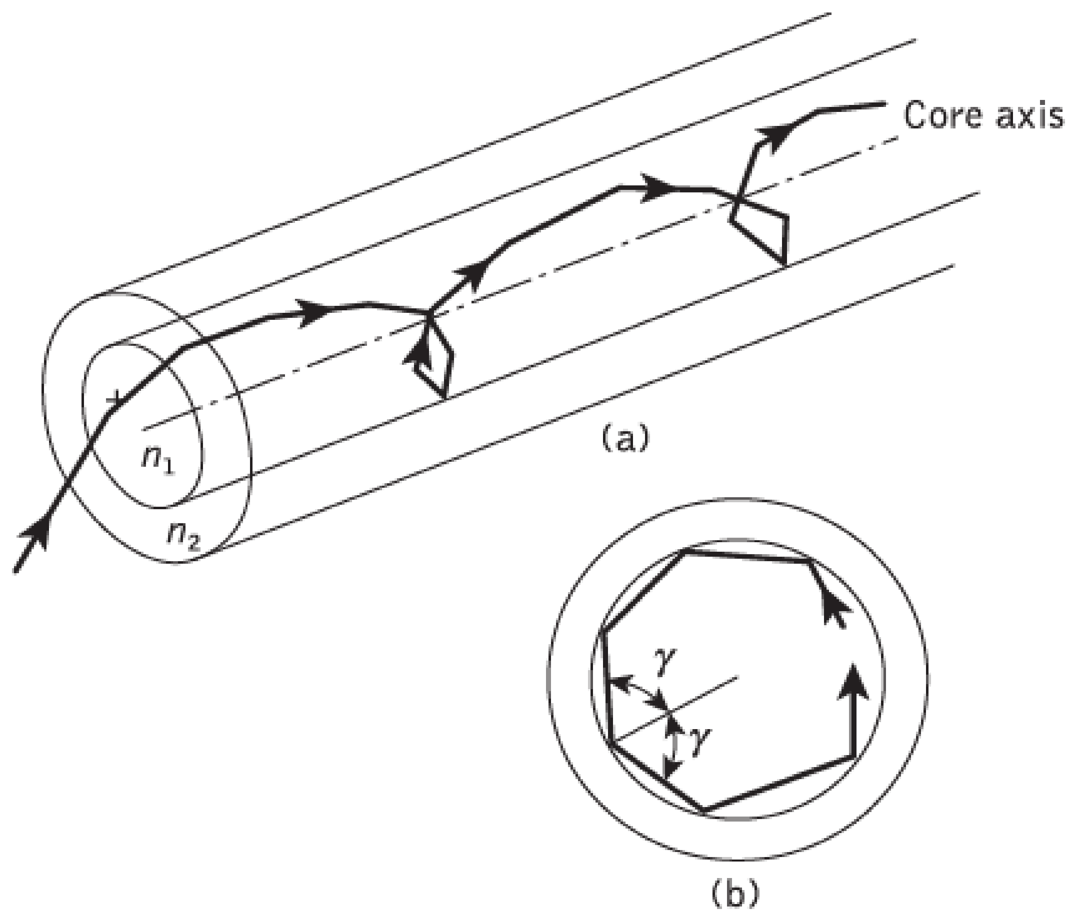
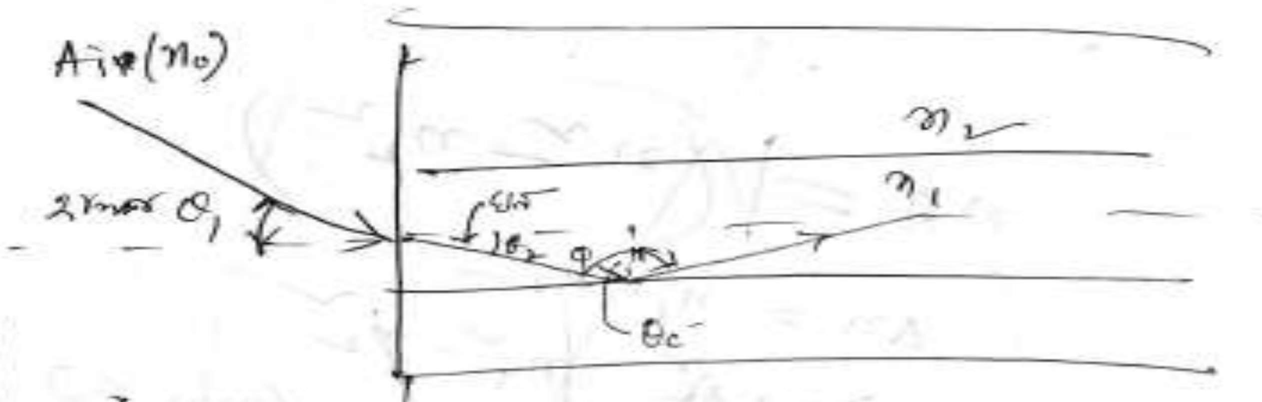


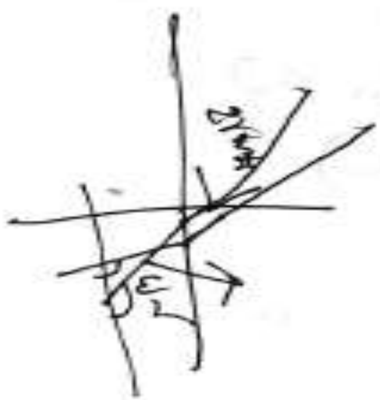
Figure 2.6 The helical path taken by a skew ray in an optical fiber: (a) skew ray path down the fiber; (b) cross-sectional view of the fiber

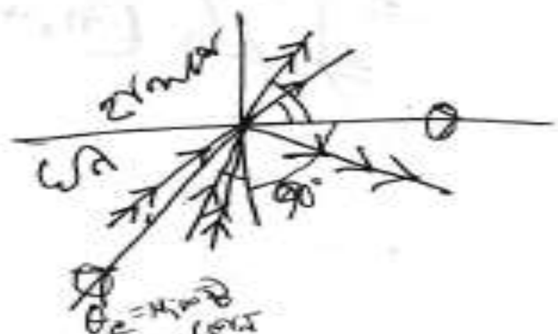
$$n_0 \sin\theta_1 = n_1 \sin\theta_2$$

$$\varphi = \frac{\pi}{2} - \theta_2$$

$$n_0 \sin\theta_1 = n_1 \sin\left(\frac{\pi}{2} - \varphi\right)$$
$$= n_1 \cos\varphi$$
$$= n_1 \sqrt{1 - \sin^2\varphi}$$







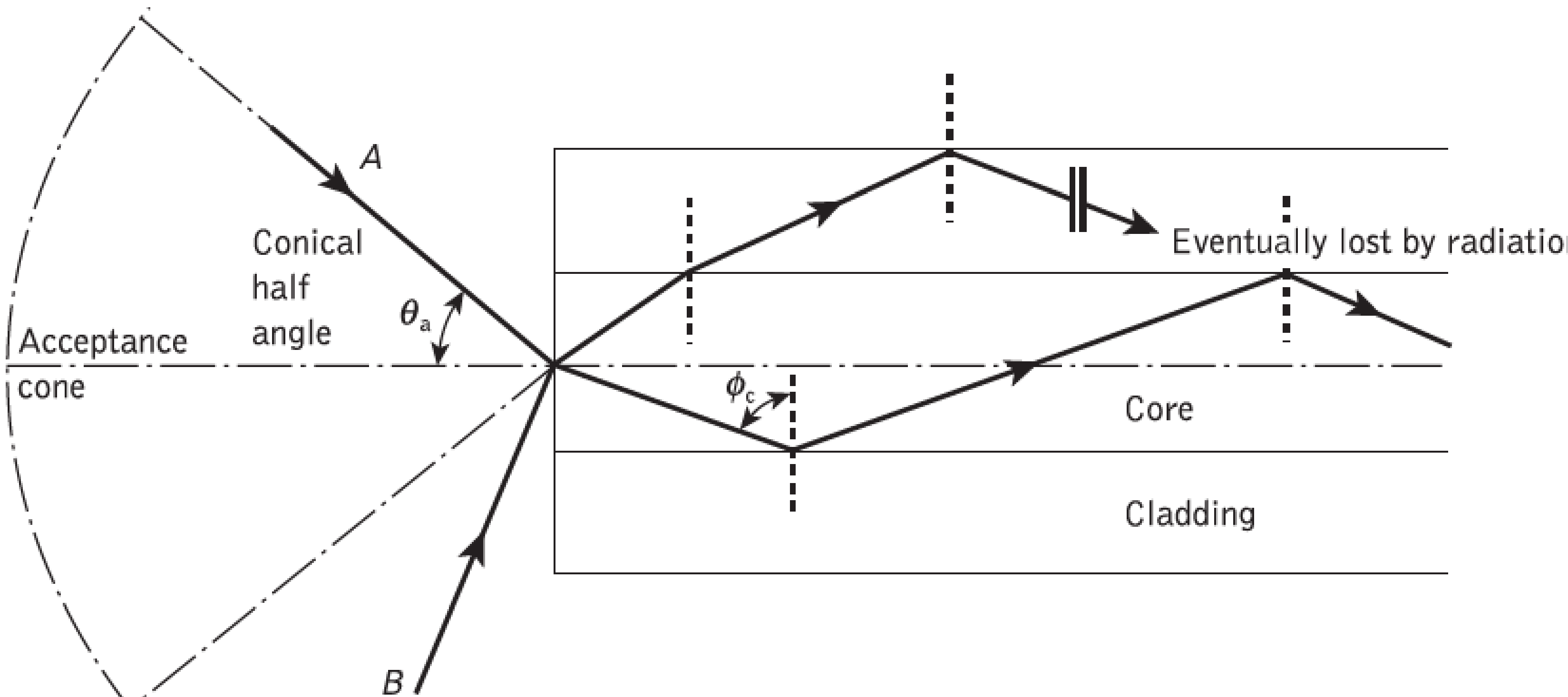


Figure 2.4 The acceptance angle θ_a when launching light into an optical fiber

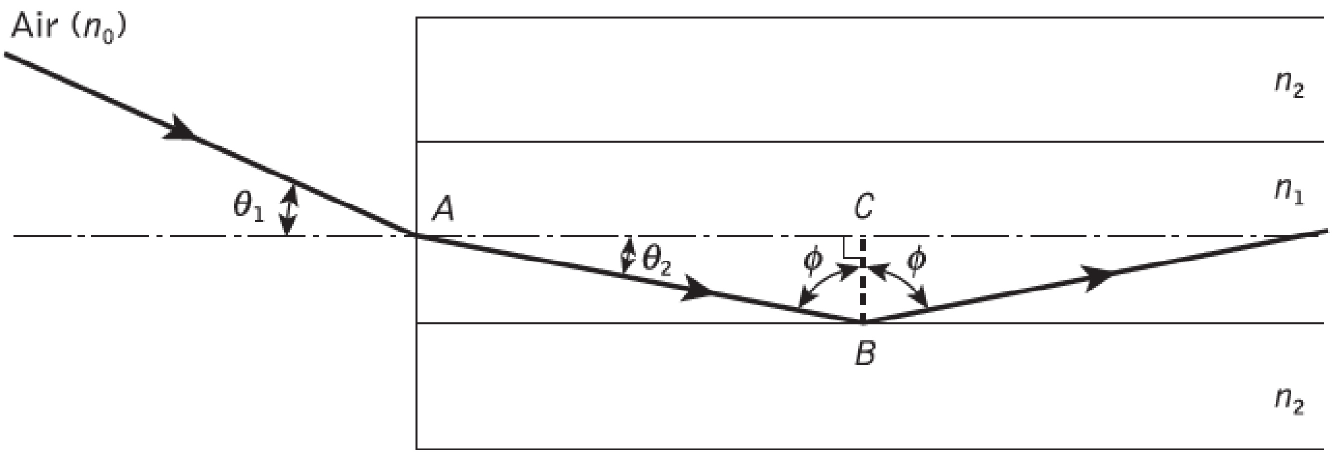


Figure 2.5 The ray path for a meridional ray launched into an optical fiber in air at an input angle less than the acceptance angle for the fiber

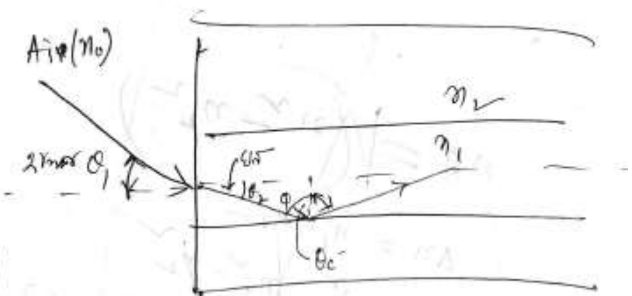
$n_0 \sin\theta_1 = n_1 \sin\theta_2$

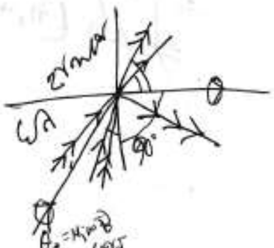
$\varphi = \frac{\pi}{2} - \theta_2$

$n_0 \sin\theta_1 = n_1 \sin\left(\frac{\pi}{2} - \varphi\right)$

$= n_1 \cos\varphi$

$= n_1 \sqrt{1 - \sin^2\varphi}$





$\cos 0 = 1$

$\sin 90 = 1$

$n_1 \sin\theta_c = n_2 \sin 90$

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

$n_0 \sin\theta_1 = n_1 \sqrt{(1 - \sin^2\phi)}$ — 2.6

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

$\phi = \phi_c$ limiting case of total reflection

θ_1 = acceptance angle $= \theta_a$

$\Rightarrow n_0 \sin\theta_a = n_1 \sqrt{1 - \sin^2\phi_c}$

$= n_1 \sqrt{1 - \frac{n_2^2}{n_1^2}}$

$= n_1 \sqrt{\frac{n_1^2 - n_2^2}{n_1^2}}$

$= \sqrt{n_1^2 - n_2^2}$ — 2.7 is defined as

NA = numerical aperture

$= \sqrt{n_1^2 - n_2^2}$ — 2.8

$NA = n_0 \sin\theta_a = \sqrt{n_1^2 - n_2^2}$

n_0 for air $= 1$

$\therefore \sin\theta_a = \sqrt{n_1^2 - n_2^2}$ over the range

incident meridional rays will be propagated within the fiber

$0 \le \theta_1 \le \theta_a$

$\Rightarrow \cancel{\Delta/2 n_1^2}$

The NA may also be given in terms of the relative refractive index difference bet^n the core & the cladding which is defined as

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2} \text{ --- (A)}$$

$$\simeq \frac{(n_1 - n_2)(n_1 + n_2)}{2n_1^2}$$

$$= \frac{(n_1 - n_2)\,\cancel{2n_1}}{\cancel{2n_1^2}} \quad \text{~~for~~ } \cancel{\Delta \ll 1} \quad \text{for } \Delta \ll 1$$

অর্থাৎ যদি n_1 ও n_2 প্রায় সমান

$$\cancel{\simeq \frac{n_1 - n_2}{n_1} \; \frac{n_1}{}} \text{ --- 2.9}$$

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

$$\cancel{= n_1}$$

(A) $2\Delta n_1^2 = n_1^2 - n_2^2$

$$\Rightarrow \sqrt{n_1^2 - n_2^2} = \sqrt{2\Delta n_1^2}$$

$$\Rightarrow NA = n_1\sqrt{2\Delta} \text{ --- (B)}$$

relationship is very useful measure of light-collecting ability of a fiber.

They are independent of fiber core diameter & will hold for diameters as small as 8 μm.