Lifelong Learning Programme

Unit Title	Forming Images
Topic	Physics - Light and optics
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Aims of unit	Students will understand how images are formed in a flat mirror.
Indicative content	Light reflects from a shiny surface in a specific direction so that the reflected angle is equal to the incoming or incident angle. Light spreading out from a point on a source reflects from the flat mirror and then spreads out further so as to appear to come from another point on the other side of the mirror called the image point. The image point is the same distance behind the mirror as the source point is in front of the mirror.
Resources needed	All of the materials are simple and can be purchased at a home improvement store.
Teacher notes	This unit is based on a series of laboratory investigations. Students should work in cooperative groups of 3-4 students. The activities require only simple mathematics and focus primarily on qualitative understanding of the content.

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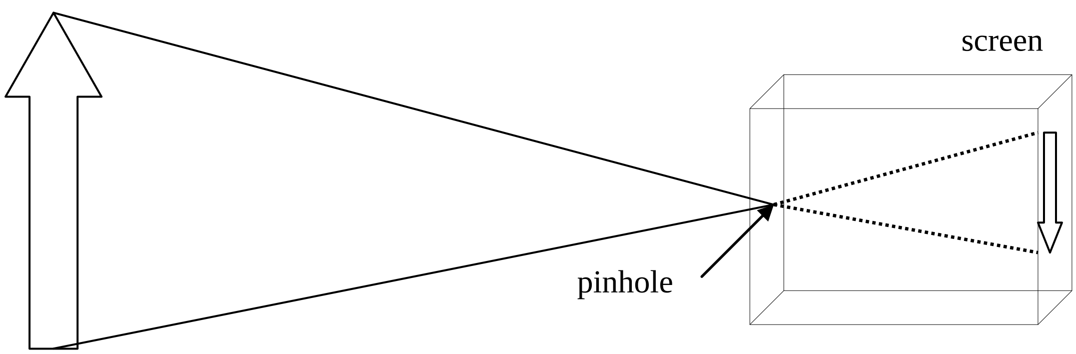
Optics – Forming Images

In today's lab, you will begin our investigation of how light forms images. First, you will build and investigate a pinhole box, in which the straight line motion of light rays results in images. Then, you will investigate how the reflection of light rays from smooth surfaces can also form images.

LESSON 1: PINHOLE BOX

A pinhole box can be constructed by passing light rays through a tiny opening (a pinhole) in a box or tube. The light rays then form an image on a screen placed inside or at the back of the box. Large boxes and long cardboard tubes will make excellent pinhole boxes or tubes. This is called a pinhole camera.

You will be using a large, long box for your pinhole box. One end of the box has a large hole, while the other end has a small hole. This box has a movable screen so that you can study the effect of placing the screen at different distances from the hole. A diagram of the pinhole box is shown below.



The "object" that you will view with our pinhole box is a pyramid of light bulbs on the other side of the room. Note that the pyramid is asymmetrical. Anything that is brightly illuminated can serve as an object.

In some of the lab instructions below, you will be asked to measure the size of the image, as we wish to find out what this size depends on. For consistency, you should measure the distance between the centers of 2 circles of light:

This is a good measurement:

This is not a good measurement:

1. Tape a piece of aluminum foil over the small hole in the end of the box. Use a pin to poke a small hole in the foil. Place the moveable screen in the center of the box.

Position the box so that the pinhole is aimed at the “object”, and look through the large hole in the opposite end of the box. You should be able to see an image of the object appear on the screen. You may need to move around a bit, so that the pinhole, screen, large viewing hole and your eyes are all aimed at the pyramid. You will also need to look carefully, as the image may be faint.

If you have difficulty getting your ruler into the box, just place a scrap of paper next to the screen, mark the locations of the light centers on the scrap, remove the scrap, and then measure the distance.

Q1: Draw a sketch of your observations below. Approximately how big is the image?

Is the image right-side up or upside down? Why do you think this is so?

Is the image left-right correct or left-right inverted? Why do you think this is so?

2. You now want to determine if the size of the pinhole affects the size of the image. Place the box in a location that can be easily reproduced. Position the screen at the back of the box. Record the size of the image.

Image size =

Use a nail to enlarge the pinhole in the aluminum foil. Do not make a second hole; just gently push the nail through the existing hole to make it larger! Replace the box in its location, with the screen at the back of the box. Record the size of the image.

Image size =

Q2: How does the size of the pinhole affect the size of the image?

How does the size of the pinhole affect the brightness of the image? Why?

How does the size of the pinhole affect whether the image is right-side up or upside down? Why?

3. You next want to investigate how the location of the pinhole and the location of the screen affect the size of the image we observe on the screen. Place the screen at the center of the box, and place the box in a reproducible position. Record the size of the image below:

Size of image =

Keep the box in this same position, while you slowly move the screen closer to the pinhole.

Q3: What happens to the image? Does the image get bigger or smaller?

4. Keep the box in its same position, and move the screen farther from the pinhole than in step #3.

Q4: What happens to the image? Does the image get bigger or smaller?

5. Return the screen to its original location in step #3. Keep the screen in this location and move the entire box closer to the object than in step #3.

Q5: What happens to the image? Does the image get bigger or smaller?

6. Keep the screen in the same location, and move the entire box farther from the object than in step #3.

Q6: What happens to the image? Does the image get bigger or smaller?

Q7: Answer each of the following questions with the best choice of: gets larger, gets smaller, stays the same.

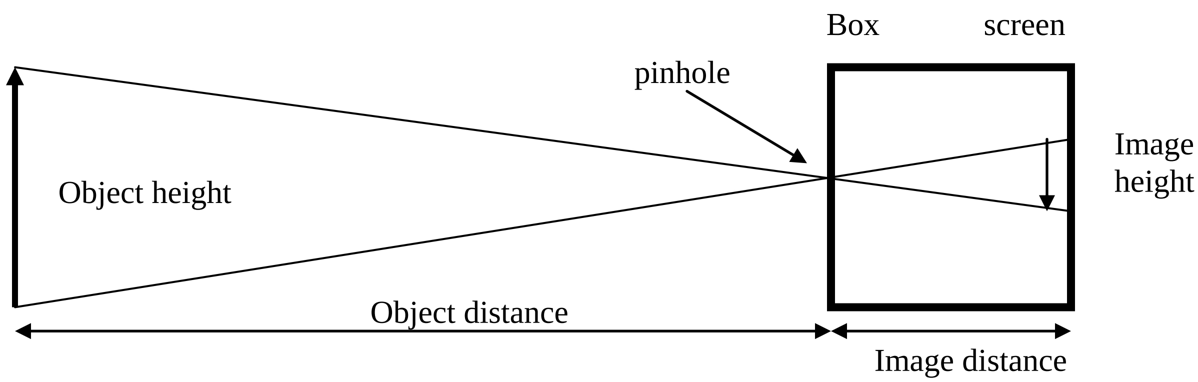
The size of the image ____________________________ if the pinhole is not moved, and the screen is moved farther away from the pinhole.

The size of the image ______________________________ if the pinhole is not moved, and the screen is moved closer to the pinhole.

The size of the image ______________________________ if the screen is not moved, and the pinhole is moved farther away from the object.

The size of the image ______________________________ if the screen is not moved, and the pinhole is moved closer to the object.

7. Many of the properties of a pinhole box can be understood with geometry. The picture below shows how light from the object produces an image. Notice that there are two triangles: one triangle involves the object and the pinhole, while the other triangle involves the pinhole and the image. These are similar triangles, and so are related to one another.



$$\frac{\text{length of big triangle}}{\text{height of big triangle}} = \frac{\text{length of small triangle}}{\text{height of small triangle}}$$

$$\frac{\text{object's distance}}{\text{object's height}} = \frac{\text{image's distance}}{\text{image's height}}$$

Adjust the screen so that it is 40 cm from the pinhole. Measure the height of the object, i.e. the center-to-center distance between the circles of light.

Measured height of object =

Now measure the height of the image, i.e. the center-to-center distance between the circles of light. It is important that you employ the same criterion for determining the size of the object and for determining the size of the image. (It is difficult to measure distances in the dark, but please do your best and be as careful and consistent as possible!)

Measured height of image=

Use the geometric relationship above to determine the distance from the object to the pinhole, and record this below:

Predicted distance of object=

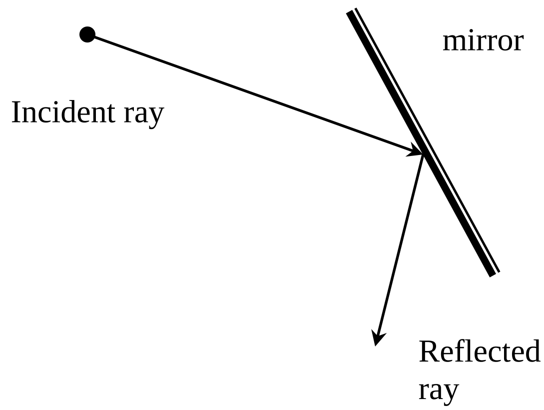
Q8: Do your results agree within reason? Explain. What was the main source of experimental uncertainties, and how could these have been minimized?

Q9: Would it ever be possible to construct a pinhole box in which the size of the image was actually larger than the size of the object? Explain why or why not. Include a sketch to indicate why this is so.

LESSON 2: HOW DOES LIGHT REFLECT FROM A FLAT MIRROR?

The worksheet for this activity is located at the end of the lab report. You will need to attach the completed worksheet to the lab report before you hand it in.

In this activity, you will use a narrow light beam and a mirror to investigate the properties of reflection. Direct the bean of light toward the mirror. The angle of incidence is measured from the mirror to the incident ray. The reflected ray is measured from the mirror up to the reflected ray.



Notice that the angle of incidence is defined as the angle between the mirror and the incident ray, while the angle of reflection is defined as the angle between the mirror and the reflected ray.

1. Place the front of the mirror over the position shown on your worksheet. Position everything so that the ray hitting the mirror follows the path shown on the sheet. Use a pencil and ruler to draw the path of the reflected light ray. (Since the ray may be a little wide, you will want to draw the line in the center of the light ray which you observe.)

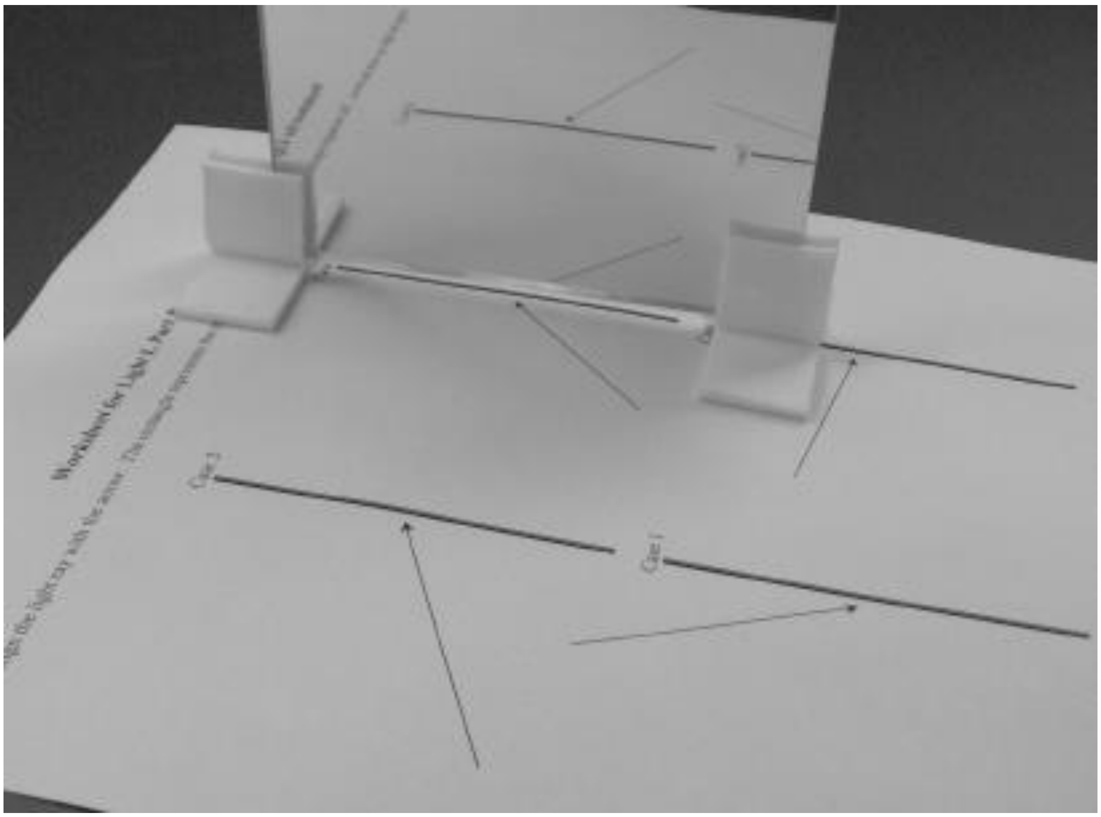
2. Repeat this for the other mirror positions and paths of incoming light rays.

3. Next, use your protractor to measure the angle of incidence (the angle between the incident light ray and the mirror) and the angle of reflection (the angle between the reflected light ray and mirror.) Record these angles below.

Case #	Angle of incidence	Angle of reflection
1		
2		
3		
4		

Q1: What pattern do you observe? Write a one-sentence rule concerning the relationship between the angle of incidence and the angle of reflection.

Q2: A light ray hits a mirror traveling perpendicular to the mirror. What happens to the light ray when it reflects? What was the angle of incidence? What was the angle of reflection? Draw this situation, and use arrows to indicate direction.



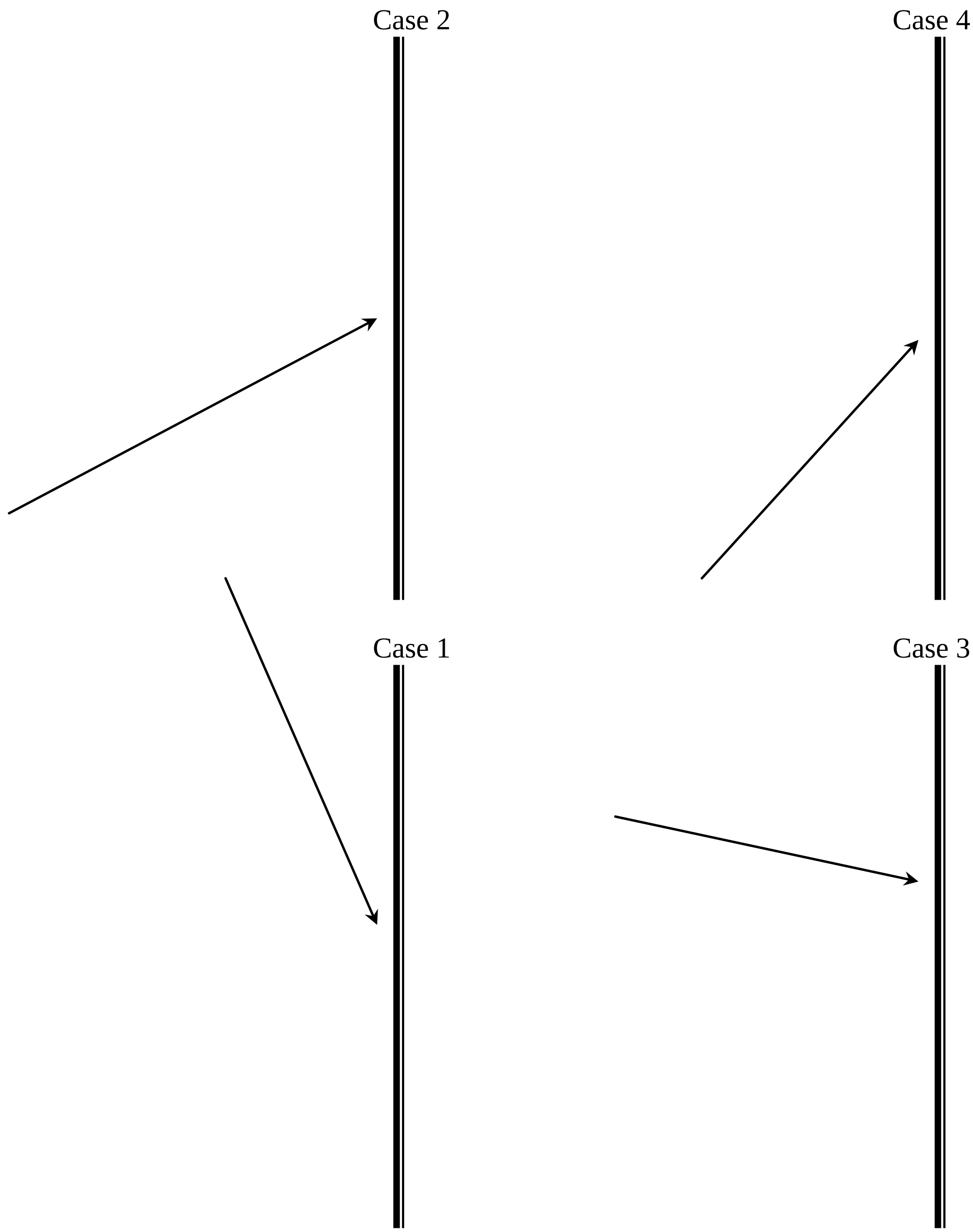
Prediction: Check your method for predicting the path of the reflected light ray. Draw a mirror position on a separate piece of paper and an incoming light ray. (Your incident light ray should not strike the mirror perpendicular to the mirror!) Use your earlier results to predict the direction of the reflected ray. Draw this as a solid line.

Note that predictions are not just guesses. Use all of your knowledge and the equipment at your table to come up with the best idea. You may use a protractor to predict a reflected ray.

<u>Test Your Prediction</u>: Use your equipment to test these predictions. Were you correct? If not, draw (as a dashed line) the actual path of the reflected ray; why do you think your initial prediction was not correct.

Worksheet for Lesson 2

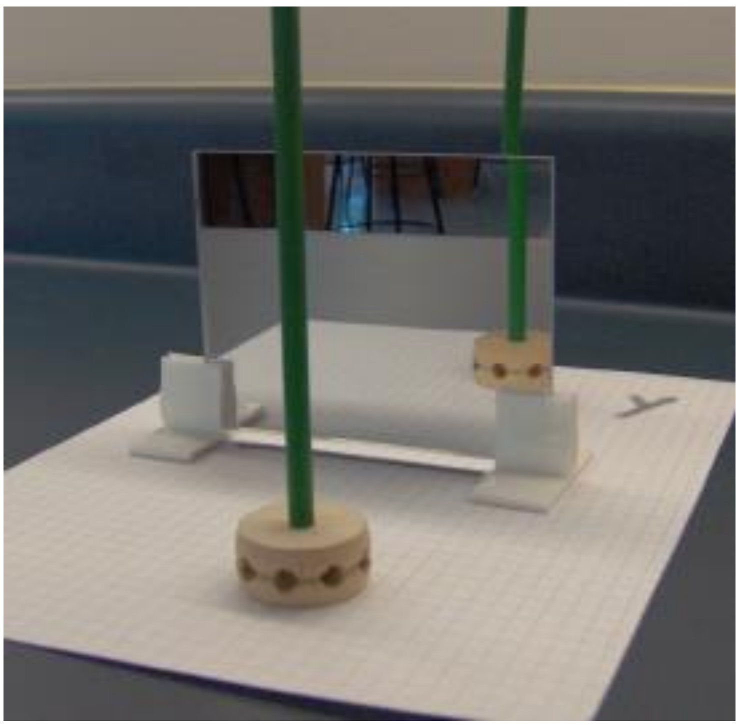
Align the light ray with the arrow. The rectangle represents the mirror. Be accurate!!



LESSON 3: HOW ARE IMAGES FORMED IN A FLAT MIRROR?

At the end of lesson 2, you prepared a one-sentence rule about the relationship between the angle of incidence and the angle of reflection. If you were precise in your measurements, you probably concluded that the angle of incidence was equal to the angle of reflection. You discovered the Law of Reflection. The only difference between what you did and scientist is that scientists measure the angle not from the surface of the mirror but rather from an imaginary line called the normal. The normal is at a 90* angle to the surface of the mirror. The following activities are designed to further investigate the properties of images formed by a flat mirror.

1. Position a mirror to stand in the middle of a piece of narrow lined paper, so that the front of the mirror occurs on one of the lines. Draw a straight line along the front of the mirror so that the position of the mirror is accurately recorded. We will be using the lines of the paper to measure distances in front of and behind the mirror; for a more accurate measurement, you could replace the lined paper with plain paper and use a ruler.



2. Prepare two post-and-wheels, which we will call X and Y. Place post-and-wheel Y at some distance behind the mirror, so that the post is directly over a line of the paper.

Place post-and-wheel X in front of the mirror. Adjust the position of X so that when you look at the mirror from any angle, it appears as if there is only one post, which has a top section that is real and belongs to Y, and has a bottom section that is an image of X. You will have found the correct position of X when you can move your head from side to side, and still see only one post. The position of X will be measured by comparing the post to the lines on the paper.

Q1: Count the lines on the paper, starting from the front of the mirror and answer the Following questions:

What is the distance of X in front of the mirror?

What is the distance of Y behind the mirror?

3. Report this for another distance, either closer to or farther away from the mirror.

Q2: What is the distance of X in front of the mirror?

What is the distance of Y behind the mirror?

Q3: Based on your observations, state a general rule for where the image of an object is located compared to the surface of the mirror.

Prediction 1: Suppose post A is placed 6 spaces behind the mirror, and post B is placed 9 spaces behind A and thus farther from the mirror. How far in front of the mirror should post C be placed so that its image is superimposed on post A? How far in front of the mirror should post D be placed so that its image is superimposed on post B?

Test Your Prediction: Try this out. Were you correct? Explain.

LESSON 4: HOW ARE IMAGES FORMED BY A FLAT MIRROR?

In this activity, we will use the Law of Reflection (which you discovered in the lesson 2) to understand how images are formed by a flat mirror.

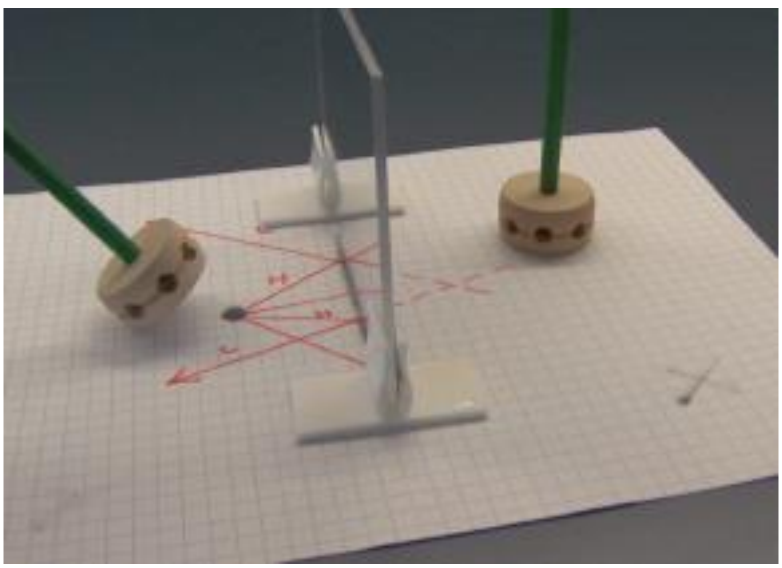
YOU MUST COMPLETE SECTIONS 1-7 BEFORE COMING TO LAB. BRING YOUR COMPLETED PREDICTIONS FOR THE DOT AND TRIANGLE TO LAB, WHERE YOU WILL TEST THEM.

1. Place a mirror on a piece of paper, and draw a straight line representing the location of the front surface of the mirror. Draw a dot about 6 cm in front of the mirror; the dot represents the location of an object. Remove the mirror.

2. Use your ruler to draw five straight lines starting at the dot and hitting the mirror line at five different positions. These are some of the paths taken by light rays from an object at the dot. Use different colored pencils to distinguish among the five rays.

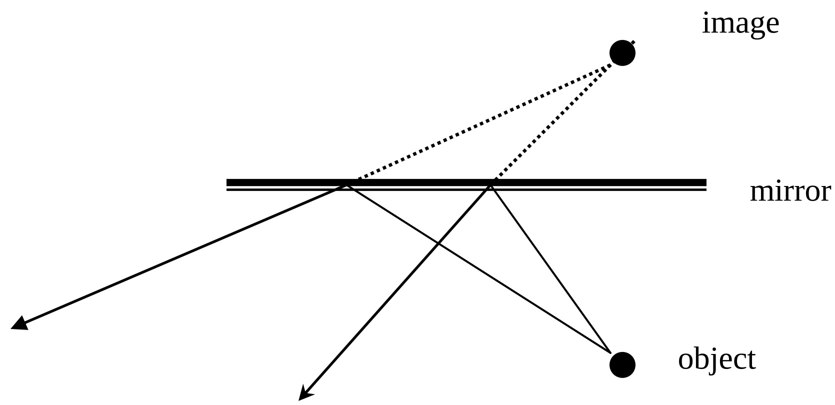
3. Use your ruler and protractor to draw the path taken by the reflected light ray in each of the five cases.

4. Place an "I" by each ray that would be incident on the mirror. Place an "r" by each ray that would be reflected from the mirror. Draw an eye by each ray that enters your eye.



The reflected rays enter your eyes coming from different directions. Your brain knows that theses rays came from a single object, and so extends back the direction of each ray along a straight path until it finds the point where the extended rays all intersect. The brain then believes that this intersection point is the location of the object from which these rays originated. This is the location of the image. Let's carry out what the brain does.

5. Extend back each of the reflected light rays into the region behind the mirror. You should draw these paths as dashed lines with your colored pencils, since these paths do not represent paths taken by real light rays. Place an x at the location where the dashed lines intersect. This is your prediction of where the image should be located. This is why the brain thinks that the object is located behind the mirror.



6. Repeat this activity with a triangle. Draw a line representing the front surface of a mirror. Draw a triangle, such that none of the sides or vertices of the triangle touch the mirror.

Carefully predict the location and shape of the triangle's image by drawing at least 3 rays from each vertex of the triangle: as before, draw the incident rays, the reflected rays, and (as dashed lines) the extensions of the reflected rays behind the mirror. Once you have predicted the locations of the images of the three vertices, then you can connect the vertices to show how the image should appear.

Bring your completed predictions for the dot and triangle to lab.

7. You are now ready to check your predictions of what the image should look like and where it should be located.

<u>Test Your Prediction for the Dot, Method 1</u>: Place the mirror so that its front surface is along the line you drew. Check your prediction of the image's location by placing a wheel-and-post at the location of the large dot, and use another wheel-and-post to find the location of the image. Mark this location with a red pencil. Does this agree with your prediction? Explain.

<u>Test Your Prediction for the Dot, Method 2</u>: You will use a half-silvered mirror for method 2. The half-silvered mirror reflects some light (and so behaves like a mirror) and allows other light to pass through (and so you can see behind the mirror). Place the half-silvered mirror so that its front surface is along the line you drew. Look through the mirror and see the image of the large dot. Does this actual image agree with (i.e. lie on top of) your predictions? Explain.

<u>Test Your Prediction for the Triangle</u>: Check your prediction by placing a half-silvered mirror with its front surface along the line. Look through the mirror and you should be able to see the actual image of the triangle as well as your predicted image. If these do not agree, use a red pencil to draw the actual image. Was your prediction verified by this test? Explain.

LESSON 5: HOW DOES A PERISCOPE HELP US TO SEE?

Periscopes are useful for reflecting light into your eyes, so that you are able to see something you would not normally be able to see. For example, the crew of a submerged submarine uses a periscope to see what is happening at the surface of the water in front of them. You can use a periscope for looking around corners or over walls without being seen. The basic periscope uses two mirrors.

VERTICAL PERISCOPE

You will design a periscope similar to what the submarine would use. We will call this type of periscope, periscope A. Put a lab stool on top of your lab table. Place a target like the wheel-and-post on the stool. Student #1 should sit on the floor, slightly in front of the table and facing the table. Student #1 should look straight ahead; the wheel-and-post is, of course, not directly visible to student #1. Now use the two mirrors, each of which is about 10 cm x 13 cm. Student #1 should hold one of the mirrors. Student #2 should hold the other mirror in such a way that Student #1 can see the wheel-and-post in the mirror, and so that the center of mirror #1 is directly below the center of mirror #2. This means that you should be able to connect the center of mirror #1 to the center of mirror #2 by drawing a vertical line.

Student #3 should use a protractor and plumb line to measure the tilt of each mirror.

Carefully draw the positions of the two mirrors. Be sure to indicate which way each mirror is tilting and which side of the mirror is reflecting light.

> **Q1:** What is special about the tilt of the mirrors and the position of one mirror relative to the other?

Q2: Draw light rays on your picture above that indicate how Student #1 is able to see the wheel-and-post. Place arrows on the rays to indicate the direction in which the light is traveling.

Q3: Is the image of the wheel-and-post right side up or upside down? Explain.

Next let's design a periscope which will allow us to see behind us. We will call this type of periscope, periscope B. Student #1 should turn around so that she or he is no longer facing the table, and should again hold one of the mirrors. Student #2 should hold the other mirror so that Student #1 is able to see the wheel-and-post in the mirror, and the center of one mirror is directly over the center of the other mirror.

Student #3 should use a protractor to measure the tilt of each mirror, and record these below. Again, carefully draw the positions of the two mirrors, and be sure to indicate which way each mirror is tilting and which side of the mirror is reflecting light.

Q4: What is special about the tilt of the mirrors and the position of one mirror relative to the other?

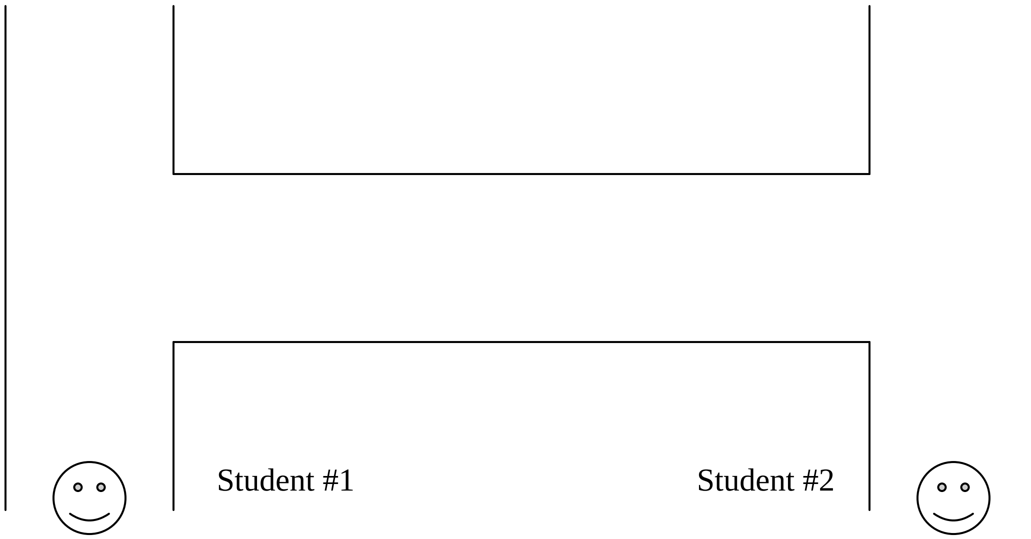
Q5: Draw light rays on your picture above that indicate how student #1 is able to see the wheel-and-post. Place arrows on the rays to indicate the direction in which the light is traveling.

Q6: Is the image of the wheel-and-post right side up or upside down? Explain, and note any differences with Q3.

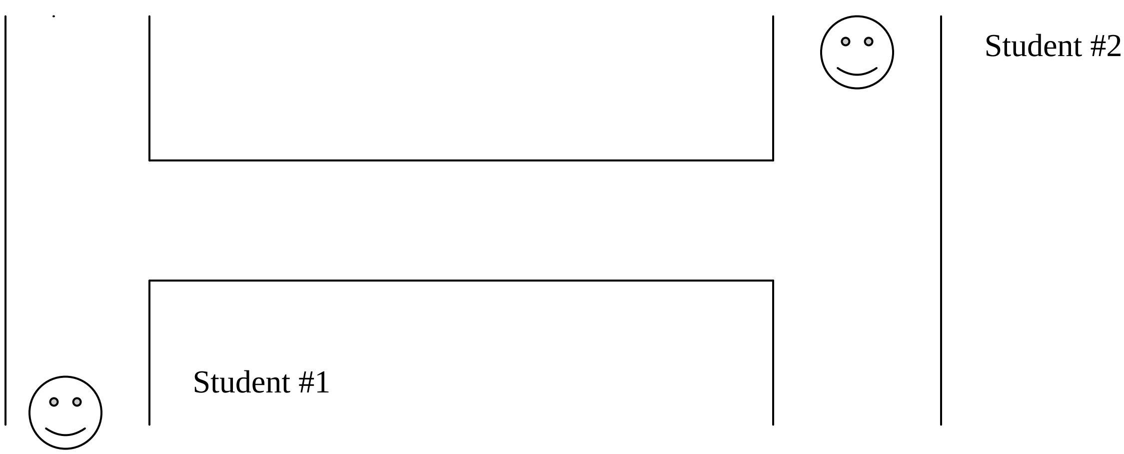
Q7: We recommended an optimum size mirror for this activity. Discuss what would probably have happened if you had used larger mirrors. Discuss what would probably have happened if you had used smaller mirrors.

HORIZONTAL PERISCOPE:

Prediction 1:A floor map is shown below. Student #1 is holding up his hand, with some number of fingers showing. Student #2 is in another corridor and cannot directly see student #1. Sketch below a "periscope" design using two mirrors that will allow student #2 to see the number of fingers held up. Is this a type A or type B periscope? Be careful to clearly indicate the location and exact tilt of each mirror? And indicate which side of the mirror is reflecting. Draw light rays on your picture above which indicate how student #2 is able to see the fingers. Place arrows on the rays to indicate the direction in which the light is traveling.



Prediction 2: A floor map is shown below. Student #1 is holding up his hand with some number of fingers showing. Student #2 is in another corridor and cannot directly see student #1. Sketch below a "periscope" design using two mirrors that will allow student #2 to see the number of fingers held up. Is this a type A or type B periscope? Be careful to clearly indicate the location and exact tilt of each mirror, and indicate which side of the mirror is reflecting. Draw light rays on your picture above which indicate how student #2 is able to see the fingers. Place arrows on the rays to indicate the direction the light is traveling.



Test Your Prediction 1: Borrow 2 large mirrors and find a section the lab or building that resembles the area in prediction 1. A line along the sides of the floor tiles, and which is parallel to a wall. The centers of the mirrors should be positioned at some point along this line. One student should portray student #1 and hold up some number of fingers. Two students should each hold a mirror in the predicted locations. A fourth student should portray student #2. Does this work? Comment.

Test Your Prediction 2: Now find a section of the lab or hallway that resembles the area in prediction 2. Again, the centers of the mirrors should be positioned somewhere along the floor-tile line. One student should portray student #1 and hold up some number of fingers. Two students should each hold a mirror in the predicted locations. A fourth student should be student #2. Does this work? Comment.

LESSON 6: WHAT PART OF A FULL-LENTGH MIRROR DO YOU NEED TO SEE YOURSELF?

Do you really need a mirror that extends from the floor to the ceiling if you want to see a complete image of yourself? How small a mirror could you purchase, and still be able to see your entire body?

1. Select a person, whom we will call person A. Measure A's "vital statistics" and answer the questions below.

> **Q1:** What is the height of person A?
>
> **Q2:** How far below the top of person A are her eyes located?

Prediction 1: Do you think A will need a mirror that is as tall as she is?

Prediction 2: Do you think the length of mirror that person A needs will depend on how far away from the mirror she stands?

2. A tall mirror is located in the lab room. Person A should stand at some distance from the mirror (any distance greater than 1 meter). Make sure that person A can see her entire image, and that the mirror is perfectly vertical and that person A stands perfectly vertical, and looks straight ahead.

> **Q3:** How far is person A standing from the mirror?

3. The other people should tape pieces of paper over the sections of the mirror that A does not need to see her entire image. Continue this until the only uncovered section of mirror is that which is needed by person A to see her image.

> **Q4:** How far above the floor is the top of the section of mirror needed by person A to see her entire image?
>
> **Q5:** How far above the floor is the bottom of the section of mirror needed by person A to see her entire image?
>
> **Q6:** What is the minimum length of mirror needed by person A to see her entire image?

4. Remove the papers from the mirror. Person A should now stand at least several feet behind her original position.

> **Q7:** How far is person A standing from the mirror?

5. Repeat the activity of covering the mirror until the only uncovered portion is the section of mirror needed by A to see her entire image.

> **Q8:** How far above the floor is the top of the section of mirror needed by A to see her entire image?
>
> **Q9:** How far above the floor is the bottom of the section of mirror needed by A to see her entire image?
>
> **Q10:** What is the minimum length of mirror needed by A to see her entire image?
>
> **Q11:** Do you think the length of mirror that A needs to see her entire image depends on how far away from the mirror she stands?
>
> **Q12:** Is there a relationship between where the top of the useful mirror section needs to be located and A's vital statistics? What is this relationship?
>
> **Q13:** Is there a relationship between the minimum length needed for the mirror and A's vital statistics? What is this relationship?

6. Now let's understand our observations by using ray diagrams. We will use the Law of Reflection (which you experimentally determined earlier) that states that the angle of reflection is equal to the angle of incidence. For our first diagram, assume that the person's eyes are located on the top of her head, and that she is 2 meters tall.

Draw the light ray which illuminates her foot, reflects from the mirror and enters her eyes; this is the light ray that allows the person to see her feet.

Draw the light ray which illuminates the top of her head, reflects from the mirror and enters her eyes; this is the light ray which allows the person to see the top of her head.

> **Q14:** Based on your diagram above, how far above the floor should the top of the mirror be placed so that she can just see the top of her head?
>
> **Q15:** Based on your diagram above, how far above the floor should the bottom of the mirror be placed so that she can just see her feet?
>
> **Q16:** Based on your diagram above, what is the minimum length mirror she needs to see her entire body? What is the relationship between this length and the height of her body?

7. For the second diagram, assume that the person's eyes are located 10 cm below the top of her head, and that she is 2 meters tall.

Draw the light ray which illuminates her foot, reflects from the mirror and enters her eyes; this is the light ray that allows the person to see her feet.

Draw the light ray which illuminates the top of her head, reflects from the mirror and enters her eyes; this is the light ray which allows the person to see the top of her head.

> **Q17:** Based on your diagram above, how far above the floor should the top of the mirror be placed so that she can just see the top of her head?
>
> **Q18:** Based on your diagram above, how far above the floor should the bottom of the mirror be placed so that she can just see her feet?
>
> **Q19:** Based on your diagram above, what is the minimum length mirror she needs to see her entire body? What is the relationship between this length and the height of her body?
>
> **Q20:** Does the minimum length mirror which you need depend on the distance of your eyes below the top of your head?
>
> **Q21:** Does the location at which you hang the minimum length mirror depends on the distance of your eyes below the top of your head?

Prediction 3: Now let's return to your colleague, person A. Use person A's vital statistics to mathematically calculate the following, and show your work.

> distance above floor of top of minimum length mirror:
>
> distance above floor of bottom of minimum length mirror:
>
> length of minimum length mirror:

<u>Test Your Prediction</u>: How doe your predictions above agree with your earlier observations? Comment.

> **Q22:** What should you consider if you want to buy a minimum length mirror, but there are several people of different heights in your family, and each person wants to see his or her entire image? And how should you hang this mirror?

Prediction 4: Select two of your colleagues who have very different heights. (Borrow someone from another lab group if necessary. We really want 2 people of very different heights!)

Record their vital statistics below. From these, predict the minimum length mirror needed so that each person can see his or her entire image, and how this mirror should be positioned on the wall.

Person B: height =   top of head to eyes =

Person C: height =   top of head to eyes=

prediction of top of mirror to floor =

prediction of bottom of mirror to floor =

prediction of mirror length?

Test Your Prediction: Cover the mirror to expose only the predicted area. Can your two colleagues see themselves fully in the mirror? Do they need the entire exposed area, or cold you cover more area?