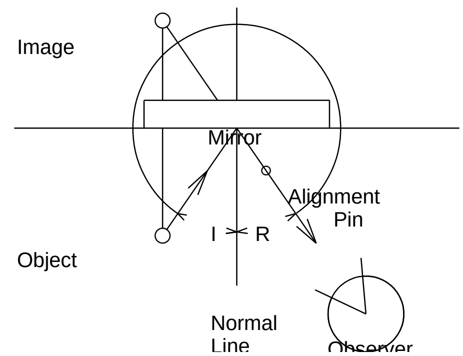
15055 Optics Materials

Purpose:
To investigate the properties of reflection, refraction, and lens optics.

Accessories:
Graph paper (rectangular and polar grid)
Cardboard
Paper tape
Cardboard barrier with circular hole
Battery or 1.5 volt power supply
Grease pencil or overhead projector pen
Tape

Reflection:
Required Materials:
Plane mirror Cardboard sheet
White paper Protractor
Plasticine Pins
Tape

Begin by drawing two mutually perpendicular lines through the middle of a sheet of plain white paper and tape this on top of a piece of cardboard sheet. Using a grease pencil or an overhead projector pen, mark a thin line across the width of the mirror somewhere near the middle of the mirror's length. Align the back surface of the mirror with one of the perpendicular lines, then center the line on the mirror with the second line on the paper as shown. Use some plasticine to hold the mirror in position.



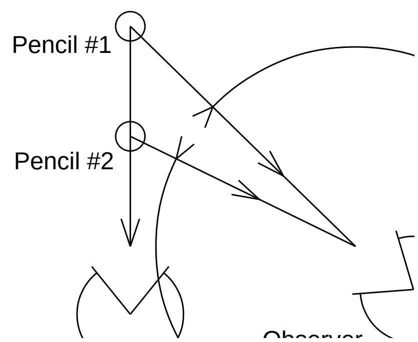
Suppose you look at the image of a pin in a mirror with one eye. You have no way of telling where the light rays reaching your eye hit the mirror. However, if the mirror has a line drawn on it, and you move your head until you see that the image is lined up with the mark, then you know how the light from the pin reached your eye; it first left the pin (object) and traveled in a straight line to the mark, and was then reflected from the mark directly to your eye. To get a permanent record of the direction of the reflected ray, you can place a second pin in line between your eye, the mark, and the object pins' image in the mirror. That is, the image of the first pin, the line drawn on the mirror, and the second pin will all be in line. The angle between the incident ray and the line perpendicular to the mirror (normal to the mirror) is called the angle of incidence. The angle between the reflected ray and the mirror's normal line is called the angle of reflection. The purpose of this experiment is to study the relation between these two angles.

To get an accurate measurement of the angle of incidence, where should you place the first pin (the object pin)? Close to, or far from the mirror? Does the same reasoning apply to positioning the second pin (the sighting pin)? Try several different distances.

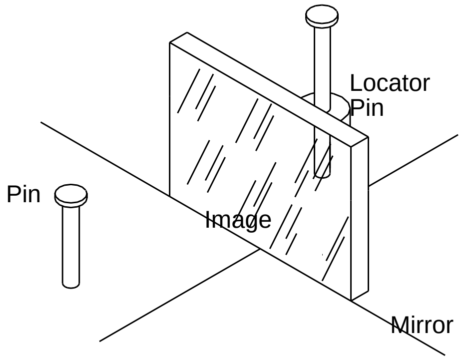
After choosing a suitable distance from the mirror, begin collecting data by sticking the object pin into the cardboard base and aligning the sighting pin with the mark on the mirror and the image of the object pin. Label these points as O1 (Object, trial 1) and S1 (Sighting, trial 1). Repeat this procedure for several different locations of the object pin. Draw lines connecting the mark on the mirror with the first position of the object pin and with the first position of the sighting pin. What do these lines represent?

After drawing the corresponding lines for the other positions of the pins, you can measure the angle of incidence and the angle of reflection for each position of the object pin. Make a graph of the angle of reflection as a function of the angle of incidence. What simple relation exists between the angle of incidence and the angle of reflection?

Images Formed by a Plane Mirror:
Required Materials:
Plane mirror Cardboard sheet
White paper Protractor
Plasticine Pins
Tape Two pencils



Hold a pencil vertically at arm's length. In your other hand, hold a second pencil about 15 cm closer to you than the first. Without moving the pencils, look at them while you move your head from side to side. Now bring the pencils closer together and observe the apparent relative motion as you move your head. This apparent motion of the pencils is known as parallax. As you move the pencils closer and closer together, the amount of parallax will become smaller and smaller. Where must the pencils be if there is to be no apparent relative motion, that is, no parallax between them?



You can use parallax to locate the image of a pin seen in a plane mirror. Support a plane mirror vertically on the table using a small amount of plasticine. Stick a pin into the cardboard about 10 cm in front of the mirror. Stick a second pin into the small end of one of the cork stoppers; this will be our locator pin. Where do you think the image of the pin is? Move your head from side to side while looking at the object pin and the image. Locate the position of the image by placing the locator pin (cork and pin) behind the mirror and moving it around until there is no parallax between the locator pin and the image. When the locator pin is correctly positioned, it will always line up with the image in the mirror regardless of the observer's position. Locate the position of the image for several different positions of the object pin. Don't forget to label the positions of the object pin and the image (position of the locator pin)! In each case, where is the image located with respect to the object pin and the mirror?

You can also locate the position of an object by drawing rays that show the direction in which light travels from the object to your eye. Stick a pin vertically into a piece of paper resting on a sheet of cardboard. This will be the object pin. Establish the direction in which light comes to your eye from the pin by sticking two additional pins into the paper along the line of sight. Your eye should be at arm's length from the pins as you stick them in place so that all three pins will be in clear focus simultaneously. Look at the object pin from several widely different directions and, with more pins, mark the new lines of sight to the object pin. Where do these lines intersect? You can use the same method to locate an image.

On a fresh piece of paper, locate the position of the image of a pin seen in a plane mirror by tracing at least three rays from widely different directions. Mark the position of the mirror before removing it. Where do the lines of sight converge? Draw rays showing the path of the light from the object pin to the points on the mirror where the light was reflected to your eye. Is the point of convergence the position of the image? How can you tell. Arrange two mirrors at right angles on the paper with a pin as an object somewhere between them. Locate all the images by parallax. From what you have learned about reflection in this experiment, show that these images are where you would expect to find them.

Refraction:
Required Materials:
Polar graph paper
Cardboard sheet
Clear semicircular dish
Protractor
Water
Pins
Tape

It is convenient to study the refraction of light in terms of the angle of incidence and the angle of refraction. When light passes from air into water, for example, the angle of refraction is the angle between a ray in the water and the normal to the water surface. In this experiment we shall try to find the relation between this angle and the angle of incidence.

Use a pin to scratch a vertical line down the middle of the straight side of a semicircular transparent plastic box. Fill the box half full of water and align it on a sheet of polar graph paper resting on soft cardboard. Make sure the bottom of the vertical line on the box falls on the center of the graph paper. Stick a pin on the line passing beneath the center of the box at right angles with the flat side of the box as shown. Be sure the pin is vertical. Now look at the pin through the water from the curved side and move your head until the pin and the vertical mark on the box are in line. Mark this line of sight with another pin.

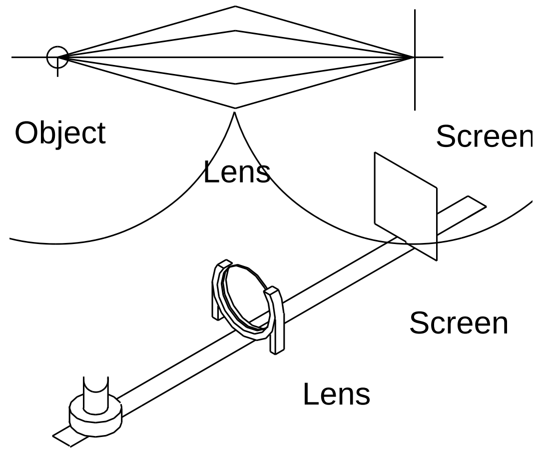
What do you conclude about the bending of light as it passes from air into water and from water into air at an angle of incidence of 0 degrees.

Change the position of the first pin to obtain an angle of incidence of about 10 degrees. With the second pin mark the path of light going from the first pin to the vertical line on the box and through the water. Repeat this for angles of incidence up to about 80 degrees. To insure a sharp image of the first pin at large angles, it should never be placed more than 4 cm away from the vertical line on the box. It may be necessary to move the first pin closer to the vertical line at large angles of incidence to get a sharper image of the pin. The pin holes make a permanent record of the angles. Is the difference between the angles of incidence and of refraction constant?

Plot the angle of incidence (I) as a function of the angle of refraction (r). (the fact that the angle of incidence in this experiment is the independent variable need not bother you.) Is the ratio of angle (I) to angle (r) constant over any part of the graph? If so, express the relation between (I) and (r) as an equation. Is the path of the light through the water reversible? Investigate this with your apparatus. Plot sin(I) as a function of sin(r). What simple mathematical relationship do you think best describes the refraction of light over the whole range of angles of incidence?

If time permits, repeat the experiment with a different liquid. Again, plot the angle of incidence as a function of the angle of refraction. Does this liquid refract light differently than water?

Images Formed by Lenses:
Converging lenses, Required Materials:
Converging lens
Lens holder
Light w/socket
Meter stick
Tape
Paper tape
White card



Look through a converging lens at an object. Is the image you see larger or smaller than the object? Is it right side up or upside down? Do the size and position of the image change when you move the lens with respect to the object? To investigate the images formed by a converging lens, arrange a lens and a lighted flashlight bulb on a long strip of paper as shown. Start with the bulb at one end of the paper tape and locate its image by using a small white card as a screen. Is the image right side up or upside down? Now move the object toward the lens in small steps, marking and labeling the position of both the object and image as you go. Continue this until the image moves off the end of the tape and can no longer be recorded (approximately 1 meter). How does the change in the position of the image compare with that of the object? Where on your tape do you expect the image to be when the object is at least several meters away? Check this experimentally. With the object far away, you may find it easier to locate its image on a piece of paper. When the object is very far away, the image will be located at the principal focus of the lens. How can you convince yourself that the lens has two principal foci, one on each side and at the same distance from the center of the lens?

Now place the bulb as close to the lens as possible, and again locate the image by parallax. Is the image upside down or right side up? Again move the object in small steps away from the lens, marking and labeling the positions of the object and image until the image is no longer on the tape. Measure S(o) and S(I), the distance from the principal foci to the object and image respectively, for the pairs of points. (The distance S(o) is measured from the principal focus on the object side of the lens, and S(I) is always measured from the principal focus on the opposite side from the object.) Since S(I) clearly decreases when S(o) increases, try plotting S(I) as a function of 1/S(o). What can you conclude about the mathematical relation between S(o) and S(I)? Where will the image be if the object is placed at the principal focus? Can you see it?

Diverging lenses, Required Materials:
Diverging lens
Lens holders
Converging lens
Meter stick
Tape
Paper tape
White card
Light w/ socket
Opaque card w/small hole

You can investigate the properties of a diverging lens by observing its effect on a parallel light beam. You can use a light bulb placed at the principal focus of a converging lens to get the parallel beam. It is best to work with a narrow beam which you can get by mounting the converging lens directly behind a barrier with a circular hole. The barrier can be supported by a small piece of plasticine.

Now let the parallel beam pass through the diverging lens and strike a piece of paper. Measure the diameter of the light circle for different distances from the paper to the lens. Plot the diameter of the circle as a function of the distance from the lens. From the graph, can you find the principal foci? Can you get a magnified image from a diverging lens? Can you get a real image with a diverging lens?

Time Allocation:
To prepare this product for an experimental trial should take less than ten minutes. Actual experiments will vary with needs of students and the method of instruction, but are easily concluded within one class period.