PURDUE UNIVERSITY DEPARTMENT OF PHYSICS

Physics 24100

Electricity & Optics

Lecture 23 – Chapter 31 sec. 2,5

Fall 2012 Semester

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Clicker Question

- The intensity of sunlight at the distance of Earth's orbit is about 1.4 kW/m^2.
- The orbit of Mars is roughly twice the distance from the sun as Earth's orbit.
- With what intensity does sunlight arrive on the surface of Mars?

(a) 1.4 kW/m^2
(b) 2.8 kW/m^2
(c) 0.70 kW/m^2
(d) 0.35 kW/m^2
(e) Not enough information

Clicker Question

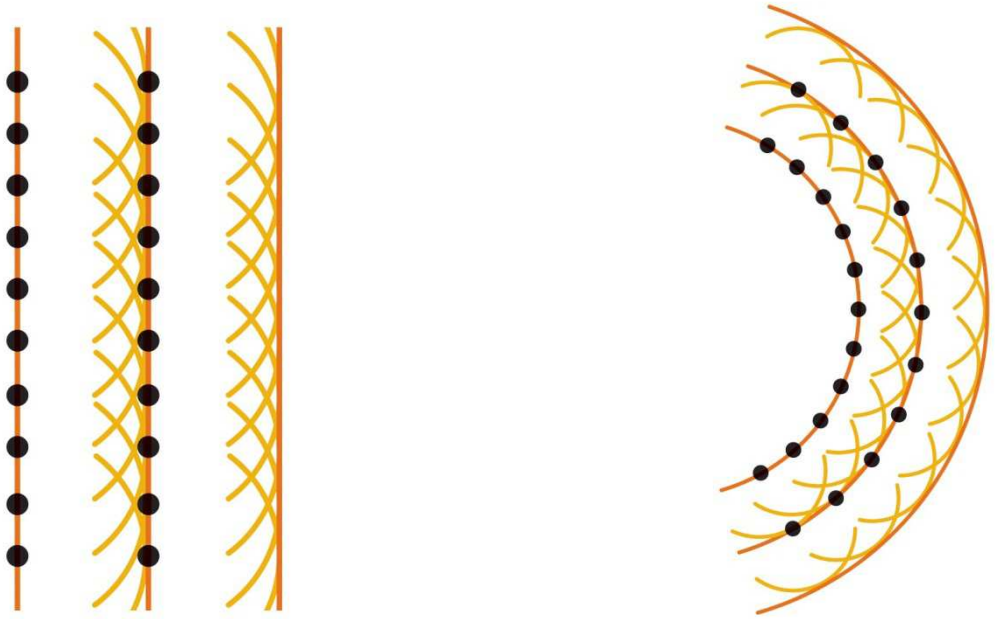
- Light intensity from a point source:

$$I(r) = \frac{P}{4\pi r^2}$$

- Mars is approximately twice as far from the sun as Earth so the intensity of light at its surface is 1/4 what it is on Earth:
  $(7\ kW/m^2)/4 = 0.35\ kW/m^2$
- Actually, Mars is about 1.5 times as far away but this varies by 20% because of its elliptical orbit.

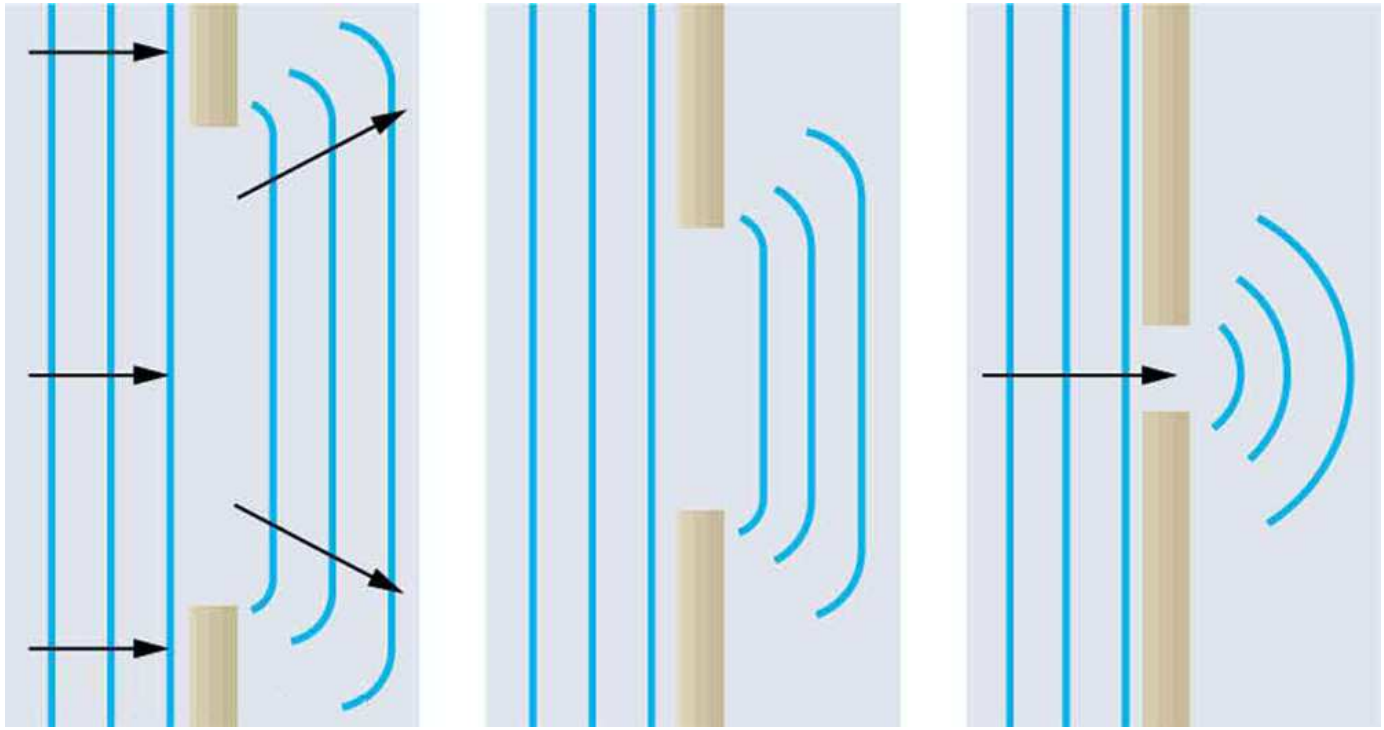
Propagation in Transparent Media

- Huygen's Principle: Light is continuously re-emitted in all directions from all points on a wave front
  - Further developed by Fresnel and Kirchhoff
  - Destructive interference except in the forward direction



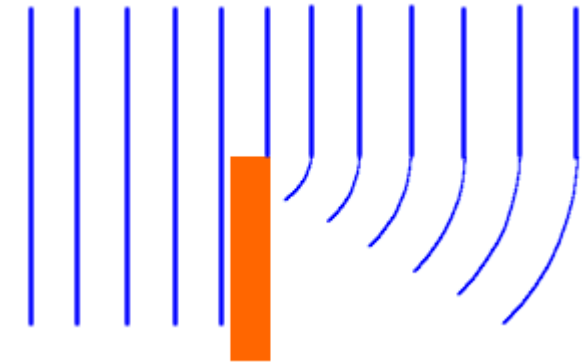
Propagation in Transparent Media

- Can you observe Huygen's wavelets?

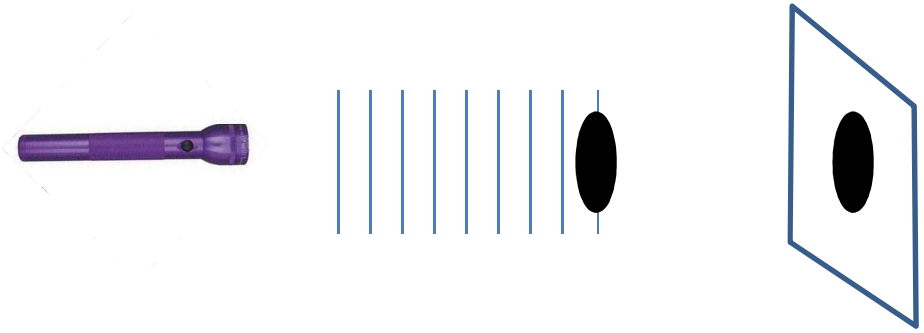


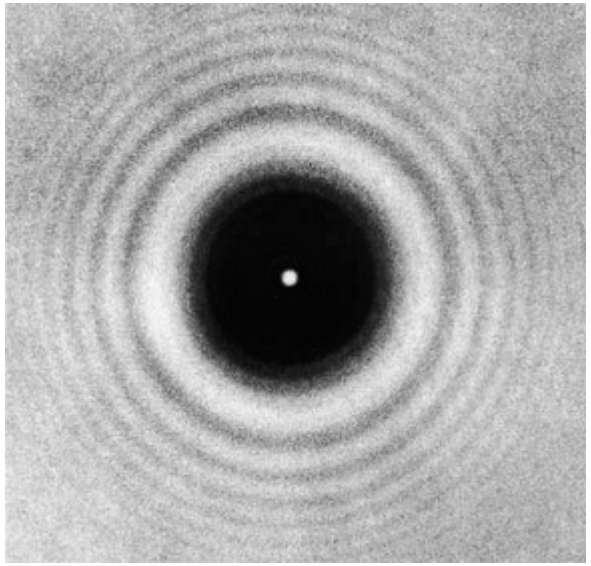
Propagation in Transparent Media

- Light will “bend” around obstacles:



Easier to observe with coherent light
(like from a laser)





Propagation Of Light

- Speed of light in vacuum:

$$c = 2.998 \times 10^8 \ m/s$$

- In transparent materials, the speed of light is slower…
- The "index of refraction" is the ratio:

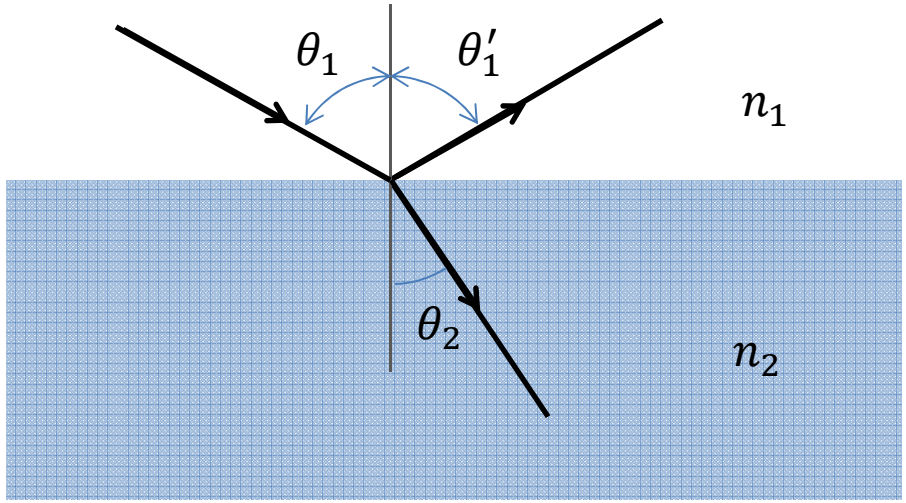
$$n = \frac{c}{v}$$

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

medium	index of refraction *n*
vacuum	exactly 1
air (STP)	1.00029
H_2O (20^0 C)	1.33
crown glass	1.52
diamond	2.42

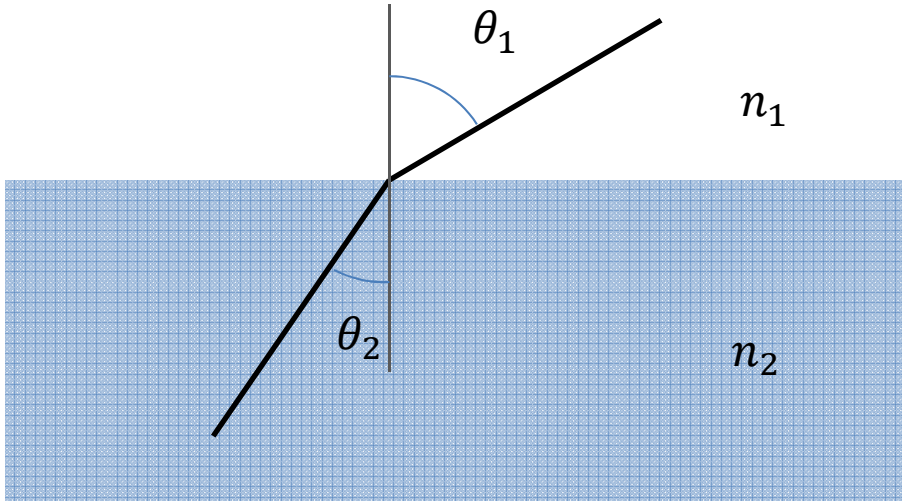
Geometric Optics

- When the wavelength is much smaller than the size of any objects with which it interacts.
- Two effects:
  - Reflection from a surface $\theta_1' = \theta_1$
  - Refraction through an interface between two materials



Propagation in Transparent Media

- Fermat's principle: *light travels between two points such that the time of travel is a minimum*.
  - Does not refer to the wave nature of light
- Two points in the same media: straight line
- Two points in different media: not a straight line

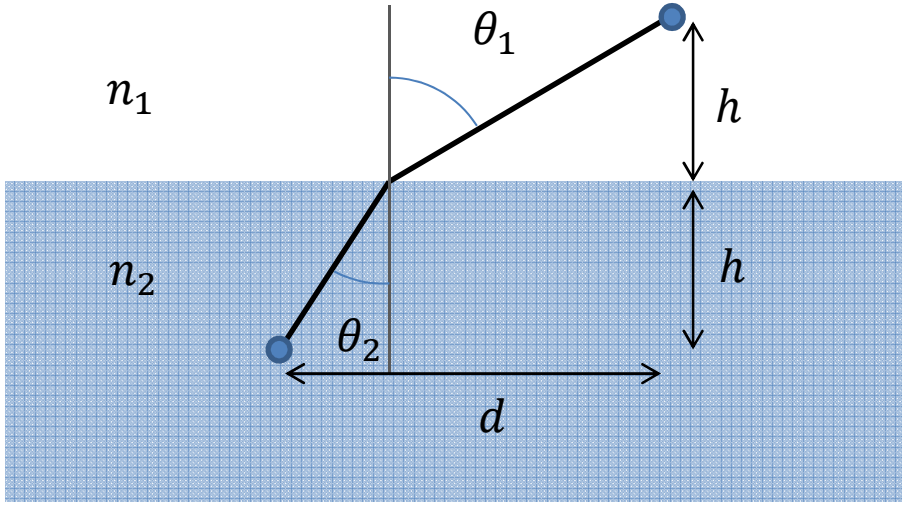


$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

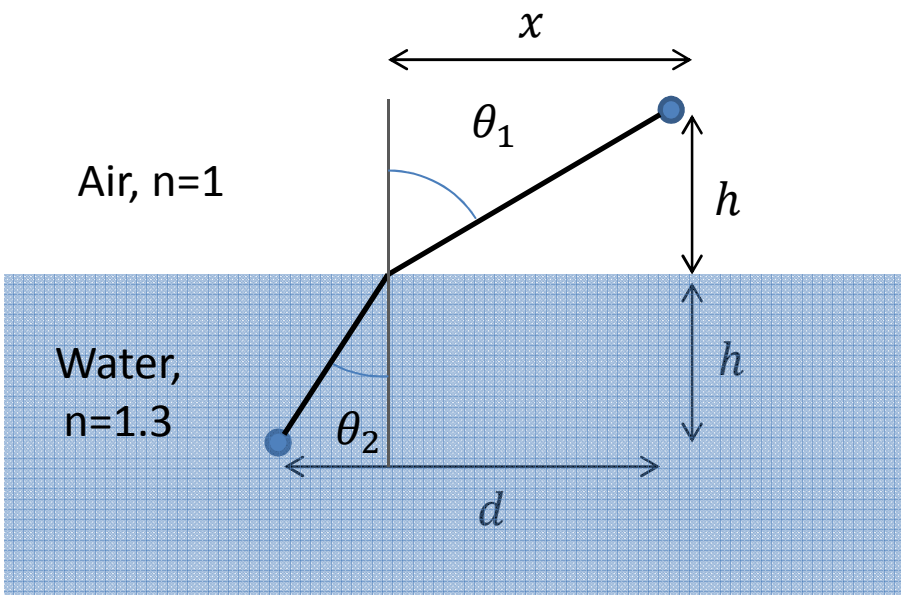
(Snell's Law)

Propagation in Transparent Media

- Example: Suppose $n_1=1$ and $n_2=1.3$ (eg, water) and $h=1\ m$ and $d = 2\ m$… does Snell's law really give the shortest time?

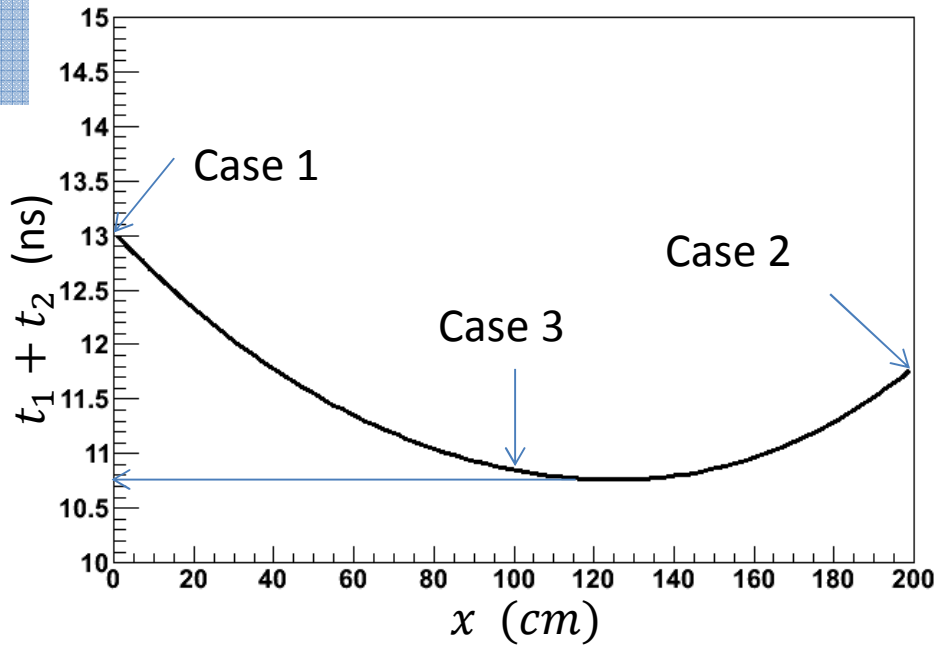


Propagation in Transparent Media



$$t_1 = \frac{d_1}{c} = \frac{\sqrt{x^2 + h^2}}{c}$$

$$t_2 = \frac{n\, d_2}{c} = \frac{n\sqrt{(d-x)^2 + h^2}}{c}$$



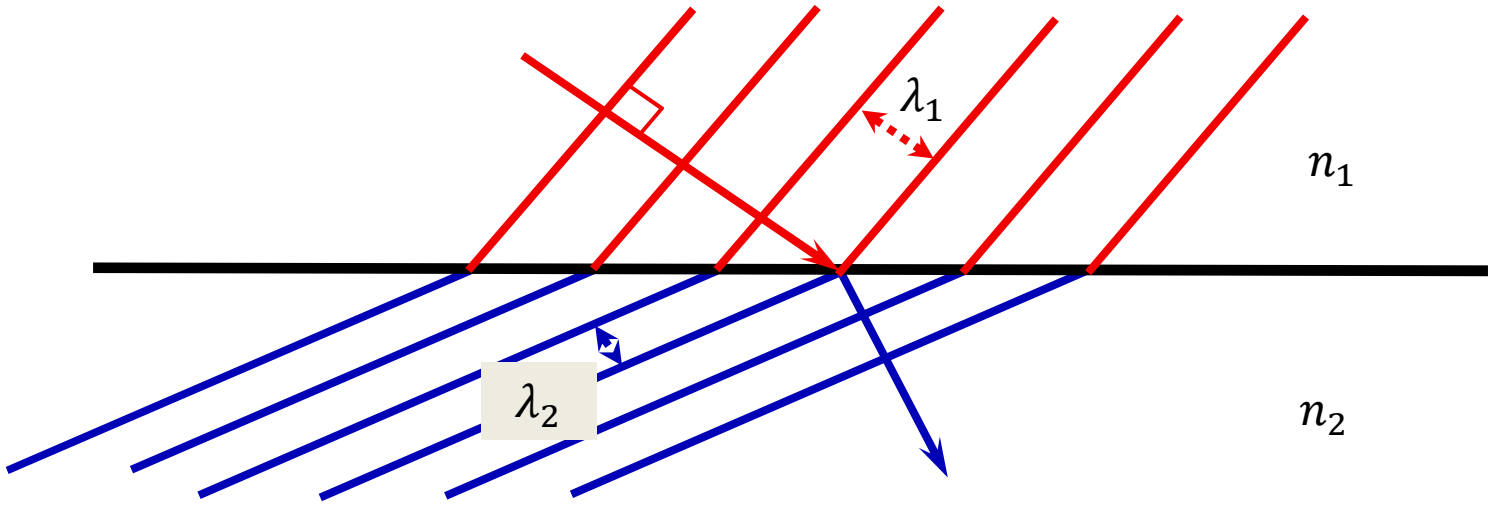
T_{min}=10.76 ns

Propagation in Transparent Media

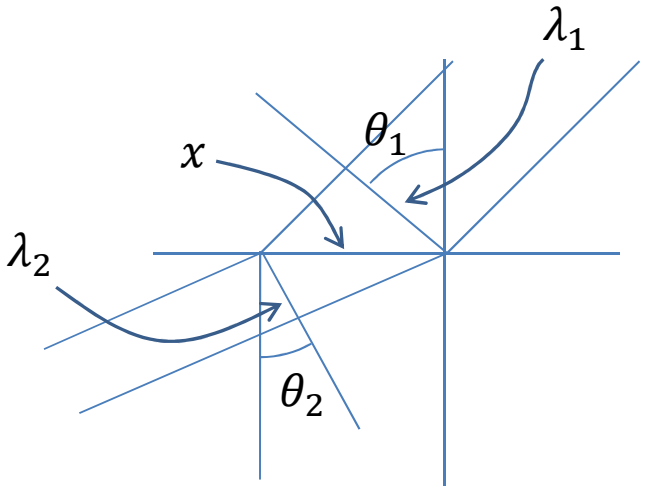
- The speed changes in different media, but the frequency remains the same
  - Wavelength is shorter in the “slow” medium:

$$\lambda = \frac{v}{f} = \frac{c}{nf}$$

- The phases must be constant everywhere on a wave front:



Propagation in Transparent Media



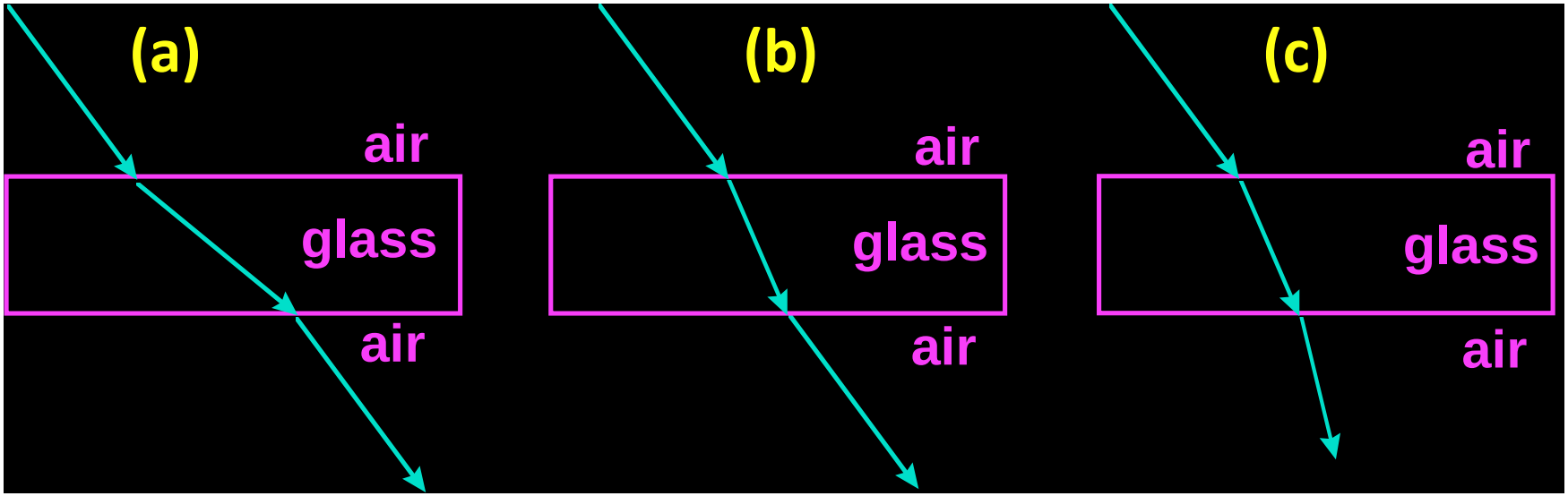
$$x\cos(90^o - \theta_1) = x\sin\theta_1 = \lambda_1$$
$$x\cos(90^o - \theta_2) = x\sin\theta_2 = \lambda_2$$
$$x = \frac{\lambda_1}{\sin\theta_1} = \frac{\lambda_2}{\sin\theta_2}$$
$$\lambda = \frac{c}{nf}$$
$$\frac{c}{f}\frac{1}{n_1\sin\theta_1} = \frac{c}{f}\frac{1}{n_2\sin\theta_2}$$

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

- When light enters a medium with a larger index of refraction, it bends towards the direction that is normal to the surface.

Question

- Which of the following ray diagrams could represent the passage of light from air through glass and back to air? (n_{air}=1 and n_{glass}=1.5)



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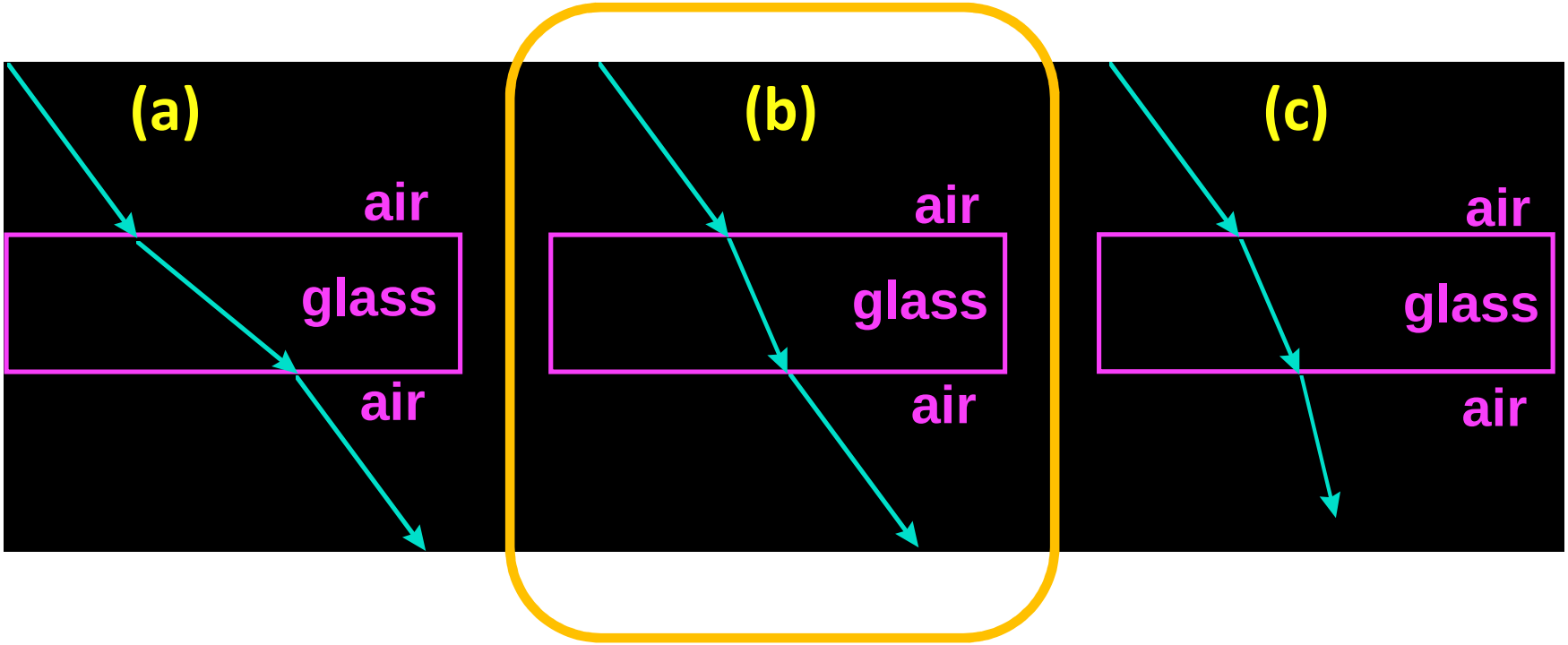
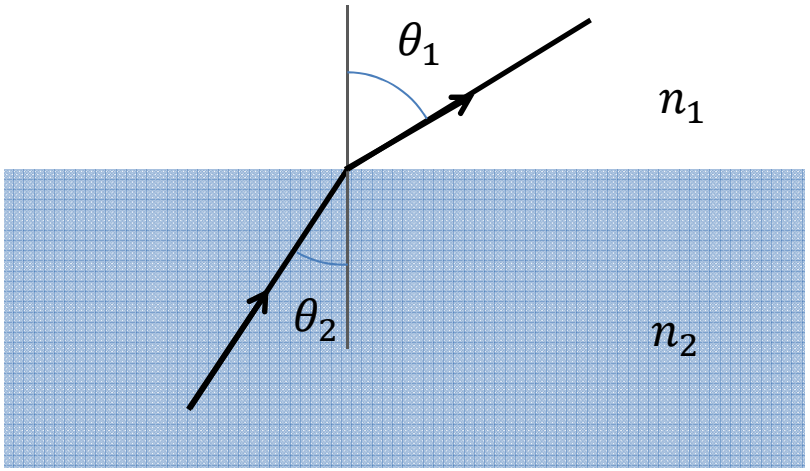
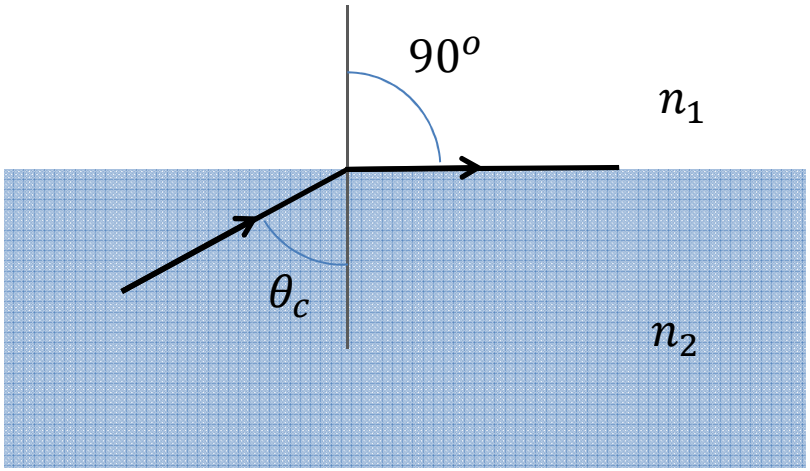
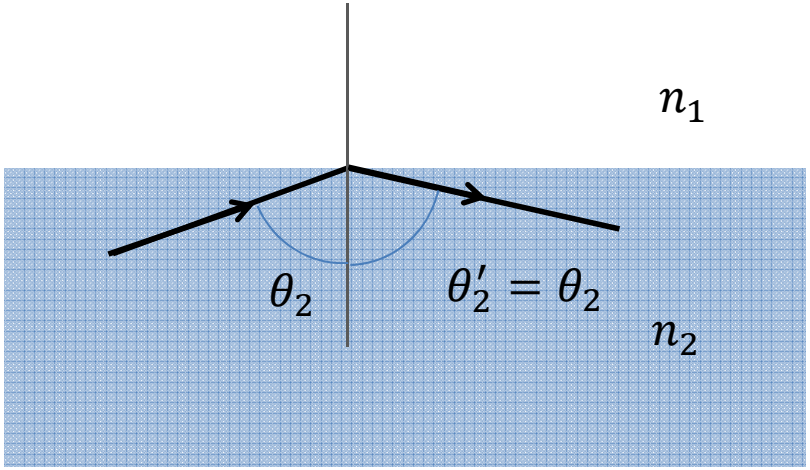


Total Internal Reflection





- What happens when $\theta_1 \geq 90^o$?

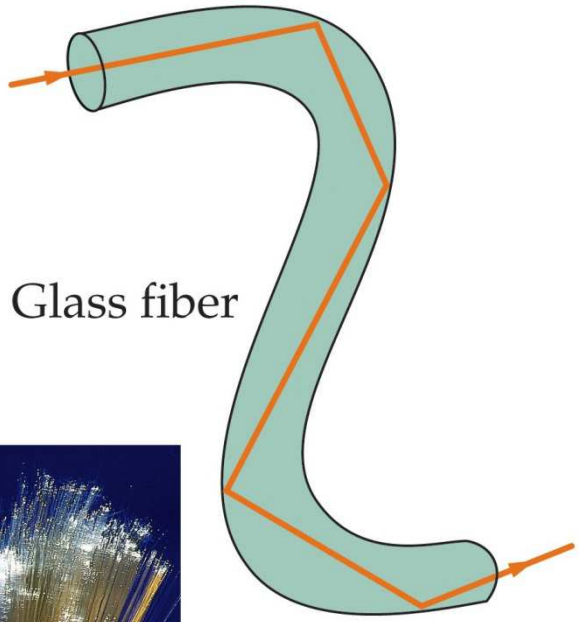


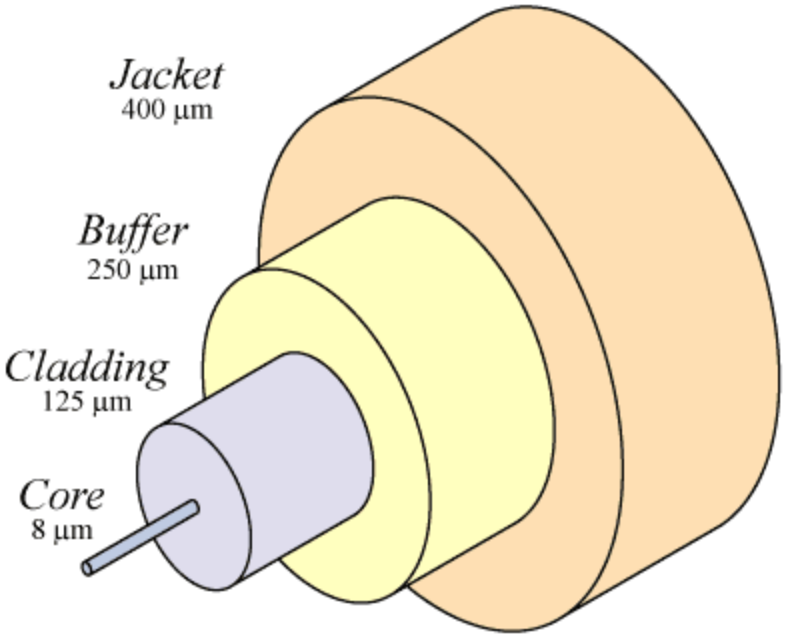
Critical angle:

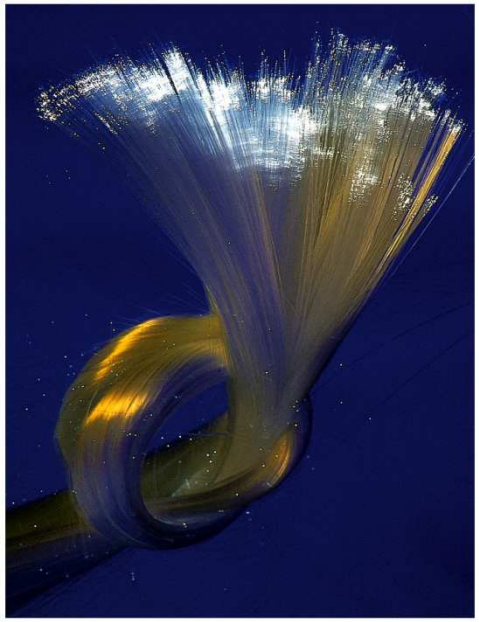
$$n_2 \sin\theta_c = n_1$$

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

Total Internal Reflection



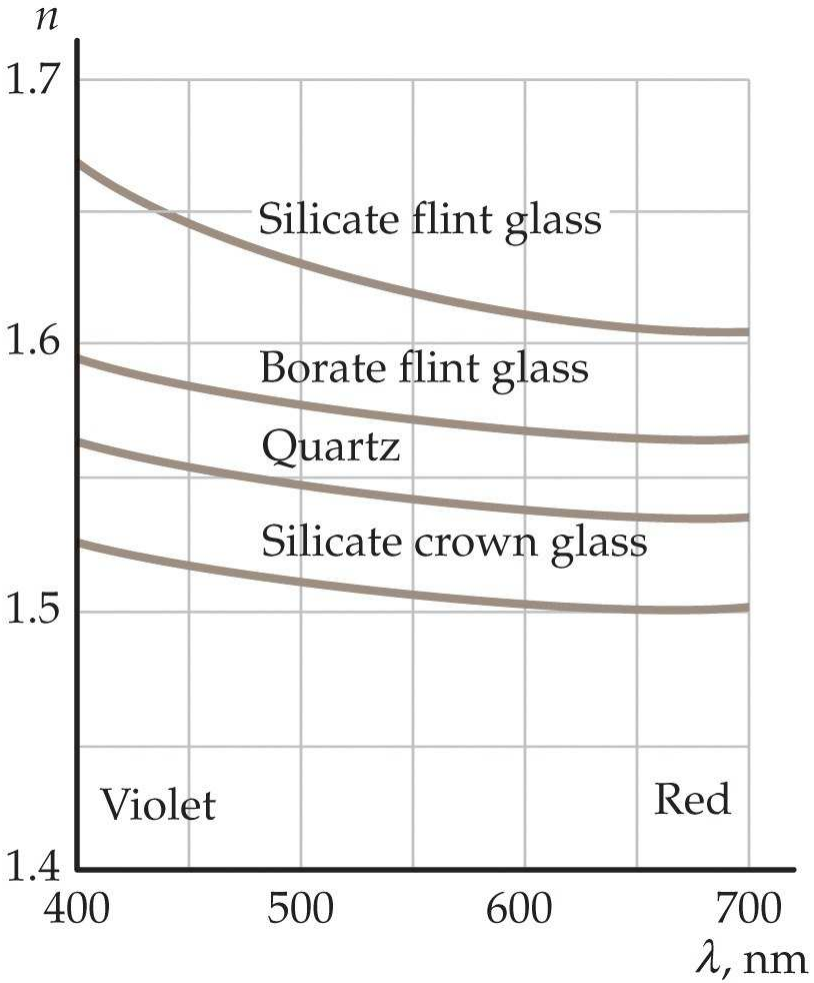


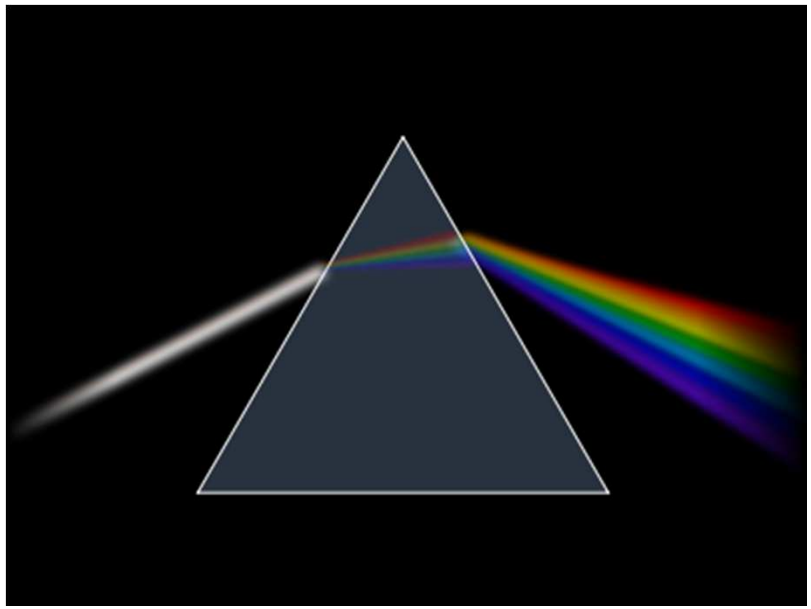


The cladding has a lower index of refraction than the core. The buffer protects the cladding and jacket provide mechanical stability.

Dispersion

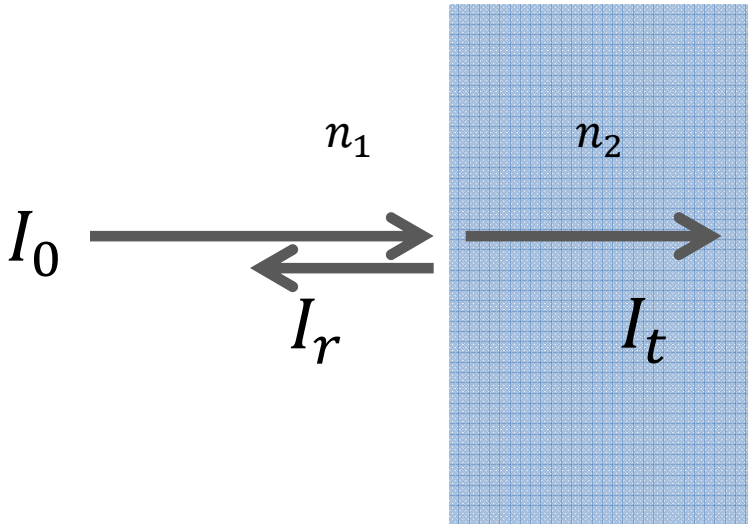
- The index of refraction is a function of wavelength





Transmission and Reflection

- How much light is reflected from a surface?
- For the special case when $\theta = 0$…



$$I_r = I_0 \left(\frac{n_1 - n_2}{n_1 + n_2} \right)^2$$

$$I_t = I_0 - I_r = I_0 \frac{4 n_1 n_2}{(n_1 + n_2)^2}$$

Notice that $I_r \to I_0$ when $n_2 \to n_1$

Reflection

- How much light is reflected from window glass?

Air: *n=1* Glass: *n=1.5*

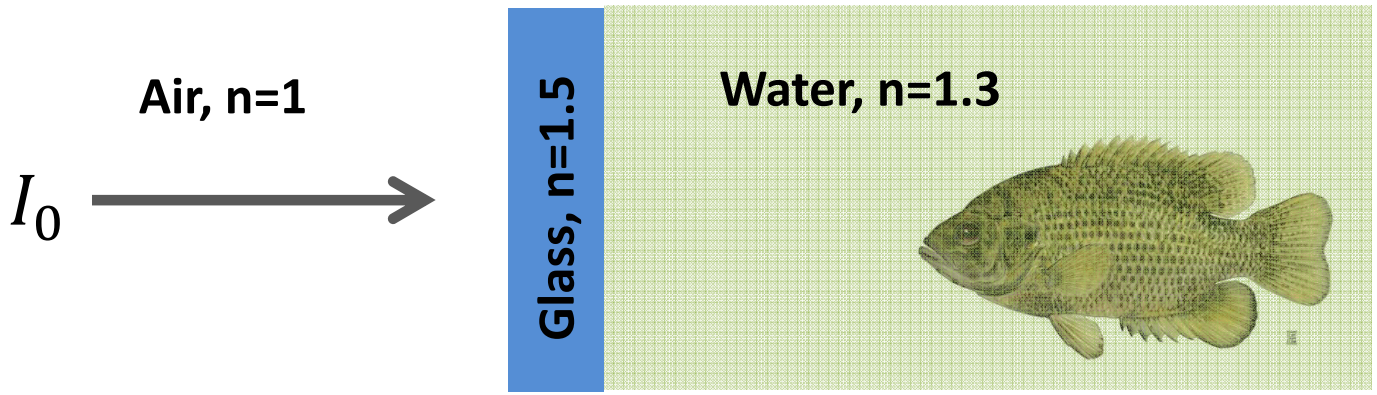
$$I_r = I_0 \left(\frac{1.5 - 1.0}{1.5 + 1.0} \right)^2 = I_0 \left(\frac{0.5}{2.5} \right)^2 = 0.04\, I_0$$

(Only 4%)

- It's the same at both surfaces…
  - Of the 96% that is transmitted into the glass, 4% is reflected from the other glass-air interface
  - Approximately 7.8% of the light is reflected in total.

Question

- Compare how much light is reflected from a window, or from the side of a fish tank?



(a) More from the fish tank
(b) Less from the fish tank
(c) The same from both