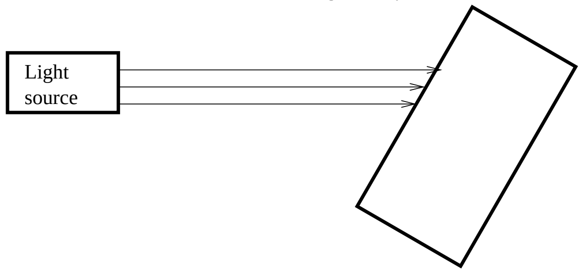
Lab $10\frac{1}{2}$
Refraction and Lenses

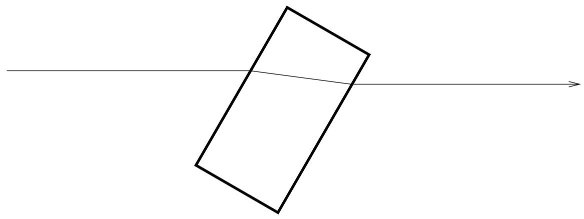
Over the next few classes, we're going to examine how telescopes work, but first we need to figure out some aspects of the behavior of light when it passes through transparent materials such as glass.

The apparatus for this lab consists of a light source that produces a set of parallel beams from lasers, along with a variety of transparent and reflective objects for the light to interact with. All of these objects can be attached magnetically to a small whiteboard, so that they can be easily positioned in various ways.

Part 1: Refraction. Plug in the light source and attach it to the whiteboard. Put the clear plastic rectangle in front of the source, so that the light rays hit it at an angle like this:



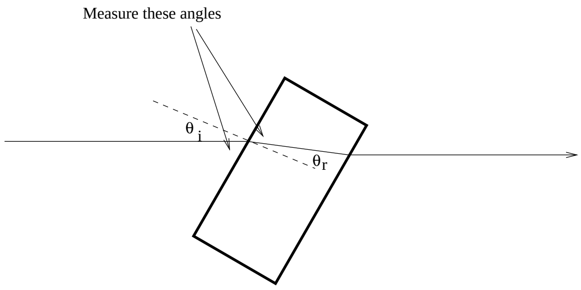
Put a piece of paper under the rectangle. Trace the outline of the rectangle on the paper. Also, trace the path of one of the rays as it enters the rectangle, and the same ray as it exits the other side. Use a straightedge to make sure your lines are straight. Then remove the paper, and draw a straight line connecting the points where the ray entered and exited the rectangle. You should end up with a picture like this:



The light ray bends when it enters the plastic. This phenomenon is called *refraction*. There is a rule called Snell's Law that describes the amount of bending:

$$\sin\theta_i = n\sin\theta_r.$$

In this law, n is a constant called the *index of refraction* of the material. The angles θ_i and θ_r are called the angle of incidence and angle of refraction. They're defined to be the angles the light ray makes with a line perpendicular to the surface where the light ray entered the material, like this:

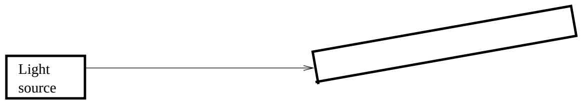


It's easier to measure the angles that the light ray makes with the edge of the rectangle, instead of the angle that it makes with the perpendicular line. So measure these two angles, and use them to determine the angles θ_i and θ_r.

Now use these angles in Snell's Law (the equation above) to determine the value of the index of refraction n.

The value of n is supposed to be the same no matter what incident angle you choose. To test this, rotate the rectangle so that the light rays hit it at a different angle. Repeat the procedure above to determine θ_i, θ_r, and n. Do you get roughly the same value of n as before?

Part 2: Total internal reflection. Once the light ray has entered the surface, it has to bend again in order to get back out. (That's why the rays that leave the rectangle end up parallel to the ones that go in.) Sometimes the rays can't bend enough to make it back out, and in this case they are reflected, bouncing back and forth inside the material. To see this, take the long, thin rectangular piece of plastic, and arrange it so that one of the light rays enters at a slight angle like this:



If you adjust the angles right, you should be able to see the light ray bounce back and forth from side to side inside the plastic. Using total internal reflection, light signals can be transmitted over very great distances through fiber optic cables.

Part 3: Lenses. A curved piece of refracting material can act as a lens, bringing light to a sharp focus. Lenses are found in your eyes, as well as corrective lenses (eyeglasses or contact lenses), cameras, microscopes, etc. For this course, of course, the most important application of lenses is in telescopes. We'll examine how telescopes work in future classes. For the moment, let's just figure out some general properties of lenses.

Take one of the three lenses labeled 1,2,3, and place it in front of the light source. You should see the light rays bending to come (approximately) to a *focal point* on the far side of the lens. The *focal length* of a lens is defined to be the distance from the center of the lens to the focal point. Determine the focal lengths of all three lenses. (The easiest way to do this is to mark the focal point on the white board, and also to mark the edges of the lens. Then you can remove the lens and measure the distance from the focal point to the middle of the lens.)

These three lenses are all called *converging* lenses, because they cause the light to converge to a point. There are also *diverging* lenses, which generally have concave rather than convex surfaces. Put the lens labeled 5, which is a diverging lens, in front of the light source and see what it does. A diverging lens causes the light rays to spread out *as if* all the rays were coming from a focal point on the same side of the lens as the light source.

To see how this works, trace the paths of several of the rays after they exit the lens. Also, mark the positions of the edges of the lens. Now remove the lens and, using a straightedge, extend the rays *backwards* until they come together at a single point. The distance from the center of the lens to this focal point is called the focal length of the lens. Measure the focal length of this diverging lens.

Part 4: Combinations of lenses. Put one of the converging lenses (1,2,3) in front of the light source, and then put another one of the converging lenses right in front of the first one. The two lenses should behave approximately like a single lens. Is it a converging or a diverging lens? How does the focal length of the combined lenses compare with the focal length of the original lenses? (I'm not looking for a measurement here, just a general observation.)

Try the same thing with a combination of a converging and a diverging lens. Does the combination behave like a converging lens or a diverging lens?

Remove the other lenses and place the lens labeled 4 in front of the light source. Is this a converging lens or a diverging lens? Is its focal length larger or smaller than those of lenses 1,2,3,5?

Place the diverging lens (5) right in front of lens 4. Does the combination of lenses 4 and 5 behave like a converging lens or a diverging lens?

By now, you should have seen that sometimes a combination of a converging and a diverging lens acts like a converging lens, and sometimes it acts like a diverging lens. There is a general rule for predicting, for any given pair of lenses, which way the combination of the two will behave. Can you guess what this general rule might be?