Announcements

1. Presentation schedule
   Thursday, 3/20/03 @ 5 PM
   Friday, 3/21/03 @ **2 PM**
   Sunday, 3/23/03 @ **1:30 PM**

2. Exam 2 revisions – due Monday ≤ 3/24/03

3. Anonymous questionnaires – please respond

4. Today's topic – Reflection and refraction of light (Chap. 35)

Digression on optical forces

Arthur Ashkin from Bell Laboratories received the 2003 Keithley award

"For theoretical and experimental contributions to the understanding of laser cooling and trapping of atoms and particles, for demonstrating the optical gradient forces on atoms and the trapping of atoms with light, and for inventing optical tweezers and showing how they can be used to measure the physical forces generated by biological molecular motors."

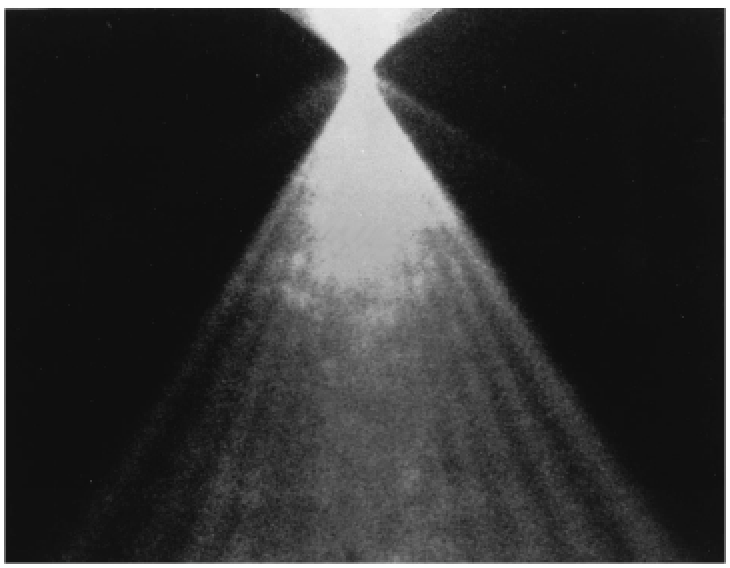


FIG. 1. A photograph of a 10-μm glass sphere trapped in water with green light from an argon laser coming from above. The picture is a fluorescence image taken using a green-blocking, red-transmitting filter. The exiting (refracted) rays show a notable decrease in beam angles relative to the incident rays. The increased forward momentum of the light results in an upward force on the glass bead needed to balance the downward scattering force. The stria in the forward-scattered light is a common Mie-scattering ring pattern (courtesy A. Ashkin).

From RMP 70, 685 (1998)

Nobel lecture by Steven Chu

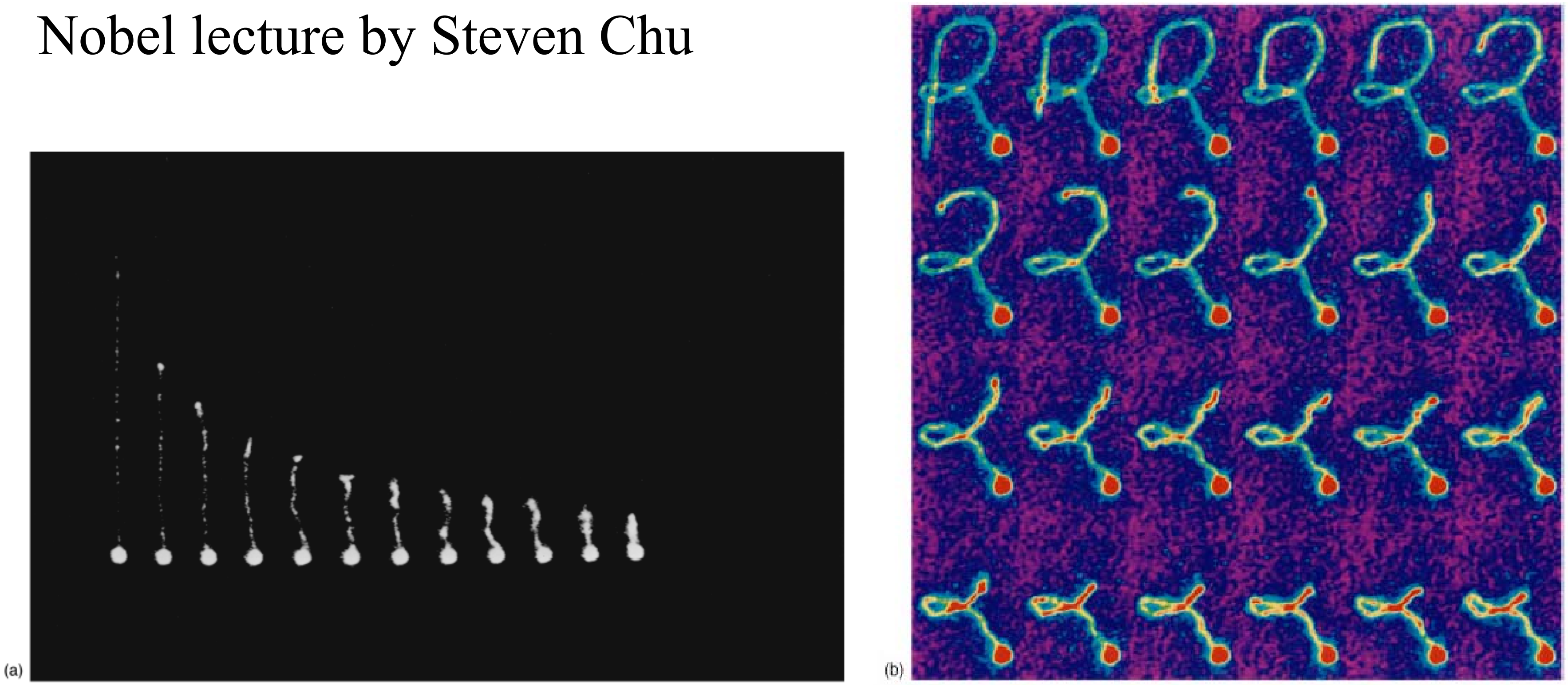
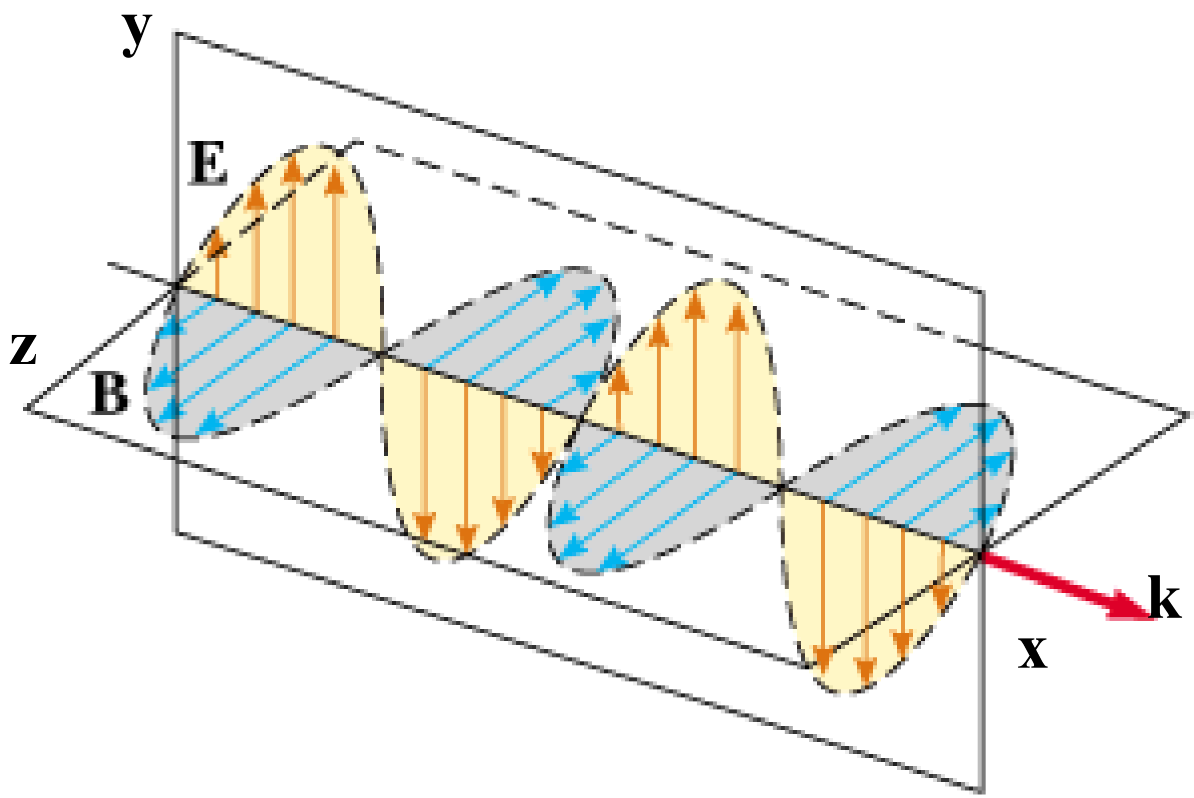


FIG. 11. (a) A series of video images showing the relaxation of a single-molecule "rubber band" of DNA initially stretched by flowing fluid past the molecule. The DNA is stained with approximately one dye molecule for every five base-pairs and visualized in an optical microscope (Perkins, Smith, and Chu, 1994). (b) (Color) The relaxation of a stained DNA molecule in an entangled solution of unstained DNA. The molecule, initially pulled through the polymer solution with an optical tweezers, is seen to relax along a path defined by its contour. This work graphically shows that polymers in an entangled solution exhibit "tubelike" motion (Perkins, Smith, and Chu, 1994). This result and a separate measurement of the diffusion of the DNA in a similar polymer solution (Smith, Perkins, and Chu, 1995) verifies de Gennes' reptation theory used to explain a general scaling feature of viscoelastic materials.

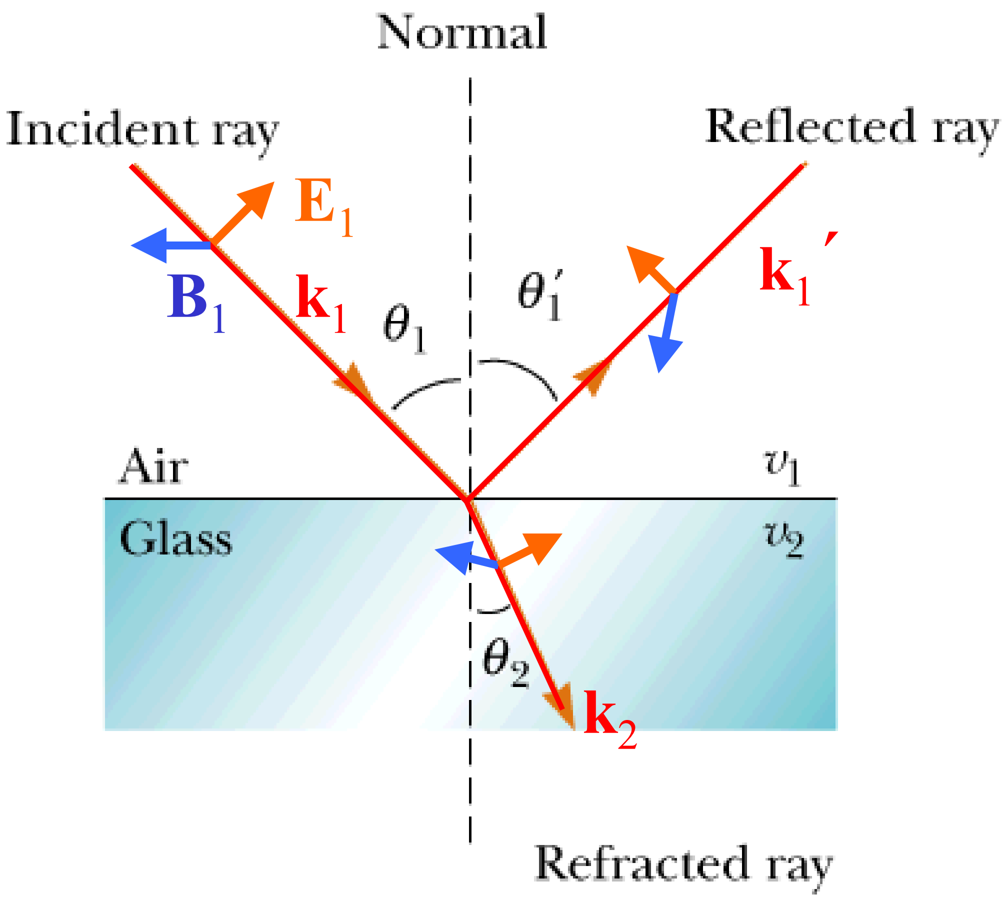
A single plane-polarized electromagnetic wave:



$$E_y(x,t) = E_{\max}\sin\left(kx - \omega t + \varphi\right)$$

$$B_z(x,t) = B_{\max}\sin\left(kx - \omega t + \varphi\right)$$

Consider the behavior of a plane-polarized electromagnetic wave near the surface of two materials:

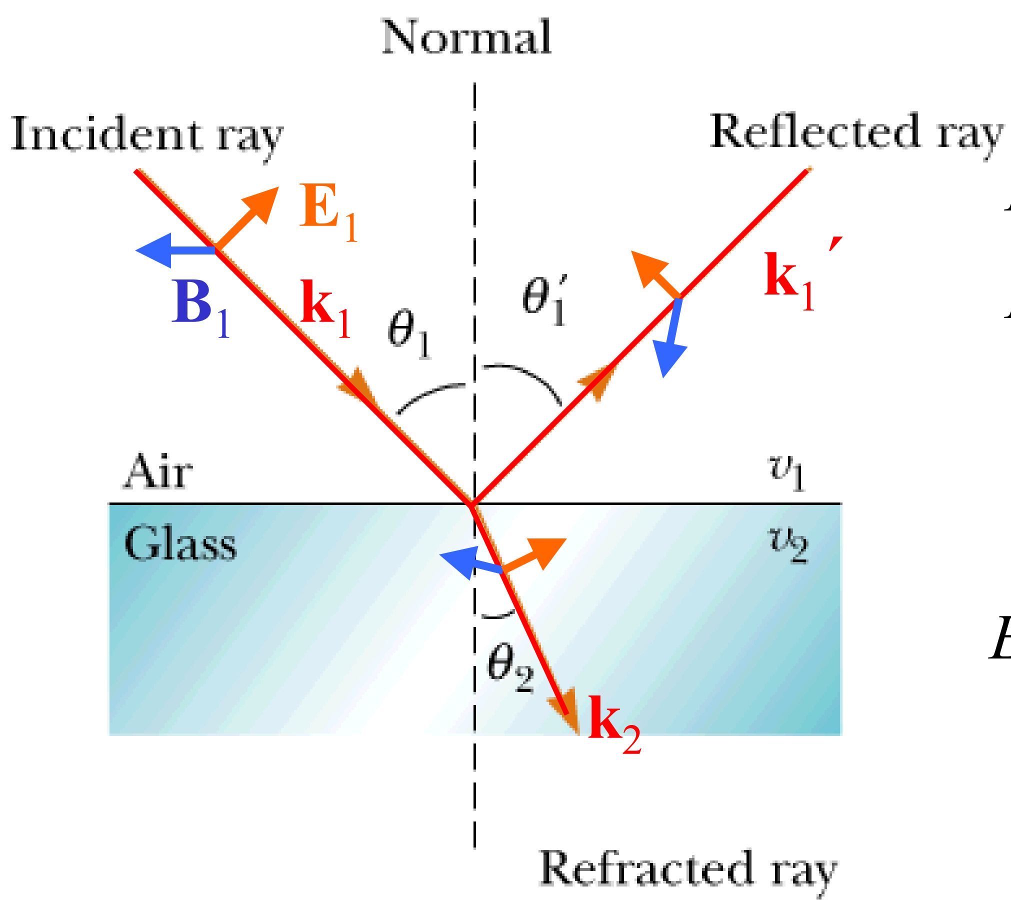


Wave equations

$$\frac{\partial^2 E_y}{\partial t^2} = v_1^2 \frac{\partial^2 E_y}{\partial x^2}$$

$$\frac{\partial^2 E_y}{\partial t^2} = v_2^2 \frac{\partial^2 E_y}{\partial x^2}$$

Consider the behavior of a plane-polarized electromagnetic wave near the surface of two materials -- continued:



Periodic waves:

$$E_1 = E_{\max_1} \sin(\mathbf{k}_1 \cdot \mathbf{r} - \omega_1 t)$$

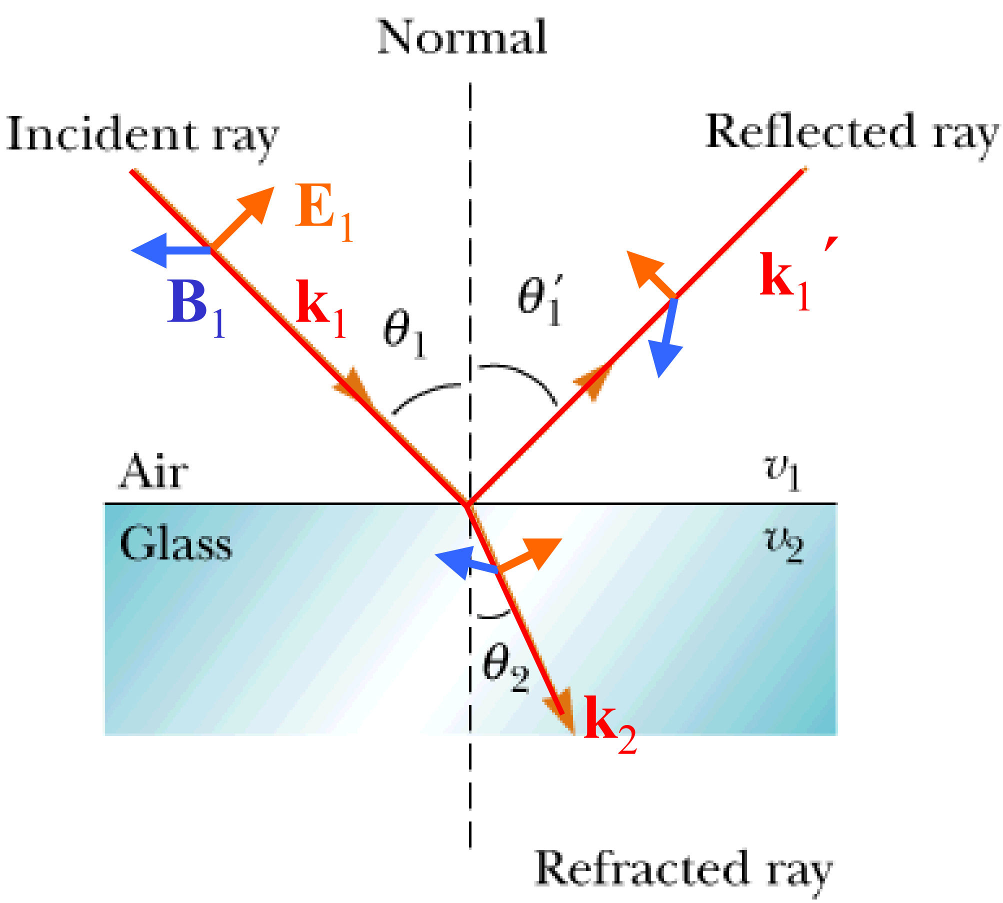
$$E_1' = E_{\max_1}' \sin(\mathbf{k}_1' \cdot \mathbf{r} - \omega_1' t)$$

$$\frac{\omega_1}{k_1} = \frac{\omega_1'}{k_1'} = v_1$$

$$E_2 = E_{\max_2} \sin(\mathbf{k}_2 \cdot \mathbf{r} - \omega_2 t)$$

$$\frac{\omega_2}{k_2} = v_2$$

Consider the behavior of a plane-polarized electromagnetic wave near the surface of two materials -- continued:



$$\frac{\omega_1}{k_1} = \frac{\omega_1'}{k_1'} = v_1$$

$$\frac{\omega_2}{k_2} = v_2$$

If $\omega_1 = \omega_1' = \omega_2$

$$k_1 v_1 = k_1' v_1 = k_2 v_2$$

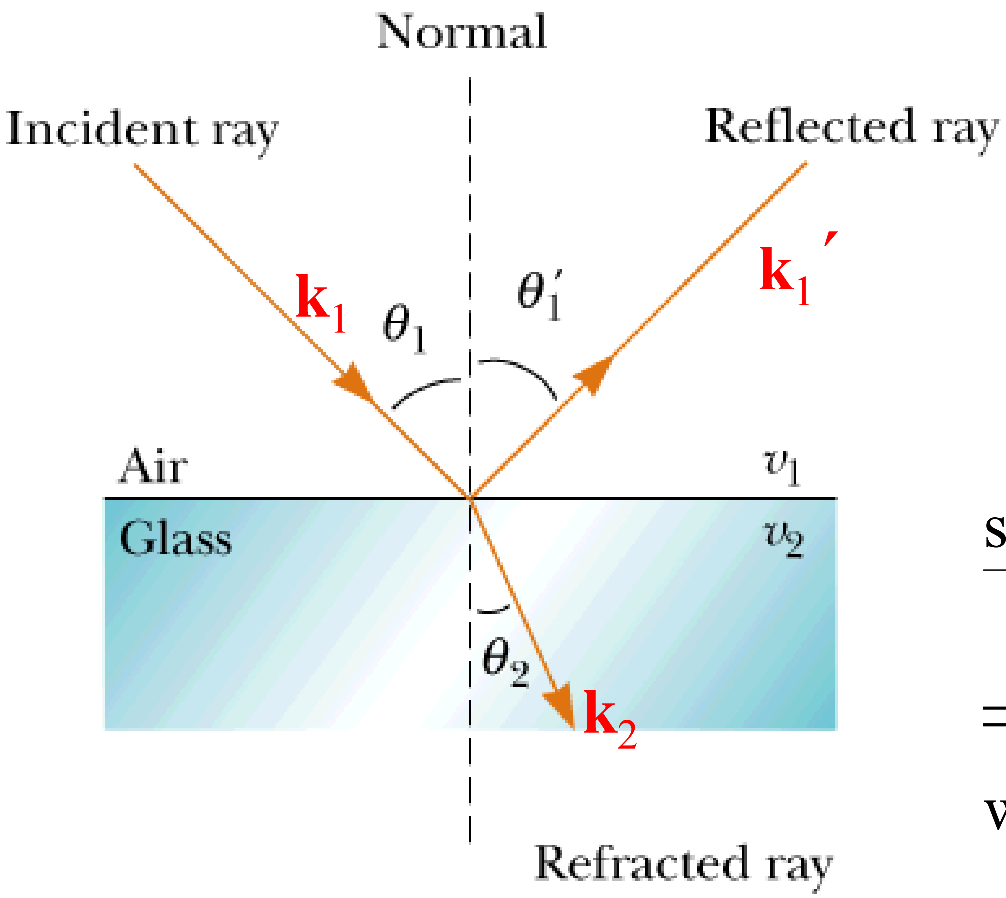
Define: $n_1 \equiv c / v_1$

$n_2 \equiv c / v_2$

Some values of index of refraction (λ = 589 nm)

Material	n
Metal	∞
Diamond	2.4
Glass	1.5-1.7
Ethyl alcohol	1.4
Water	1.3
Air	1.0

Results from solving this boundary-value problem:



$$\theta_1 = \theta_1'$$

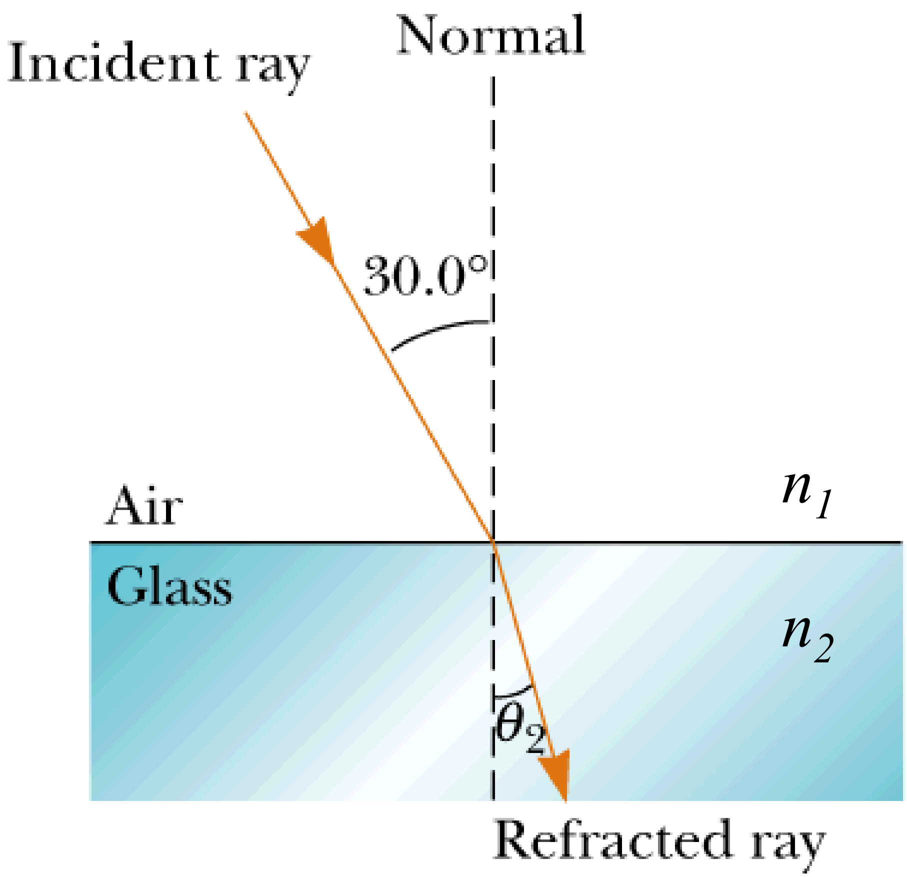
$$\frac{\sin\theta_1}{v_1} = \frac{\sin\theta_2}{v_2}$$

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

where, $v_1 = c / n_1$

$v_2 = c / n_2$

Refraction



Snell's law:

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

$$\theta_2 = \sin^{-1}\left(\frac{n_1}{n_2}\sin\theta_1\right)$$

$$= 17.5^o$$

for $n_1 = 1, n_2 = 1.66$

More results --

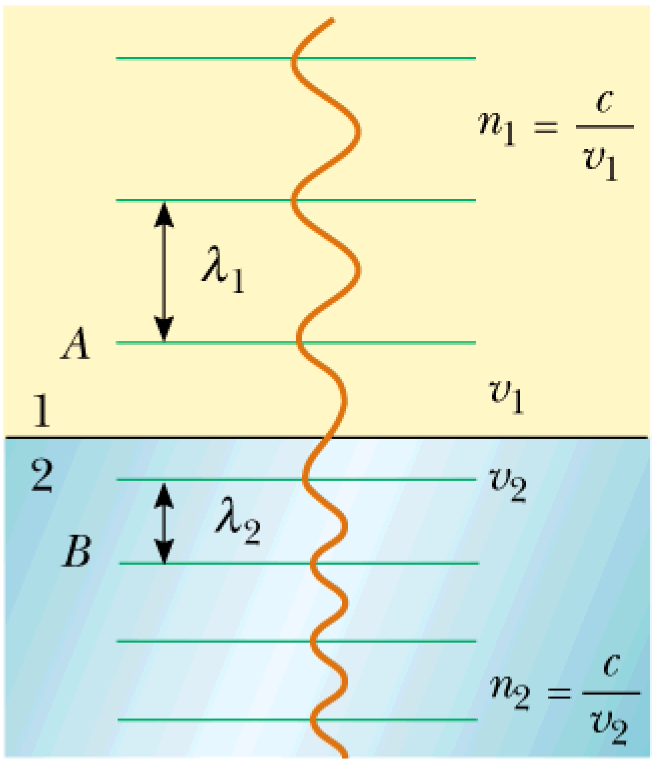
$$k_1 v_1 = k_1' v_1 = k_2 v_2$$

$$\Rightarrow \frac{k_1}{n_1} = \frac{k_1'}{n_1} = \frac{k_2}{n_2}$$

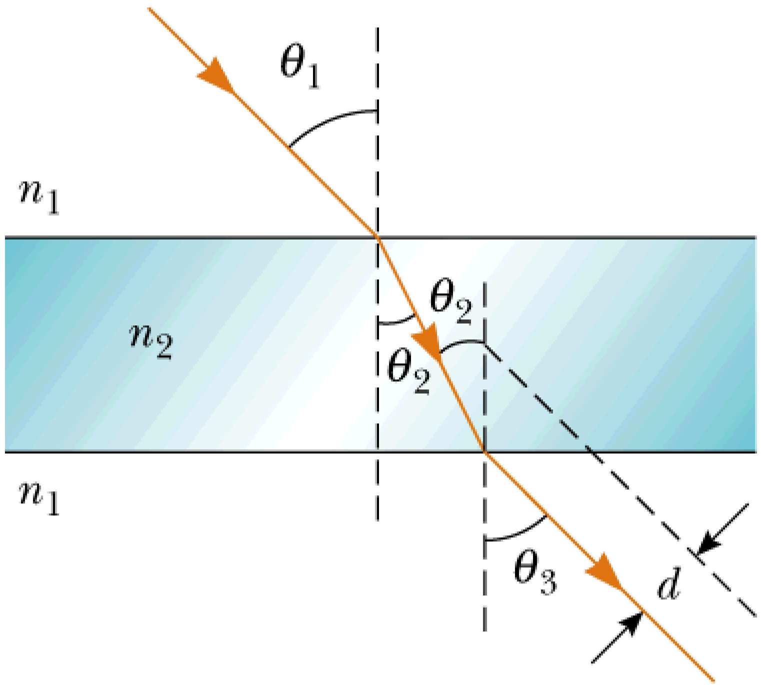
$$\Rightarrow \lambda_1 n_1 = \lambda_1' n_1 = \lambda_2 n_2$$

View at "normal" incidence –

$(\theta_1 = \theta_2 = 0)$



More examples

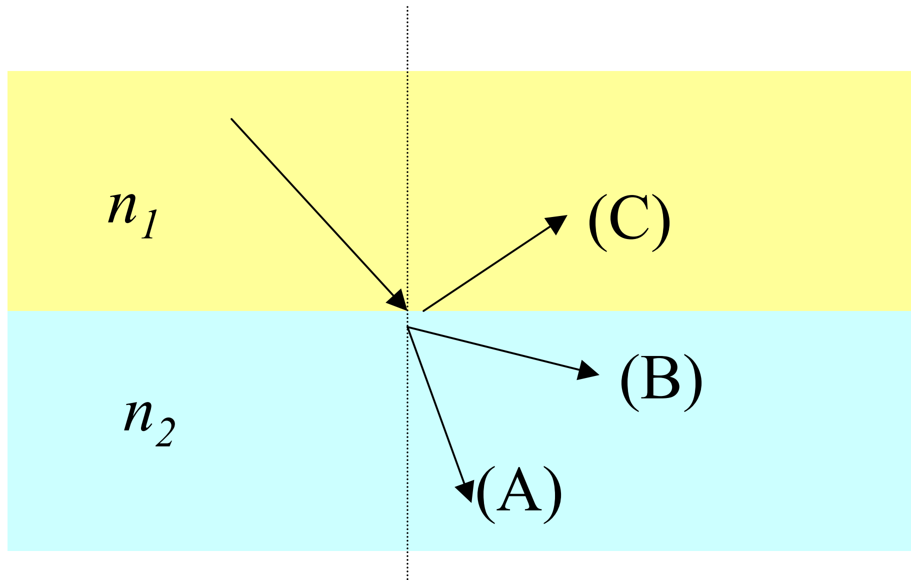


$$\theta_1 = 30^o, n_1 = 1, n_2 = 1.66$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1}{n_2}\sin\theta_1\right)$$

$$= 17.5^o$$

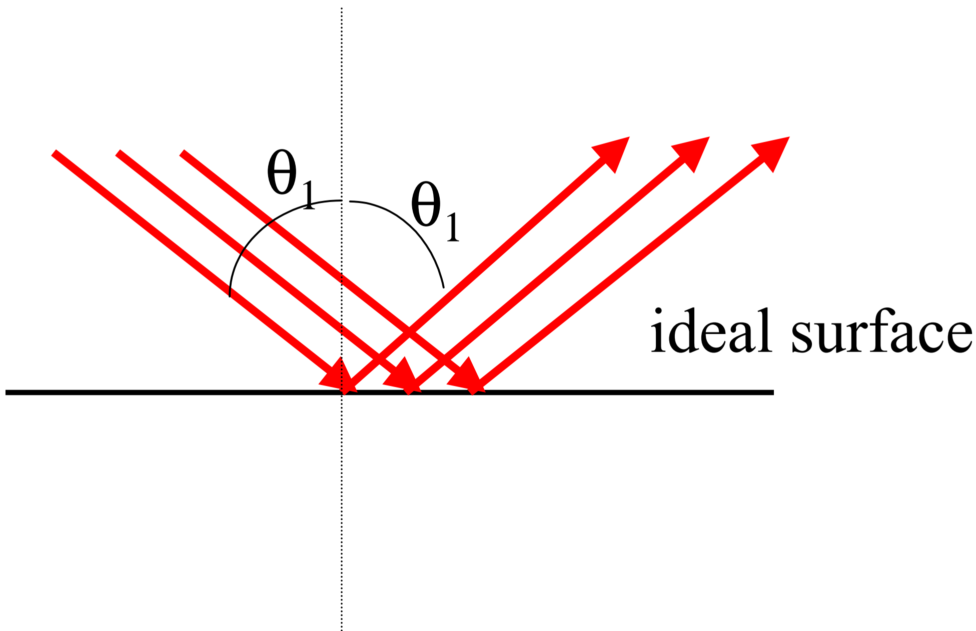
$$\theta_3 = 30^o$$



Peer instruction question

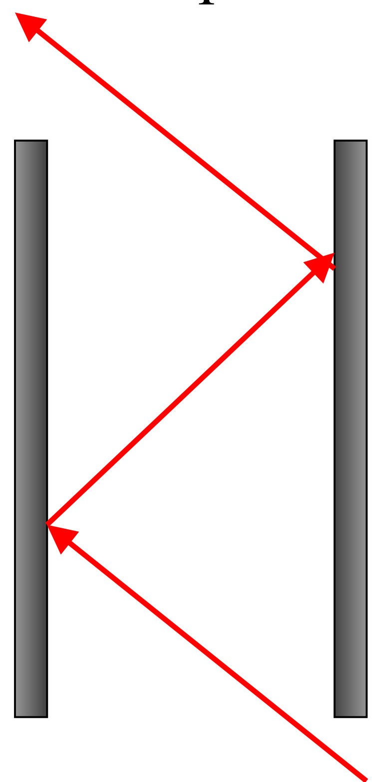
If $n_1 > n_2$, which ray represents the most likely refraction?

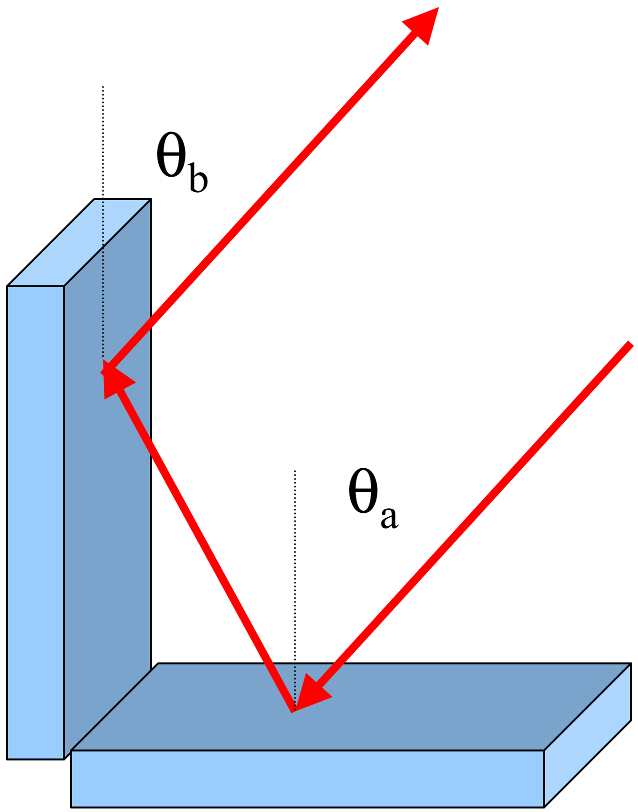
Reflection



Ray tracing

Example: 2 mirrors





Peer instruction question

What can you say about the relationship between θ_a and θ_b?

(A) $\theta_a = \theta_b$

(B) $\theta_a = 90^o - \theta_b$

(C) Insufficient information.

Reflection from a rough surface