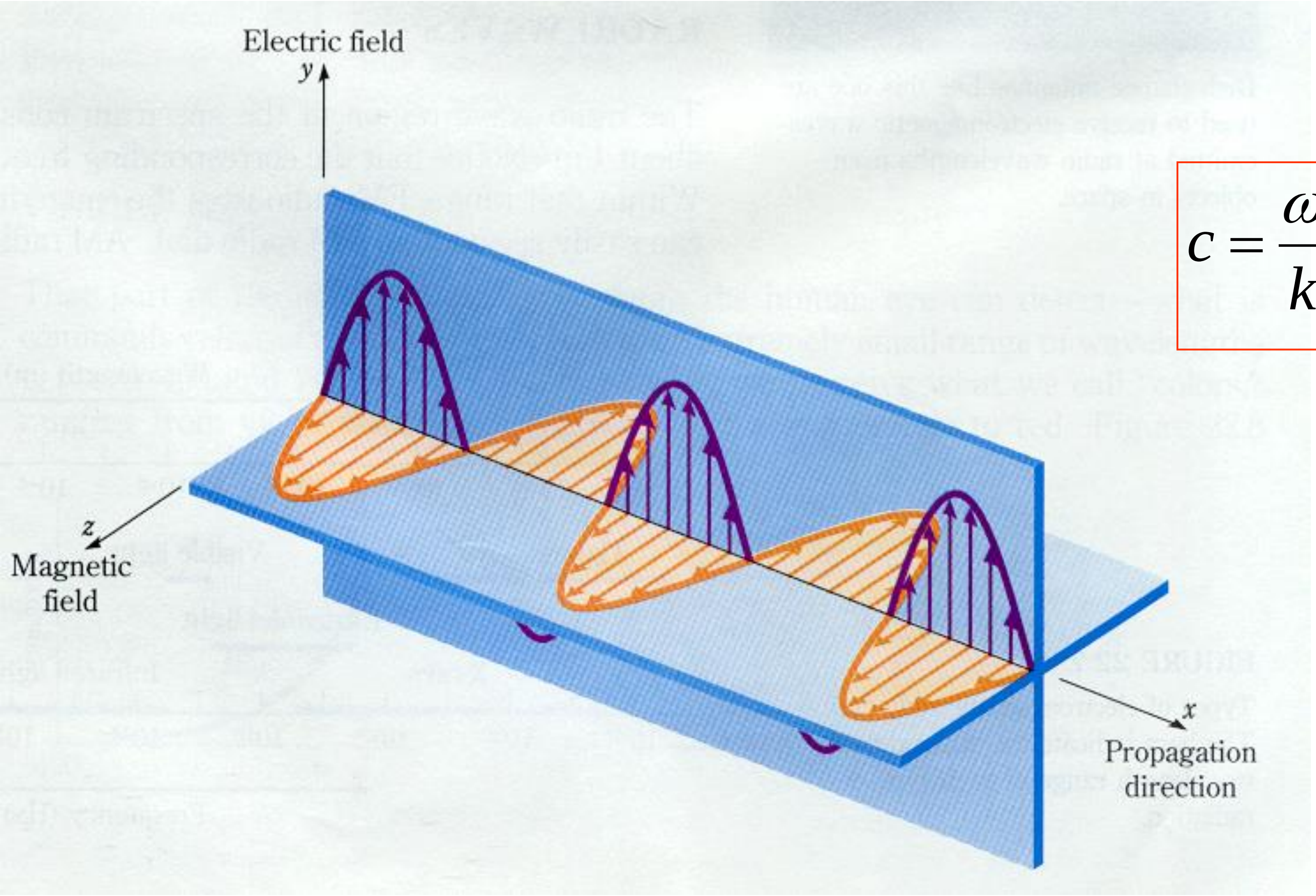
Copyright statement

- The images and the pictures in this lecture are provided by the CDs accompanied by the books
  1. University Physics, Bauer and Westfall, McGraw-Hill, 2011.
  2. Principles of Physics, Halliday, Resnick, and Walker, Wiley, 8^{th} and 9^{th} Ed.
- The rest is made by me.

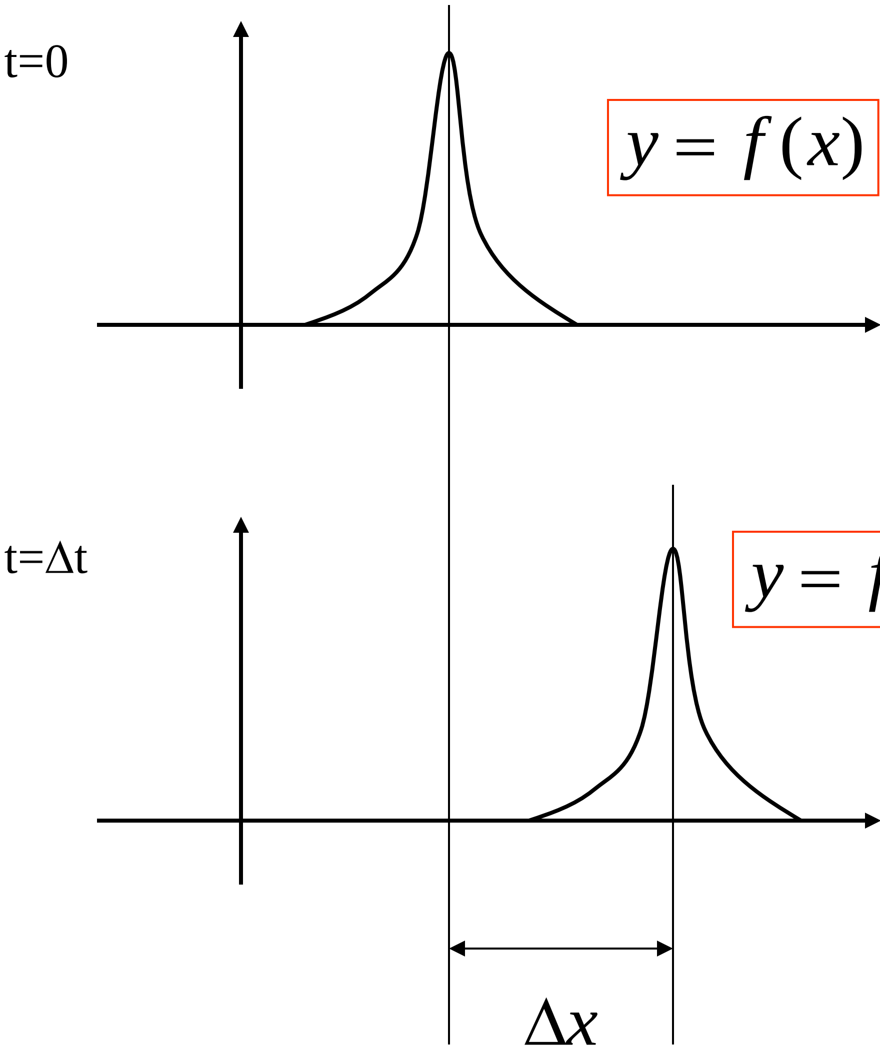
Picture of propagating EM waves



$$c = \frac{\omega}{k} = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

$$E = E_m \sin(kx - \omega t), \quad B = B_m \sin(kx - \omega t)$$

EM wave and Maxwell eq. : wave equation



$$y = f(x)$$

$$y = f(x - \Delta x)$$

$$y(x,t) = f(x - vt)$$

$$\frac{\partial^2 y}{\partial x^2} - \frac{1}{v^2}\frac{\partial^2 y}{\partial t^2} = 0$$

$$y(x,t) = y_m \sin(kx - \omega t)$$

Electromagnetic wave and Maxwell's equations

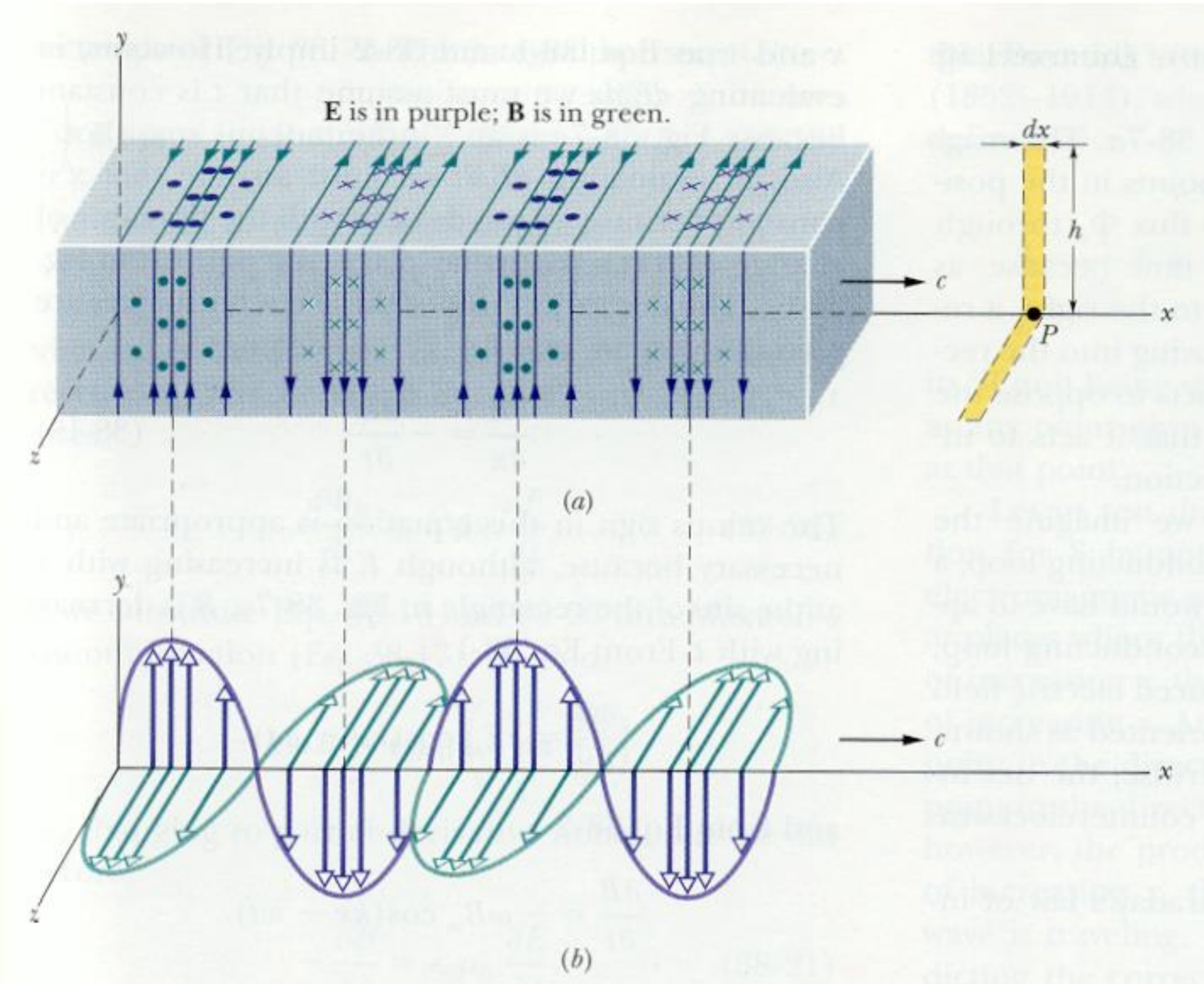
$$\frac{\partial^2 E(x,t)}{\partial x^2} - \frac{1}{c^2}\frac{\partial^2 E(x,t)}{\partial t^2} = 0$$

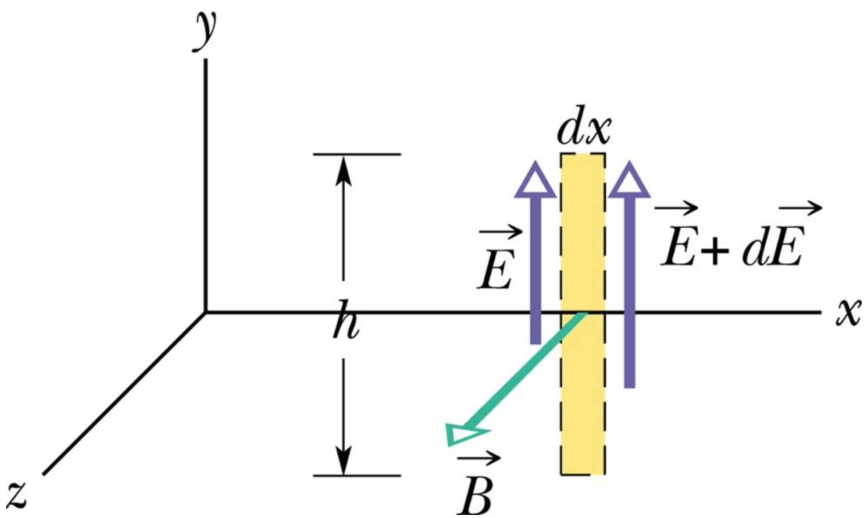
$$\frac{\partial^2 B(x,t)}{\partial x^2} - \frac{1}{c^2}\frac{\partial^2 B(x,t)}{\partial t^2} = 0$$

$$E(x,t) = E_m \sin(kx - \omega t)$$

$$B(x,t) = B_m \sin(kx - \omega t)$$

EM waves and Maxwell's equations





Faraday's law

$$\oint \vec{E}\cdot d\vec{s} = -\frac{d\Phi_B}{dt}$$

$$\oint \vec{E}\cdot d\vec{s} = (E+dE)h - Eh = hdE$$

$$hdE = -hdx\frac{dB}{dt}$$

$$\Phi_B = Bhdx \rightarrow \frac{d\Phi_B}{dt} = hdx\frac{dB}{dt}$$

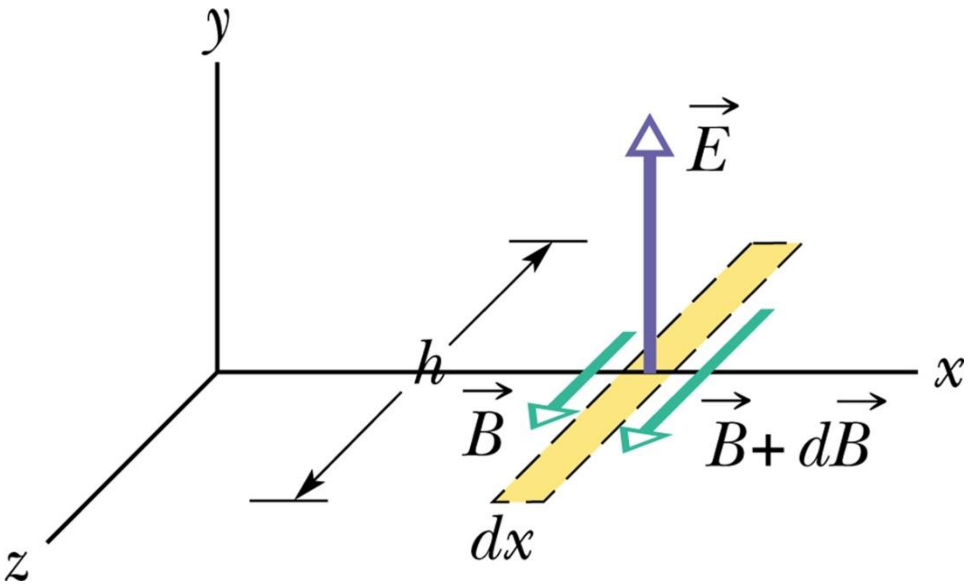
$$\frac{dE}{dx} = -\frac{dB}{dt}$$

$$\frac{\partial E}{\partial x} = -\frac{\partial B}{\partial t}$$

$$\frac{\partial E}{\partial x} = kE_m\cos(kx-\omega t)$$

$$\frac{\partial B}{\partial t} = -\omega B_m\cos(kx-\omega t)$$

$$\longrightarrow \boxed{\frac{E_m}{B_m} = \frac{\omega}{k} = c}$$



Maxwell's induction law

$$\oint \vec{B}\cdot d\vec{s} = \mu_0\epsilon_0 \frac{d\Phi_E}{dt}$$

$$\oint \vec{B}\cdot d\vec{s} = -(B+dB)h + Bh = -hdB \qquad -hdB = \mu_0\epsilon_0 h dx \frac{dE}{dt}$$

$$\Phi_E = Ehdx \rightarrow \frac{d\Phi_E}{dt} = hdx\frac{dE}{dt} \qquad -\frac{\partial B}{\partial x} = \mu_0\epsilon_0 \frac{\partial E}{\partial t}$$

$$-kB_m \cos(kx-\omega t) = -\mu_0\epsilon_0\omega E_m \cos(kx-\omega t)$$

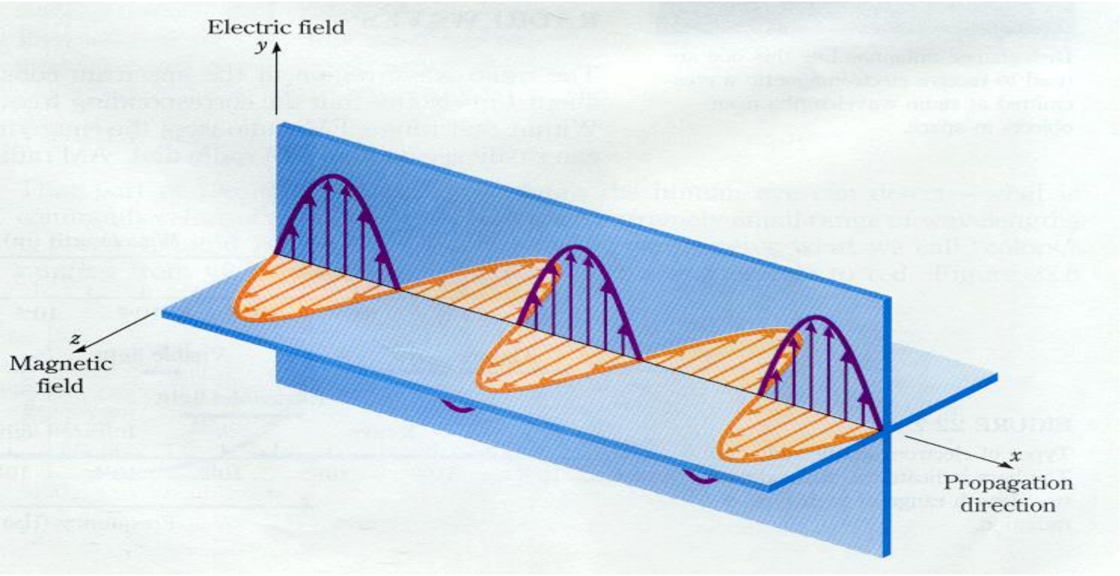
$$\frac{E_m}{B_m} = \frac{1}{\mu_0\epsilon_0(\omega/k)} = \frac{1}{\mu_0\epsilon_0 c}$$

$$c = \frac{1}{\sqrt{\mu_0\epsilon_0}}$$

Energy transfer of EM waves: Poynting vector

1. Energy transfer of EM waves: radiation
2. Poynting vector : energy flux of EM waves (unit, dim?)

$$\mathbf{S} = \frac{1}{\mu_0}\mathbf{E}\times\mathbf{B}$$



Poynting vector and the intensity of EM waves

$$\mathbf{S} = \frac{1}{\mu_0}\mathbf{E}\times\mathbf{B}$$

$$\begin{aligned} \mathbf{E}(t) &= E_m \sin(kx - \omega t)\hat{y}, \\ \mathbf{B}(t) &= B_m \sin(kx - \omega t)\hat{z}. \end{aligned}$$

$$S = \left(\frac{\text{energy/time}}{\text{area}}\right)_{\text{inst}} = \left(\frac{\text{power}}{\text{area}}\right)_{\text{inst}}.$$

$$S = \frac{1}{\mu_0}EB = \frac{1}{c\mu_0}E^2$$

$$\begin{aligned} S &= \frac{1}{c\mu_0}E^2 = \frac{\epsilon_0 E^2}{c\mu_0\epsilon_0} = c(\epsilon_0 E^2) \\ &\rightarrow \frac{\text{energy}\cdot\text{velocity}}{\text{volume}} = \frac{\text{energy}}{\text{area}\cdot\text{time}} \end{aligned}$$

Poynting vector, intensity and energy density

$$\mathbf{S} = \frac{1}{\mu_0}\mathbf{E}\times\mathbf{B}$$

$$\begin{aligned}\mathbf{E}(t) &= E_m \sin(kx - \omega t)\hat{y},\\ \mathbf{B}(t) &= B_m \sin(kx - \omega t)\hat{z}.\end{aligned}$$

$$\frac{E_m}{B_m} = c$$

$$I = \overline{S} = \frac{1}{c\mu_0}\overline{E}^2$$

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

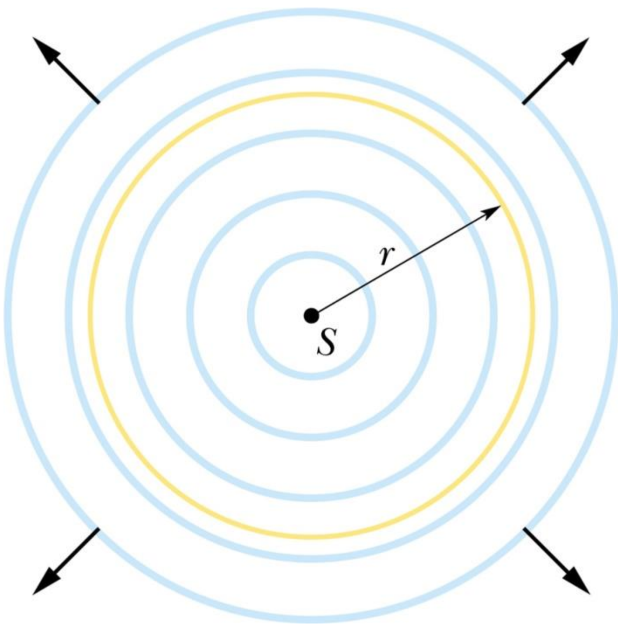
$$I = S_{\text{avg}} = \left(\frac{\text{energy/time}}{\text{area}}\right)_{\text{avg}} = \left(\frac{\text{power}}{\text{area}}\right)_{\text{avg}}.$$

$$I = S_{\text{avg}} = \frac{1}{c\mu_0}[E^2]_{\text{avg}} = \frac{1}{c\mu_0}[E_m^2 \sin^2(kx - \omega t)]_{\text{avg}}$$

$$E_{\text{rms}} = \frac{E_m}{\sqrt{2}}$$

$$I = \frac{1}{c\mu_0}E_{\text{rms}}^2$$

Change of intensity with distance



$$I = \frac{P_s}{4\pi r^2}$$

Linear momentum transfer of EM waves: radiation pressure

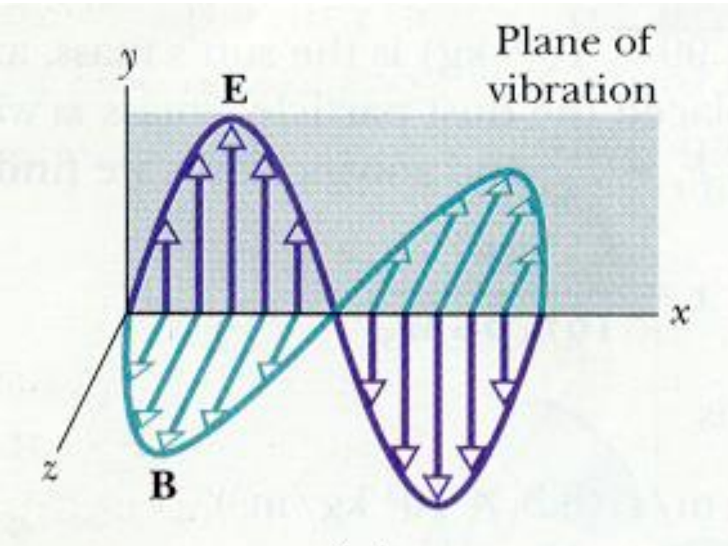
$$\Delta p = \frac{\Delta U}{c} \text{ 모두 흡수}$$

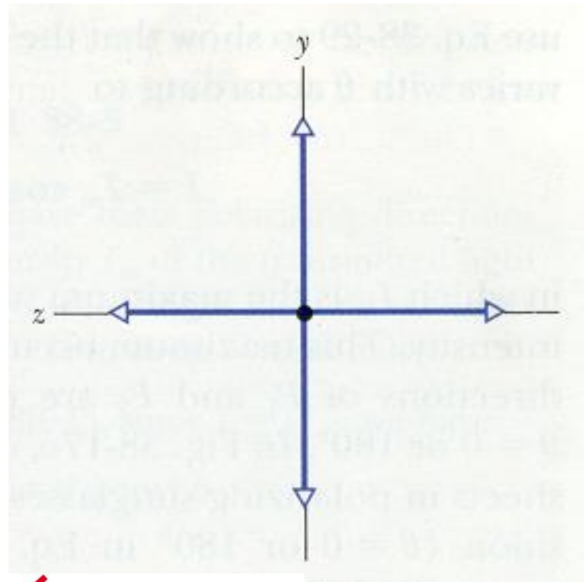
$$\Delta p = \frac{2\Delta U}{c} \text{ 모두 반사}$$

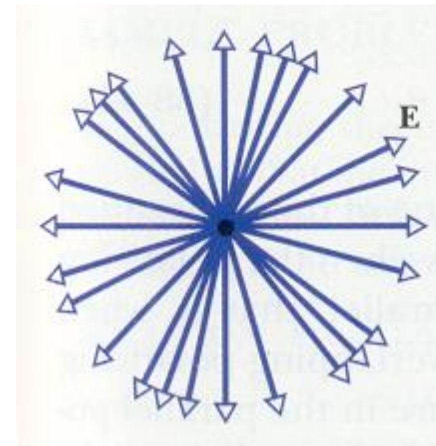
$$F = \frac{\Delta p}{\Delta t}, \quad \Delta U = IA\Delta t$$

$$F = \frac{IA}{c}, p_r = \frac{I}{c} \text{ 모두 흡수}, \quad F = \frac{2IA}{c}, p_r = \frac{2I}{c} \text{ 모두 반사.}$$

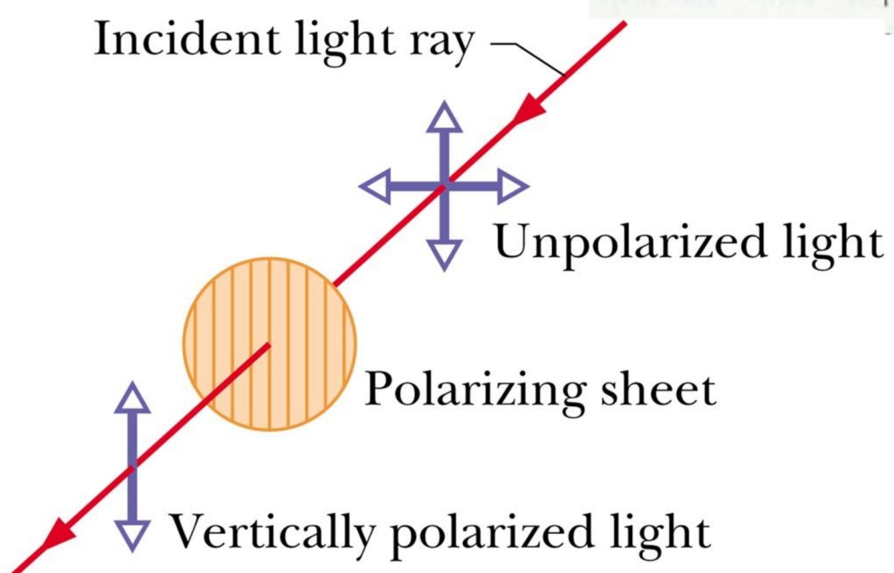
Polarization of EM waves

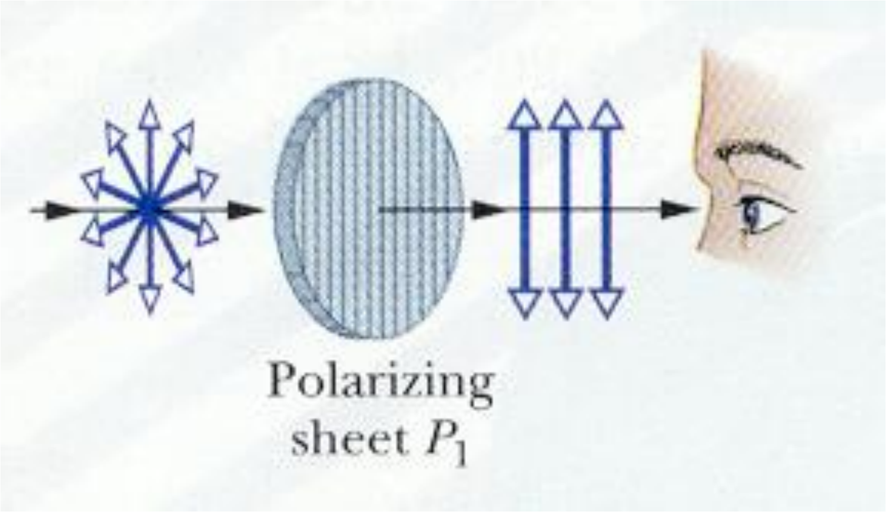


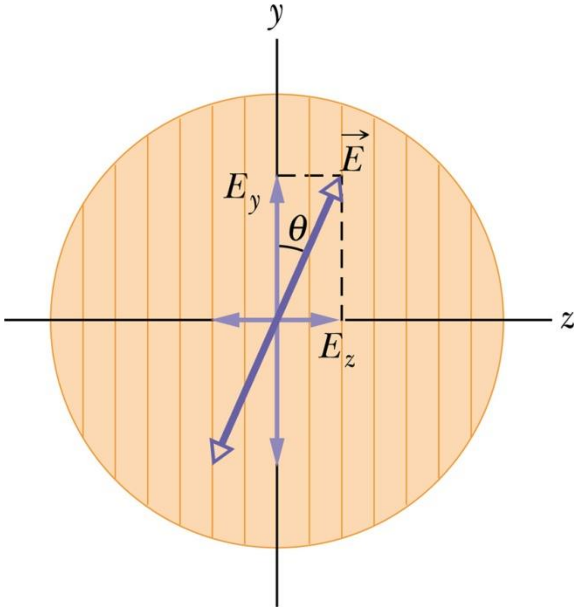




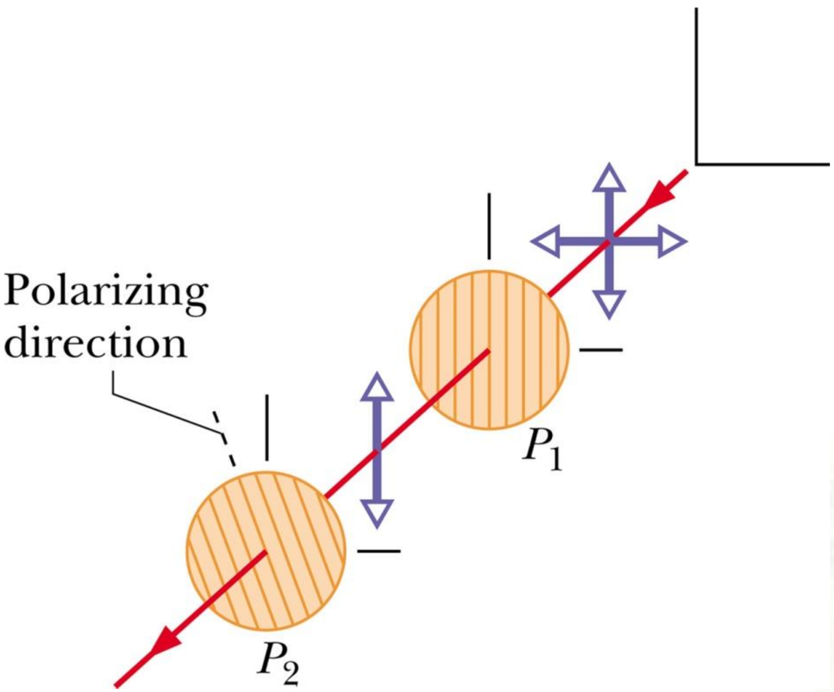
편광 안된 파동



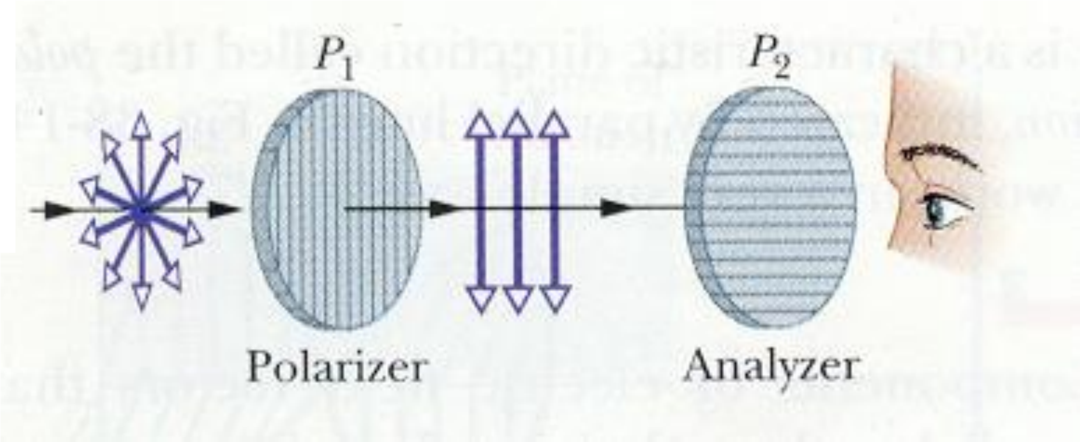




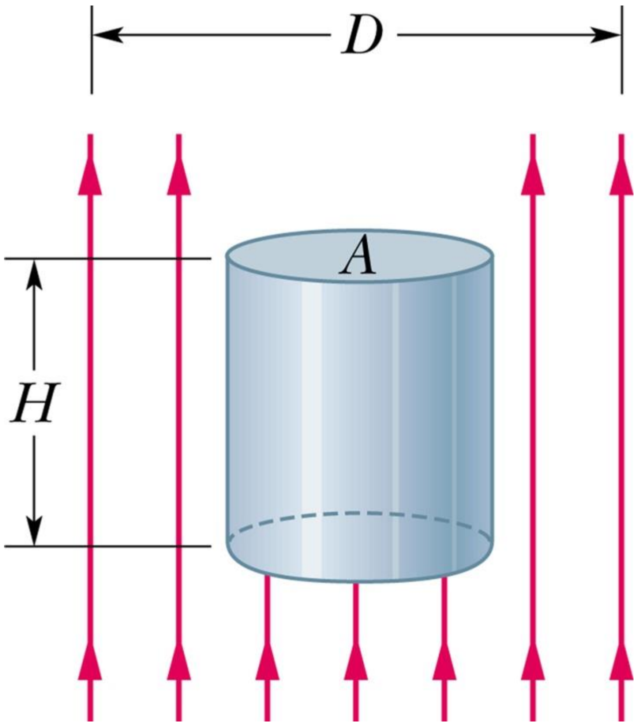
$$I \propto \left|\mathbf{E}^2\right|$$



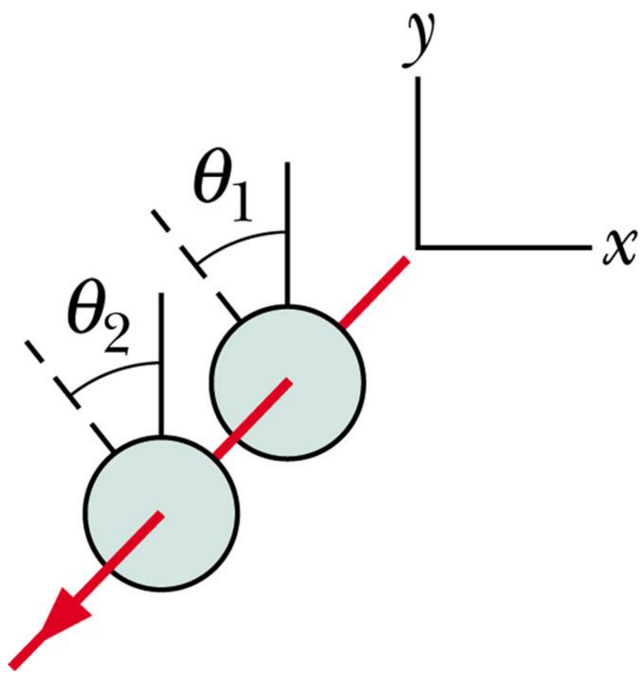
$$I = I_m \cos^2\theta$$



Problem 1

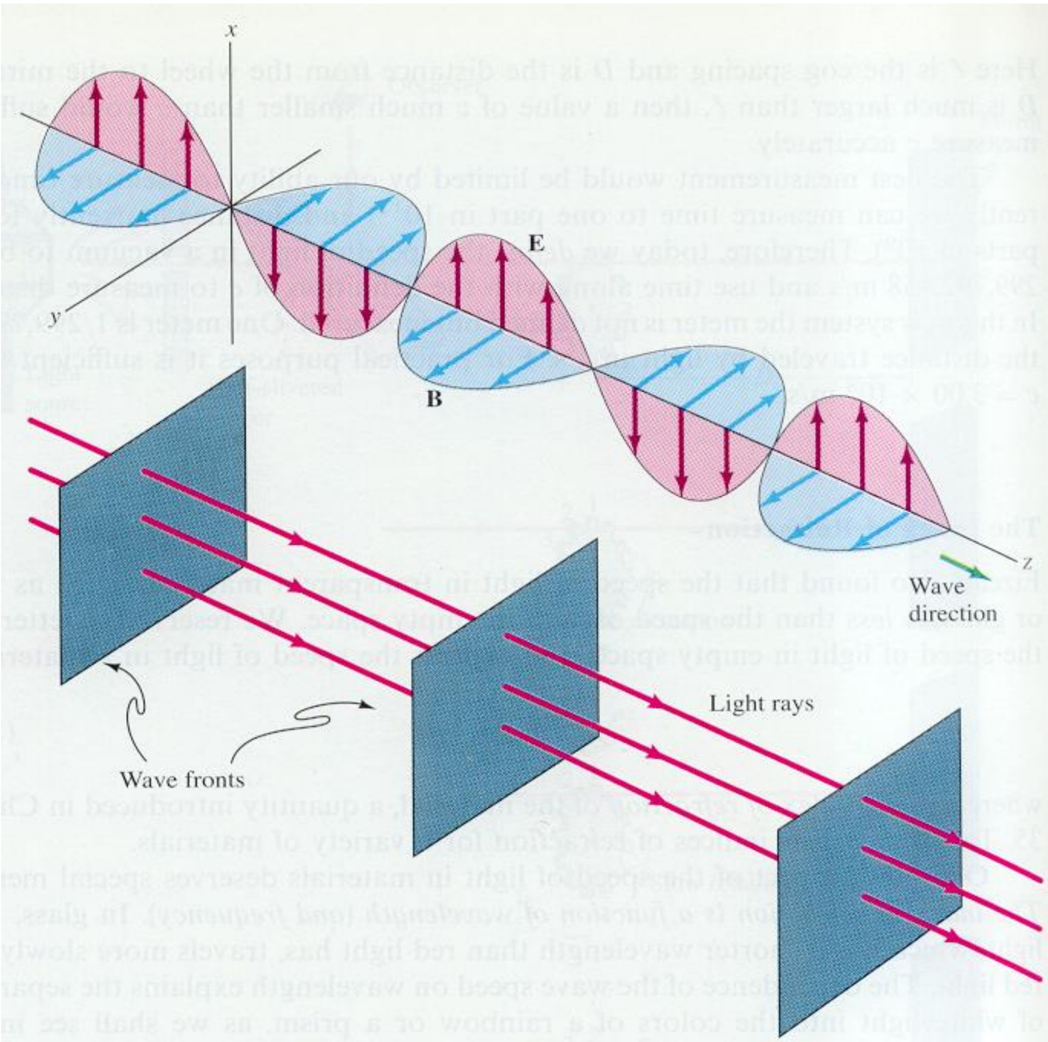


Problem 2



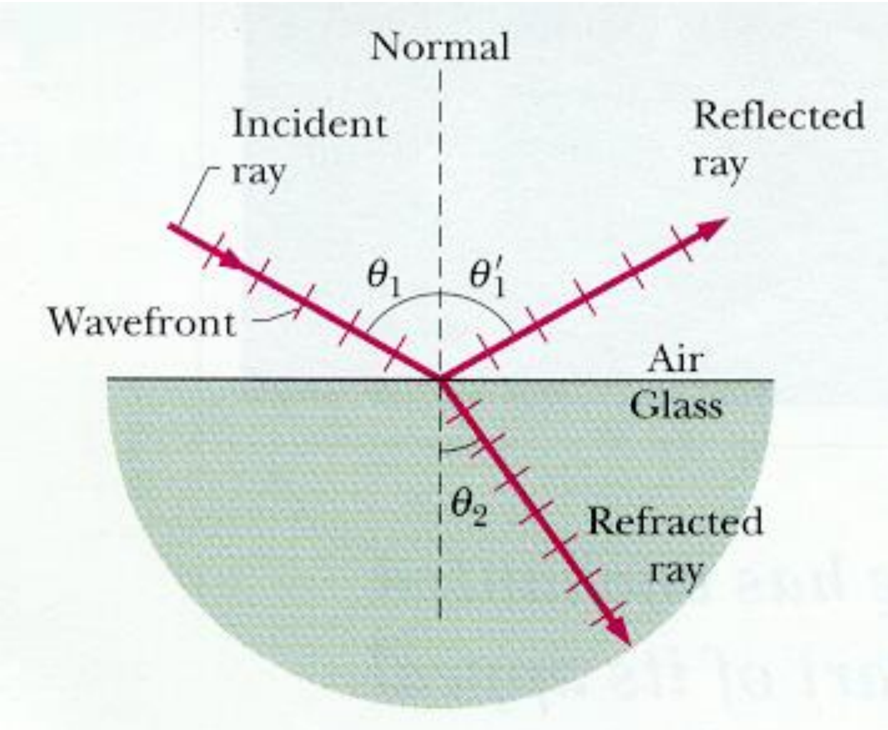
Chap. 34 Wave optics

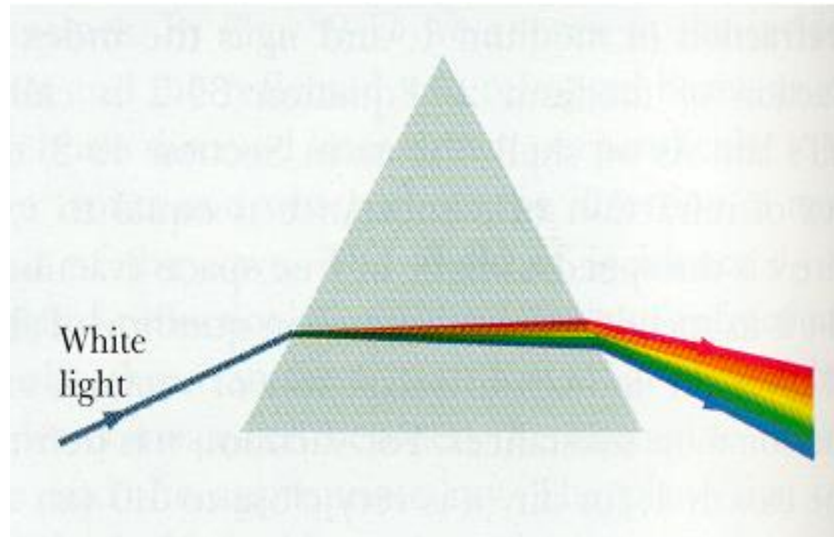
Geometric optics



$$\lambda << D$$

Reflection and refraction



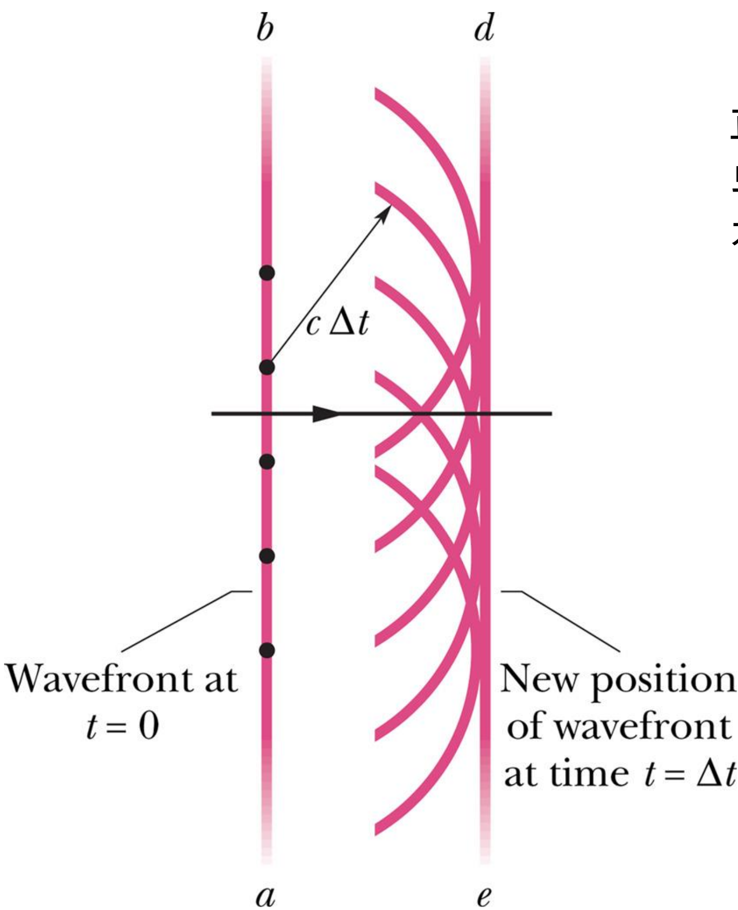


반사법칙 : $\theta_1 = \theta'_1$

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

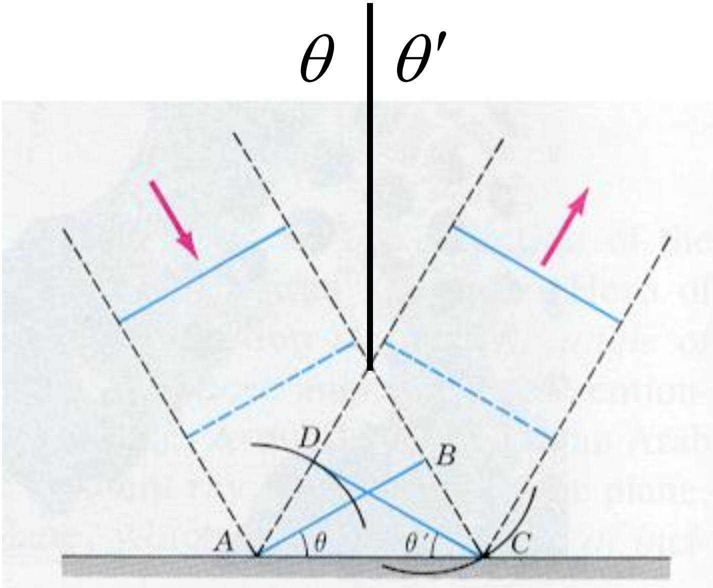
굴절률 : $n \equiv \dfrac{c}{v}$

Huygens's principle



파동면의 모든 점은 2차 구면파의 점샘이 된다. 시간 t 후의 파동면은 2차파동들의 접면이 된다.

Law of reflection

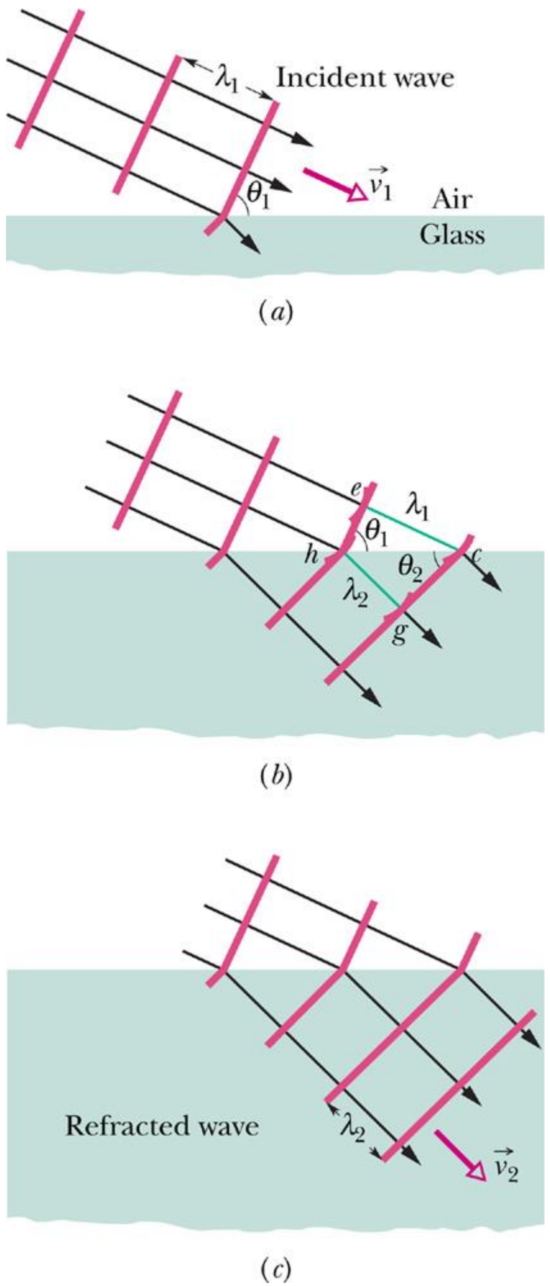


$$\Delta(ABC) = \Delta(ADC)$$

$$BC = AD$$

$$\angle D = \angle B = 90^{\circ}$$

$$\boxed{\theta = \theta'}$$



Snell's law

$$\frac{\lambda_1}{v_1} = \frac{\lambda_2}{v_2} \rightarrow \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2}$$

$$\sin\theta_1 = \frac{\lambda_1}{hc} \quad (\Delta hce)$$

$$\sin\theta_2 = \frac{\lambda_2}{hc} \quad (\Delta hcg)$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2}$$

Refractive index $n = \dfrac{c}{v}$ $\qquad n_1 = \dfrac{c}{v_1}, \quad n_2 = \dfrac{c}{v_2}$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{c/n_1}{c/n_2} = \frac{n_2}{n_1}$$

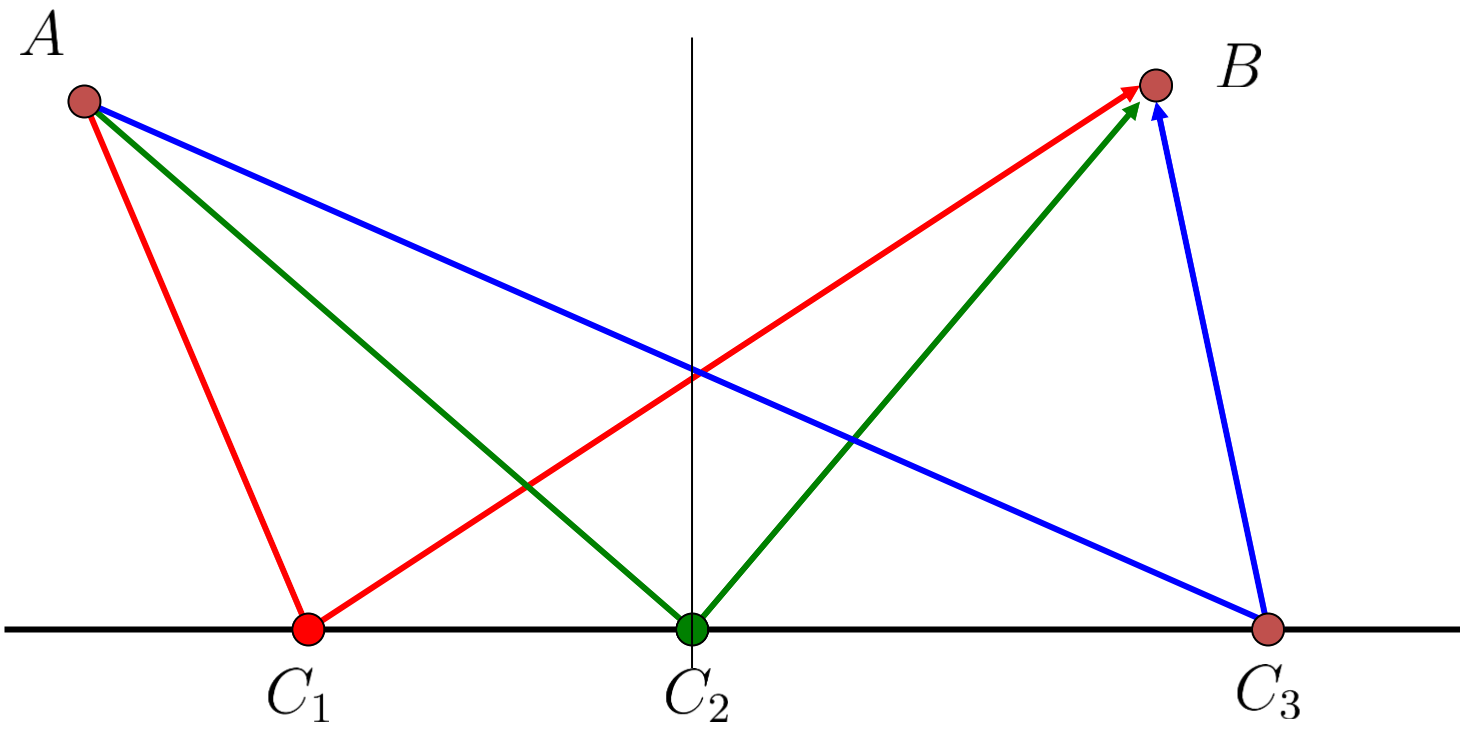
굴절법칙 $\quad n_1 \sin\theta_1 = n_2 \sin\theta_2$

Fermat's principle

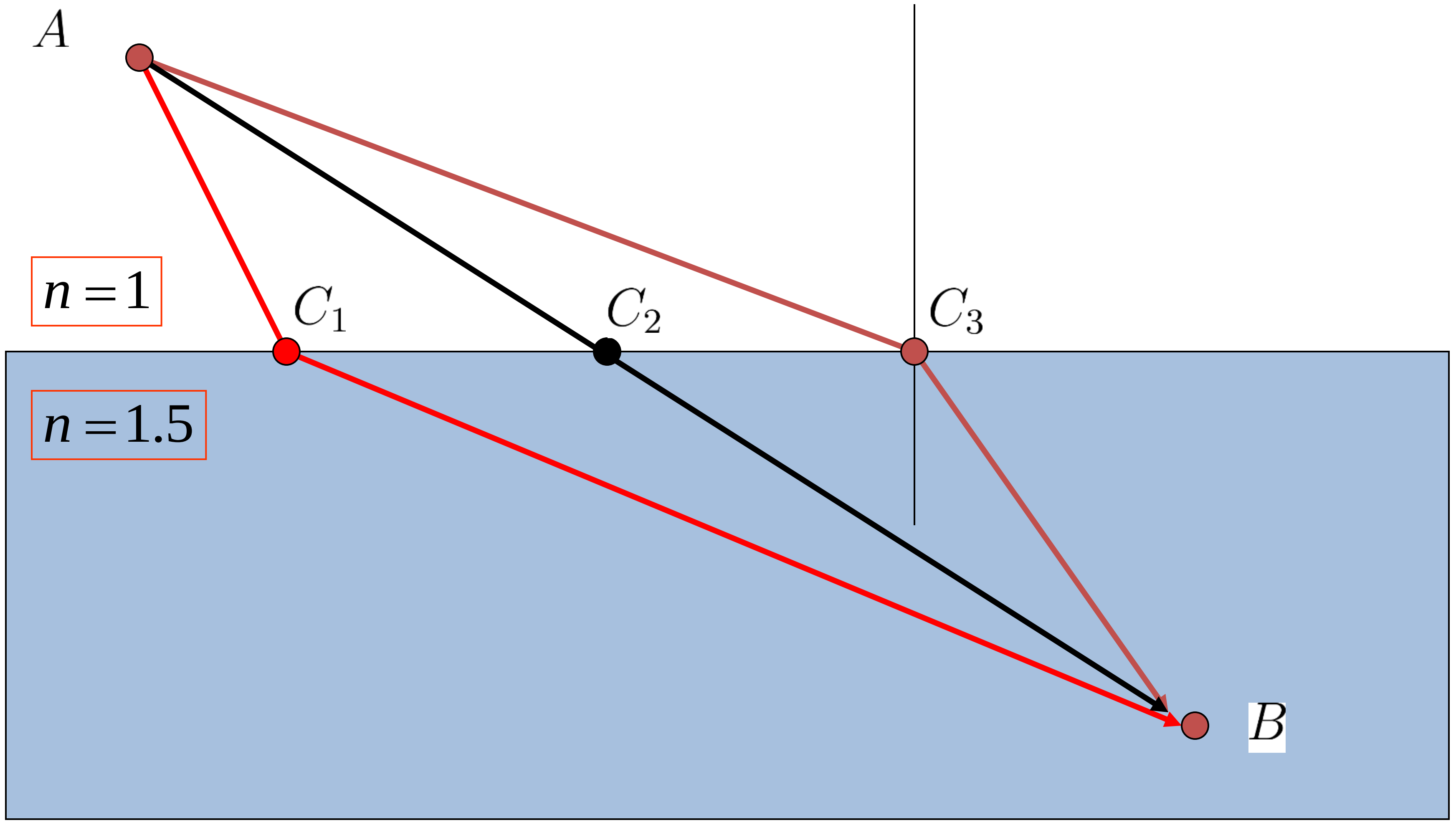
빛이 A 지점에서 B 지점으로 이동할 때에는 이동에 가장 짧은 시간이 걸리는 경로를 선택한다.

직진의 법칙

Law of reflection and Fermat's principle



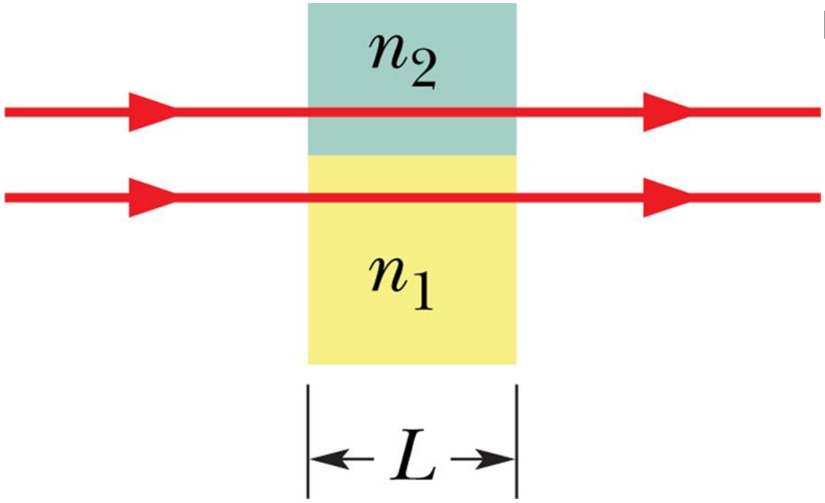
Snell's law and Fermat's principle



Wavelength and refractive index

wavelength $\lambda_n = \lambda \frac{v}{c} = \frac{\lambda}{n}$ frequency $f_n = \frac{v}{\lambda_n} = \frac{c/n}{\lambda/n} = \frac{c}{\lambda} = f$

Optical path difference and phase difference



매질 1에서 파장의 갯수 $N_1 = \frac{L}{\lambda_{n_1}} = \frac{Ln_1}{\lambda}$

매질 2에서 파장의 갯수 $N_2 = \frac{L}{\lambda_{n_2}} = \frac{Ln_2}{\lambda}$

$$N_2 - N_1 = \frac{L}{\lambda}(n_2 - n_1)$$