Lab Project #2: Flashlight Laser Maze

The CHALLENGE: Design and build an optical maze that has the fastest path for light to travel through while hitting all the targets.

BEHIND THE CHALLENGE: Your job is to investigate different line lengths, transformations and angles while building a hands-on project that demonstrates these principles in action. You will apply your math skills by measuring line lengths, different types of angles, calculating reflections, and practice your geometry drawing skills as you construct the path through the maze.

MATERIALS:

- Red laser (inexpensive red keychain lasers work great)
  or a flashlight (one where you can focus the beam will be easier to work with)
- Index cards (lined or blank), 10, any size
- Paper clips (10)
- Scissors and tape
- Markers (pick darker colors)
- Small mirrors (1" square or round, you'll need about 10). Craft stores carry these inexpensively, or you can make your own by covering small squares of cardboard with aluminum foil, or use mirrors from compacts or makeup kits

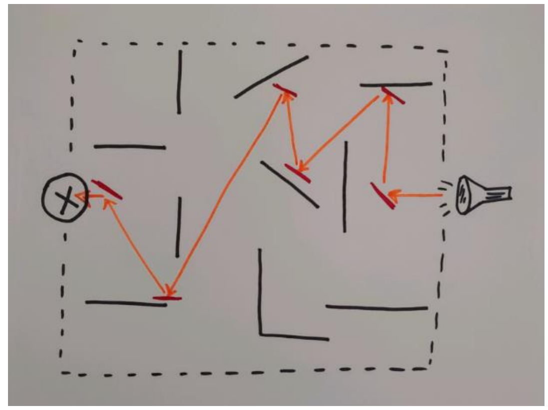
Optional materials:

- Glass microscope slide or use a window
- Transparent objects (like prisms, glass of water, clear gelatin, lenses, ice, etc.)
- Mirror-like surfaces (choose very reflective surfaces to minimize light loss)
- An old DVD or CD (one you don't care if it gets scratched)

CONDITIONS:

- Light source must hit at least three different targets before reaching endpoint.
- You may use up to two targets of the same type (for example: two mirrors).
- Maze may not exceed 3 feet by 3 feet square.
- Path must be in two dimensions (not just pinging back and forth).

PROCEDURE:



You are to create a maze that hits at least three targets. Before designing your maze, first you need to learn about the different types of targets you want to use. Each has their own unique properties.

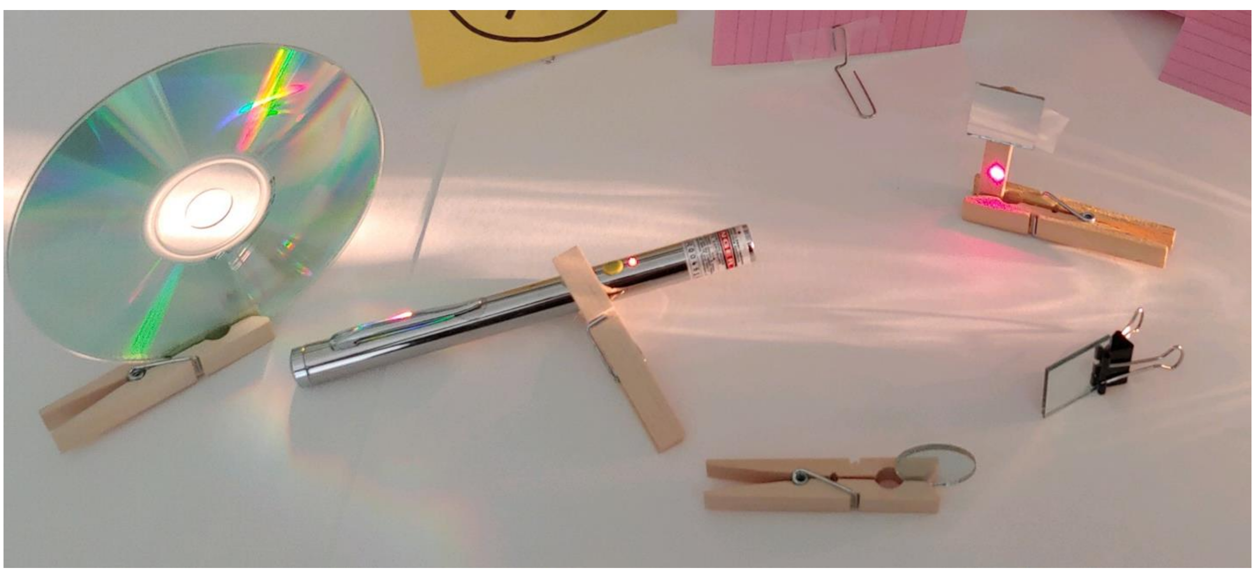
Note: If you are using a flashlight instead of the recommended laser, this experiment will work best with a *strong* flashlight with a *focused* beam.

Tip: You can make the beam from your laser visible by having it pass through particles, like a steamy bathroom (after someone is done with a hot shower); or through water with a drop of milk mixed in… you get the idea. You need *particles* to *illuminate* the beam of light to make it visible.

Plain water, no milk

Water with one drop of milk

First, let's play with different materials. Go into a dark room with your light, reflective and transparent objects, and see which one you think will work best for this challenge.



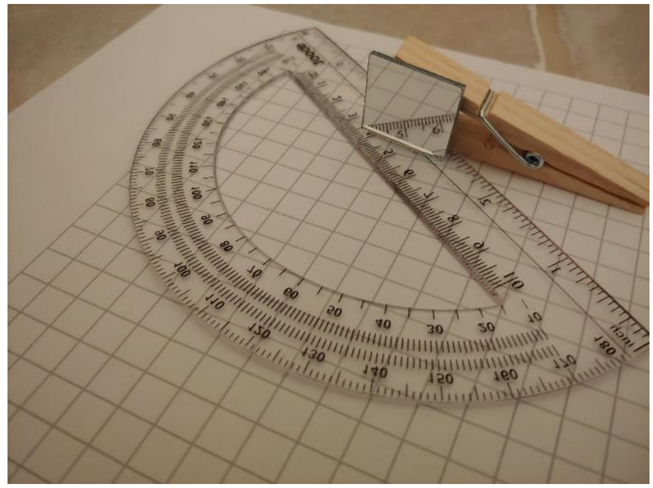
Next, you'll need to make "stands" for each of the objects you want to use. There are lots of different ways of making these objects stand up in the orientation, by propping them up against blocks or other solid objects, using clothespins (image above), or using paperclips and tape. Not all objects need to be reflective, some can be beam splitters or narrow slits.

SPECIAL NOTE FOR FLASHLIGHT users: You probably noticed in the dark room that the light from a flashlight goes all over the place. To focus your beam, you can place it in a small box, like a shoebox, and cut a narrow slit at one end using a sharp kitchen knife (get an adult to help you with this). This will allow only a thin sliver of light to come through.

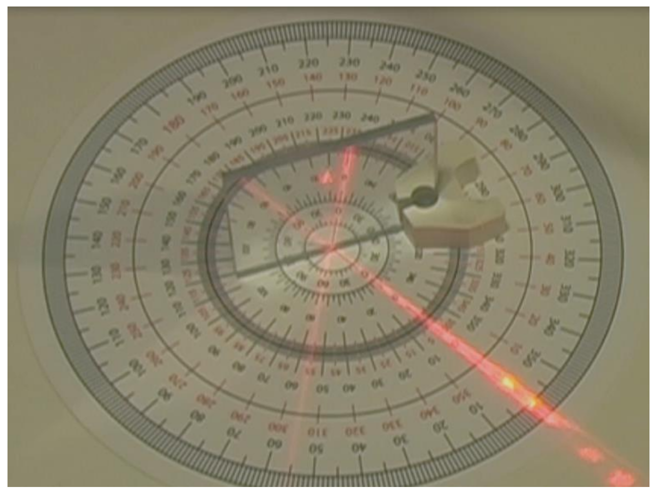
If there is not enough light coming through work with, widen the slit a little by rocking the knife back and forth slightly. If that still doesn't let through enough light, use a brighter flashlight and/or cut a second or third slit in addition.

Hint: If you make a mistake and cut your slit too large, simply cover it with duct tape (or similar) and then make your new cut through the tape itself.

Once you have a light source (either laser or flashlight), and you've made sure that you can see the beam, it's time to do a test run with one of your targets and a protractor.



Choose an easy target to work with, like a mirror. Set it a mirror so that the light reflects off the mirror and you can see both the incoming beam and the reflected beam. Place the mirror on the center hole (origin) of the protractor (as shown in image right).



Turn down the lights and using your light source, bounce the beam of light off the mirror. Orient the mirror and light source so it's easy to read the reflected angle on the protractor.

Practice reading the angles with different reflective targets. You'll find some produce easier reflections to read than others.

Select three targets you want to use. You may use up to two of the same types of targets (like two mirrors).

Which types of targets are you going to use in your maze? List them here:

STEPS: Now it's time to make your maze!

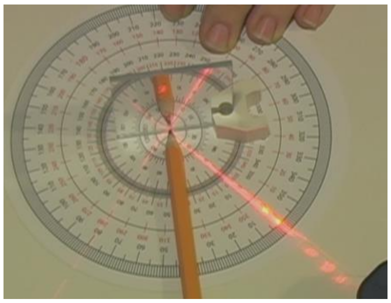
1. Design and build your maze using your light source and three different targets (not including the endpoint).
2. Think about the best way to get through your maze in a way that is easy for you to measure line length and refleted angles.
3. Once your maze is complete, take a picture of the maze with the lights on and also with the lights off. See if you can get the beam of light to show up in the dark image.
4. In the space provided below, make a scale drawing of your light maze, labelling all line lengths and angles. You'll want to include enough detail so that I could make this same exact maze just by looking at your drawing.

THE MATH:

To get your light beam through the maze, you need to change the angle of the path that it takes. You can do this by either *reflecting* the angle or *refracting* the angle. Let's find out which one you used in your light maze.

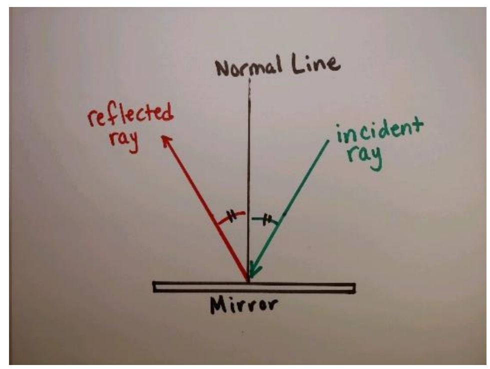
HINT: I've provided videos that walk you through each of these, so please watch the videos that go with this lab if you haven't yet. They will make everything a lot more clear!

Reflected Angles



A *reflected* angle happens when a ray of light bounces off a flat mirror. The light approaching the mirrir is known as the *incident ray* and the ray leaving the mirror is the *reflected ray*. The *normal line* is perpendicular to the surface of the mirror.

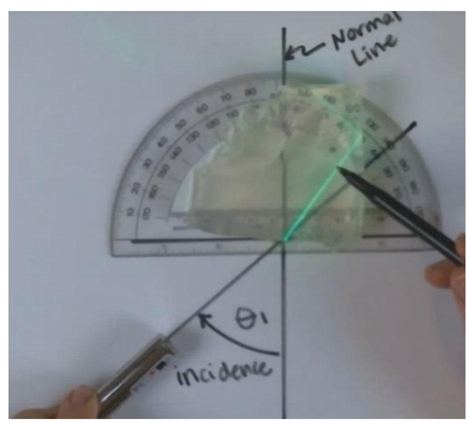
The important concept to note here is that the angle measured between the normal line and either one of the rays are identical.



With the mirror on the protractor's origin, rotate the mirror a little each direction and notice what happens to the reflected ray and how both angles change to match each other.

Refracted Angles

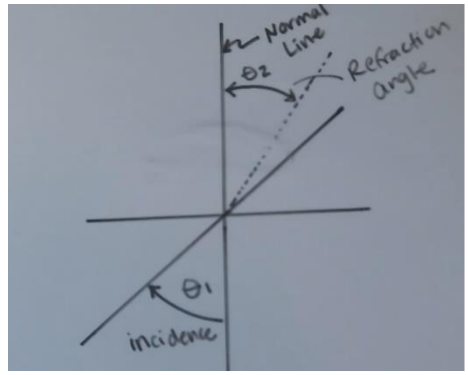
Another way to change the angle that the light takes is by passing it through a transparent object, like a prism or a piece of glass (like a microscope slide).



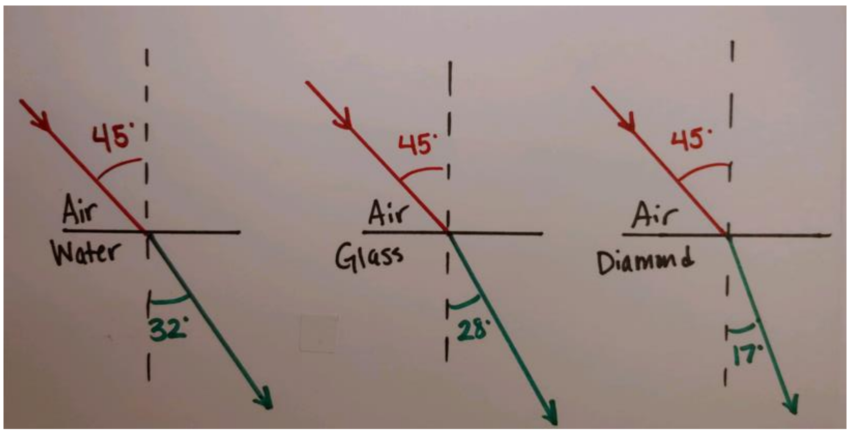
When light passes a boundary between two different substances, like going from air into water, the light will change both speed and wavelength.

When light crosses into a new type of material, it will either speed up or slow down and also tranform into a wave with a larger or shorter wavelength. This is called *refraction.*

A *refracted* angle bends the light because light is changing what it is traveling through. In the image at the right, the green laser beam changes angle when it hits the clear gelatin. It turns a little bit counterclockwise toward the *normal line*.



How much light bends when it crosses into a new substance depends on where it was coming from and what it's going into. The amount it bens can be found by taking the difference between the angle of refraction and the angle of incidence (incoming angle).



In the space below, you will make a drawing similar to the one shown here at the left.

Let's measure how much the angle bends when it crosses a boundary.

What are three transparent objects you want to use for this part of the lab?

If the room is dark enough and your light is bright enough, you may notice that while most of the beam bends as it moves from air to water, some of it also reflects off the surface of thw water! You can use this image below (or take your own photo).

Measure three of the angles in the image and label if the light is being reflected or refracted.

Think about your light maze. How can you use this idea about *reflection – refraction* as a "beam splitter" in your light maze? Is there a way you can use it as the first target and make a light maze with *two* paths through the maze? Sketch out your ideas here:

BONUS CHALLENGE! Snell's law for Refraction

In physics, we use the Snell's Law equation to determine how much bend there will be with the light if we already know the two substances (mediums) that the light will be traveling through.

In our example, we have a cup of water. We will aim a laser beam down toward the surface of the water. Where does the beam go?

Since the light is passing from a medium where it travels faster than the one it's going into, the light will angle *toward* the normal line. Once the light ray enters the water, it travels in a straight line until it crosses another boundary.

When scientists first did this experiment, they measured both angles and plotted the results on a graph to see if there was a relationship between the two angles… and there is!

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

n_1 = incident index

n_2 = refracted index

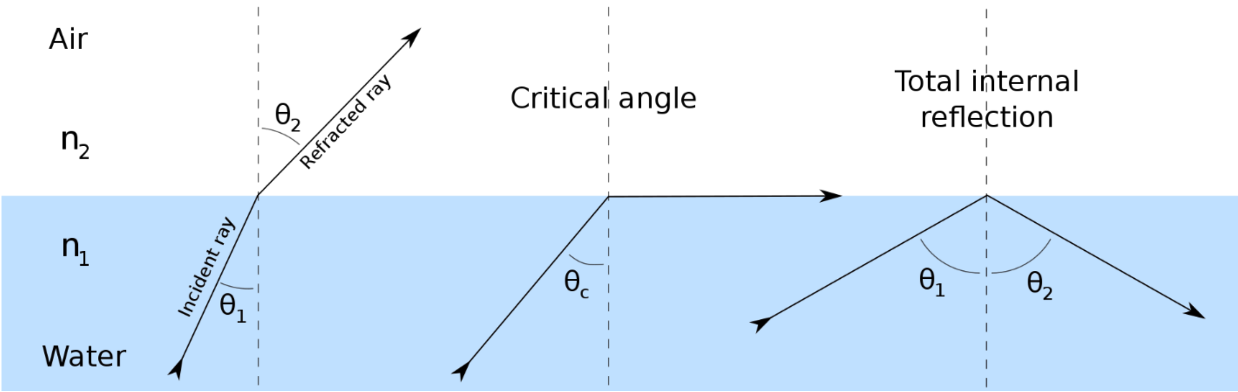
θ_1 = incident angle

θ_2 = refracted angle

The value of *n* for water is 1.33, and for air is 1.0. If light is coming in at 45°, what is the refracted angle in the water? Draw and label both rays of light with their appropriate angles:

Now shine the laser up through the bottom of the cup, and notice what happens when it hits the surface of the water.

Depending on how steep your incident angle is, the light will either bend as it moves into the air, or move along the boundary between the two mediums (this is called the *critical angle*), or bounce off the underside and stay in the water.



Can you do this with your light and cup of water? Can you get all three to occur? If so, what do you measure for your *critical angle*? (HINT: A critical angle is the largest angle that the light can refract before turning into a total internal reflection angle.)

Draw and label both rays of light with their appropriate angles:

You can calculate the critical angle if you know what both mediums are using this equation:

$$\theta_{critical} = \sin^{-1}\left(\frac{n_{refraction}}{n_{incident}}\right)$$

What angle did you measure the water-air experiment on page 11?________________

Using the equation above, what is the critical angle?

How close is your result to what you measured on the previous page?

What do you expect the critical angle to be if we substitute cooking oil (*n* = 1.467)?