Optics overview

Summer school

PolyPhotonics Summer School

Constantine Korikov

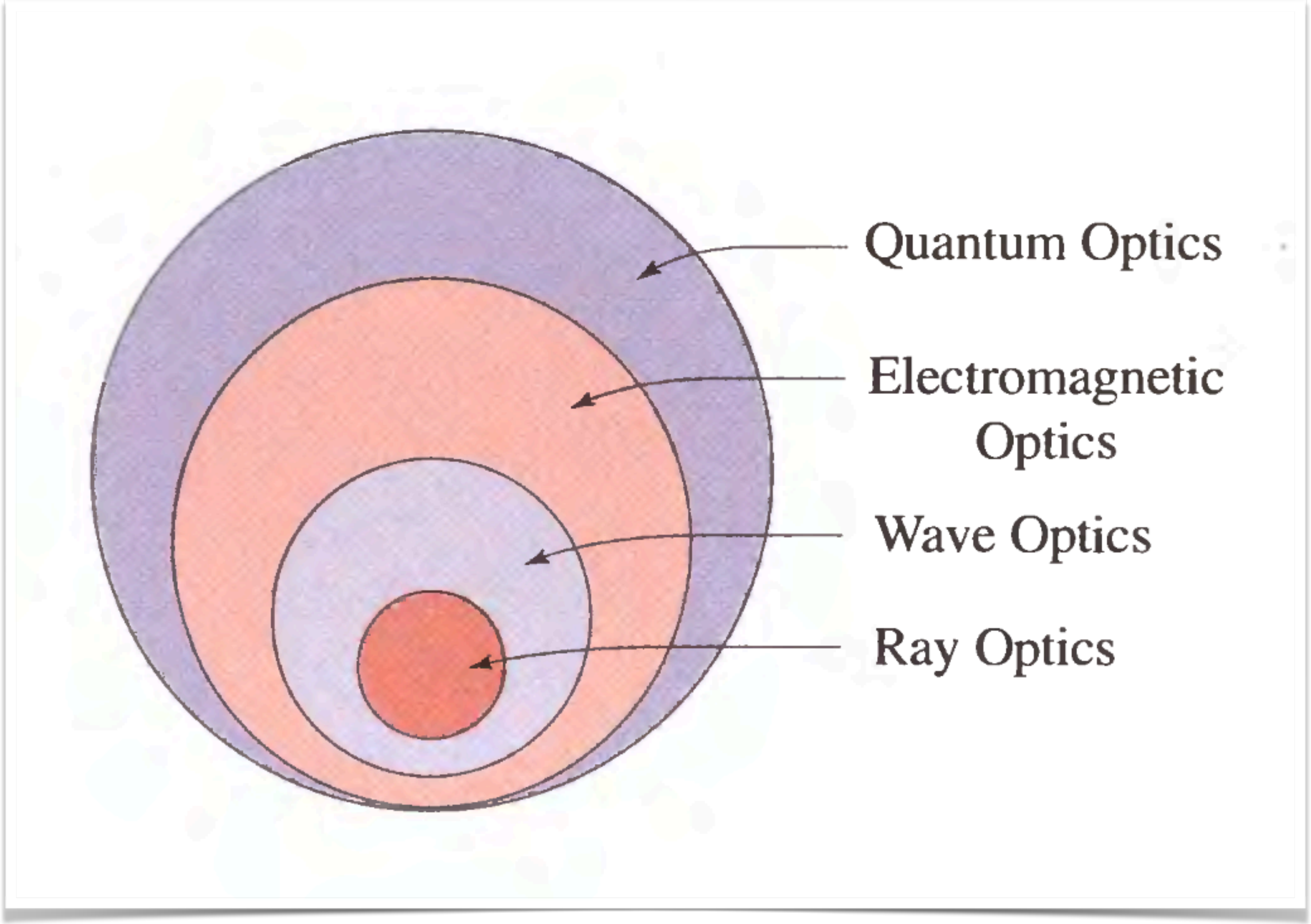
Constantine Korikov
PhD in Theoretical Physics (Casimir effect)

Associate Professor
Peter the Great St.Petersburg Polytechnic University

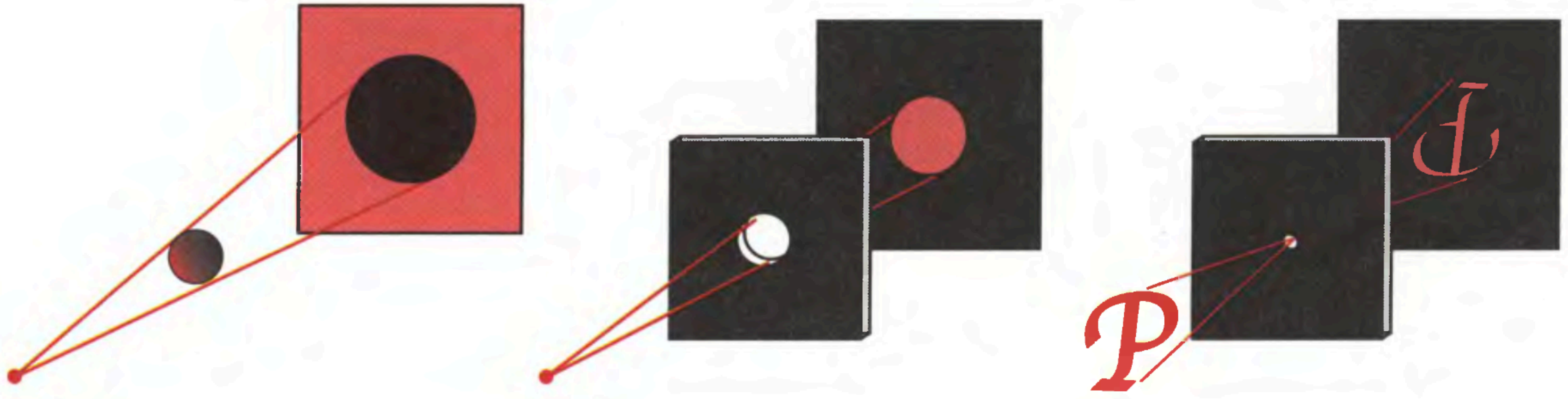
Research Engineer
Huawei Russian Research Institute

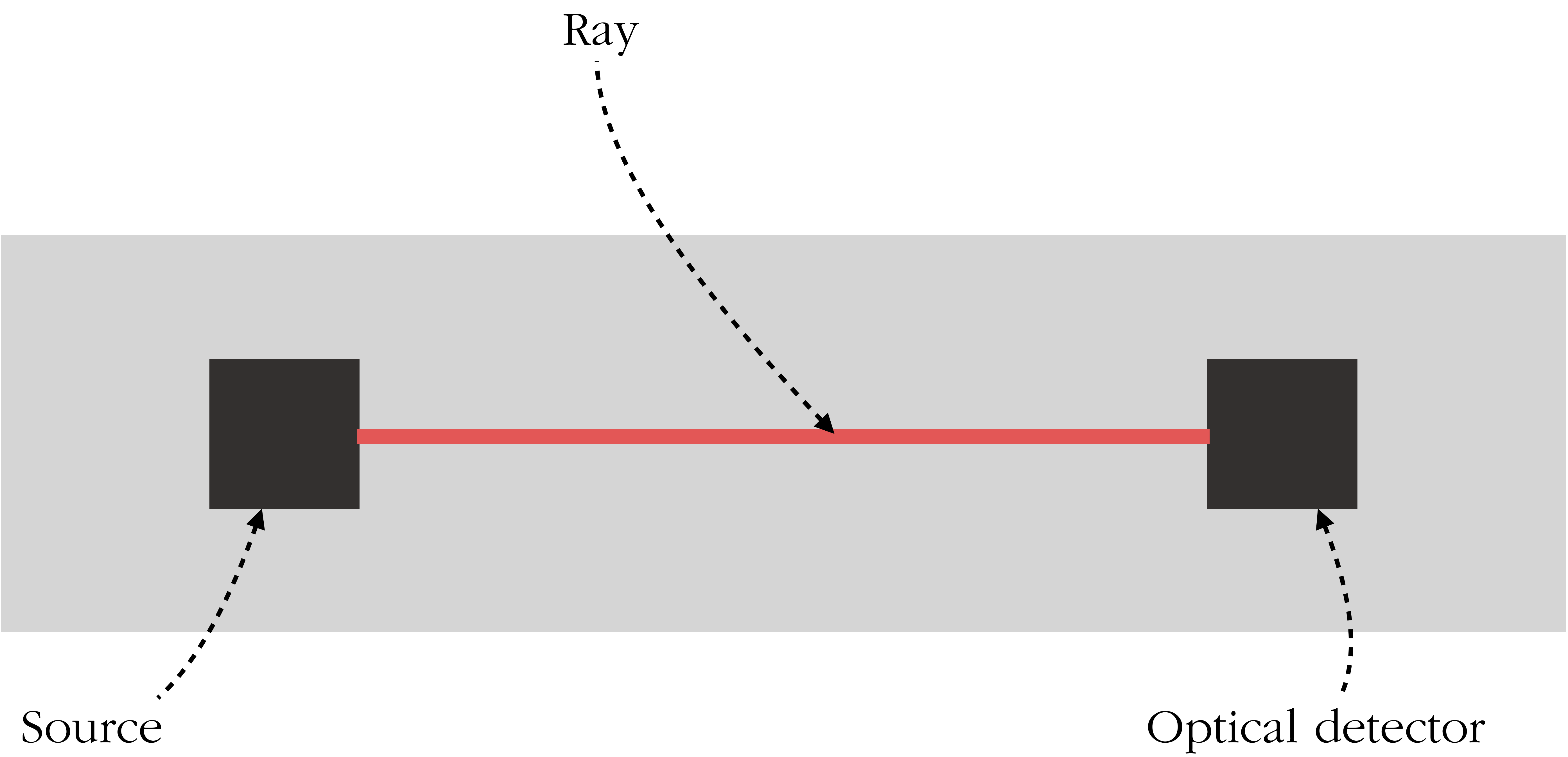
Optics is the branch of physics that studies the behaviour and properties of light, including its interactions with matter and the construction of instruments that use or detect it.[1] Optics usually describes the behaviour of visible, ultraviolet, and infrared light. Because light is an electromagnetic wave, other forms of electromagnetic radiation such as X-rays, microwaves, and radio waves exhibit similar properties.[1]

Wikipedia


Quantum Optics
Electromagnetic Optics
Wave Optics
Ray Optics

Ray Optics

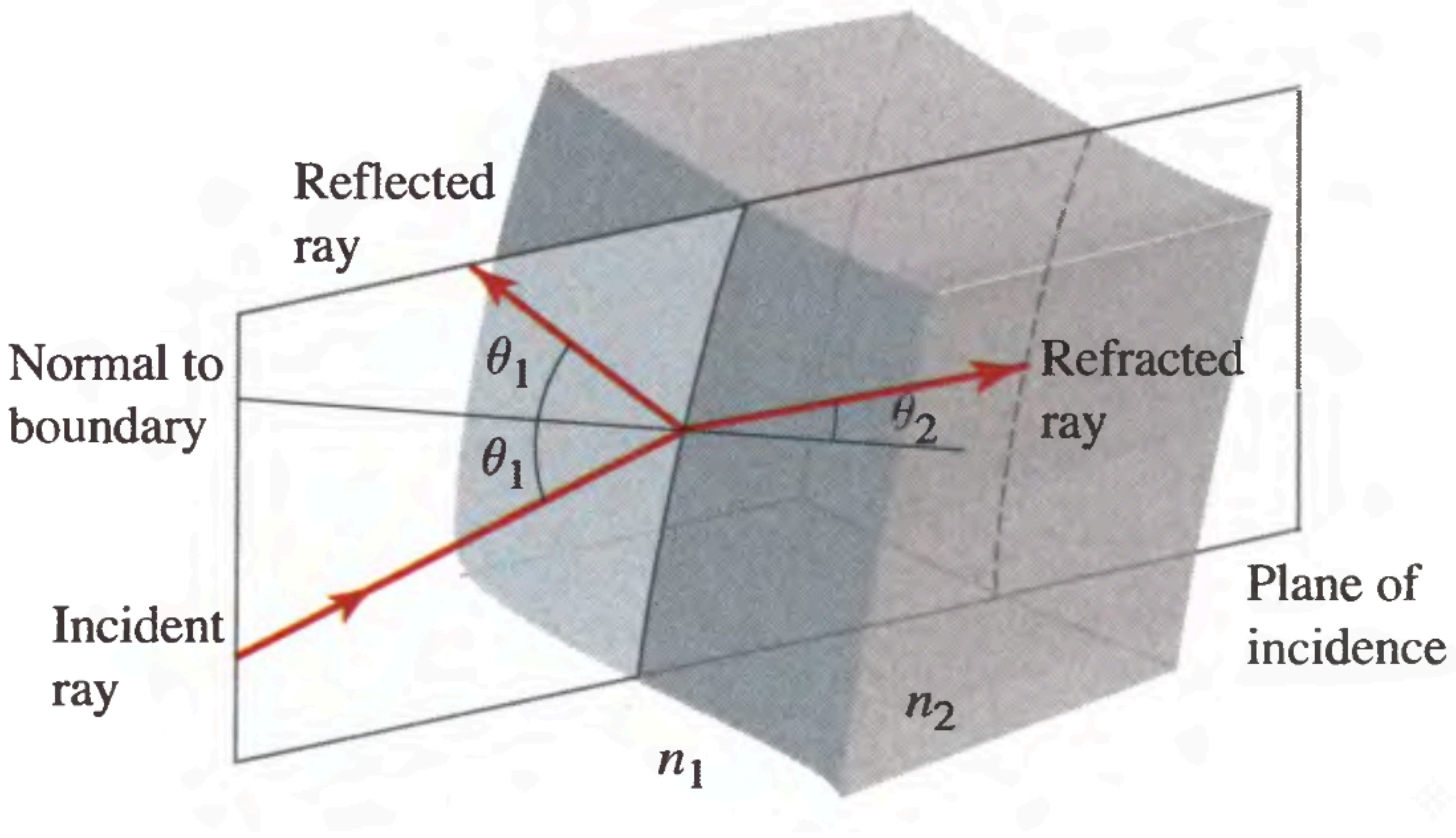

P



$$c = \frac{c_o}{n}$$

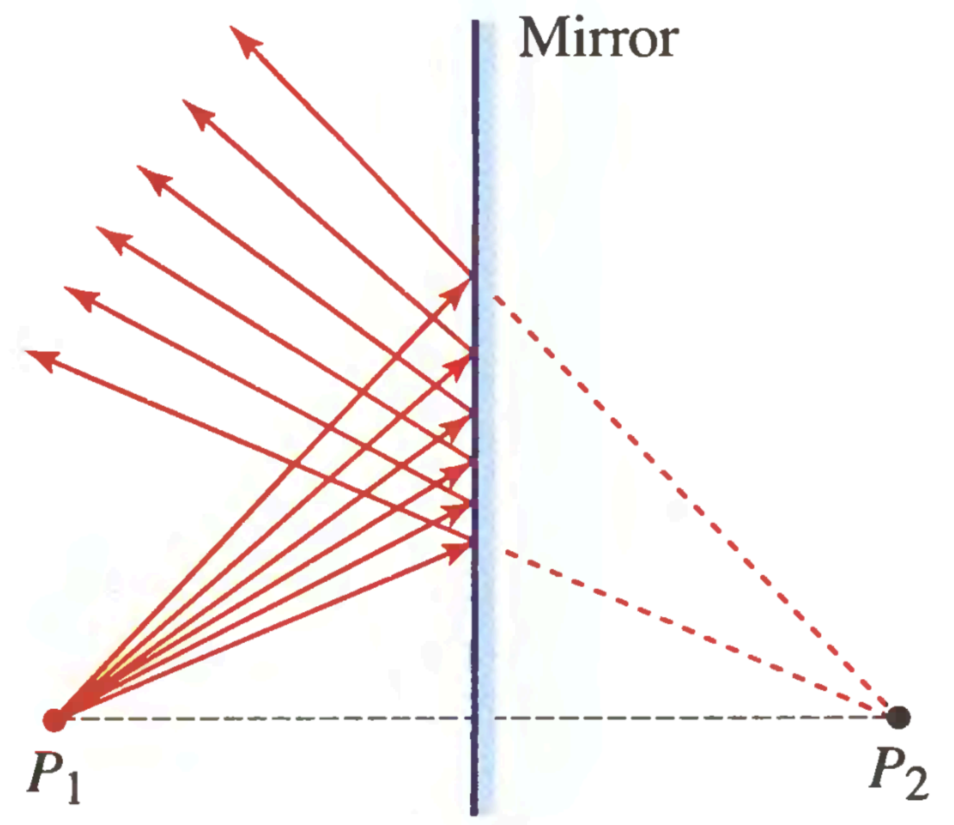
$$\delta \int_A^B n(\mathbf{r})\, ds = 0,$$

Fermat's principle

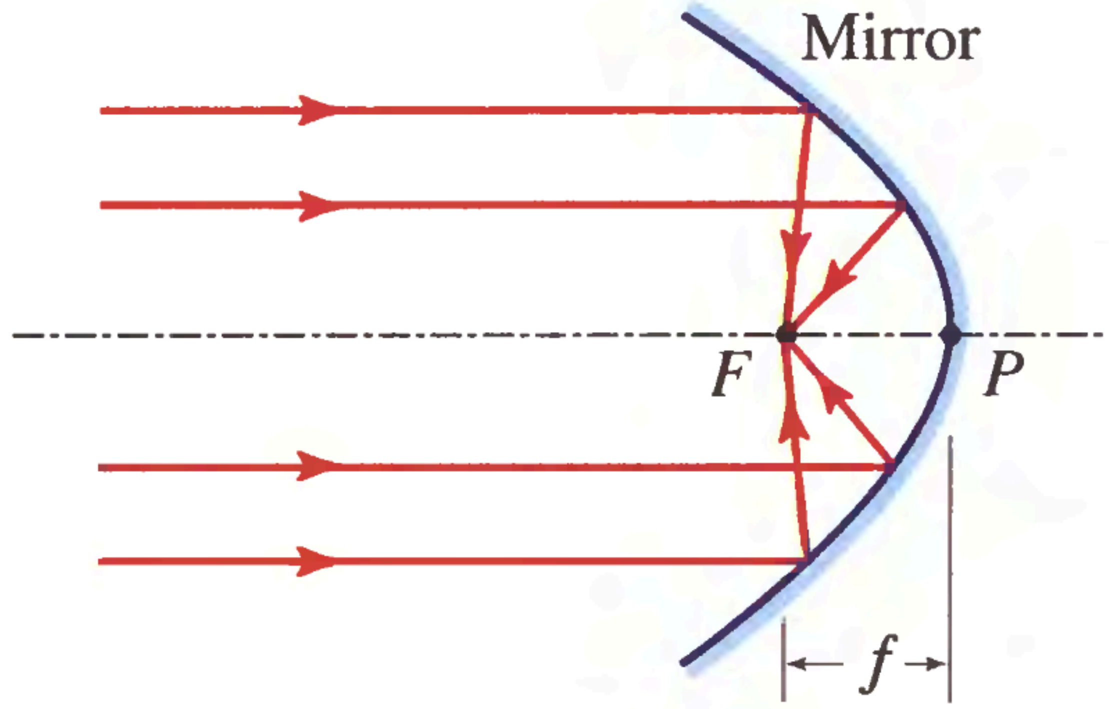


$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

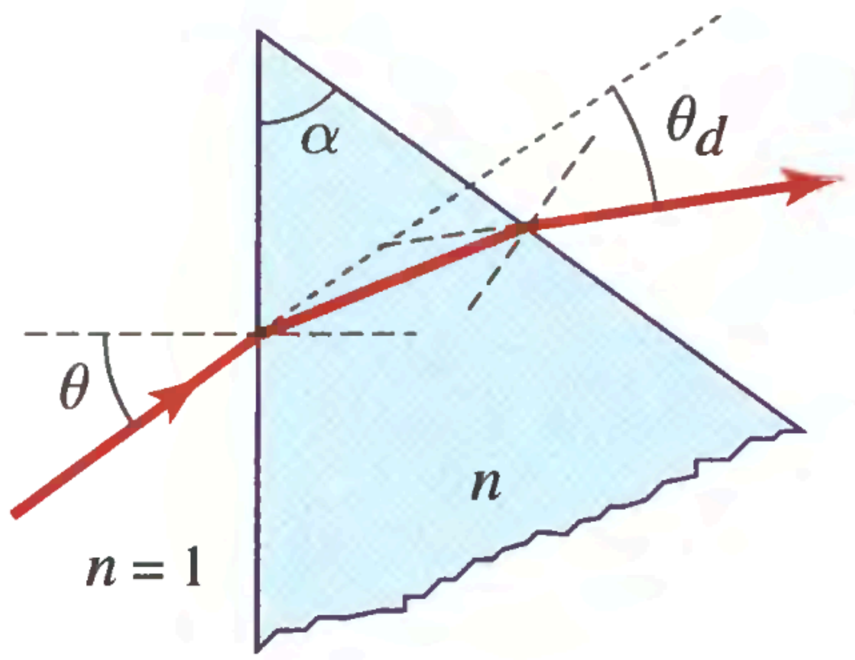
Snell's law



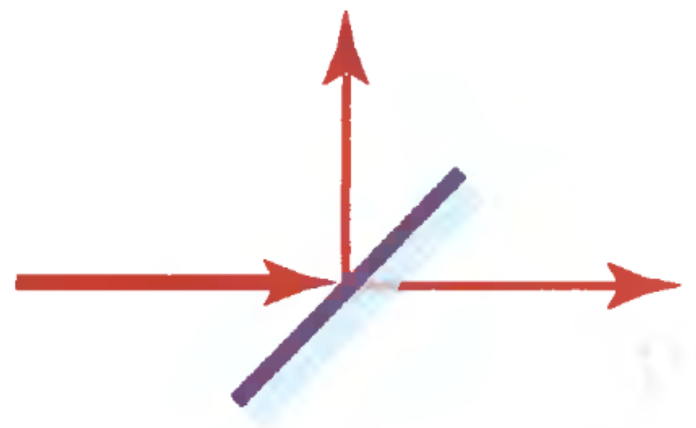
Planar mirror



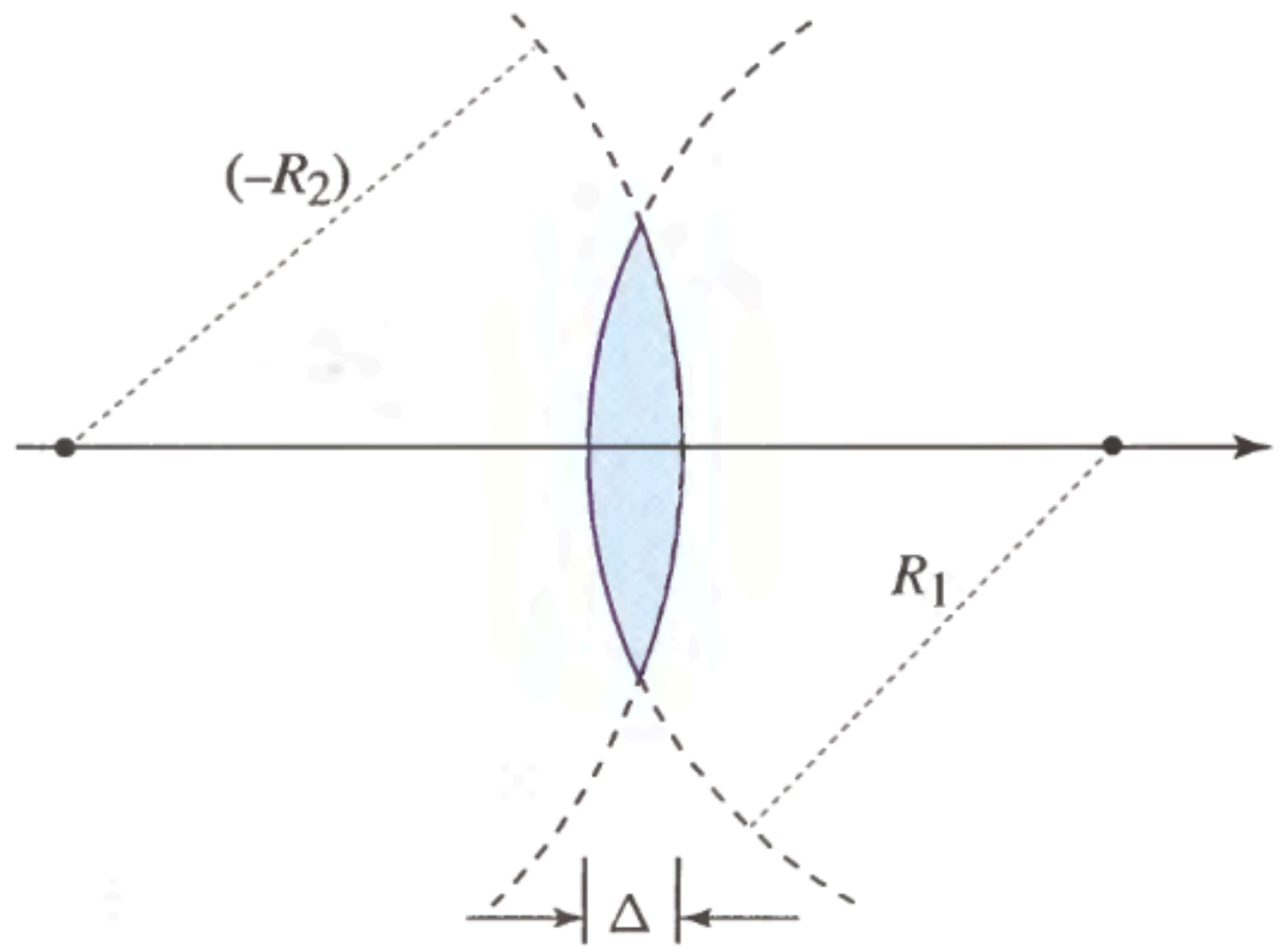
Paraboloidal mirror



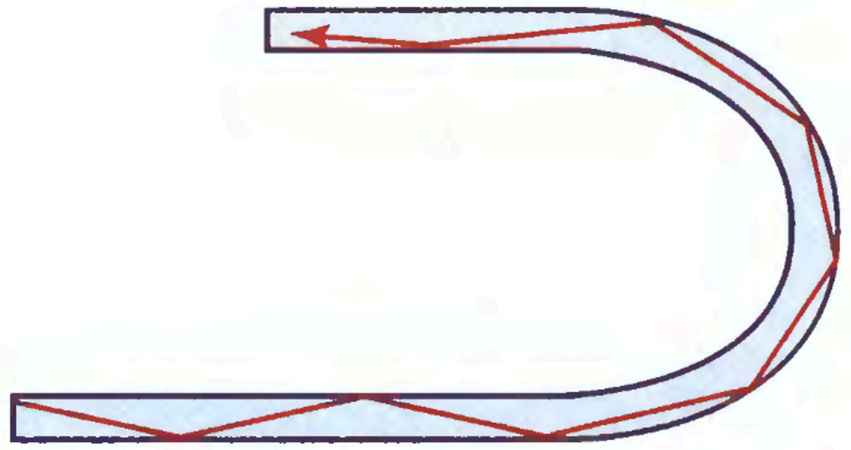
Prism



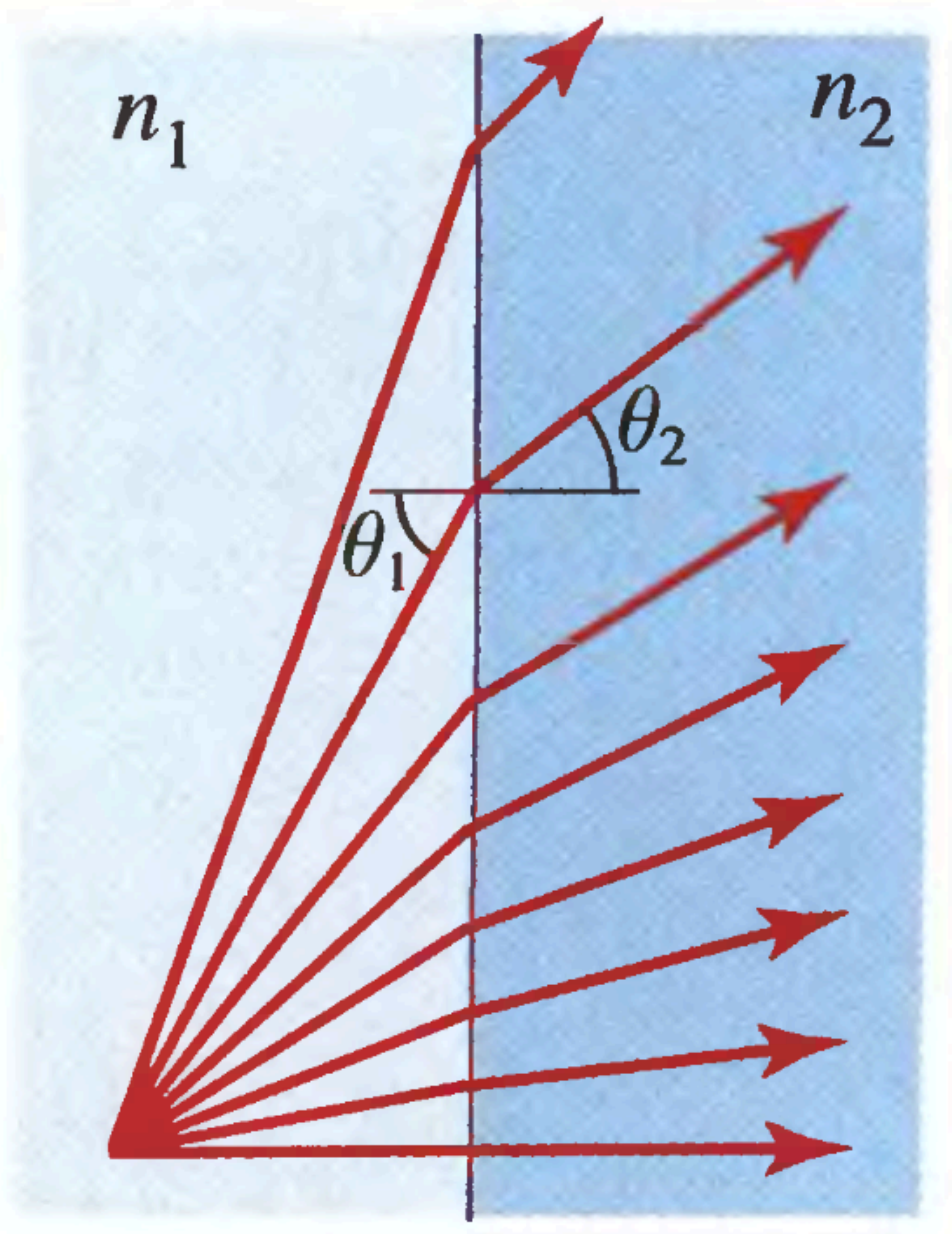
Beamsplitter



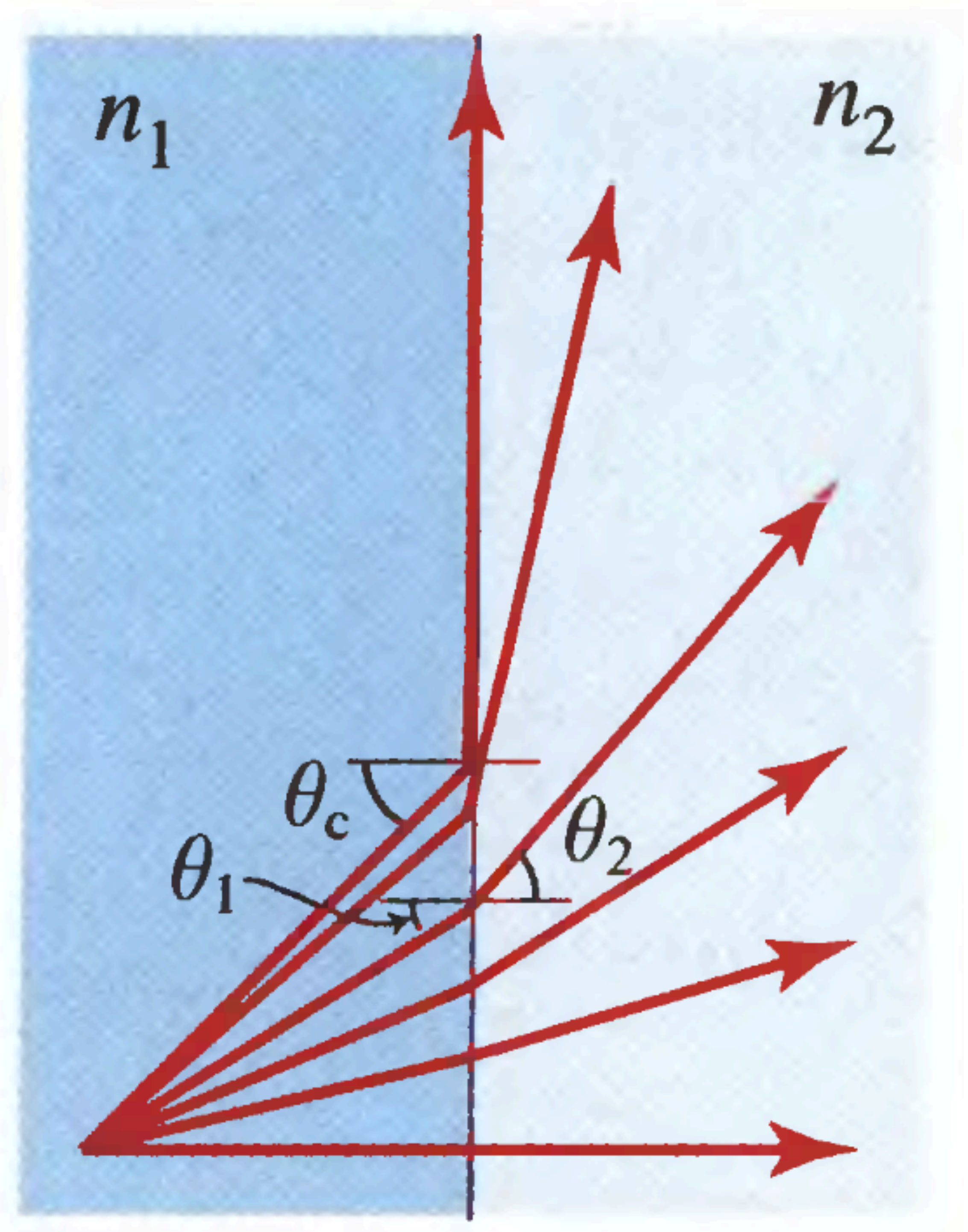
Lens



Optical fiber



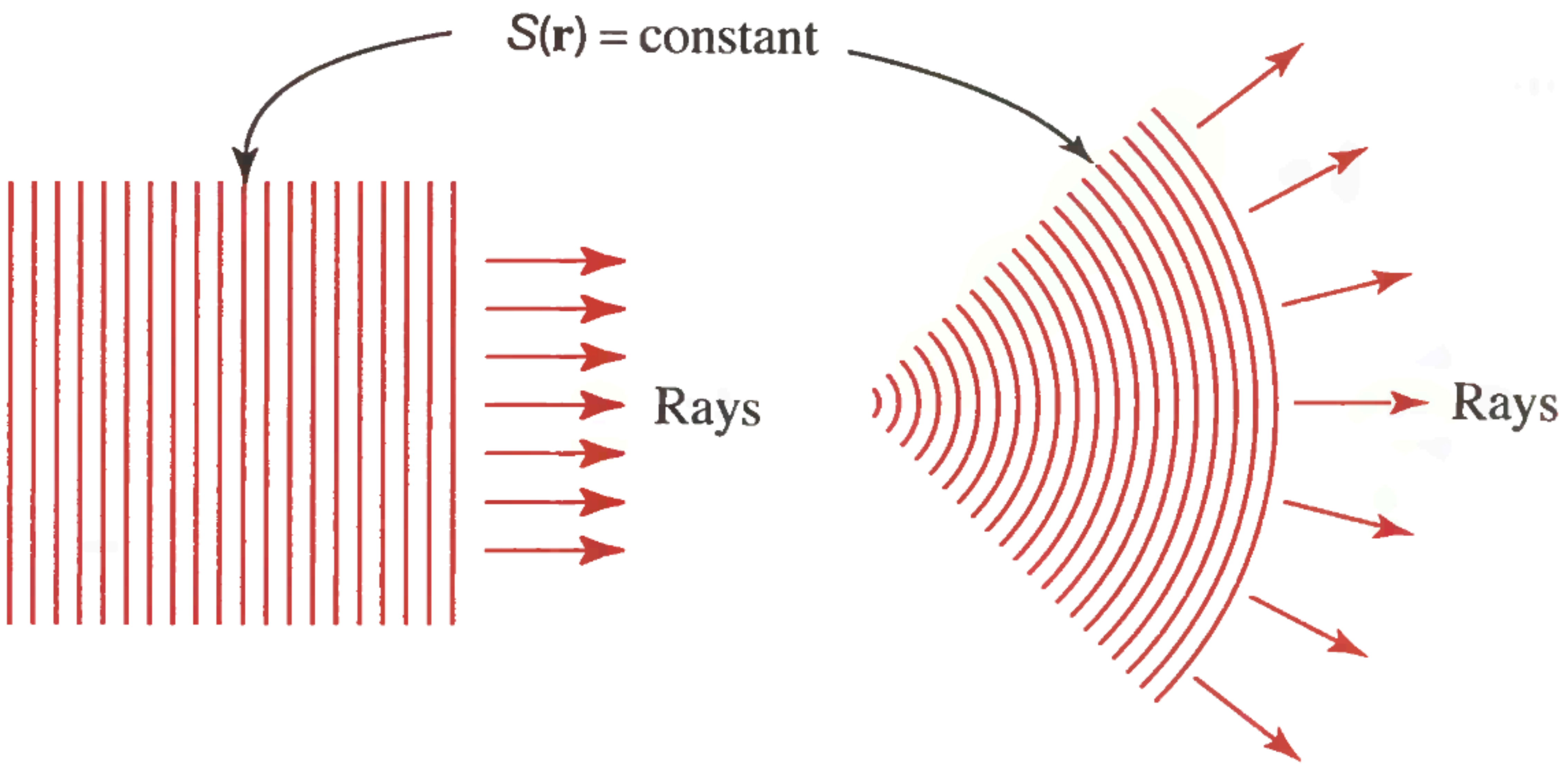
External refraction



Internal refraction

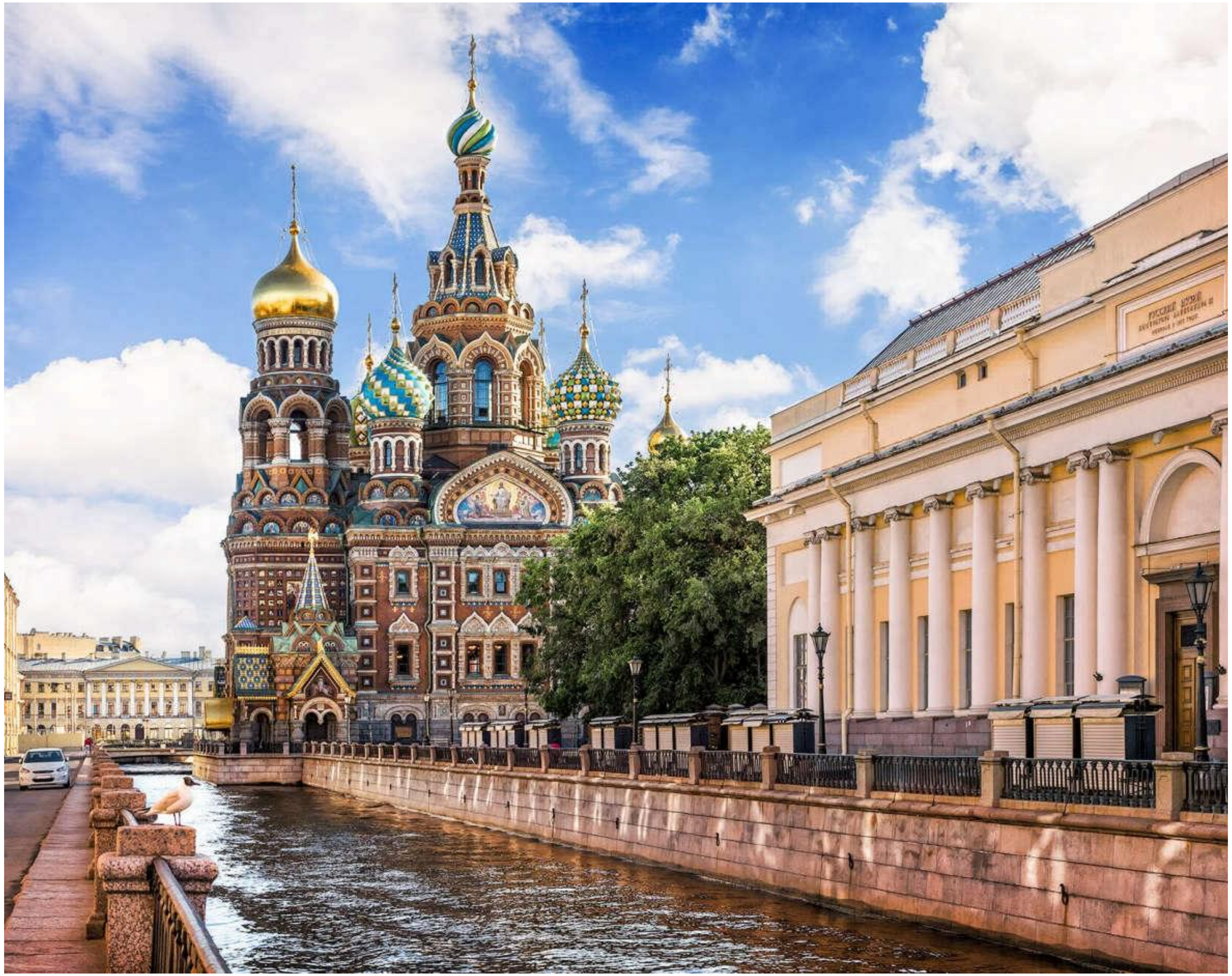
$$\theta_c = \sin^{-1}\frac{n_2}{n_1}$$

Total internal reflection

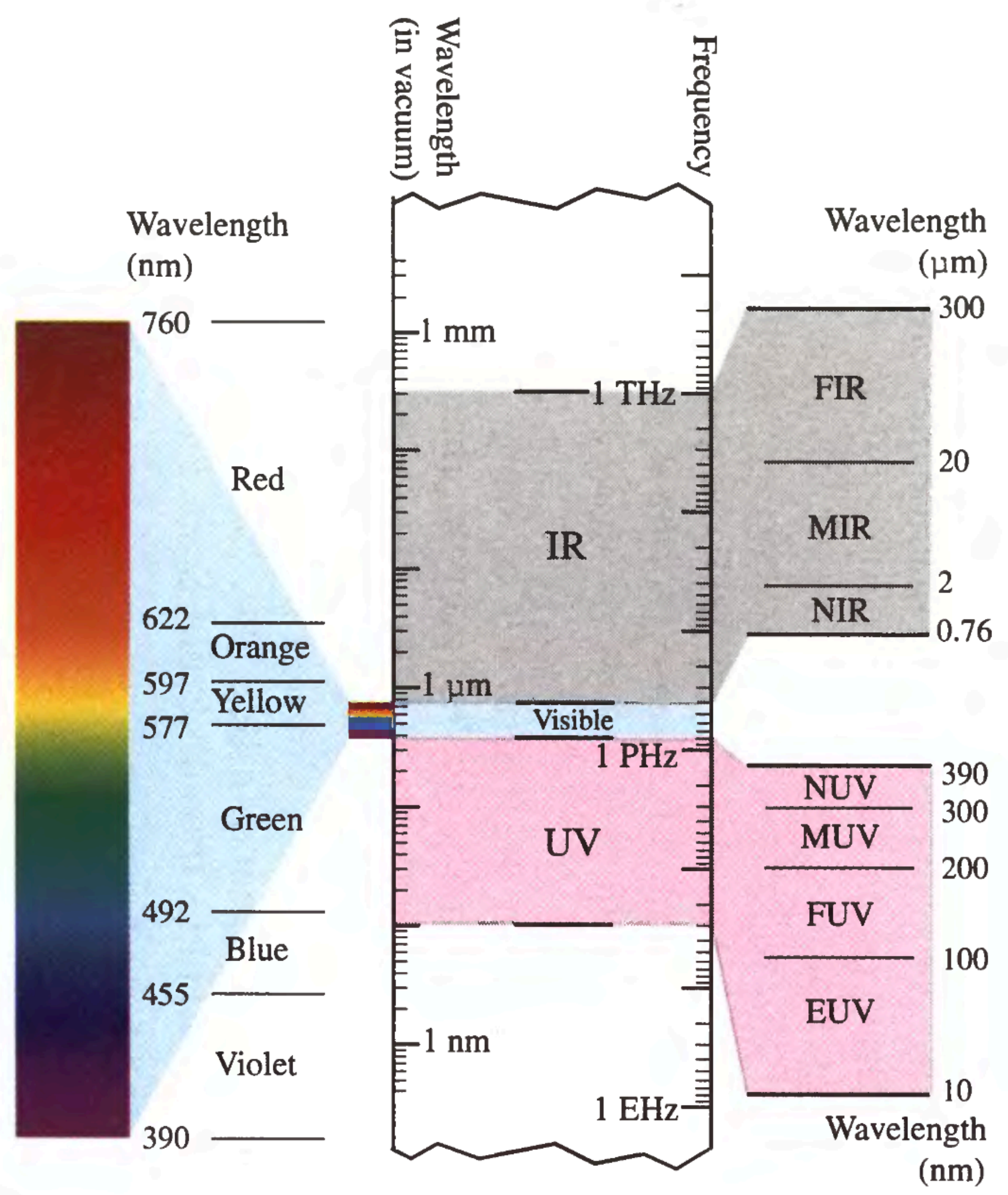


$$\left(\frac{\partial S}{\partial x}\right)^2 + \left(\frac{\partial S}{\partial y}\right)^2 + \left(\frac{\partial S}{\partial z}\right)^2 = n^2$$

Eikonal equation



Wave Optics

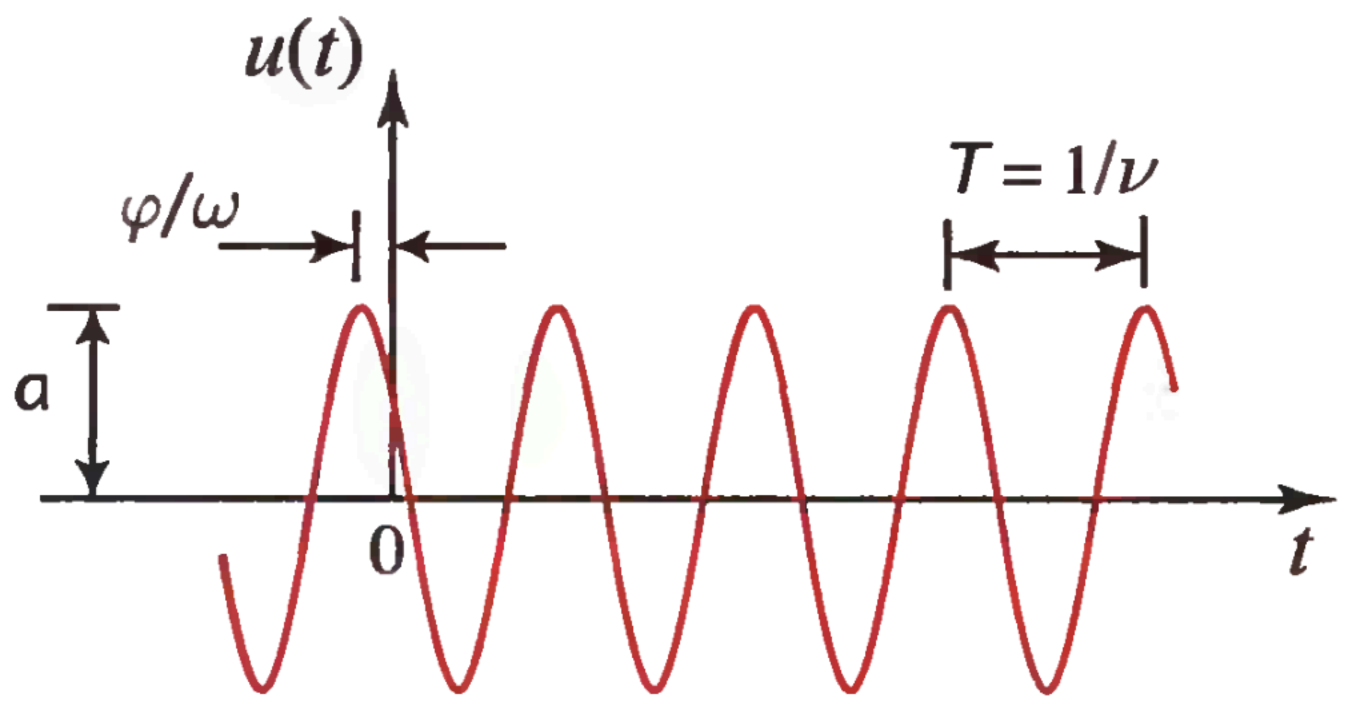

Wavelength (nm)
760
622
597
577
492
455
390
Red
Orange
Yellow
Green
Blue
Violet
Wavelength (in vacuum)
Frequency
1 mm
1 μm
1 nm
1 THz
1 PHz
1 EHz
IR
Visible
UV
Wavelength (μm)
300
20
2
0.76
FIR
MIR
NIR
390
300
200
100
10
NUV
MUV
FUV
EUV
Wavelength (nm)

$$\nabla^2 u - \frac{1}{c^2}\frac{\partial^2 u}{\partial t^2} = 0$$

Wave equation

$$u(\mathbf{r}, t) = \mathfrak{a}(\mathbf{r}) \cos[2\pi\nu t + \varphi(\mathbf{r})]$$

Wave



$$\nabla^2 u - \frac{1}{c^2}\frac{\partial^2 u}{\partial t^2} = 0$$

Wave equation

$$U(\mathbf{r}, t) = U(\mathbf{r}) \exp(j2\pi\nu t)$$

$$u(\mathbf{r}, t) = \mathbf{Re}\{U(\mathbf{r}, t)\}$$

Trick
(Complex amplitude)

$$\nabla^2 U + k^2 U = 0$$

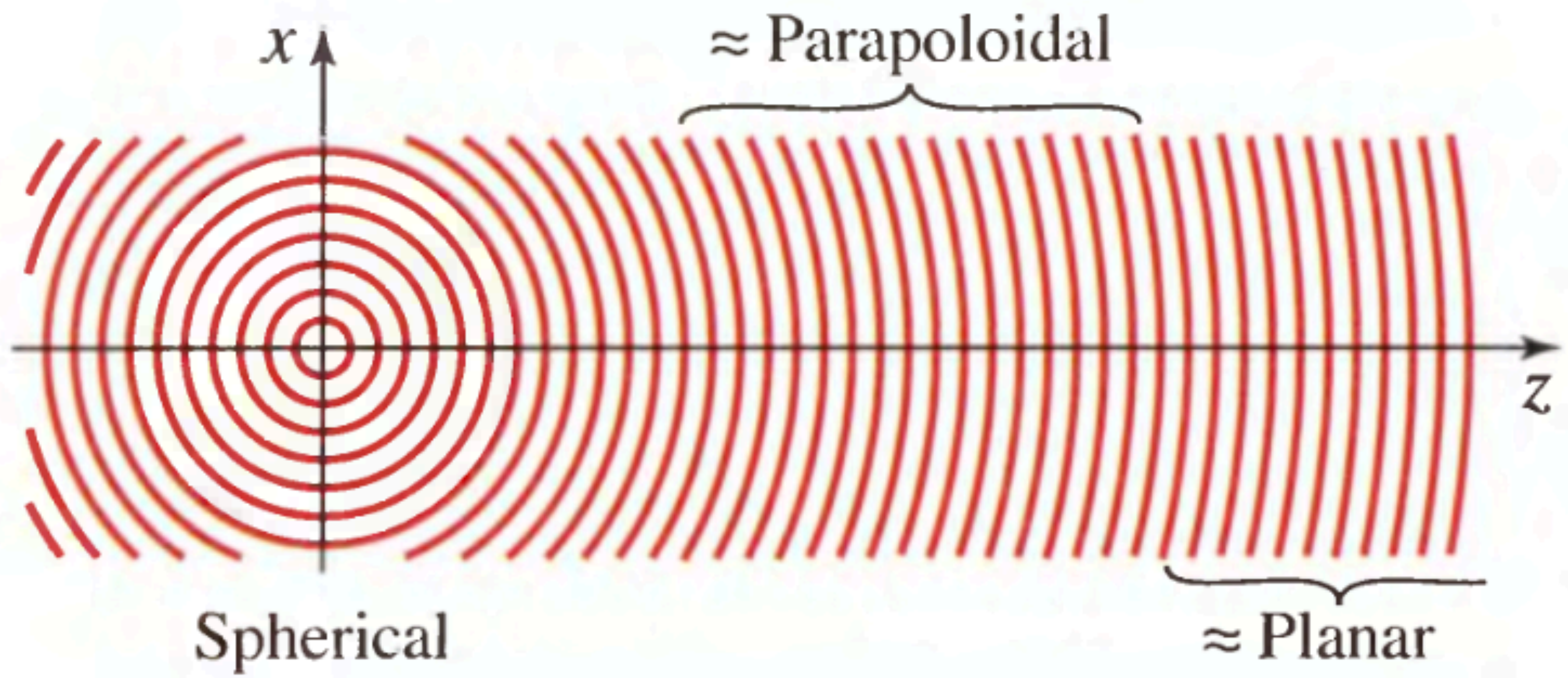
Helmholtz equation

$$k = \frac{2\pi\nu}{c} = \frac{\omega}{c}$$

wave number

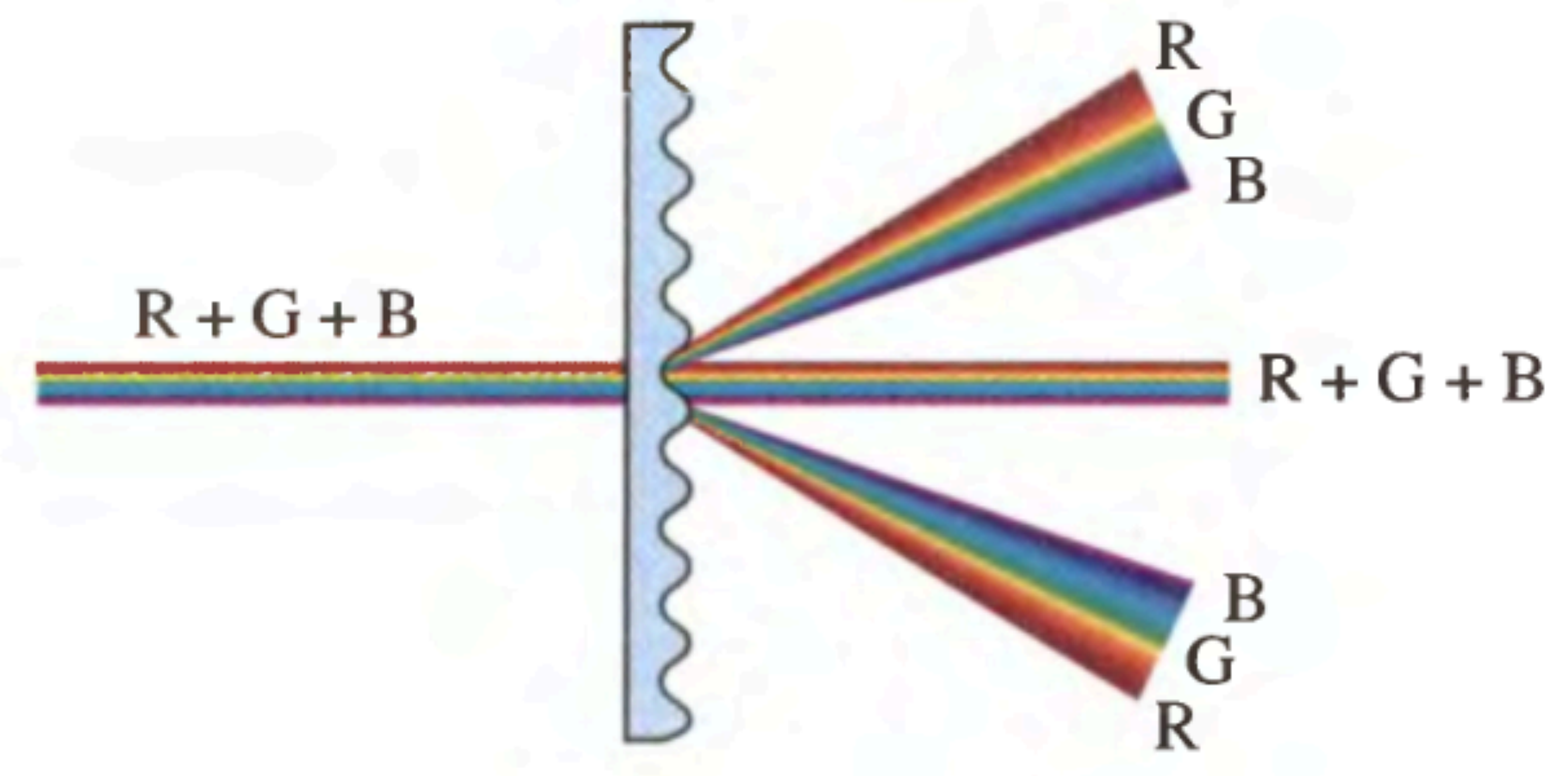
$$\lambda = \frac{c}{\nu}$$

wave length

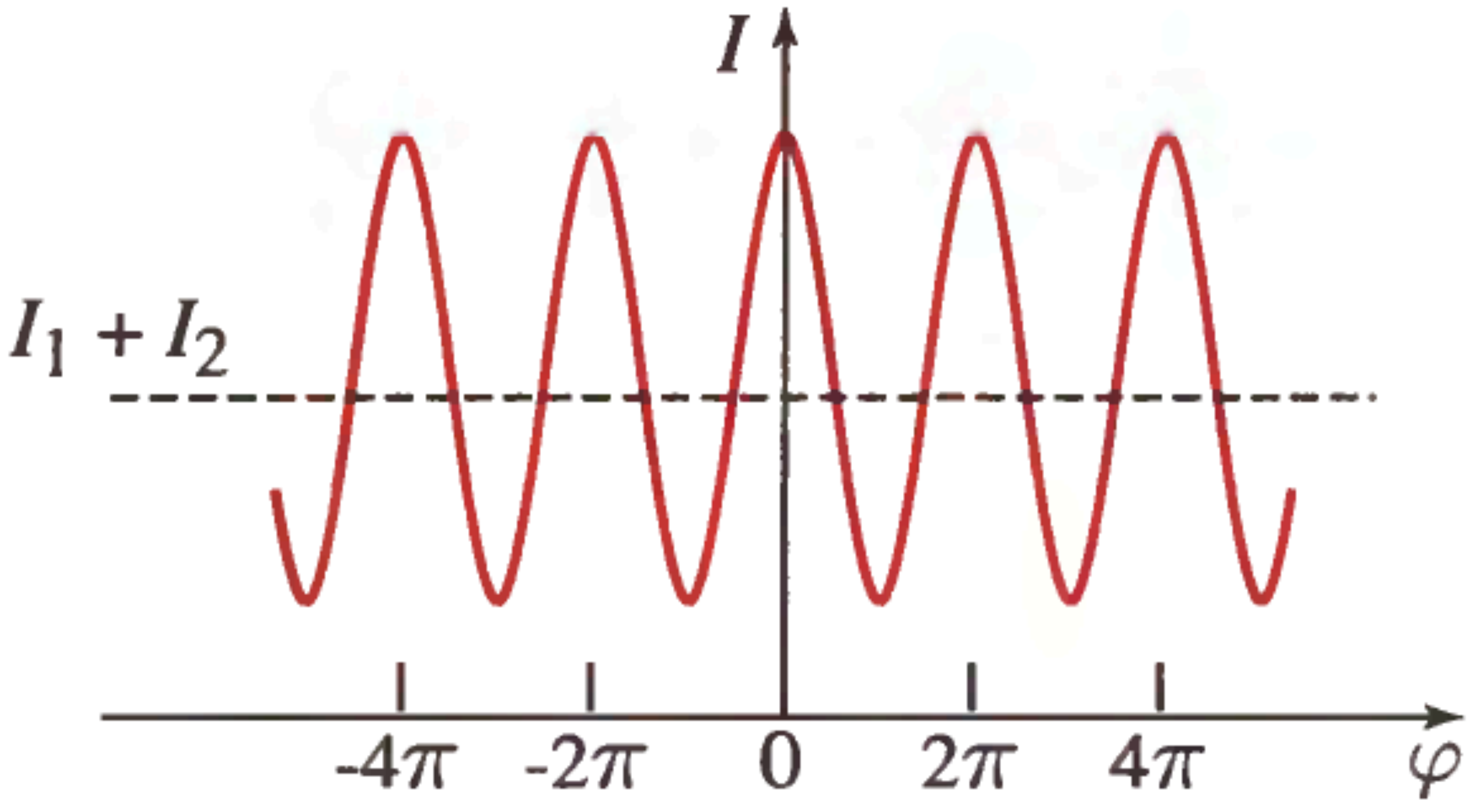


$$U(\mathbf{r}) = \frac{A_0}{r}\exp(-jkr)$$

$$U(\mathbf{r}) = A\exp(-j\mathbf{k}\cdot\mathbf{r}) = A\exp\left[-j(k_x x + k_y y + k_z z)\right]$$

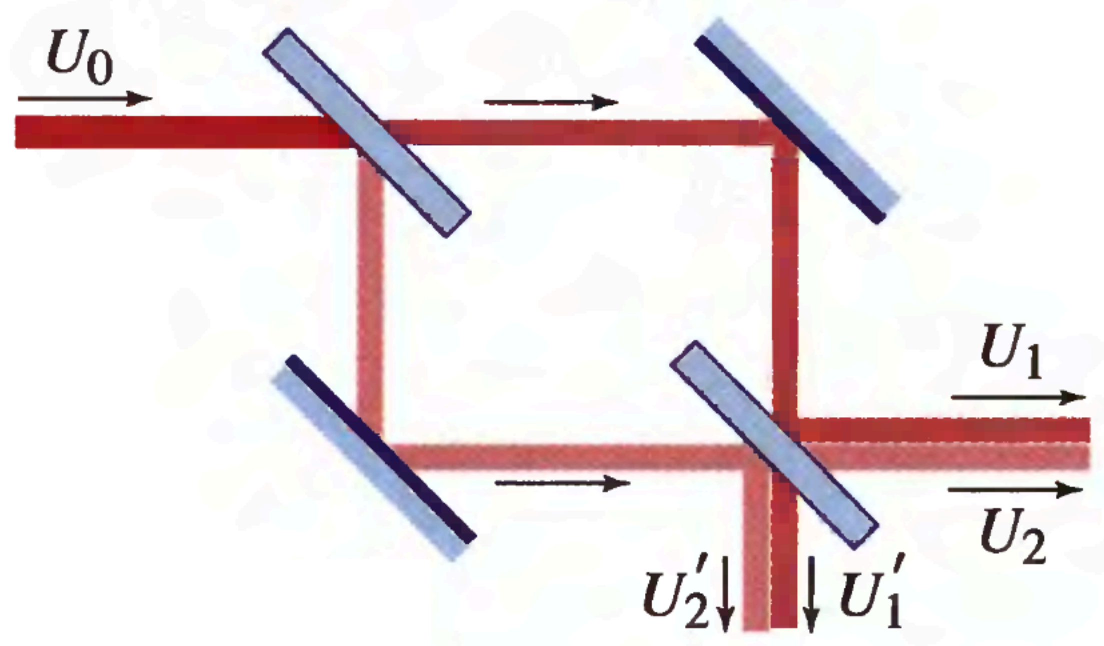


Diffraction grating

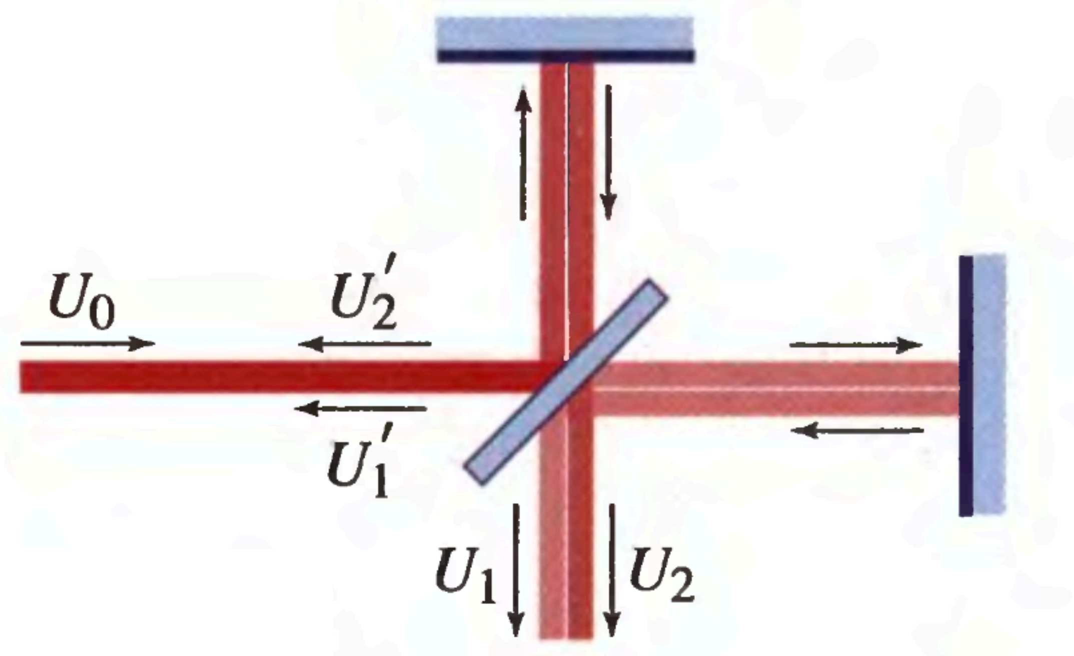


$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\varphi$$

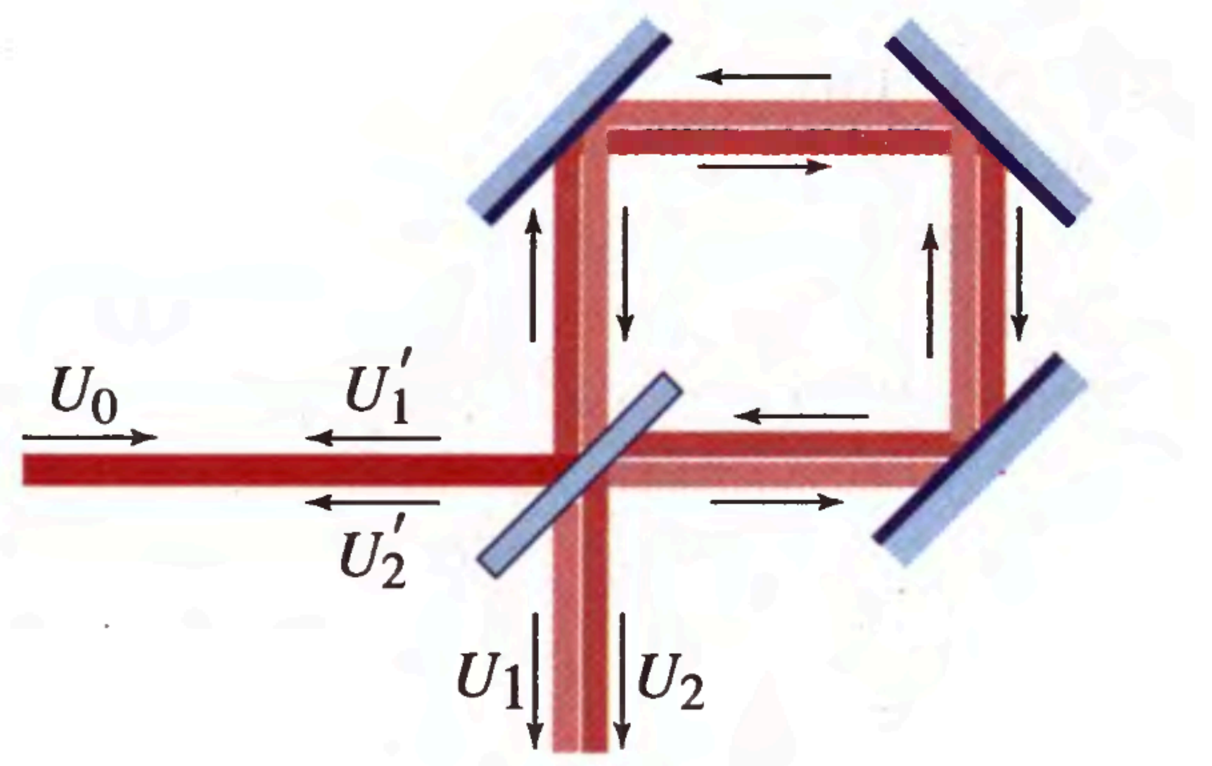
Interference



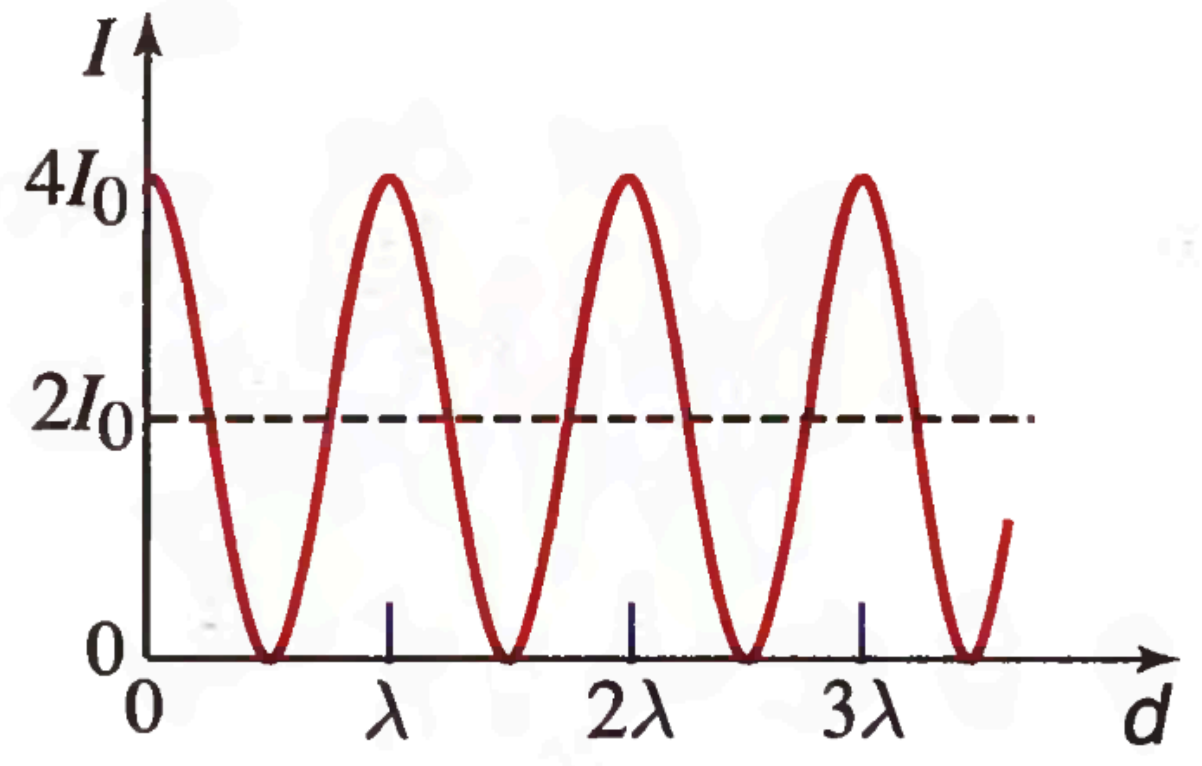
Mach-Zehnder
interferometer



Michelson
interferometer



Sagnac
interferometer



$$u(t) = \int_{-\infty}^{\infty} v(\nu) \exp(j2\pi\nu t)\, d\nu$$

$$v(\nu) = \int_{-\infty}^{\infty} u(t) \exp(-j2\pi\nu t)\, dt$$

Fourier transform

EM Optics

$$\nabla \times \mathcal{H} = \epsilon_o \frac{\partial \mathcal{E}}{\partial t}$$

$$\nabla \times \mathcal{E} = -\mu_o \frac{\partial \mathcal{H}}{\partial t}$$

$$\nabla \cdot \mathcal{E} = 0$$

$$\nabla \cdot \mathcal{H} = 0$$

Maxwell's equation
(free space)

$$\nabla \times \mathcal{H} = \epsilon_o \frac{\partial \mathcal{E}}{\partial t}$$

$$\nabla \times \mathcal{E} = -\mu_o \frac{\partial \mathcal{H}}{\partial t}$$

$$\nabla \cdot \mathcal{E} = 0$$

$$\nabla \cdot \mathcal{H} = 0$$

Maxwell's equation
(free space)

$$\nabla^2 u - \frac{1}{c_o^2}\frac{\partial^2 u}{\partial t^2} = 0$$

Wave equation

$$c_o = \frac{1}{\sqrt{\epsilon_o \mu_o}}$$

$$\nabla \times \mathcal{H} = \epsilon_o \frac{\partial \mathcal{E}}{\partial t}$$

$$\nabla \times \mathcal{E} = -\mu_o \frac{\partial \mathcal{H}}{\partial t}$$

$$\nabla \cdot \mathcal{E} = 0$$

$$\nabla \cdot \mathcal{H} = 0$$

Maxwell's equation
(free space)

$\longrightarrow$

$$\nabla \times \mathcal{H} = \frac{\partial \mathcal{D}}{\partial t}$$

$$\nabla \times \mathcal{E} = -\frac{\partial \mathcal{B}}{\partial t}$$

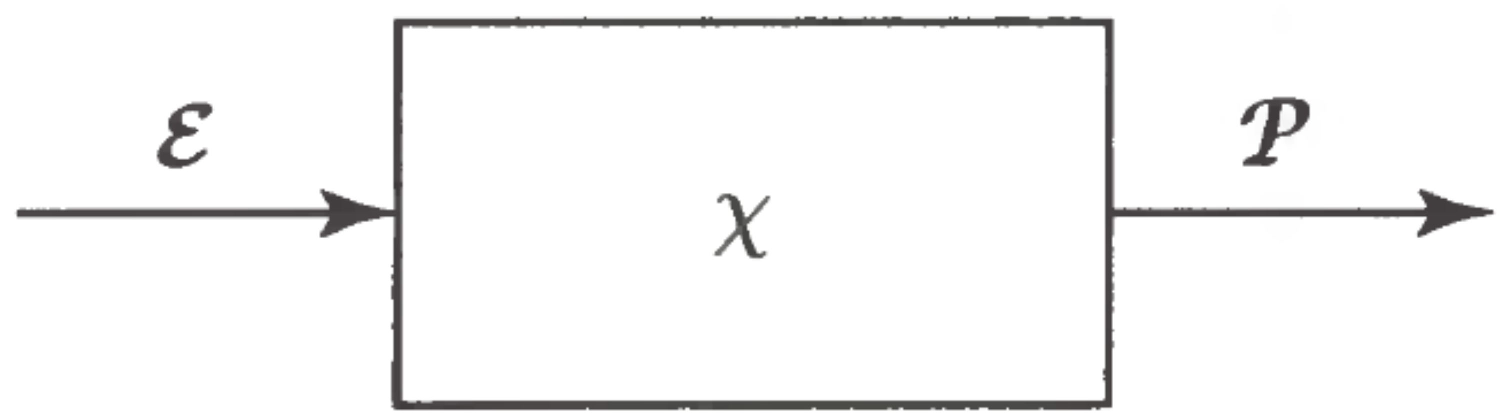
$$\nabla \cdot \mathcal{D} = 0$$

$$\nabla \cdot \mathcal{B} = 0.$$

$$\mathcal{D} = \epsilon_o \mathcal{E} + \mathcal{P}$$

$$\mathcal{B} = \mu_o \mathcal{H} + \mu_o \mathcal{M}$$

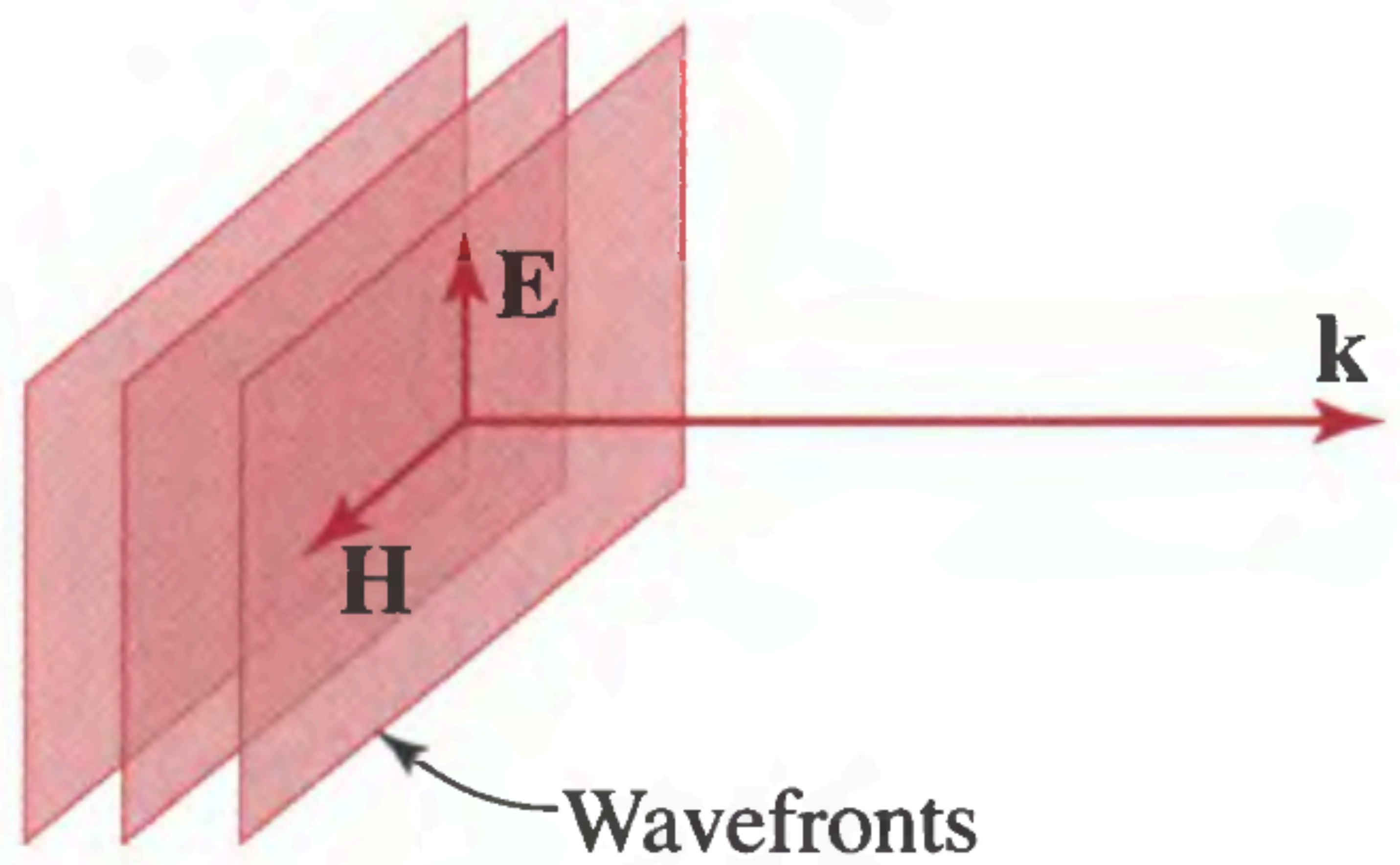
Maxwell's equation
(media)



$$\mathcal{P} = \epsilon_o \chi \mathcal{E}, \quad \mathcal{D} = \epsilon \mathcal{E}, \quad \epsilon = \epsilon_o (1 + \chi)$$

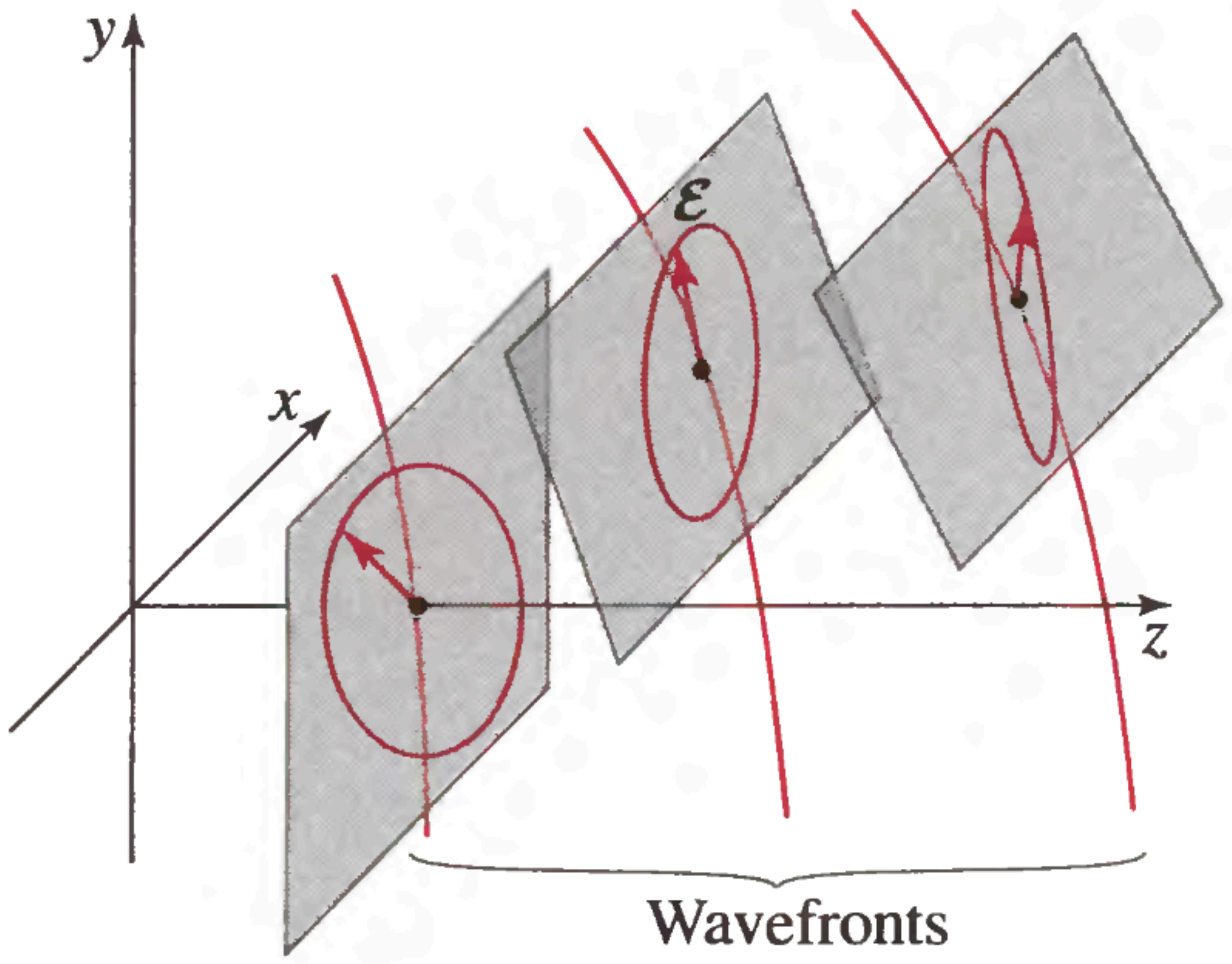
$$\mathcal{B} = \mu \mathcal{H}$$

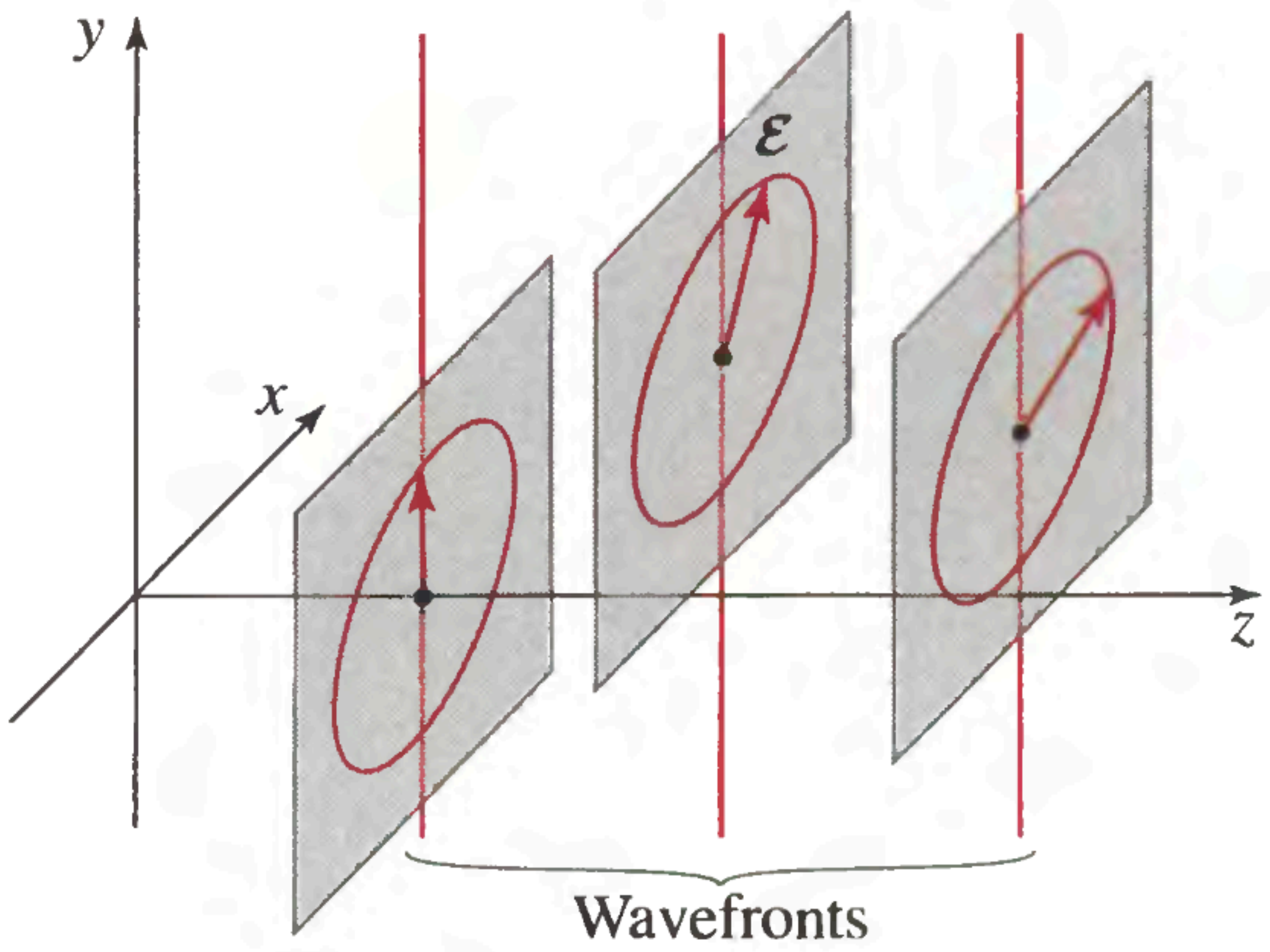
$$n = \frac{c_o}{c} = \sqrt{\frac{\epsilon}{\epsilon_o} \frac{\mu}{\mu_o}}$$



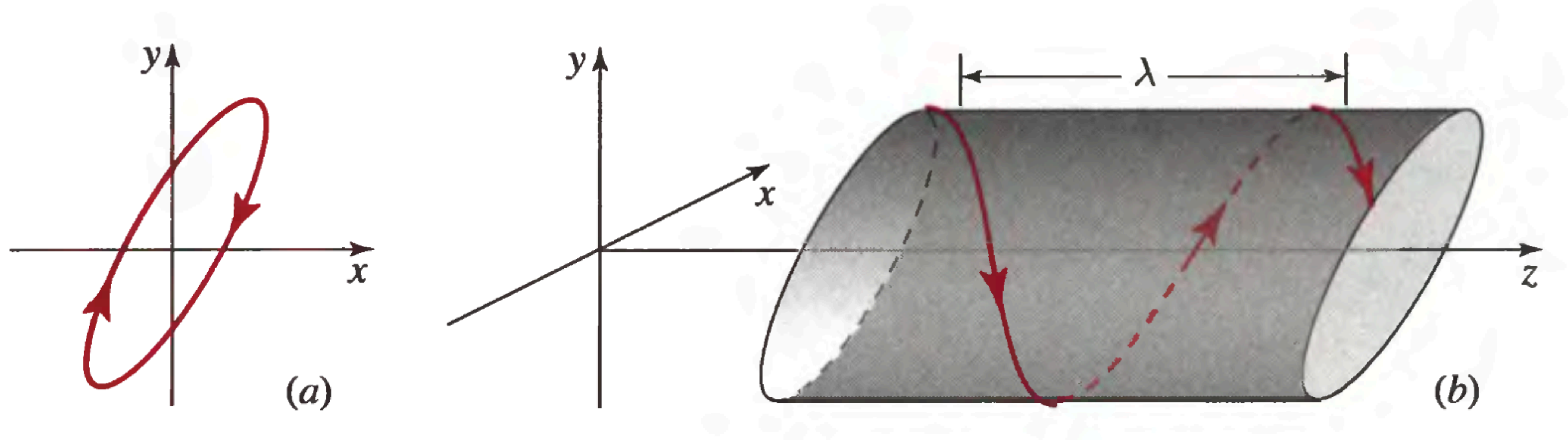
$$\mathbf{H}(\mathbf{r}) = \mathbf{H}_0 \exp(-j\mathbf{k}\cdot\mathbf{r})$$
$$\mathbf{E}(\mathbf{r}) = \mathbf{E}_0 \exp(-j\mathbf{k}\cdot\mathbf{r})$$

Plane wave

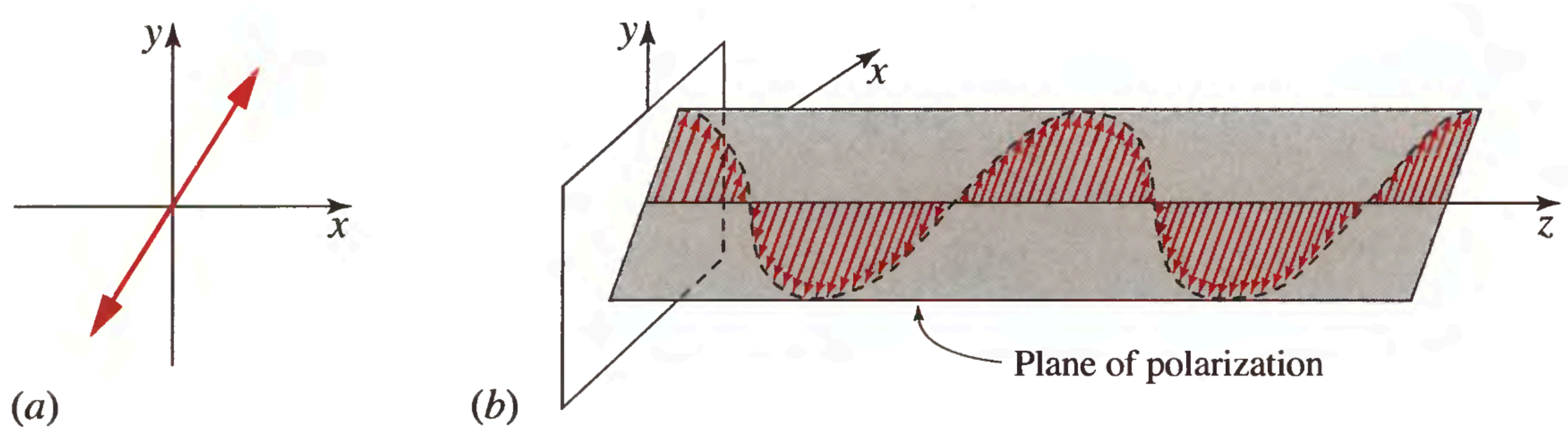




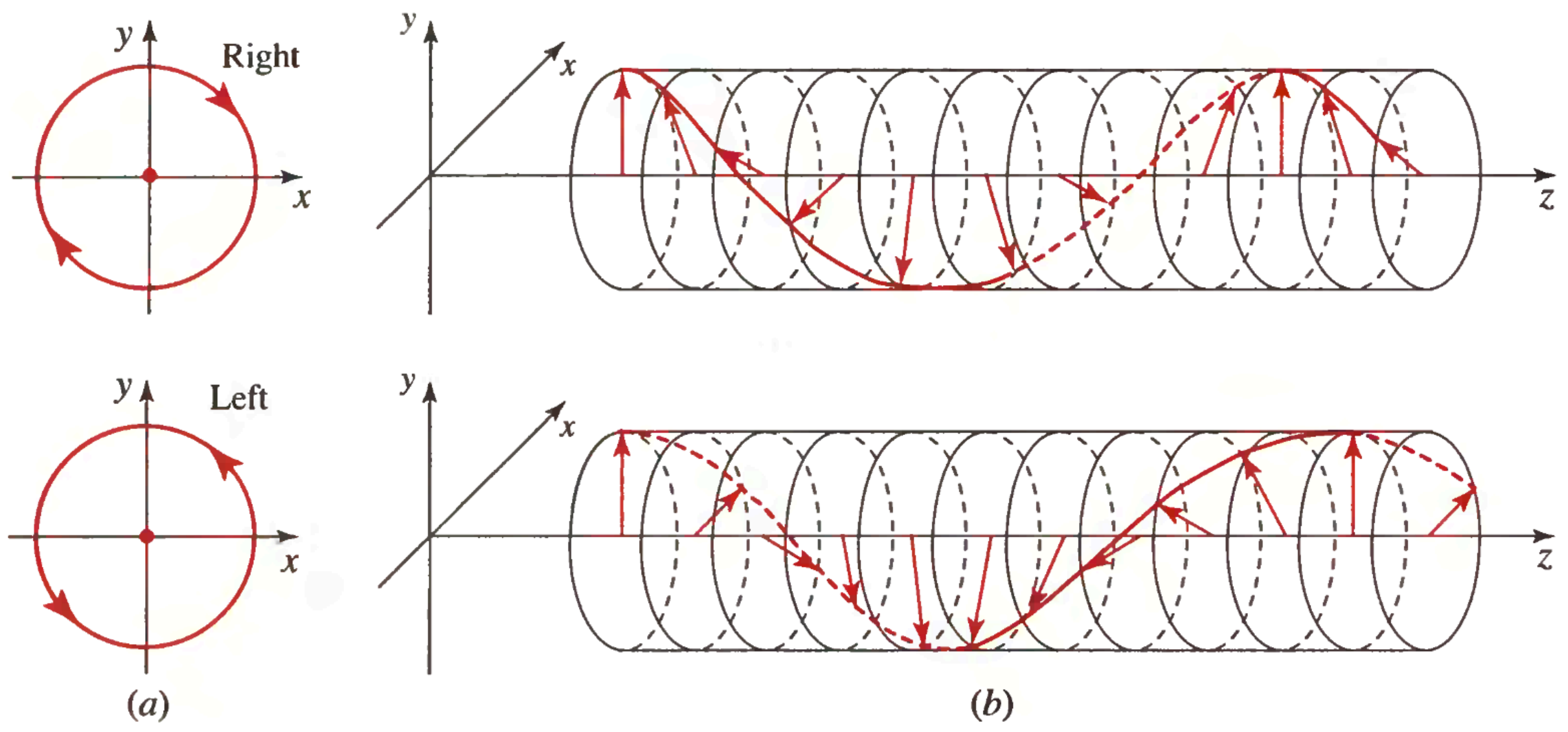
Polarized wave



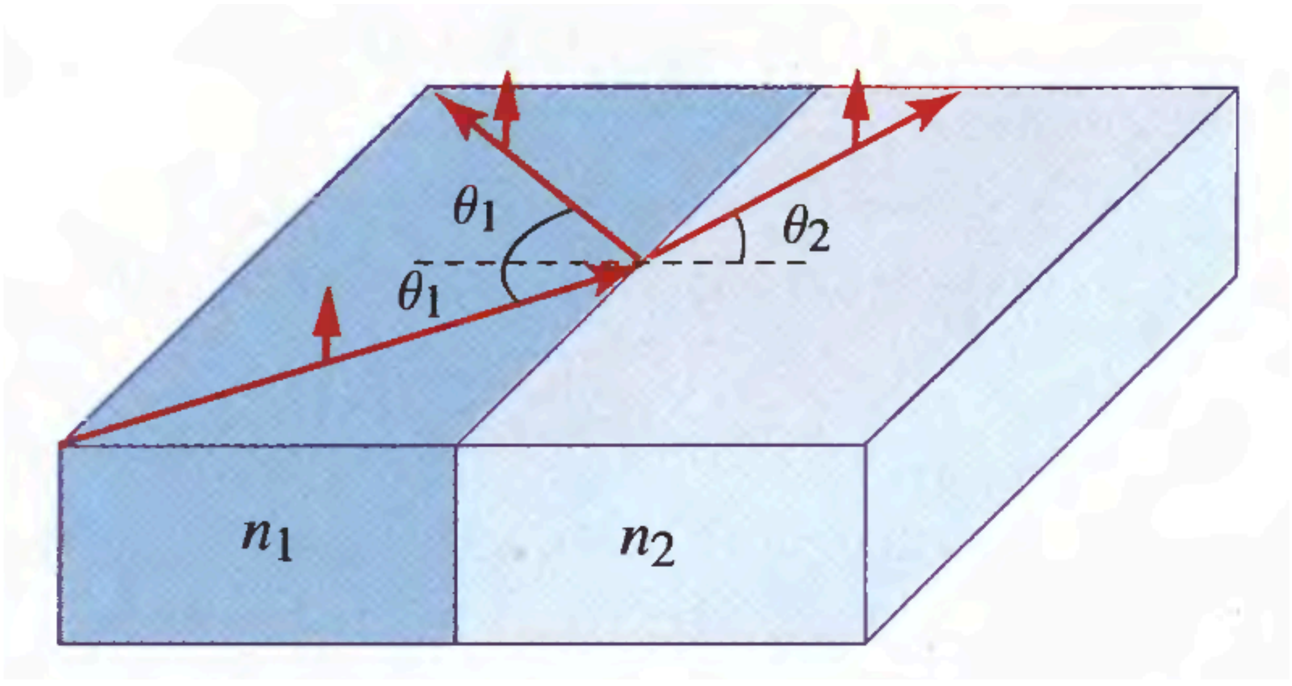
Elliptically polarised wave



Linearly polarised wave



Circulary polarised wave

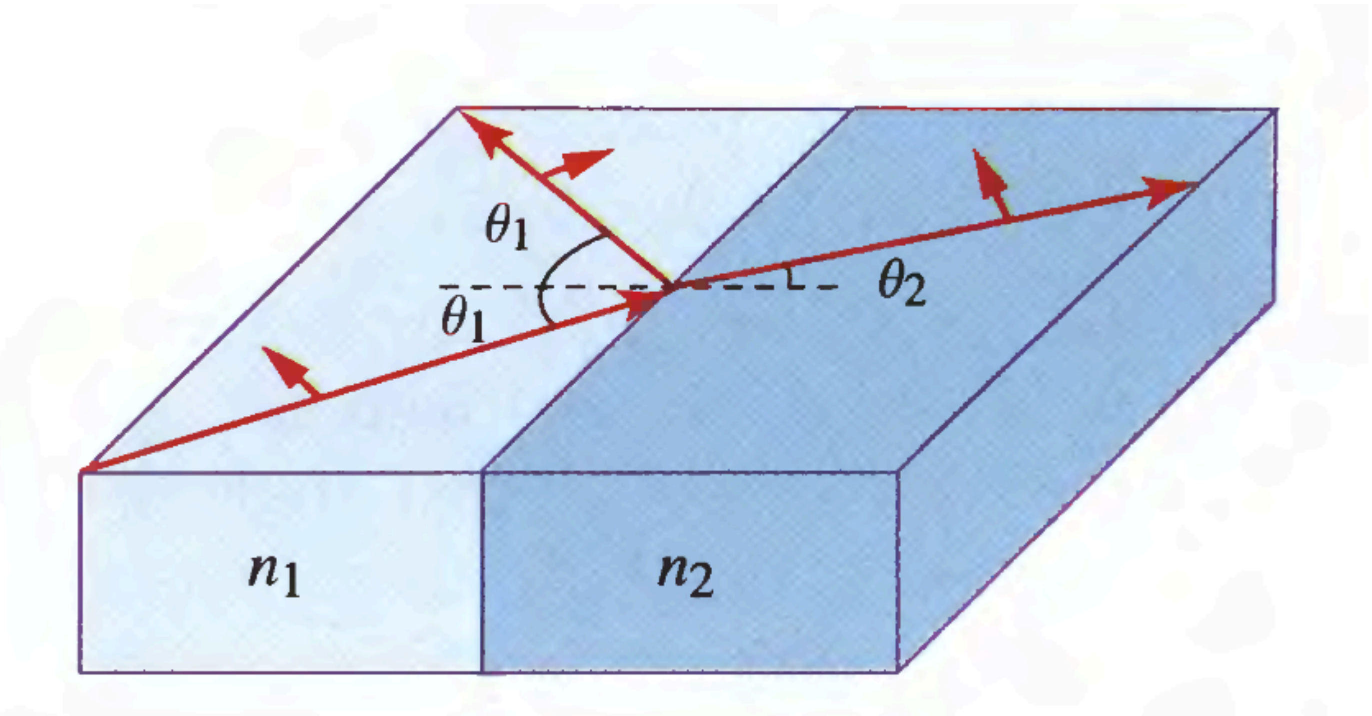


TE wave

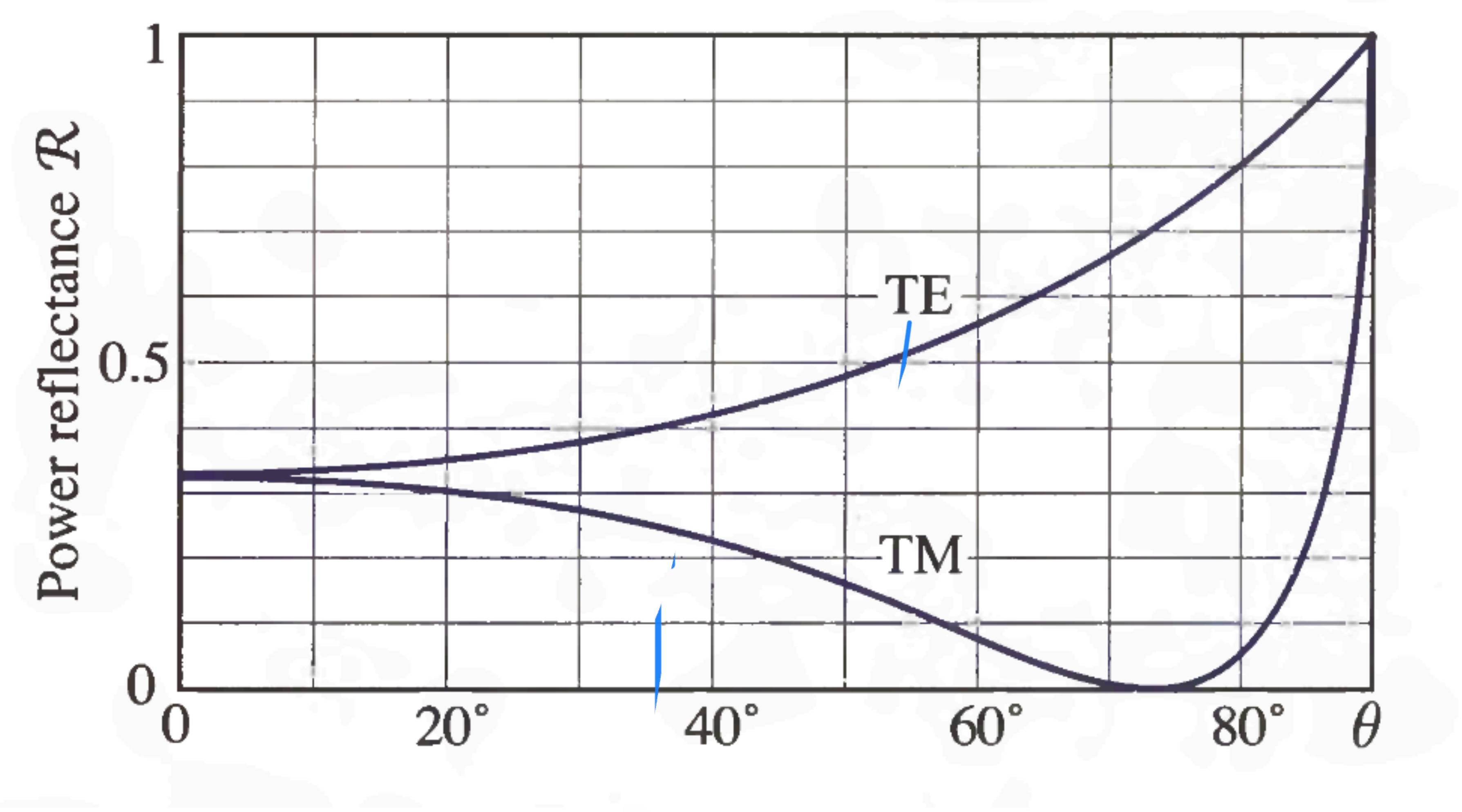
$$\mathrm{r}_x = \frac{n_1 \cos\theta_1 - n_2 \cos\theta_2}{n_1 \cos\theta_1 + n_2 \cos\theta_2}, \qquad \mathrm{t}_x = 1 + \mathrm{r}_x$$

$$\mathrm{r}_y = \frac{n_1 \sec\theta_1 - n_2 \sec\theta_2}{n_1 \sec\theta_1 + n_2 \sec\theta_2}, \qquad \mathrm{t}_y = (1 + \mathrm{r}_y)\,\frac{\cos\theta_1}{\cos\theta_2}$$

Fresnel equations

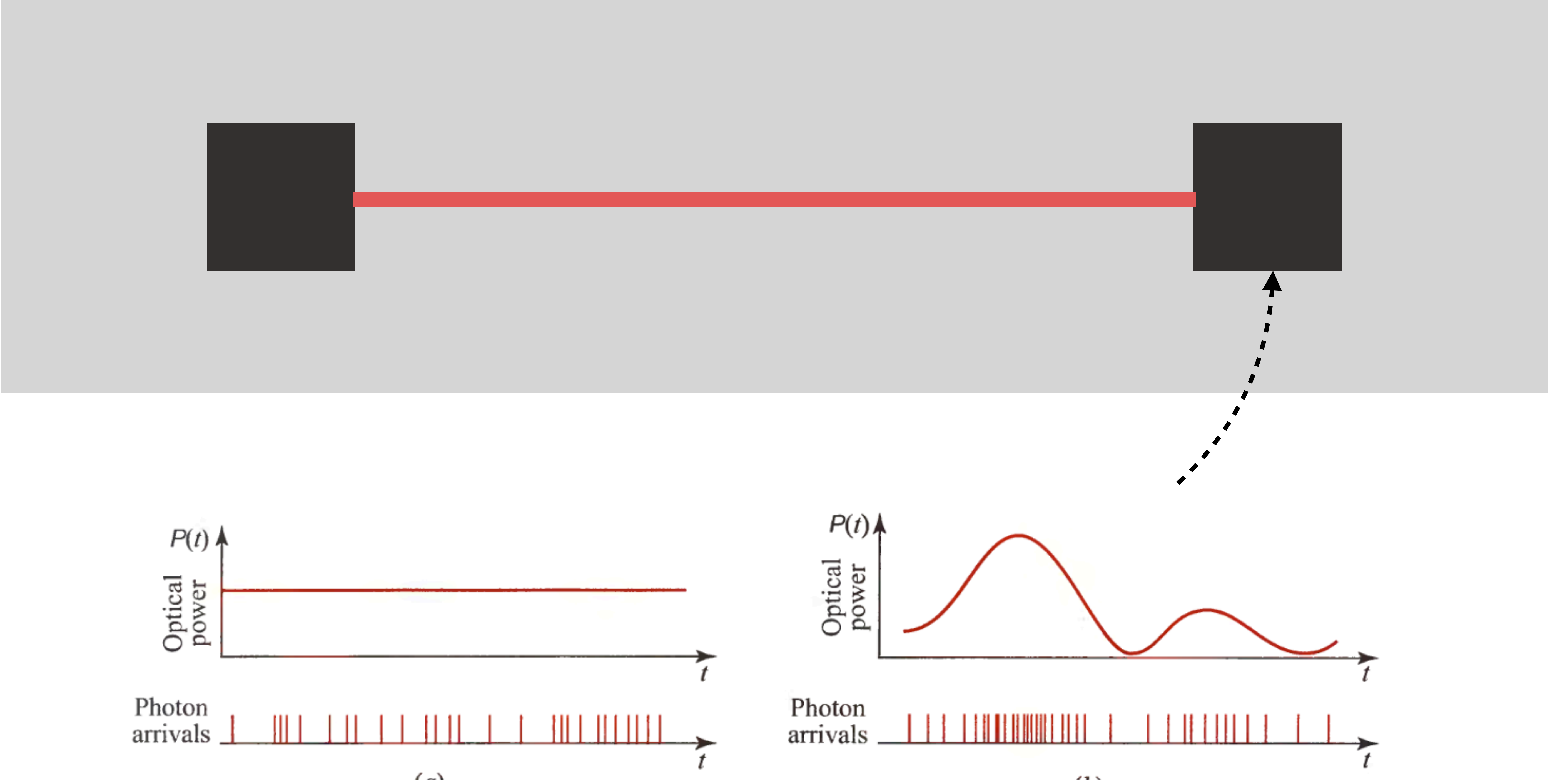


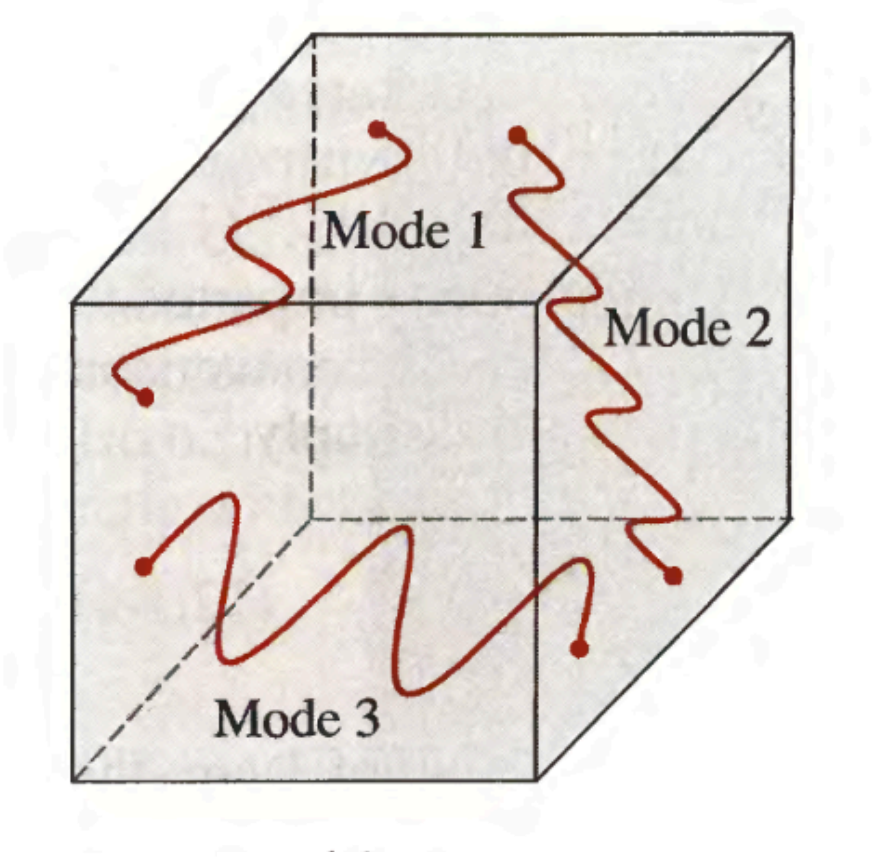
TM wave

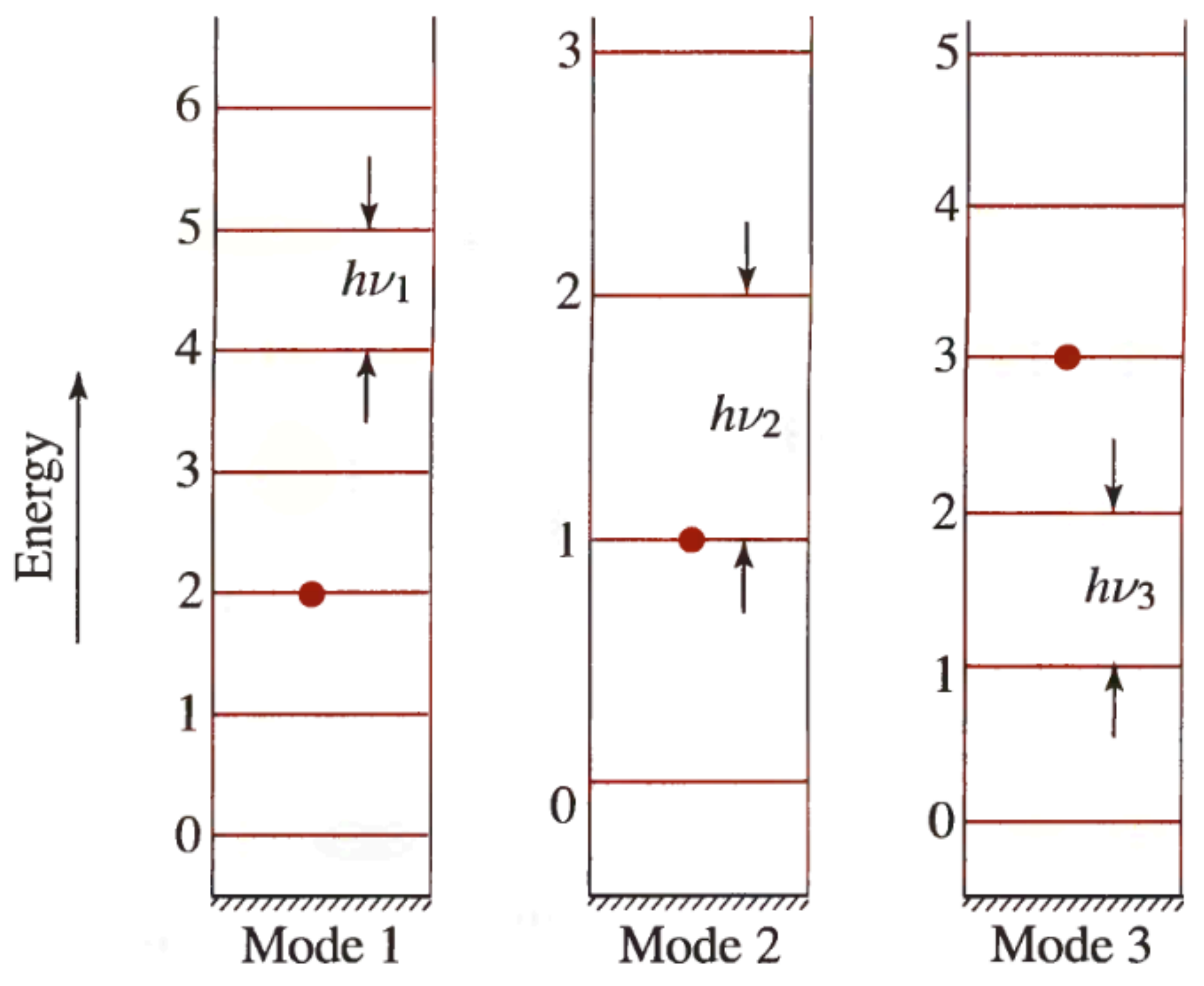


$\mathcal{R} = |\mathrm{r}|^2$.

Quantum Optics

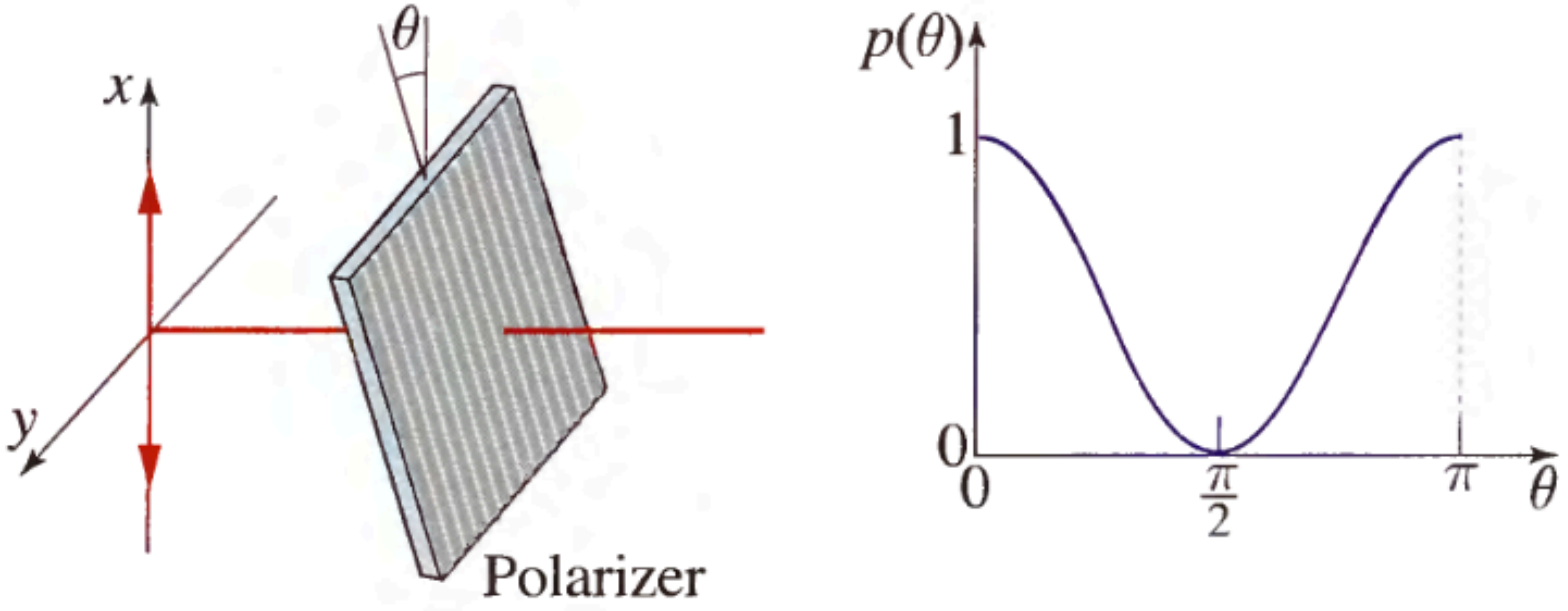

P(t)
Optical power
t
Photon arrivals
t
P(t)
Optical power
t
Photon arrivals
t



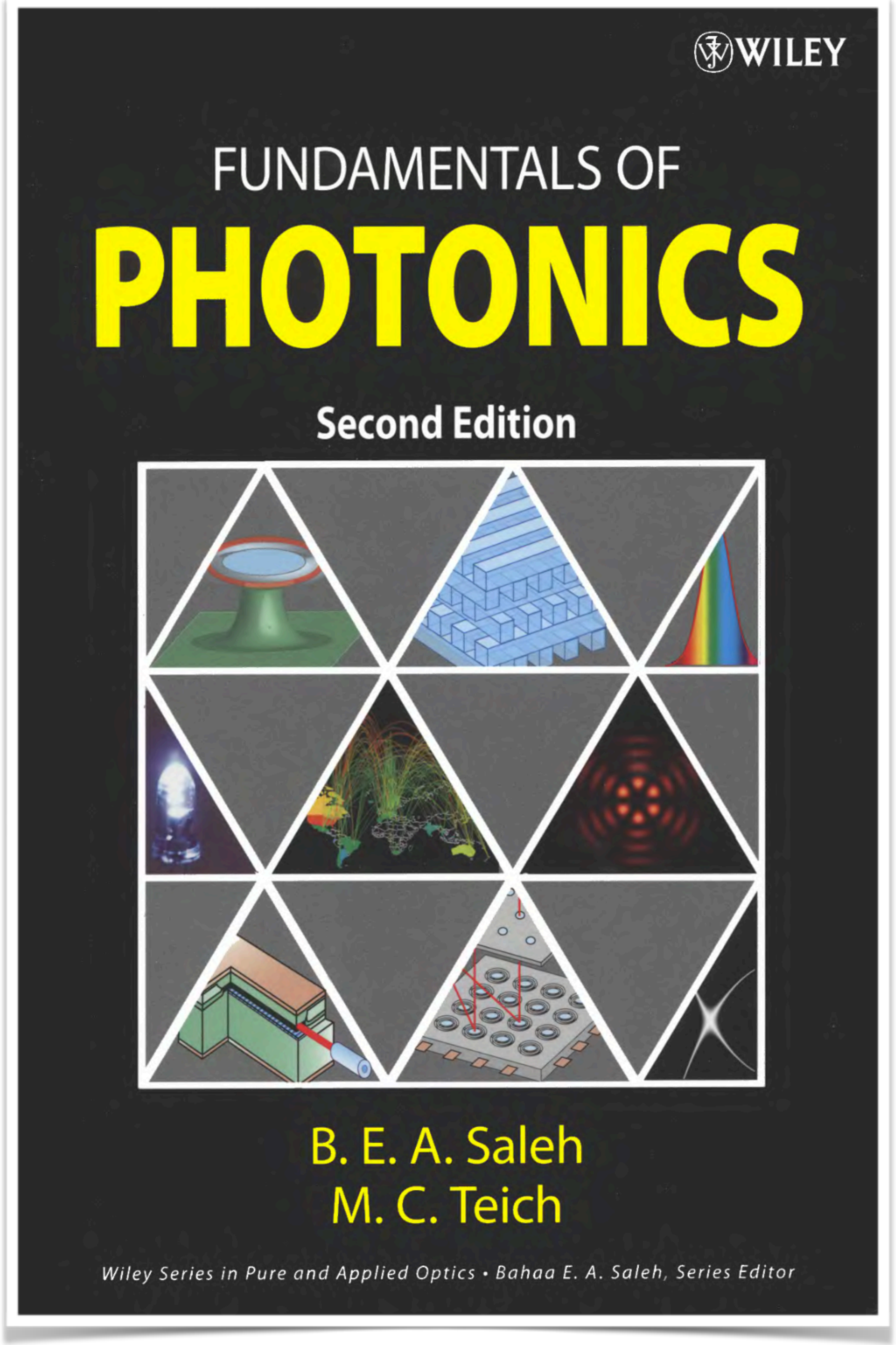


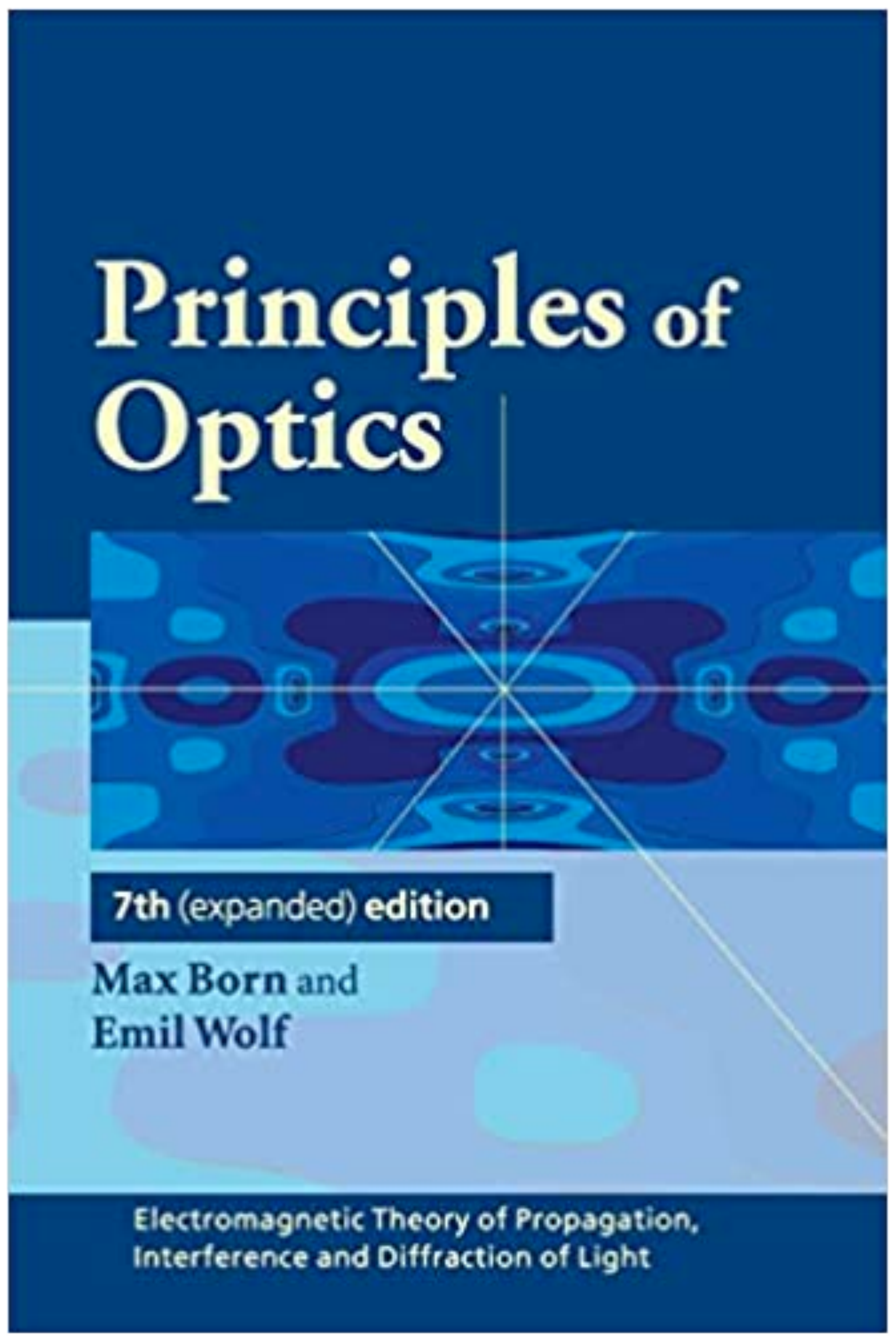
$$E_n = (n + \tfrac{1}{2})\, h\nu, \qquad n = 0, 1, 2, \ldots .$$

$$\mathbf{E}(\mathbf{r}, t) = \sum_{\mathbf{q}} A_{\mathbf{q}}\, U_{\mathbf{q}}(\mathbf{r})\, \exp(j2\pi\nu_{\mathbf{q}} t)\, \widehat{\mathbf{e}}_{\mathbf{q}}$$



θ
x
y
Polarizer
p(θ)
1
0
0
π/2
π
θ


WILEY
FUNDAMENTALS OF
PHOTONICS
Second Edition
B. E. A. Saleh
M. C. Teich
Wiley Series in Pure and Applied Optics • Bahaa E. A. Saleh, Series Editor


Principles of Optics
7th (expanded) edition
Max Born and
Emil Wolf
Electromagnetic Theory of Propagation,
Interference and Diffraction of Light

korikov.constantine@spbstu.ru