

## Experiment #1: Reflection, Refraction, and Dispersion

Purpose: To study reflection and refraction of light at plane and curved surfaces, as well as the phenomenon of dispersion.

Equipment:

Ray Box with Slits  
Optical Accessories (flat mirror, 3-sided chrome mirror, plastic biconvex lens,  
plastic plane-parallel slab, glass 60° prism)  
Several Sheets of White Paper  
Ruler  
Protractor  
Flashlight

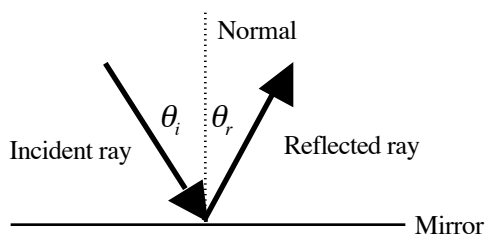
NOTE ABOUT OPTICAL ACCESSORIES--- The following 4 items are NOT used in this lab: the metal arc, the plastic triangle, the plastic hemi-circle, and the plastic biconcave lens!

Discussion:

This laboratory begins your exercises in optics—specifically, geometric optics. Traditionally, an introductory geometric optics lab exhaustively defines the concepts of reflection, refraction, angles of incidence, normal vectors, and so forth. But rather than lecture to you outright, you will be guided experimentally to discover these laws for yourself.

Procedure:

1. Label a blank piece of paper with a (1). Allow a single incident ray to strike the plane mirror at an oblique angle and be reflected from it. Trace the face of the mirror and the incident and reflected rays. Draw a line perpendicular to the mirror face at the point of reflection—this is the normal to the mirror at that point. Measure the angle of incidence  $\theta_i$  and the angle of reflection  $\theta_r$  with respect to the normal using a protractor. In the results section, discuss how the angles of incidence and reflection are related. Your two measured angles are not exactly equal: why not? Discuss possible error sources.



2. Label another page (2). Allow a single ray to strike the plane mirror at an oblique angle and be reflected. Trace the face of the mirror and the incident and reflected rays,  $i$  and  $r$ . Without moving the incident ray, rotate the mirror about the point of intersection with the incident ray through a small angle  $\gamma$ . Trace the new mirror face and the new reflected ray,  $r'$ . Measure  $\gamma$  with a protractor. Also measure the angle  $\phi$  between  $r$  and  $r'$ . How is  $\phi$  related to  $\gamma$ ?

Supplementary Problem 1: Derive the exact relationship between  $\phi$  and  $\gamma$ , and compare it to your experimental result.

3. Label a new page (3). Allow a single ray to strike the midpoint of the concave mirror at an oblique angle. Trace the surface of the mirror and the incident and reflected rays. Draw a tangent line to the mirror surface at the point of reflection (by allowing it to deviate away from the mirror equally in both directions) and then construct a line normal to the tangent line at the point of reflection. Measure the angles of incidence and reflection. Make a general statement about how the incident and reflected angles are related.

4. Label a page (4). Repeat step 3 for the convex mirror.

5. Label a piece of paper with a (5). Adjust the light box so that 3 parallel rays are produced. (To do this, make the separation between two rays measured near and far from the box equal to each other.) Trace the surface of the concave mirror on a sheet of paper. Allow 3 rays to reflect from the concave mirror so that they converge just off the central axis. The point where the parallel rays converge is called the focal point. Trace the rays and mark the focal point,  $F$ . The distance from the mirror to  $F$  along the central reflected ray is called the focal length,  $f$ . Now find the radius of curvature by drawing any two chords on the mirror tracing, bisecting the chords, and finding the point  $O$  where these bisectors intersect; the distance from the mirror to  $O$  along a bisector is the radius of curvature,  $R$ . What is the relationship between the radius of curvature and the focal length?

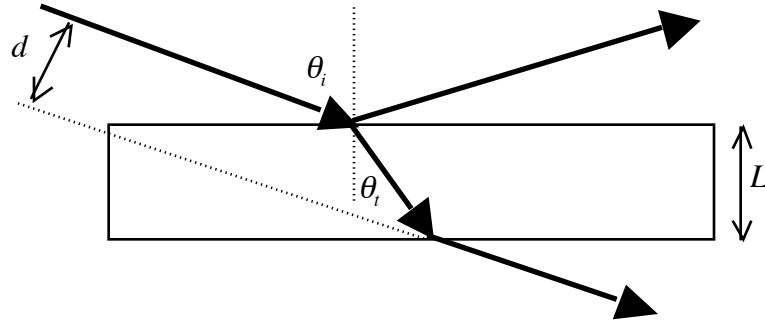
6. Label (6) on another paper. Repeat step 5 for the convex mirror. But this time you need to extend your traces of the reflected rays backwards through the mirror surface until they converge at the focal point  $F$ . Be sure to leave enough room on your paper to find  $O$ !

7. Label a page (7). Allow 3 parallel rays to strike the convex lens. Trace the lens and rays, and mark the focal point  $F$ . Now rotate the lens by a small angle about its center (without moving the light box). You should find that  $F$  hardly moved; explain why in your report. Next, rotate the lens by a fairly large angle (say  $45^\circ$ ) and trace the new lens position and rays. Explain in words what happened to the focal spot in your report; the technical name for this coma.

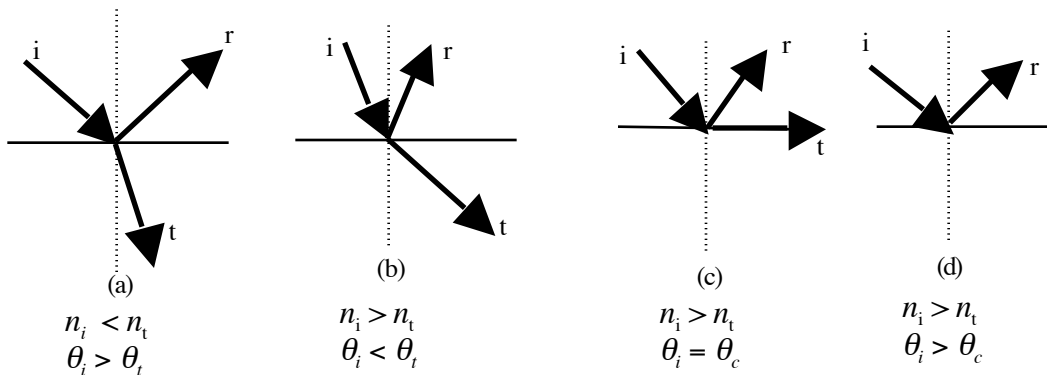
8. Label page (8). Allow a single ray to pass through the two parallel sides of the transparent plastic block at a near-grazing angle—see the figure below. Trace the parallel sides of the block and the rays entering and leaving the block. Move the block aside and connect the entry and exit points to trace the ray, which passed through the plastic block. This is the transmitted (or refracted) ray. Note that there is also a reflected ray obeying the laws of reflection, which you observed in item 1. Construct a line normal to the front surface of the block at the entry point. Measure the angle of incidence  $\theta_i$  and the angle of transmission  $\theta_t$  (which is the angle between the normal and the transmitted ray). Using Snell's Law ( $\sin\theta_t = n \sin\theta_i$ ), determine the index of refraction  $n$  of the plastic block. Compare your result to typical textbook values of indices of refraction of optical materials. Next, extend the exiting ray backwards across the slab to the incident side. It should be

parallel to the input ray. Measure the separation  $d$  between these two rays and the width  $L$  of the parallel sides of the slab on your drawing. It can be easily shown using Snell's Law and trigonometry that  $d = L \sin(\theta_i - \theta_t) / \cos \theta_t$ . Compare your measured value of  $d$  to the value calculated using this formula.

Supplementary Problem 2 (University Physics students only): Derive the above formula.



9. Snell's Law also predicts a phenomenon known as total internal reflection. When light travels through one medium (air, say) and is incident upon a second medium having a larger index of refraction (glass, say) the light will bend in the second medium towards the normal (i.e.,  $\theta_i > \theta_t$ ). See Fig. (a) below. When light travels from an optically dense material to a less dense medium, the ray will still bend at the surface but this time away from the normal so that  $\theta_i < \theta_t$ ; see Fig. (b). In either case, the angle that the ray makes with the normal in the less dense medium will be greater than the angle that the ray makes with the normal in the more optically dense medium. Note that in both cases, in addition to the refracted beam, there is also a beam reflected back into the first medium.

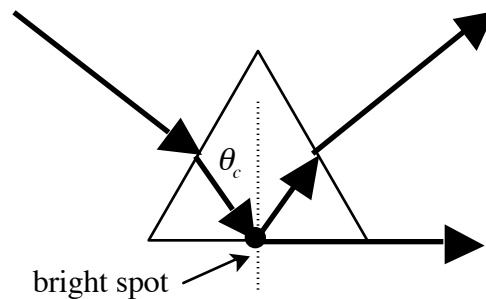


Now let's consider the following scenario. In the second case (with the incident light in the more optically dense material) the angle of transmission can reach its upper limit of  $90^\circ$ . The angle of incidence at which this occurs is called the critical angle  $\theta_c$ . If  $\theta_i = \theta_c$ , the transmitted ray becomes a surface wave grazing the interface between the two media—cf. Fig. (c) above.

Supplementary Problem 3: Derive an expression for  $\theta_c$  in terms of the indices of refraction of the incident and transmitted media  $n_i$  and  $n_t$ , respectively.

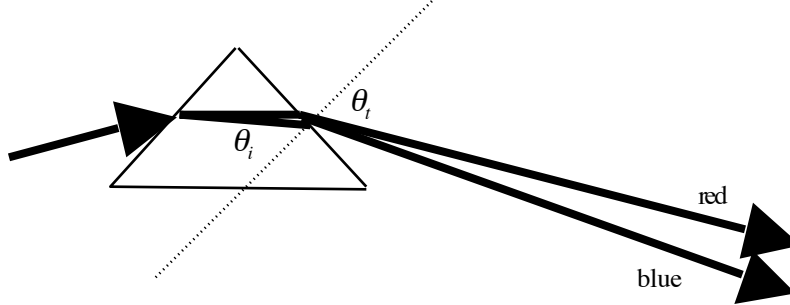
Finally, let's think about what happens if the angle of incidence is larger than  $\theta_c$ . In this case—Fig. (d)—the light is completely reflected back into the first medium. There is no refracted beam. This phenomenon is called total internal reflection.

Label a page (9). Shine a single ray onto a prism in such a manner that the incident ray (inside the glass) is at the critical angle, so that it's just barely exhibiting total internal reflection. Trace the prism, the incident and reflected rays, and the point of total internal reflection visible as a bright spot on the back face of the prism (see sketch below). Move the prism aside and draw the two rays inside the prism. Also draw the normal to the totally reflecting surface and measure the critical angle. Use this to calculate the index of refraction of the prism, assuming the index of air is 1. Compare your result to typical textbook values for glasses.



10. Another phenomenon exhibited by prisms is dispersion, which produces a spectrum of rainbow colors—see the sketch on the next page. Label a page (10). Position the prism at one end of the paper. Allow a single light ray to fall on one side of the prism at roughly the angle indicated in this sketch. Observe that the emerging light has been separated into different colors. The fact that different colors have different angles of refraction means from Snell's Law that the refractive index of the prism is different for different wavelengths of light. Trace the prism and input beam. Next, draw the rays for red, green, and violet light existing the prism. The easiest way to do this is to put a dot at the center of each color at the other end of the paper from the prism (i.e., as far away as possible from it, so that the colors will have maximum separation), and a single dot where the beam exit from the prism. (They don't all exit at exactly the same point, so choose the center point.) Now connect the appropriate dots with a sharp pencil to map the refracted rays. Also move the prism aside and draw a line connecting the input and exit points on the prism surfaces, to trace out the beam inside the prism. Finally, draw a normal to the exit face. Measure the incident angle  $\theta_i$  of the beam inside the prism with respect to this normal. Then measure the angles of transmission  $\theta_t$  of the colored beams outside the prism (again with respect to the normal). Now use Snell's Law to calculate the refractive indices of the prism for the various colors, retaining enough significant figures to show the difference between them. The second table on the next page lists the approximate wavelengths of various colors and textbook values of refractive index versus wavelength for a typical glass. Prepare a small table in Excel of your experimental values of index of refraction (y-axis) versus wavelength (x-axis) similar to the first one below. Then plot your results as symbols which are not connected by a curve. Finally, overlay on the same graph a curve (with no symbols) of the textbook values. To do this, prepare a table of values taken from a table in a textbook (if available) or eyeballed off a

graph in a textbook. A sample Excel workbook is shown below. How do your data points agree with the theoretical curve---why isn't the agreement exact? Does the refractive index, increase or decrease with wavelength? Speculate in your report on what might cause this.



Experimental Data		
Color	wavelength (nm)	measured $n$
Red	660	1.713
green	550	1.729
violet	410	1.762

Data from Cutnell & Johnson Table 26.2		
color	wavelength (nm)	flint glass $n$
red	660	1.662
orange	610	1.665
yellow	580	1.667
green	550	1.674
blue	470	1.684
violet	410	1.698

