Portland State University
General Physics Workshop
Problem Set 5

Refraction and Lenses

Equations and Relations:

Index of refraction

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

Snell's Law

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

Total internal reflection

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

Total polarization: $\tan\theta_B = \frac{n_2}{n_1}$

θ_B Brewster's angle

Thin Lens Equation

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

Magnification

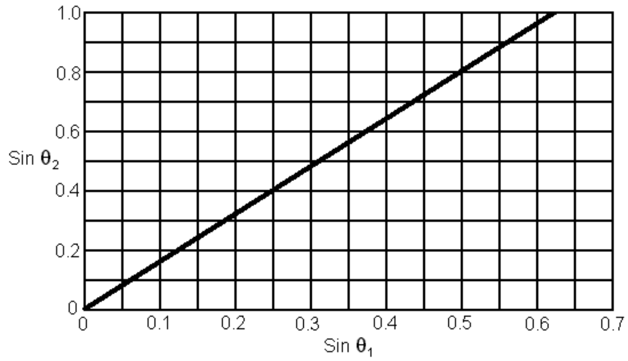
$$m = -\frac{d_i}{d_o} = \frac{h_i}{h_o}$$

1. A fish hovers beneath the still surface of a pond. If the sun is 33º above the horizon, at what angle above the horizontal does the fish see the sun? (n_{water} =1.33)

2. The sunlight reflected from the surface of a lake is completely polarized. Calculate the angle of incidence of the sunlight
   (a) in summer (n_{water}=1.333)
   (b) in winter when the lake is frozen (n_{ice}=1.309)

3. A beam of light strikes one face of a window pane with an angle of incidence of 30.0º. The index of refraction of the glass is 1.52. The beam travels through the glass and emerges from a parallel face on the opposite side. Ignore reflections.
   (a) Find the angle of refraction for the ray inside the glass.
   (b) Show that the rays in air on either side of the glass (the incident and emerging rays) are parallel to each other.

4. In an experiment a beam of red light of wavelength 645 nm in air passes from glass into air. The incident and refracted angles are θ_1 and θ_2, respectively. In the experiment, angle θ_2 is measured for various angles of incidence, and the sine's of the angles are used to obtain the line shown in the following graph.



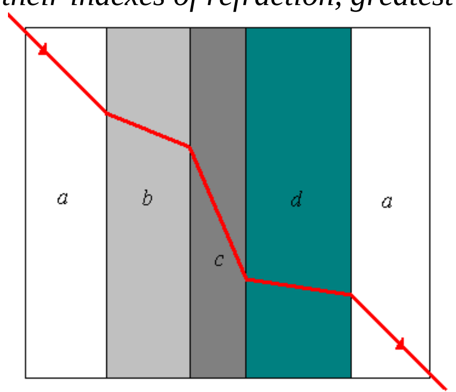
(a) Assuming an index of refraction of 1.00 for air, use the graph to determine a value for the index of refraction of the glass for the red light.

(b) Determine the frequency of the red light in air, its speed in the glass, and its wavelength in the glass.

(c) The index of refraction of this glass is 1.66 for violet light, which has a wavelength of 420 nm in air. Given the same incident angle θ_1, show with a ray diagram the difference between the refracted red and violet rays.

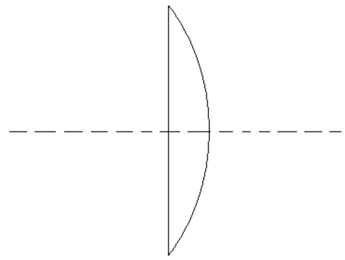
(d) Determine the critical angle of incidence θ_C for the violet light in the glass in order for total internal reflection to occur.

- *In the figure, light travels from material a, through three layers of other materials with surfaces parallel to one another, and then back into another layer of material a. The refractions (but not the associated reflections) at the surfaces are shown. Rank the materials according to their indexes of refraction, greatest first.*

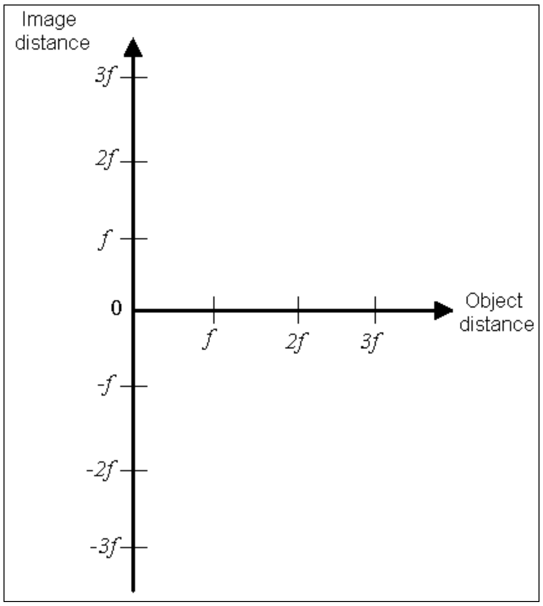


- *A ray of light passes from air into water, striking the surface of the water with an angle of incidence of 45º. Which of these quantities change as the light enters the water: wavelength, frequency, speed of propagation, direction of propagation?*

5. The plano-convex lens shown below has a focal length of 20 cm in air. An object is placed 60 cm (3*f*) from this lens.



(a) Is the image is real or virtual?
(b) What is the distance from the lens to the image?
(c) Determine the magnification of this image.
(d) The object, initially at a distance 3*f* from the lens, is moved toward the lens. On the axes below, sketch the image distance as the object distance varies from 3*f* to zero.



(e) If the index of refraction of the lens were increased, would the focal length of the lens increase, decrease, or remain the same? Explain.

6. A thin converging lens of focal length 8 cm is used as a simple magnifier to examine an object *K* that is 6 cm from the lens.
   (a) Draw a ray diagram showing the optical axis, the lens (at the origin), *K* at +6 cm, and the position of the image formed, *K'*. Be sure the height of *K'* is correct relative to *K*.
   (b) Is *K'* real or virtual? Explain.
   (c) *Calculate* the position (distance from the origin) of *K'*.
   (d) How many times greater is the image height than the object height? (I.e. calculate the ratio of the image size to the object size, $\frac{h_{K'}}{h_K}$.)
   (e) Repeat (a)-(d) for a concave lens with f = -8cm)

- *What happens to the focal length of a symmetric, converging lens as you increase:*
  (a) the index of refraction n of the lens
  (b) the magnitude of the radius of curvature of the two sides
  (c) the index of refraction n_{med} of the surrounding medium, keeping n_{med} less than n?

- *A concave mirror and a converging lens (glass with n = 1.5) both have a focal length of 3 cm when in air. When they are in water (n = 1.33), are their focal lengths greater than, less than, or equal to 3 cm?*

Additional Questions

1. Explain how the day is lengthened by atmospheric refraction.

2. Using the principles of refraction, explain why a diamond is much more brilliant than a glass replica. Why are colors observed in the light from a diamond?

3. The surface of water in a swimming pool is completely still. Describe what you would see looking straight up toward the surface from underwater.