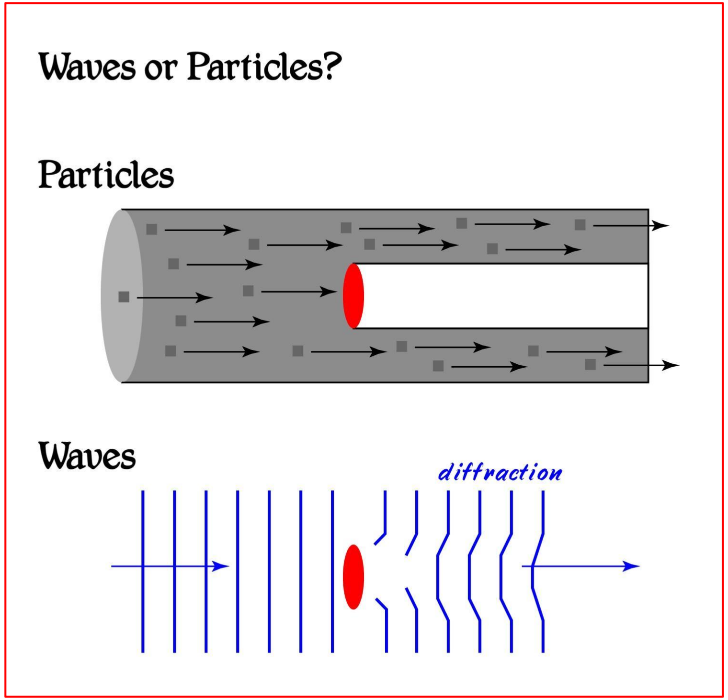
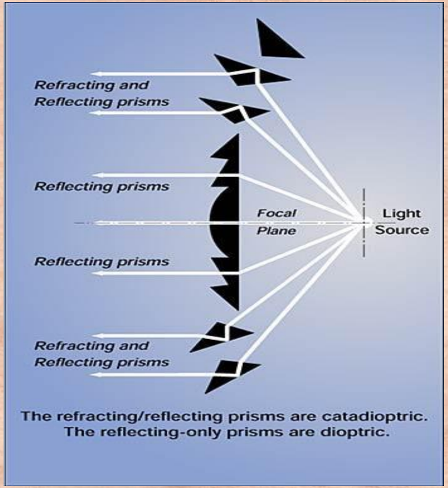
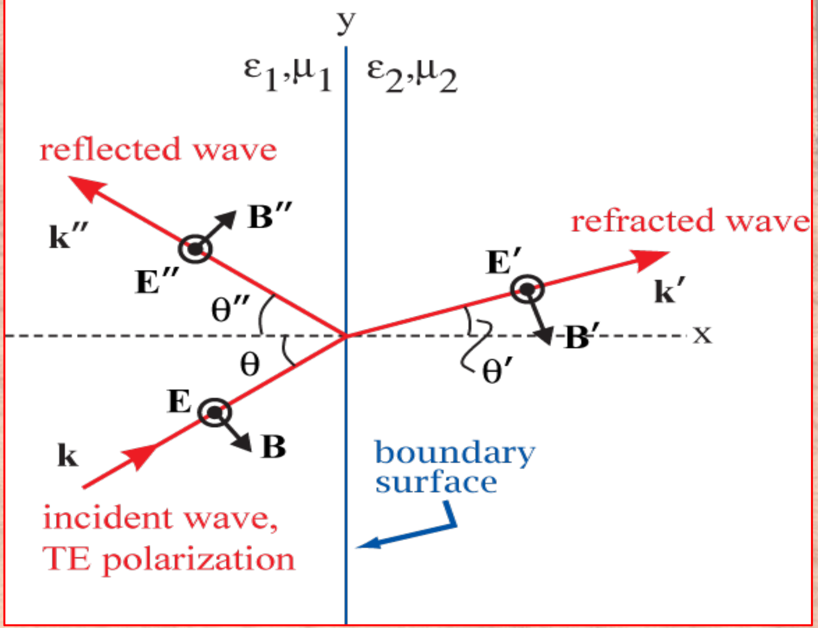


Particles: Newton
Waves: Huygens, Young, Fresnel



Augustin Fresnel (1788 – 1827)
-- mainly employed in civil engineering;
-- did research on optics in his spare time and vacations;
-- won the Grand Prix of the *Academie des Sciences* for 1819, which was awarded for the best work on diffraction ;
-- established the theory that light is a transverse wave;
-- invented the Fresnel lens for lighthouses.

Fresnel's Equations



Require the boundary conditions …

$$\epsilon_1 E_{1\perp} = \epsilon_2 E_{2\perp} \quad \text{and} \quad B_{1\perp} = B_{2\perp},$$

$$\mathbf{E}_{1\parallel} = \mathbf{E}_{2\parallel} \quad \text{and} \quad \mathbf{B}_{1\parallel}/\mu_1 = \mathbf{B}_{2\parallel}/\mu_2,$$

… to determine the ***intensities***.

Case 1: Transverse Electric **(TE)** polarization

"TE" means $\mathbf{E} \perp \mathbf{n}$

$D_\perp$: $0 = 0$ 13.2/4

$E_\parallel$: $E_0 + E_0'' = E_0'$

$B_\perp$: $B_{0x} + B_{0x}'' = B_{0x}'$

$$\frac{E_0}{v_1}\sin\theta + \frac{E_0''}{v_1}\sin\theta'' = \frac{E_0'}{v_2}\sin\theta'$$

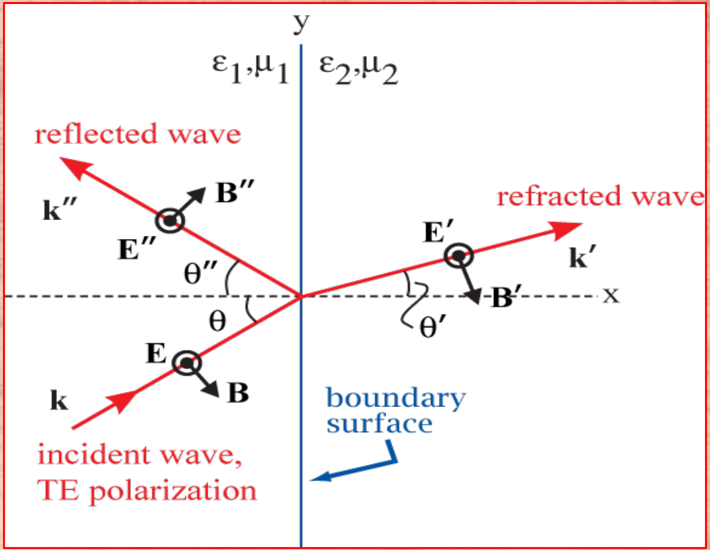
$$(E_0 + E_0'')\, n_1 \sin\theta = (E_0')\, n_2 \sin\theta'$$

Same as $E_\parallel$ above by Snell's law.

$H_\parallel$: $\frac{B_{0y}}{\mu_1} + \frac{B_{0y}''}{\mu_1} = \frac{B_{0y}'}{\mu_2}$

$$\frac{-E_0}{\mu_1 v_1}\cos\theta + \frac{E_0''}{\mu_1 v_1}\cos\theta'' = -\frac{E_0'}{\mu_2 v_2}\cos\theta'$$

Algebra problem to solve for E_0'/E_0 and E_0''/E_0.



TE polarization

$n1 = 1 ; n2 = 1.5$

Transmitted wave 13.2/5

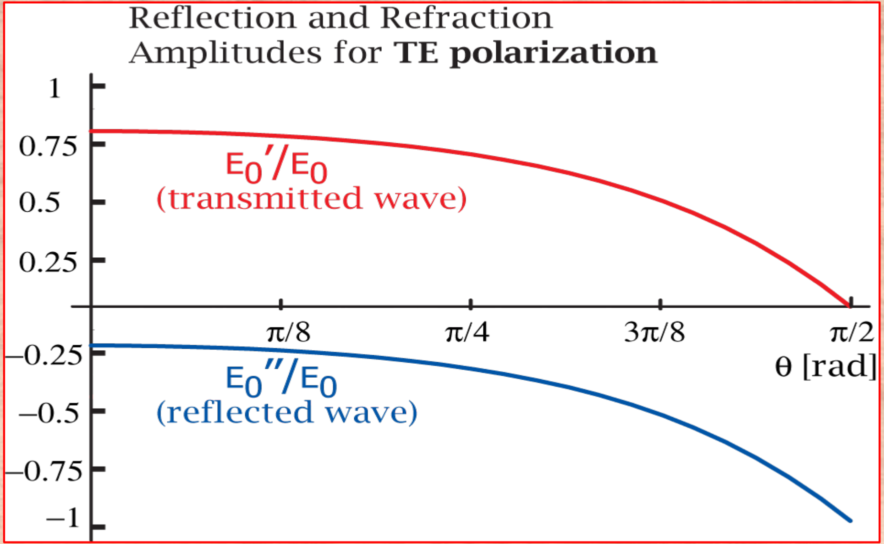
$$\frac{E_0'}{E_0} = \frac{2\mu_2 n_1 \cos\theta}{\mu_2 n_1 \cos\theta + \mu_1 n_2 \cos\theta'} \approx \frac{2 n_1 \cos\theta}{n_1 \cos\theta + n_2 \cos\theta'}$$

Reflected wave

$$\frac{E_0''}{E_0} = \frac{\mu_2 n_1 \cos\theta - \mu_1 n_2 \cos\theta'}{\mu_2 n_1 \cos\theta + \mu_1 n_2 \cos\theta'} \approx \frac{n_1 \cos\theta - n_2 \cos\theta'}{n_1 \cos\theta + n_2 \cos\theta'}$$

and don't forget, $n_1 \sin\theta = n_2 \sin\theta'$.

E_0'' is negative;
i.e., exists a 180 degree phase change upon reflection in this case.



Special cases (TE) 13.2/5

- normal incidence : $\theta = 0$ and $\theta' = 0$

$$\frac{E_0'}{E_0} = \frac{2n_1}{n_1 + n_2} \quad \text{and} \quad \frac{E_0''}{E_0} = \frac{n_1 - n_2}{n_1 + n_2}$$

$(n_1, n_2) = (1, 1.5) = (\text{air}, \text{glass})$

$$\frac{E_0'}{E_0} = 0.80 \quad \text{and} \quad \frac{E_0''}{E_0} = \frac{n_1 - n_2}{n_1 + n_2} = -0.20$$

- grazing incidence : $\theta = \pi/2$

$\theta' = \arcsin(n_1/n_2)$

$$\frac{E_0'}{E_0} = 0 \quad \text{and} \quad \frac{E_0''}{E_0} = -1.$$

100% reflection

Case 2: Transverse Magnetic (**TM**) polarization

"TM" means $\mathbf{B} \perp \mathbf{n}$

TM polarization   13.2/6

$B_\perp$: $0 = 0$

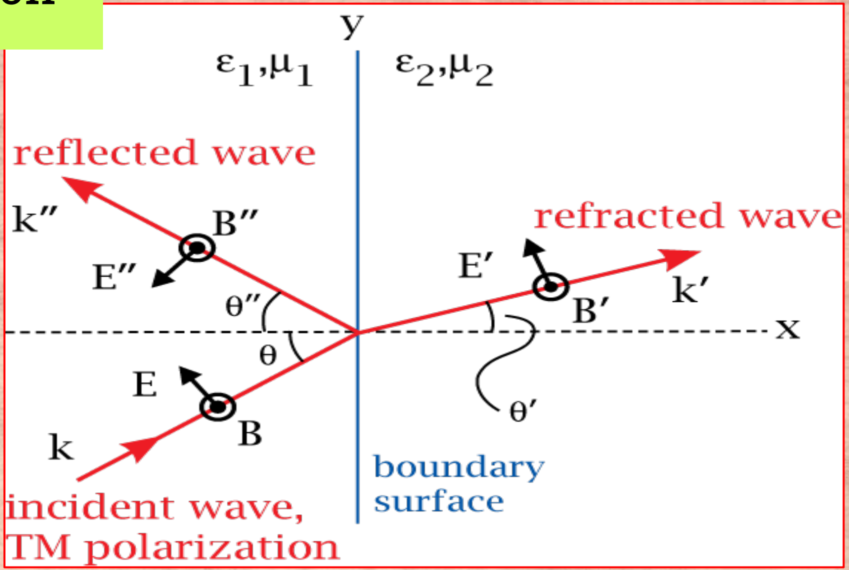
$H_\parallel$: $\dfrac{B_0}{\mu_1} + \dfrac{B_0''}{\mu_1} = \dfrac{B_0'}{\mu_2}$ $B_0 = \dfrac{E_0}{v_1}$, etc.

$E_\perp$: $E_0 \cos\theta - E_0'' \cos\theta'' = E_0' \cos\theta'$

D_n : $-\epsilon_1 E_0 \sin\theta - \epsilon_1 E_0'' \sin\theta'' = -\epsilon_2 E_0' \sin\theta'$

Algebra problem — solve for E_0' and E_0''.

Exercise: Eqs. 2 and 4 are equivalent.



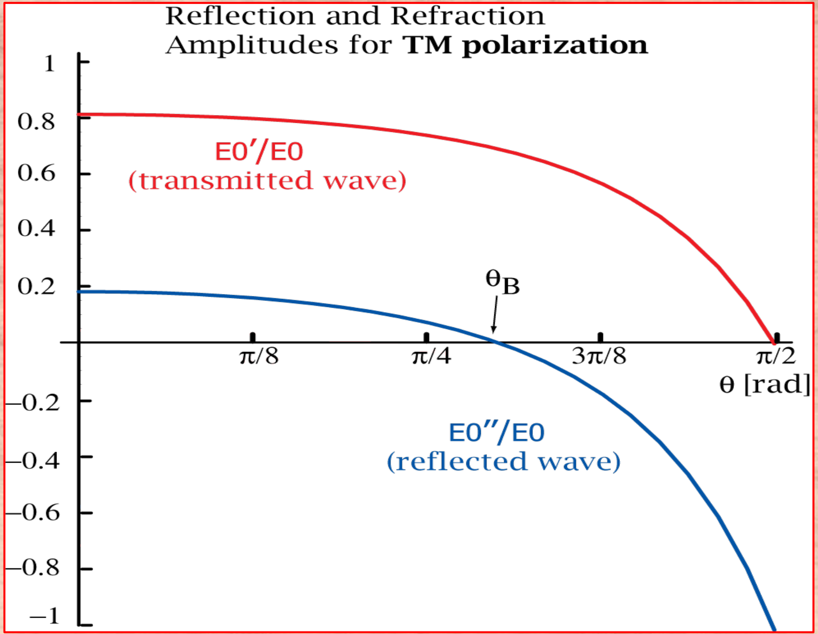
Transmitted wave 13.2/7

$$\frac{E_0'}{E_0} = \frac{2\mu_2 n_1 \cos\theta}{\mu_2 n_1 \cos\theta' + \mu_1 n_2 \cos\theta} \approx \frac{2 n_1 \cos\theta}{n_1 \cos\theta' + n_2 \cos\theta}$$

Reflected wave

$$\frac{E_0''}{E_0} = \frac{\mu_1 n_2 \cos\theta - \mu_2 n_1 \cos\theta'}{\mu_2 n_1 \cos\theta' + \mu_1 n_2 \cos\theta} \approx \frac{n_2 \cos\theta - n_1 \cos\theta'}{n_1 \cos\theta' + n_2 \cos\theta}$$

remember : $n_1 \sin\theta = n_2 \sin\theta'$!



Special cases (TM) 13.2/7

- normal incidence : $\theta = 0$ and $\theta' = 0$

$$\frac{E_0'}{E_0} = \frac{2n_1}{n_1 + n_2} \quad \text{and} \quad \frac{E_0''}{E_0} = \frac{n_2 - n_1}{n_1 + n_2}$$

0.8 0.2

n_1	n_2
1	1.5

- grazing incidence : $\theta = \frac{\pi}{2}$

$$\theta' = \arcsin\left(\frac{n_1}{n_2}\right)$$

$$\frac{E_0'}{E_0} = 0 \quad \text{and} \quad \frac{E_0''}{E_0} = -1.$$

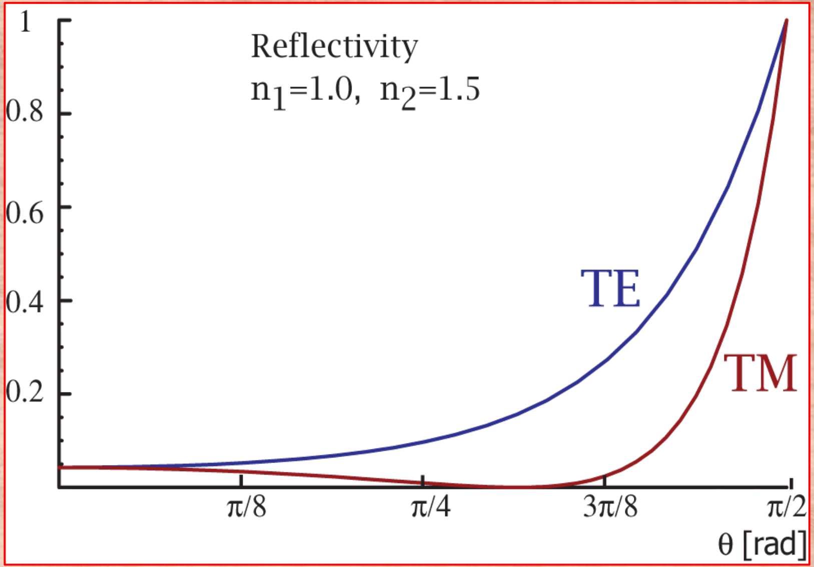
13.7/8

Reflectivity $R = \dfrac{\epsilon_1 \frac{E_0''^2}{2} v_1}{\epsilon_1 \frac{E_0^2}{2} v_1} = \dfrac{(E_0'')^2}{(E_0)^2}$

$R = \dfrac{\text{reflected intensity}}{\text{incident intensity}}$

= the fraction of incident light energy that gets reflected

$R(\theta)$



Brewster's Angle 13.7/8

For TM polarization, $R(\theta_B) = 0$.

$n_2 \cos\theta = n_1 \cos\theta'$ and $n_1 \sin\theta = n_2 \sin\theta'$ (Snell's law)

$\dfrac{\cos\theta}{\cos\theta'} = \dfrac{n_1}{n_2} = \dfrac{\sin\theta'}{\sin\theta}$

$\sin 2\theta = \sin 2\theta' \Rightarrow \begin{cases} \text{either } \theta' = 0 & \text{(NO)} \\ \text{or } \theta' = \frac{\pi}{2} - \theta & \text{(YES)} \end{cases}$

Brewster's Angle : $\theta + \theta' = \pi/2$

$n_1 \sin\theta = n_2 \cos\theta \Longrightarrow \boxed{\tan\theta_B = \frac{n_2}{n_1}}$

air (n_1) & glass (n_2) : $\theta_B = \arctan 1.5 = 56.3$ degrees

The reflected light from a dielectric surface is partially polarized (T E > T M); at Brewster's angle, it is 100% polarized (T M = 0).

That's why fishermen wear polarized sunglasses.

Sir David Brewster (1781 – 1868)

-- a professor in Scotland
-- studied light and optics
-- invented and developed many optical instruments
-- most famous invention — the kaleidoscope
-- most famous discovery — reflected light is partially or fully polarized (Brewster's angle)

It was said of him that "nobody ever had dealings with him and escaped a quarrel." He became one of the last and most contentious opponents of the wave theory of light, leading the final struggles in the 1850's.