Book 1
Light and Optics
Lab Activities

Table of Contents

Name____ Date____________________

Home Lab 1
Light Rays, Shadows, and Light Sources

Overview: Our first home laboratory investigation will be a study in how shadows and images are formed from apertures and objects. All you need to know to understand these phenomena is that light rays travel in straight lines and a little geometry. These phenomena can be observed in simple experiments performed with household materials.
To think about why shadows can sometimes look "fuzzy" and sometimes look very distinct – maybe we should go back and think about what we know about lunar eclipses (when the Earth throws its shadow of the Sun's light across the moon.

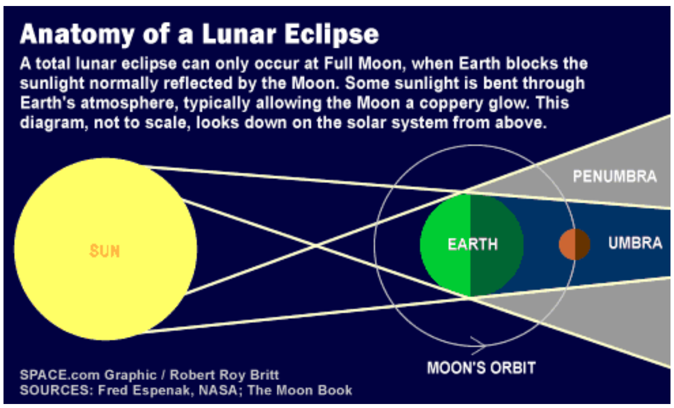


Figure 1.1

Since the Sun is not a point of light (but quite large), rays of light shining from both sides of the Sun cause two types of shadows during a lunar eclipse. Rays of light that are blocked almost parallel to the Earth and Sun axis form a darker shadow (in the umbra – all rays are blocked by the Earth). Rays of light that shine to the opposite side of the Earth are also blocked but the light rays from the Sun that shine more parallel are not blocked – thus there is a lighter shadow know as the penumbra in that region.

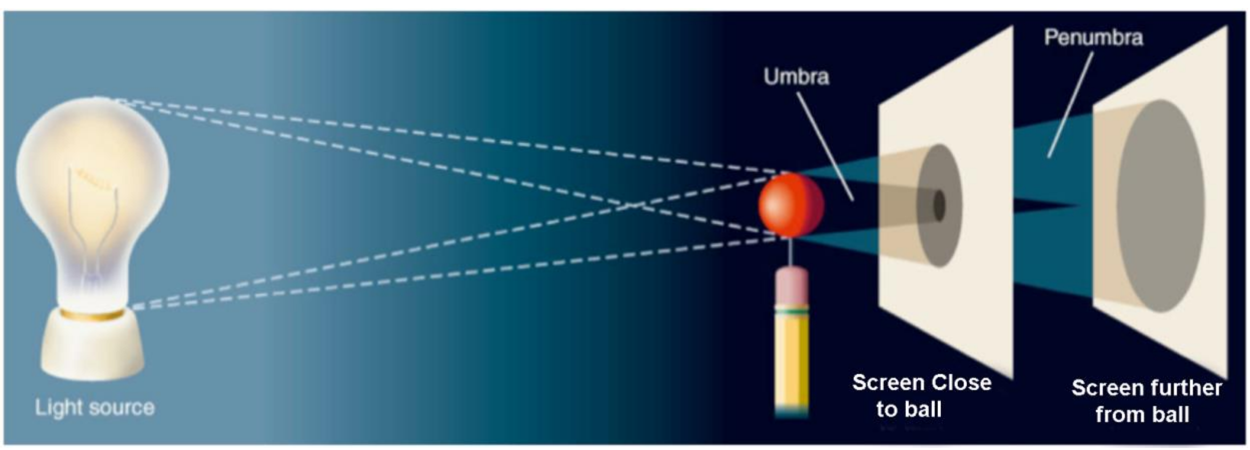
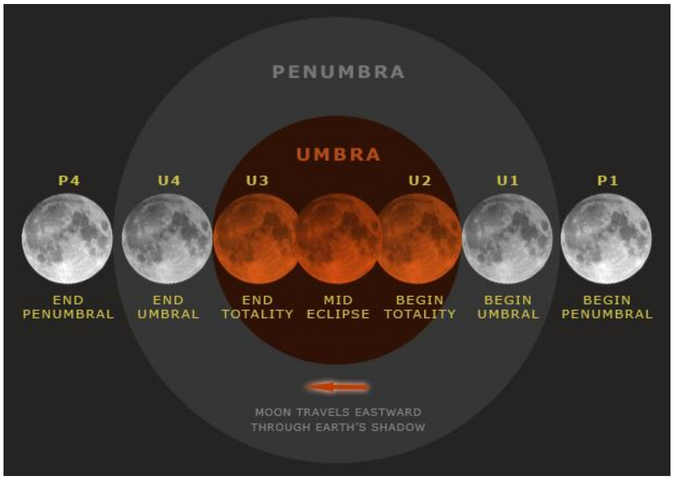


Figure 1.2

Projecting the shadow of a small ball onto a paper screen can create a similar pattern of shadows. In this first set of activities, we will closely observe the formation of shadows and determine how they have been constructed.

Name____ Date__________________



The diagram at the left shows the relationship of the umbra and penumbra shadows and the appearance of the moon during a lunar eclipse. The stunning copper color of the moon at total eclipse is caused by sunlight being refracted through the Earth's atmosphere (much like we see at sunset). Its brightness depends on the amount of dust in Earth's upper atmosphere at the time.

A beautiful multiple exposure photograph of a total lunar eclipse in the U.S. on April 22, 2008, showing the different stages of the eclipse.

Name____ Date___________________

Activity 1-1: Light Rays, Shadows, and Light Sources

Objective: Make simple observations of light and shadows to demonstrate and understand that light travels in straight lines.

Materials:

- A dark room and wall
- A flexible desk lamp and a 60 watt frosted incandescent bulb.
- Standard 8 1/2 x 11 white paper, and black construction paper.
- Masking or scotch tape, scissors, meter stick, pencil, magic marker 1.8 - 2.0 cm in diameter.

Write your observations and answer questions for each of the following:

1. In a dark room – turn on a single source of light such as the single light bulb in your desk lamp. Direct it out into the room. List the items illuminated in the room by the light – contrast where in the room is it light and dark:
   Items depend upon the layout of your room.

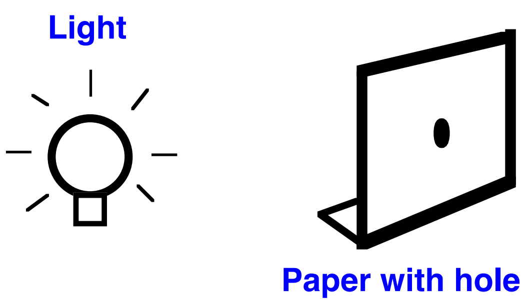
2. Move around the room - facing the light. Notice that you can see the light from many different places in the room. Describe why you can see light in more than one place in the room: The light bulb no matter how big or small has an infinite number of light rays streaming out of it and traveling in all directions. No matter where you go in the room as long as there is no obstacle in between you and the light source you will observe it. Even if there is some object in between you and the light source, light will reflect off other objects in the room and will be directed at you after the reflection.

3. Move around the room - <u>facing away from the light</u>. Describe what happens to your shadow as you move around the room: The size and direction of my shadow will change depending on how far I am from the light source. When I am close to the light source I will have a short shadow and as I move away from the light source my shadow will get longer.

Name____ Date___________________

4. Describe the relationship between the positions of the light, you, and your shadow:
   My position is always in between the light source and the shadow. The shadow is directed away from the light source.

5. Cut a small hole (diameter about 1 cm) in a large sheet of black paper and stand the paper up by folding over the bottom as shown. Put the paper (with the hole) at about 10 cm from the light bulb in your desk lamp so much of the light is blocked except what is coming through the hole. Now move your eye to a place where you can see the light passing through the hole.
Describe where you must place your eye to see this light:
The eye must be placed at the right side of the hole to see the light from the light bulb. This illustrates that light travels in straight lines.



6. Draw a simple top view diagram showing the relationship between the positions of your eye, the hole, and the light. Do not include the drawing here, but describe the relationship between your eye, hole, and light source in your drawing:
Do not include the drawing here, but describe the relationship between your eye, hole, and light source in your drawing: Your eye must be aligned with the hole and light bulb and your eye must be on the right side.

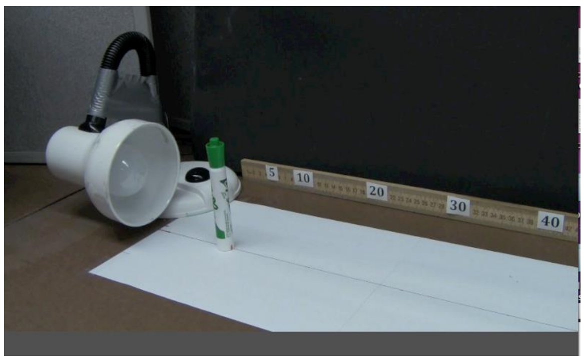
7. Describe what condition is necessary for you to see the light through the hole in the paper:
Your eye, light bulb, and hole and must lie on a straight line.

8. Take a dusty chalkboard eraser or plant mister and clap the erasers (or spray the mister) near the hole where the light comes out. Describe what you observe:
You observe light scattering from the dust or mist.

Name____ Date___________________

9. People often speak of a beam of light. Explain why someone might use those words to describe light:
The light illuminates the particles showing the path of the light, which we call a beam of light.

10. In your dark room – stand an object (”Magic” or white board marker, etc. with a diameter of 1.8 to 2.0 cm and a height of about 10 -15 cm) up on a blank sheet of paper about 10 cm from the closest point on the bulb (as shown here).



Turn on the lamp and observe the shadow on the table cast by the marker. Closely observe the shape of the shadow and where the shadow is lighter and darker. Move the marker until the shadow is predominantly penumbra.

What is the distance from the light bulb?__The umbra gets shorter as you move the marker closer to_the light source_say 1-5 cm and the penumbra dominates along the paper.

Move the marker until the shadow is dominantly umbra.

What is the distance from the light bulb?__As you move the marker further away from the light source say 50-100 cm the umbra gets longer and the penumbra is less dominate.______

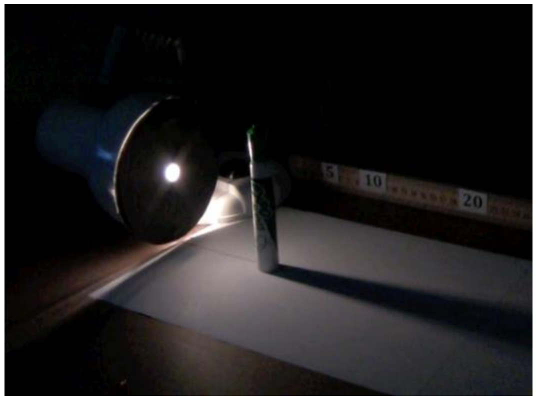
11. Cover the light source with a piece of black construction paper with a 3.0 cm diameter hole cut in the center of the black paper as shown below. This will make your light source more uniform and confine it to a diameter of 3.0 cm. You can use scotch tape to attach the black paper to your desk lamp. Repeat step 10

What is the distance from the light bulb?___When you make the light source smaller, you can now move closer to it before you reach the same size umbra. Maybe 1-3 cm______________

Mo.ve the marker until the shadow is dominantly umbra.

What is the distance from the light bulb?___ When you make the light source smaller, you can now move closer to it before you reach the same size umbra. The umbra may dominate when you reach say about 30 cm____.

12. Cover the light source with a piece of black construction paper with a 1.0 cm diameter hole cut in the center of the black paper. This will make your light source more uniform and confine it to a diameter of 1.0 cm. You can use scotch tape to attach the black paper to your desk lamp.



Repeat step 10.

What is the distance from the light bulb?__ When you make the light source even smaller, say smaller than the magic marker, then your light source is approaching what we call a point source. A pure point source has no penumbra. The penumbra is severely reduced everywhere. Since the light source diameter is smaller than the marker diameter, there will be umbra along the entire paper. You will find it hard to see a dominate penumbra anywhere.

Move the marker until the shadow is dominantly umbra.

What is the distance from the light bulb?__The umbra will dominate_everywhere.

Name____ Date_____________________

Activity 1-2: How does the nature of a shadow depend on the distance between the light source and the object projecting the shadow?

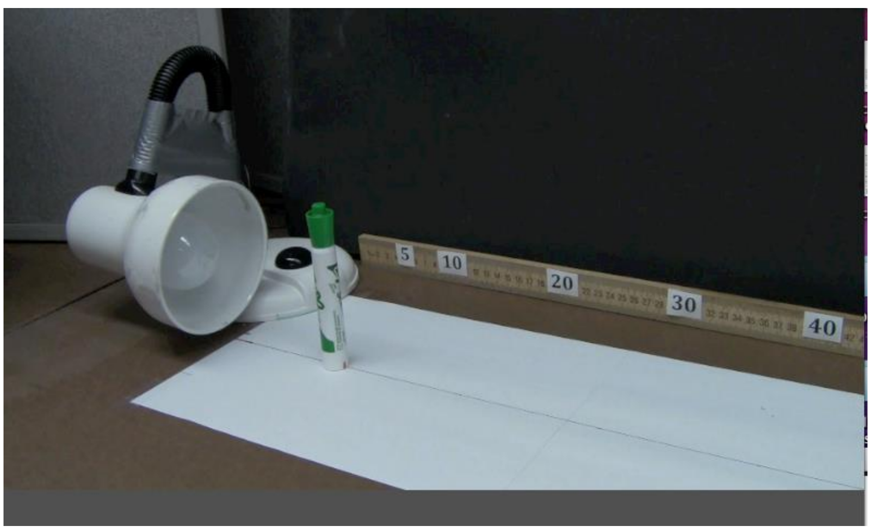
Objective: To understand and demonstrate how the nature of the shadow changes with distance between the light source and the object.

Materials:

- A dark room and wall
- A flexible desk lamp and a 60 watt frosted incandescent bulb.
- Standard 8 1/2 x 11 white paper, and heavy black construction paper.
- Masking or scotch tape, scissors, meter stick, pencil, magic marker 1.8 - 2.0 cm in diameter.

Procedure:

1. In the dark room – stand your object (”Magic” marker) up on a blank sheet of paper about 10 cm from the closest point on the bulb (as shown here).



2. Turn on the lamp and observe the shadow on the table cast by the marker.

3. Closely observe the shape of the shadow and where the shadow is lighter and darker. On the white paper draw a picture of the shadow. Closely observe the shape of the shadow and describe where the shadow is lighter or darker and where it is sharp or blurry? Write down a description of your observations here using the concepts studied in the lunar eclipse. You are required to photograph your set up and and embed the photo in your word document with this assignment.

A triangular like dark shadow lies at the base of the magic marker pointing away from the marker with the base of the triangle up against the bottom of the marker. This shape is triangular since it is a cone projected on a flat surface. This is called the umbra. Surrounding the umbra is another shadow but it is a lighter shadow and it is longer and wider as it stretches further away from the marker. It is called the penumbra.

Name____ Date______________________

4. Move the object in 5 cm steps from 5 cm to 40 cm away from the light source – observe the changes in the shadows on the table top and write down a description of the changes in the umbra and penumbra that you observe here: The umbra becomes longer tapering off more slowly to an apex that increases in distance as the marker is moved farther away from the light. The penumbra gets smaller and narrows as the marker is moved farther away from the light source

5. Predict what the shadow would look like when moved to 60 cm: As you move further away the penumbra will eventually disappear and you will have only the umbra part of the shadow looking similar to a point source of light

6. Describe the changes you observe in the shadows with this smaller light source: Making the light source smaller will make it more like a point source. The penumbra will get smaller and the umbra will get darker and longer. The contrast between shadow and light may not be as strong since the light intensity is not as strong with a hole in front of it. This may make the edges more fuzzy since the contrast between light an dark may not be as strong as before. The amount of contrast you have will depend on your specific setup and how much residual light you have in the room from other sources

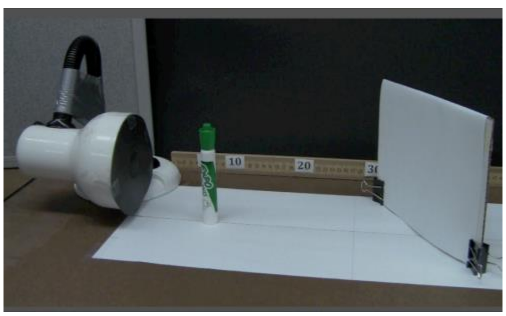
Name____ Date__________________

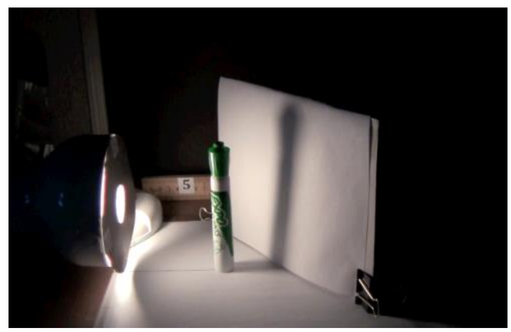
Activity 1-3: How does the nature of a shadow depend on the distance between the object and the shadow?

Objective: To understand and demonstrate how the nature of a projected shadow changes with distance between the object and the shadow on the screen.

Materials:

• A dark room and wall
• A flexible desk lamp and a 60 watt frosted incandescent bulb.
• Standard 8 1/2 x 11 white paper, and heavy black construction paper.
• Masking or scotch tape, scissors, meter stick, pencil, magic marker 1.5 - 2.0 cm in diameter, and large paper clamps.





<u>Procedure</u>:

1. Cover the light source with a piece of black construction paper with a 3.0 cm diameter hole cut in the center of the black paper. This will make your light source more uniform and confine it to a diameter of 3.0 cm. See photograph above.

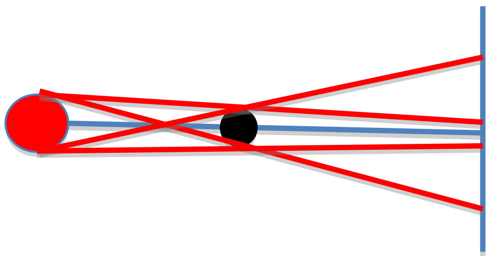
2. In the dark room, place the magic marker about 10 cm in front of the light source, which is covered with black paper with a 3 cm diameter aperture. Make a viewing screen by taping white paper over a 20 cm by 20 cm piece of cardboard and use large paper clamps to hold it vertical as shown above. Place your viewing screen 5 cm behind the magic marker. Turn on the lamp and observe the shadow cast by your object on the viewing screen. Closely observe the shape of the shadow and describe where the shadow is lighter or darker and where it is sharp or blurry? Identify these characteristics with the penumbra or umbra. You will also see the shadow on the table top as before. This will help you identify the umbra and penumbra.

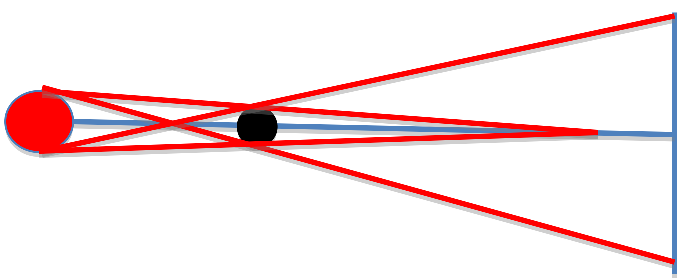
2. Move the screen back 5 more cm keeping the distance between light source and magic marker fixed. Observe the changes as in step 2 and describe them here.

3. Now move the light source back 15 cm from the magic marker. Observe the changes as in step 2 and describe them here.

4. Systematically describe the changes in the shadow as the screen moves from 5 cm to 40 cm from the magic marker. How does the penumbra and umbra change?

5. With reference to the lunar eclipse diagrams shown in Figures 1-1 and 1.2. Draw 2 diagrams to describe the differences you observed between shadows 5 cm and 40 cm from the wall. You are required to photograph or scan these diagrams and embed them in your word document with this assignment. In the first figure below the umbra and penumbra are observed on the screen. As you move the screen back the penumbra will get larger in size and the umbra will get smaller. In the second figure the screen is so far back that the umbra formation is before the screen and therefore no umbra is observed. The shadow on the screen is due to the penumbra entirely.

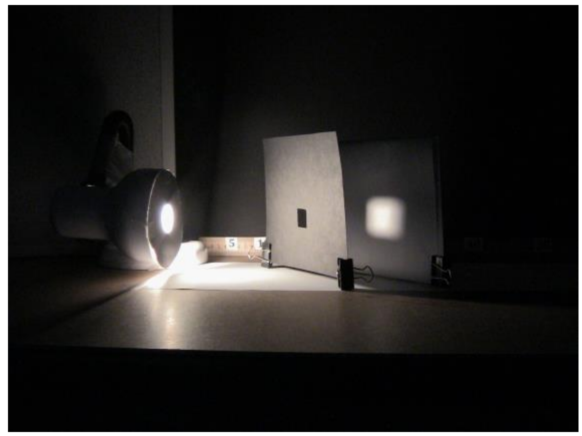




Name____ Date__________________

Activity 1-4: Square hole – round shadow – hmmm.

Objective: In this last activity we will observe how shadows may change depending on the light source, shape of the object making the shadow or image, and the location of the viewing screen.



Procedure:

1. Cut a 2 cm x 2 cm sharp edged square in a large piece of black paper (the object) and stand the cardboard about 20 cm from the light source. In a dark room – observe the light projected on a screen through the square in the cardboard. The square hole and screen should be at right angles to the beam of light. It is shown at 45 degrees in the photo so you can see it on the camera.

1. Place the screen 1 cm behind the square hole keeping the light source. Observe the image of the light projected on the screen.
2. Now move the screen to 5 cm, 20 cm, 40 cm, 60 cm, and 80 cm behind the square hole keeping the distance of the light source from the square hole fixed. As you move the screen, describe the effect on the image of the square of light you observe on the screen:

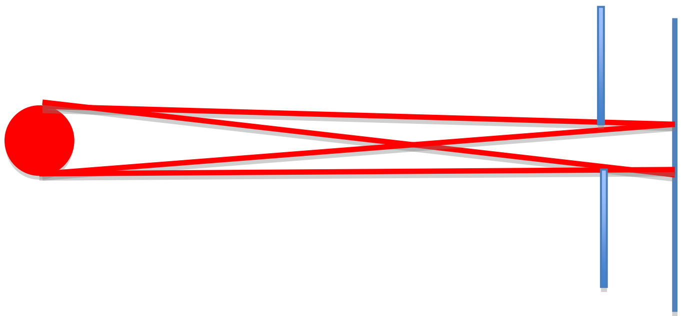
   a) The effect on the size of the square light image was:
   The size of the image got larger with each step away from the wall.

   b) The effect on the clarity/fuzziness of the square light image was:
   The clarity became worse with distance.

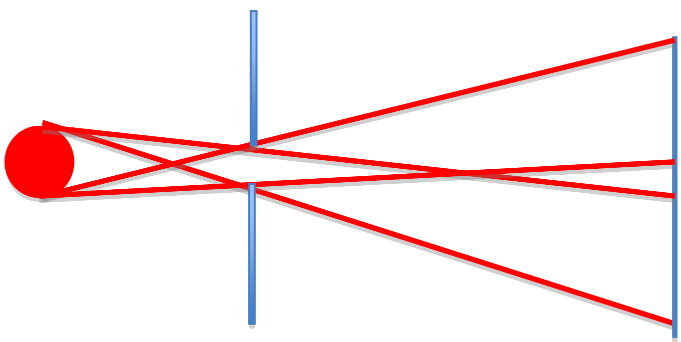
   c) The effect on the shape of the square light image was:
   When the square was about 5 cm from the screen, a distinct square was visible. As the the object was moved away from the screen, light image turned into a circle.

Name____ Date___________________

3. Draw a top view light ray diagram (just like the lunar eclipse diagram, except instead of the light being blocked by the hole – the light is projected through the hole) showing how the light is projected on the screen when the cardboard is close to the screen (far from the light). You are required to photograph or scan the diagram and embed them in your word document with this assignment.



3. Draw a top view light ray diagram (just like the lunar eclipse diagram) showing how the light is projected on the screen when the cardboard is far from the screen (close to the light). You are required to photograph or scan the diagram and embed them in your word document with this assignment.



5. Referring to the two diagrams you have just drawn – write an explanation for the effect on the size, shape, and fuzziness of the light image you observed above.

The size of the image is much smaller when the cardboard is close to the wall because the light traveling through the aperture doesn't have a chance to spread out before hitting the wall. The shape will also take on the shape of the opening when it's so close to the wall because many light waves are overlapping in the outlying shape of the aperture. The fuzziness is also less when the cardboard is close to the wall because the light waves from each point of the bulb aren't as spread out, so the light is more concentrated and clear.

6. What effect would a smaller light source have on the square of light (maybe a small flashlight instead of a lamp)? Place your black paper with a 1 cm hole cut in it in front of the light source

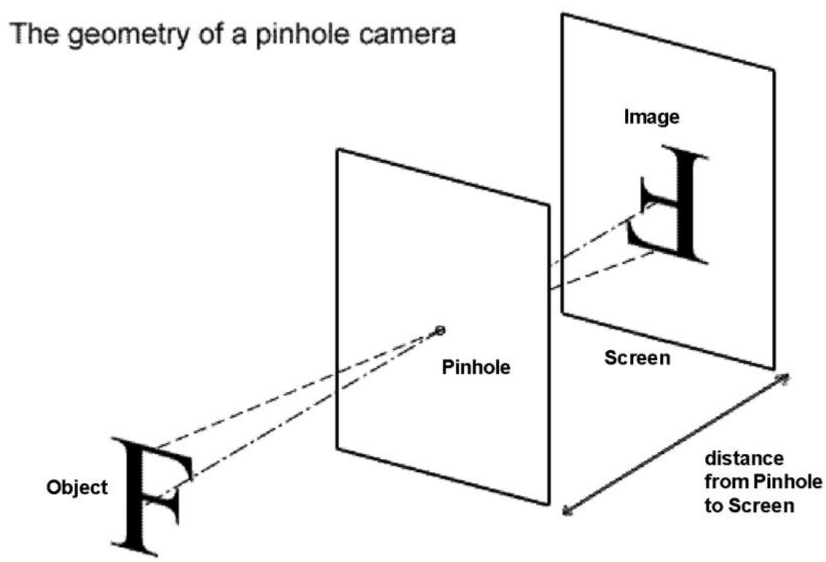
to make the light source smaller. Now describe how the size, shape, and fuzziness of the light square is affected by a smaller light source: When using a smaller light source, the light square became smaller, kept the square shape for a further distance from the wall, and was less fuzzy. The illumination was also not as bright. A smaller hole begins to approximate a point source.

7. Knowing what you know now, explain how you could help Aristotle solve his dilemma about whether one could observe a square image projected through square hole illuminated by the sun. Based on what you observed in the Lab you can answer this question.
Aristotle could have seen a square image of the round Sun if he was viewing an image displayed very close to the square opening that he constructed. How could they not have tried this?

Home Lab 2
Pinhole Viewer Box

Overview

A pinhole camera, also known as camera obscura, or "dark chamber", is a simple optical imaging device in the shape of a closed box or chamber. In one of its sides is a small hole, which, via the rectilinear propagation of light, creates an image of the outside space on the opposite side of the box.



Activity 2 - 1: Construction of the pinhole camera

Objective: To understand how light rays form images using a pinhole?

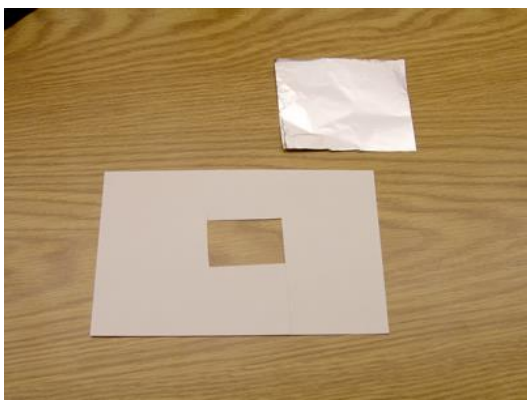
Materials:

- 1 large box (about copy paper box size)
- 1 smaller box (small enough to fit inside the big box)
- wax paper, aluminum foil, a few index cards, masking tape, cutting utensils (scissors/knife), ruler, meter stick
- 1 needle
- a 60-100 Watt white frosted light bulb (a white bulb that you can not directly see the wires inside)
- a desk lamp for the light bulb
- black paint (optional)

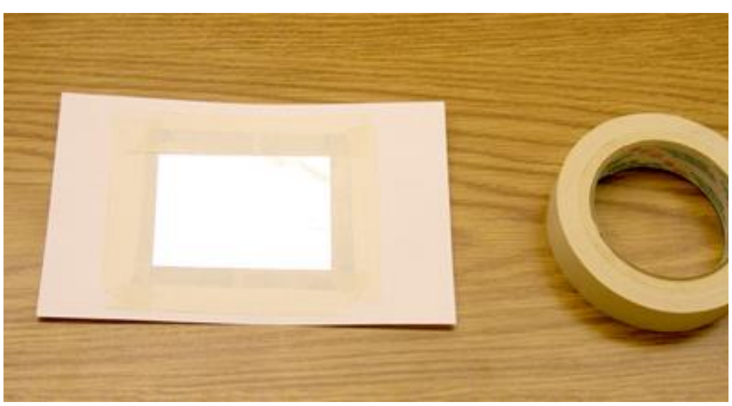
<u>Procedure</u>: Making the pinhole viewer and basic set-up

(read completely before starting)

1.) Cut a square in the index card and cut out a piece of aluminum foil slightly larger than the hole in the card.



2.) Tape the foil over the opening in the index card with masking tape (or some similar kind of tape).



3.) Lightly punch as small a hole as you can in the foil with your smallest pin (it helps to put cardboard behind the foil to keep it flat and stable and makes a hole with less ragged edges).

4.) You will need to completely close your large box to view the image inside (painting box black on the inside to reduce scattering of light is optional).

5.) Cut a small square opening in the front of the box (as shown). Place the foil with pinhole over the front opening of the box and tape it there securely. Make a viewing window by cutting out a square on the opposite side of the box.

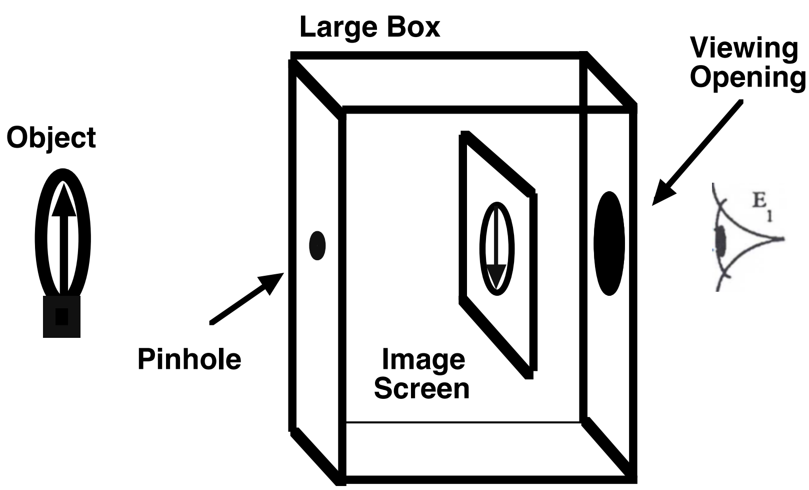
6.) To make the image viewing screen - take your smaller box, cut a large square in one end, and tape a piece of wax paper over the opening.

7.) The wax paper will be the target screen where you will see the image. The small box can be any size as long as can easily fit inside the larger box and can stand upright as in the next picture.

8.) Insert the small box (target screen) inside the big box (as shown). This picture illustrates the relationship between the pinhole foil (in the front of the box), the target screen (inside the box), and the back viewing opening in the back. Put the top on the big box and you are ready to go.

9.) This picture of the experimental set-up showing our closed pinhole box pointed at the object we will view (a 100-Watt white frosted light bulb). All viewing should be done in a dark room.

10.) A diagram of picture (9) showing the relative positions of the object, pinhole, image screen, viewing hole, and eye.



11.) You will need to draw a pattern on your light bulb – so when you view its image you can easily distinguish up/down, right/left on the bulb.

12.) It does not matter how you orient the bulb or what type lamp you use as long as the bulb is bright and that you can distinguish up/down, right/left on the bulb.

13) Photograph your pin hole viewer box showing the smaller viewing screen inside the larger box and embed in your Lab02 report at this location.

14) Photograph the front of your pin hole viewer box showing the pin hole in the aluminum foil and embed in your Lab02 report at this location.

Activity 2 - 2: Image of the light bulb

Objective: To view and study the image made by a pinhole.

Procedure:

1. In a dark room in your home or classroom (shut the blinds & turnout the lights), position the wax paper screen in the center of your pinhole box, close the box, place the pinhole in the front of the box about 50 cm from the lighted 100W bulb (the object), (see picture in step 9 in Activity 2-1).

2. Align the box until you can see a faint image of the bulb appearing on the center of the wax paper screen as viewed through the large viewing hole in the back of the box. You will need to look carefully the image may be very dim (it will help to be in the dark a few minutes). If the image is too faint to see, the pinhole may have to be enlarged slightly. Make sure you have drawn a pattern such as an upper case F on the bulb as described in the set-up section.

3. Sketch your observations in the space below including the F on the bulb or you may photograph the image and embed it in the space below. If you use a camera. you will have to turn off the flash and set the exposure for a few seconds and hold the camera very steady. This may require several attempts before you get it a good picture.

Sketch of the bulb "object" in this space

Sketch of the bulb "image" in this space

2. Briefly describe and explain the differences you observe between the object and the image – with special attention to brightness, size, up/down, and left/right changes:

Type in your observations and explanations below:

Compare the size of the image with the size of the object ______________________

Compare the brightness of the image with brightness of the object _______________

Compare the up/down relationship between the image and the object_______________

Compare the left/right relationship between the image and the object_______________

Activity 2-3 : Effect of distance between the pinhole and lightbulb (object)

Objective: To study the nature of the image as the distance between the pinhole and object (light bulb)changes.

Procedure:
(Keep the screen in the same postion in the box.):

1. Observe the image when the distance is 50 cm between the lightbulb and the pinhole then move the entire box toward the light bulb by one half the distance (25 cm) : complete the table below with regard to brightness, size, up/down, and left/right changes.

Category	**Your Prediction**	**Observation** (Describe the changes you see)	**Discussion** (Did your prediction confirm your observation? Why or why not?)
Size of the Image			
Brightness of the Image			
Up/Down Relationship			
Left/Right Relationship			

2. Move the box about twice the distance (100 cm) from the light bulb as it was originally: complete the table below with regard to brightness, size, up/down, and left/right changes.

Category	**Your Prediction**	**Observation** (Describe the changes you see)	**Discussion** (Did your prediction confirm your observation? Why or why not?)
Size of the Image			
Brightness of the Image			
Up/Down Relationship			
Left/Right Relationship			

3. Summarize the above findings by writing a brief conclusion describing how the distance between the pinhole "lens" and the lightbulb (object) effects the image we see. Complete diagram A on page 13 and use it to assist you in your explanation here, but do not sketch in the diagram here.

4. Keeping the edge of the front of the box on the table, tilt the back of the box slightly upward while looking through the back viewing hole. Decribe what happens to the image on the screen: Does the image of the bulb look different?, Explain. For questions 4, 5, and 6, record your answers below in the table. Hint: think about what component of the pinhole camera is physically changing as you manipulate the position of the back of the box.

5. Keeping the "midpoint" of the edge of the front of the box stationary on the table, slightly move the back of the box to the right while looking through the back viewing hole. Describe what happens to the image on the screen:

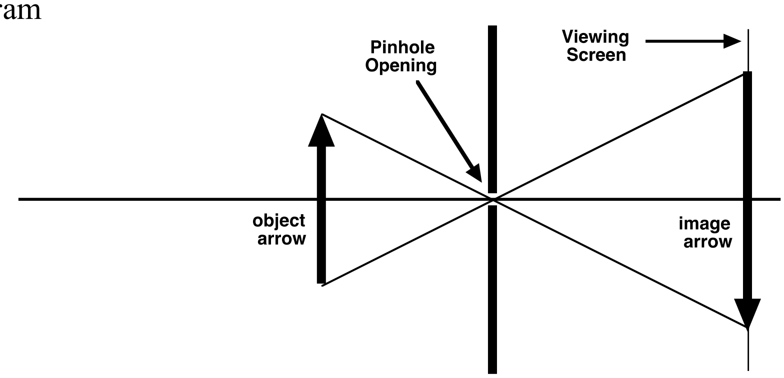
6. Keeping the "midpoint" of the edge of the front of the box stationary on the table, slightly move the back of the box to the left while looking through the back viewing hole. Describe what happens to the image on the screen:

Action	**Prediction**	**Observation** (Describe the changes you see)	**Discussion** (Did your prediction confirm your observation? Why or why not?)
Tilt the back of box upward			
Move the bck of box to the right			
Move the back of box to the left			

7. Summarize the above findings in 4, 5, and 6 by writing a brief conclusion describing how the movement of the screen effected the position of the image on the screen:

8. On the next page are 4 diagrams that represent a 2 dimensional view of your pinhole viewer. The top (sample diagram) shows how the two rays of light from the extreme ends of an object (arrow) pass through the pinhole opening and project an image of the arrow onto the viewing screen. Your task is to draw the same two extreme light rays from the ends of the oject arrow through the pinhole and draw the resulting image that would appear on the viewing screen for the remain 3 diagrams (diagrams B and C). **You will have to scan or digitally photograph your finished diagrams and submit the photo with this lab writeup**.

Sample Diagram



Date______________________

Diagram A

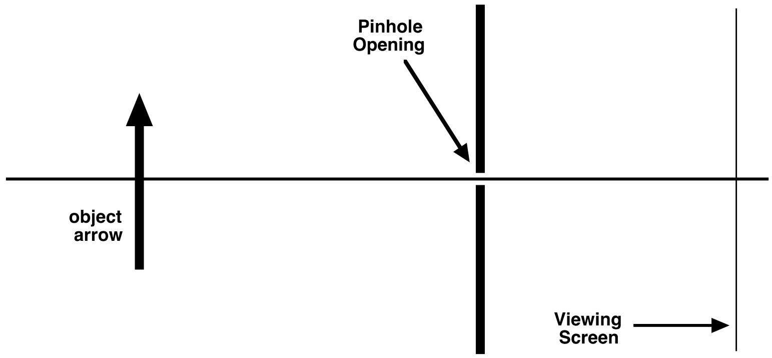


Diagram B

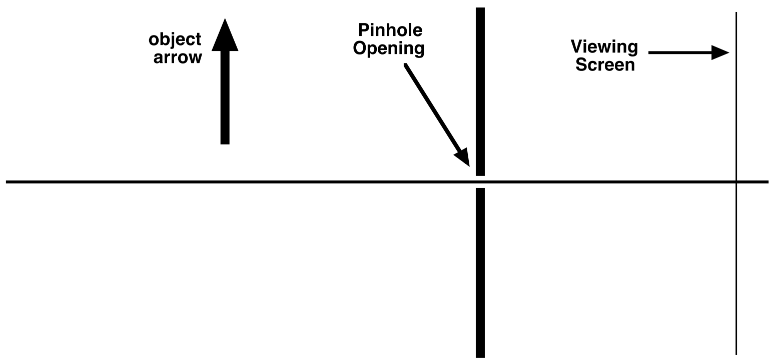
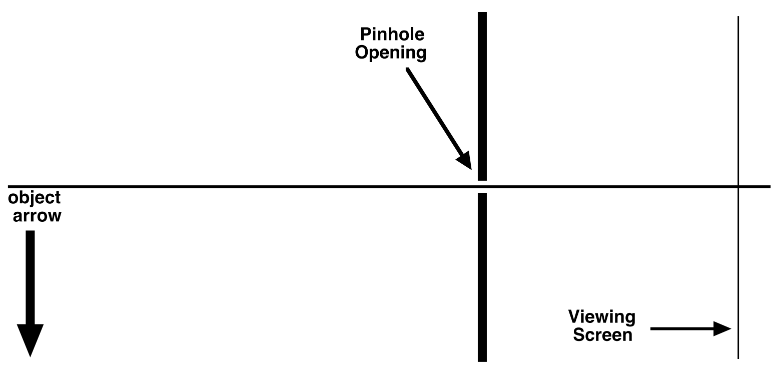


Diagram C



Name________________________ Date_______________

Home Lab 3
Pinhole Viewer Box Continued
and Measuring the Diameter of the Sun

Activity 3-1: Effect of the distance between the viewing screen and the pinhole on the image size.

Objective: To investigate and observe the changes in the properties of the image when the distance between the viewing screen and the pinhole changes.

Materials: Same as in Home Lab 2

Procedure:

1. Place the front of the box 30 cm from the light bulb, align the center of the bulb with the pin-hole in the box as best you can, and write down your exact distance between the light bulb and the pinhole (in cm): _________ cm

2 . Measure the height of the "F" you drew on on the light bulb (in cm): _________ cm

3. Place the wax paper screen at some arbitrary position toward the front of the box and measure the distance from the pinhole to the screen inside the box (in cm): _________ cm

4. With the top of the pinhole box open but blocking the light of the lamp - view the image of bulb on the screen – reach into the box and measure the height of the image ("F") of the bulb on the screen. Don't be alarmed if it is upside down (in cm): ______cm

5. Move the wax paper screen toward the middle of the box and measure the distance from the pinhole to the screen inside the box (in cm): _________ cm

6. View the image of bulb on the screen and again measure the height of the image ("F") of the bulb (in cm): _________ cm

7. Move the wax paper screen toward the back of the box and measure the distance from the pinhole to the screen (in cm): _________ cm

8.View the image of bulb on the screen and measure the height of the image ("F") of the bulb on the screen (in cm): _________ cm

Name_________________________ Date_______________

9. Fill in the Table below with your measurements you made above.

Table 3-1-1

	Screen in the Front of the Box	Screen in the Middle of the Box	Screen in the Back of the Box
Distance between Light Bulb and Pinhole in cm			
Height of "F" on bulb in cm			
Distance between Screen and Pinhole in cm			
Height of "F" on the Screen in cm			

10. On the graph below plot the data from above.

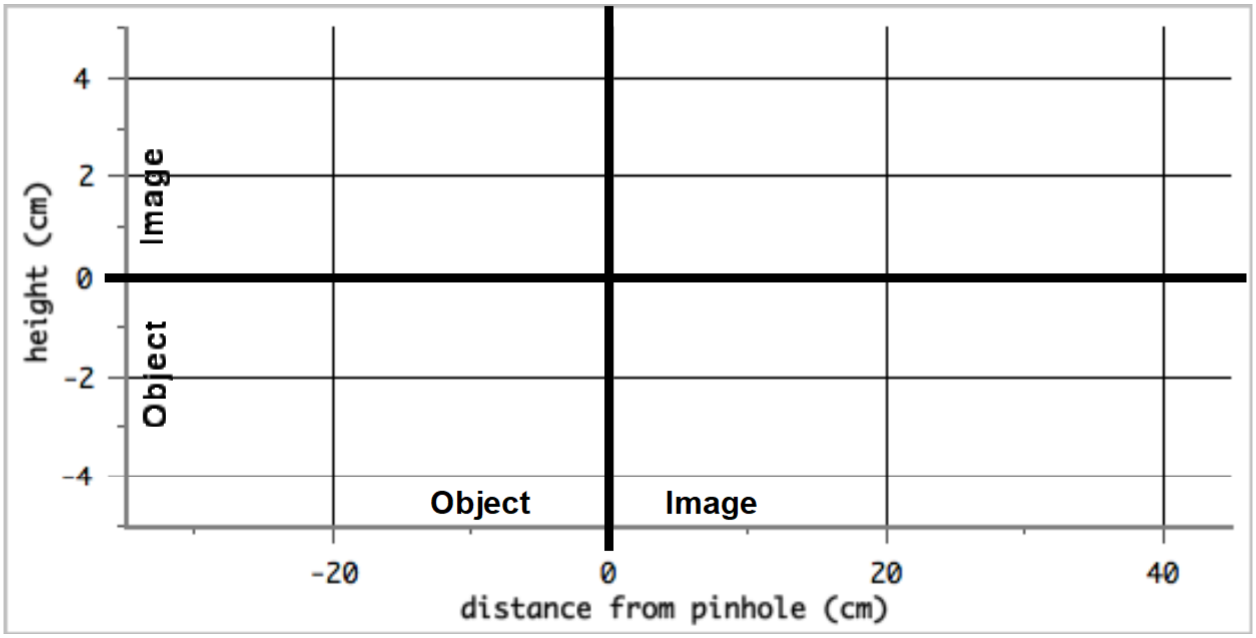
• **x-axis** is distance between the image or object and the pinhole (pinhole position = 0 cm). Plot the distance between the light bulb and the pinhole on the left of the origin (- cm) and the 3 measured image positions on the right of the origin (+cm).
• y- axis will be height of the object and the image at the above x-positions, but we want to plot it in a special way.

• **y-axis** is height of the image or object (pinhole has height = 0 cm, i.e. it is a point). Plot the height of the object as a negative height (-cm, below the origin) since it is inverted (upside-down) from all the images. Plot all the images with positive heights (+cm) remembering to plot all height values at the correct associated distance from the pinhole (i.e. x-axis values).

(**example 1:** If the height of my light bulb (object) is 1 cm and it is 20 cm from the pin hole → we would make a single point by going to the left of the origin (distance = 0 cm) line to -20 cm then down from there to height = -1 cm and mark the point. This would be in the lower, left-hand corner of the graph).

(example 2: If our image height = 2 cm and it appeared inside the box at a distance = 40 cm from the pinhole → we would go to the right of the origin to +40 cm and go up to height = +2 cm and mark the point.)

Name_________________________ Date_______________



Connect the 4 points on your graph with a line. Do you notice any relationship between the object and image points? Write a physical explanation – why the graph must have this relationship:

(Photograph or scan this graph and submit it with this assignment.)

Name_________________________ Date_______________

Activity 3 - 2: Effect of the diameter of the pinhole on the size, clarity, and brightness of the image.

Objective: To investigate and observe the changes in the properties of the image after the pinhole (aperture) has been made larger.

Procedure:

1. First before you make any changes measure the diameter of the pinhole in millimeters with a ruler as best you can. You may use a magnifying glass to help you. Diameter of Pinhole: ___mm

2. So far you have observed the properties of many images with the present small pinhole. One last time before you change the size of the pinhole aperture - carefully observe the characteristics of the image on the screen with the screen in the center of the box (pay particular attention to the size, shape, brightness, clarity, right/left, up/down relationships of the image). So make careful observations – there is no going back once the pinhole size is larger. Once the pinhole size is changed – it cannot be made smaller again, if you need a smaller hole - you will have to make a new hole in a new piece of foil. Enter your observations in the Table below.

Table 3-2-1

	Small Pinhole Diameter ______mm	Large Pinhole Diameter _____mm	Largest Pinhole Diameter _____mm
Size of Image			
Brightness of Image			
Clarity of Image			
Up/Down Relationship			
Left/Right Relationship			

2. With a larger needle (or same needle), make the pinhole opening slightly larger by poking the needle through the same original pinhole.

3. With a ruler, measure the diameter of the new larger pinhole (in mm): ______mm.

4. Observe the characteristics of the image on the screen with regard to size, shape, brightness, clarity, right/left, up/down relationships and enter your comments in the Table 3-2-1 above for the larger pinhole.

5. Now, with a small nail, make the pinhole aperture larger again.

6. With a ruler, measure the diameter of the new even larger pinhole (in mm): ______mm

Name________________________ Date_______________

6. Observe the characteristics of the image on the screen with regard to size, shape, brightness, clarity, right/left, up/down relationships and enter your comments in the Table 3-2-1 above for the largest pinhole.

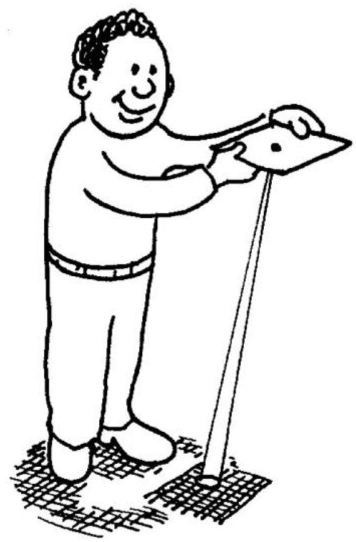
7. Taking each characteristic above (size, brightness, clarity, etc. of image) - Write a hypothesis on why each characteristic changed or did not change with the larger pinhole aperture size. Type explanation here:

Name________________________ Date_______________

Activity 3-3: Measuring the diameter of the sun

Objective:

Using only a pinhole punched through some aluminum foil and a little geometry – you can determine the diameter of the Sun.



Materials:

• Aluminum foil, tape, colored poster-board or stiff paper, needle or small nail, meter stick.

Procedure:

1. Take your poster-board (a piece at about 1 foot square) and in the center cut a hole a 2 inches in diameter.

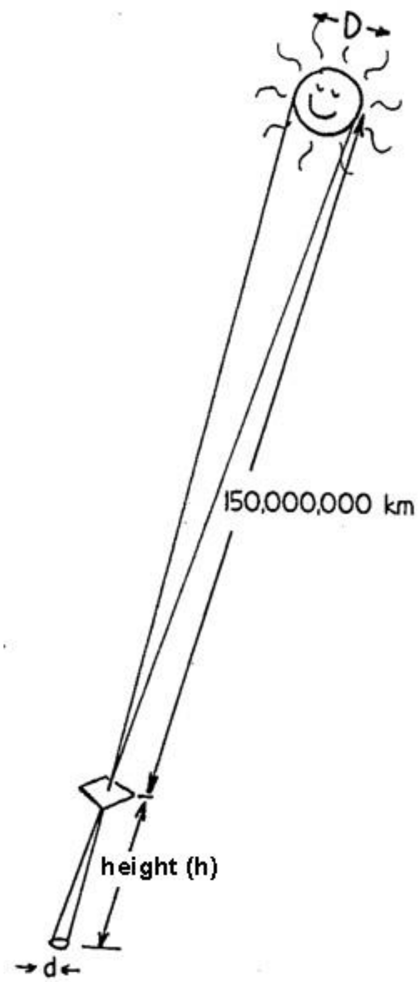
2. Cut off some aluminum foil a little larger than the hole in you poster-board and tape it over the hole.

3. Take a small nail or large pin and punch a small hole in the center of your foil. You should now have a piece of flat, stiff board where no light can penetrate through except through your pinhole).

4. With your pinhole board, meter stick, and some paper go outside on a clear day (preferably around mid-day when the sun is highest in the sky) and set-up in the sunlight (it would be good to have a partner to lend an extra set of hands to do your measurement).

Name________________________ Date_______________

5. Place paper on the flat ground and hold the pinhole board (at least 1 meter above the paper on the ground) so that the board is directly between the Sun and your paper. A shadow of the board should be cast on the paper with a light spot shining through the pinhole (as in the cartoon above). This spot is the pinhole solar image of the Sun.



* drawings converted from
Hewitt / figuring physics /
The Physics Teacher / AAPT

Name________________________ Date_______________

6.) You will need to make two measurements while holding the pinhole board steady in the same place.

a. Measure the distance from the pinhole to the solar image on the ground (h) in centimeters (cm). Remember 1 meter =100 cm.

h = __________ (cm)

b. Measure the diameter across the solar image on the paper on the ground in cm (the diameter of the spot = *d*). (You may want to measure the diameter of the spot more than once from different directions and average them together).

d = ___________(cm)

7.) With the measurements above and knowing that the Sun is approximately 1.5 x 10^{11} m (150,000,000,000 m or 150,000,000 km) away from the Earth – you can calculate the diameter of the Sun - using simple geometry from the diagram above.

8.) Realizing that the triangle that forms the image on the ground is similar to the triangle with the Sun – one can calculate the diameter of the Sun (D) using a simple ratio of the length of the sides of the triangles. Note that D will be in meters even if d and h are in cm because those units cancel out in the ratio d/h.

$$\frac{D}{1.5 \times 10^{11} m} = \frac{d}{h}$$

Show your calculation here:

D =

9.) Research the accepted value for the diameter of the Sun and compare your measured value. When you check with the accepted value, make sure the units are the same as yours. How far off was your value? If you know how, calculate the percentage deviation of your value with the accepted value.

Percentage difference = 100 x (Your Value - Accepted Value)/ (Accepted Value)
(This part of the question will not be graded)

Name____ Date___________________

Home Lab 4
Reflection of Light Rays

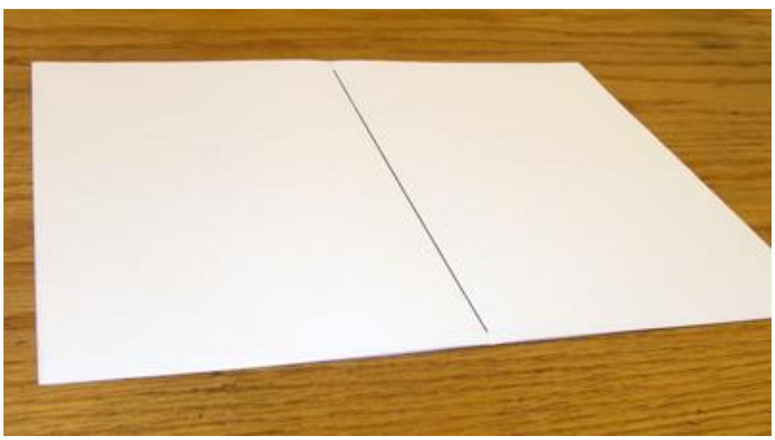
Overview: With a simple flat mirror, paper, and a ruler we can demonstrate how we see reflections of different objects in mirrors.

Activity 4 - 1: Tracing reflected light rays from a mirror.

Objectives: To determine how rays of light reflect off the surface of mirrors.

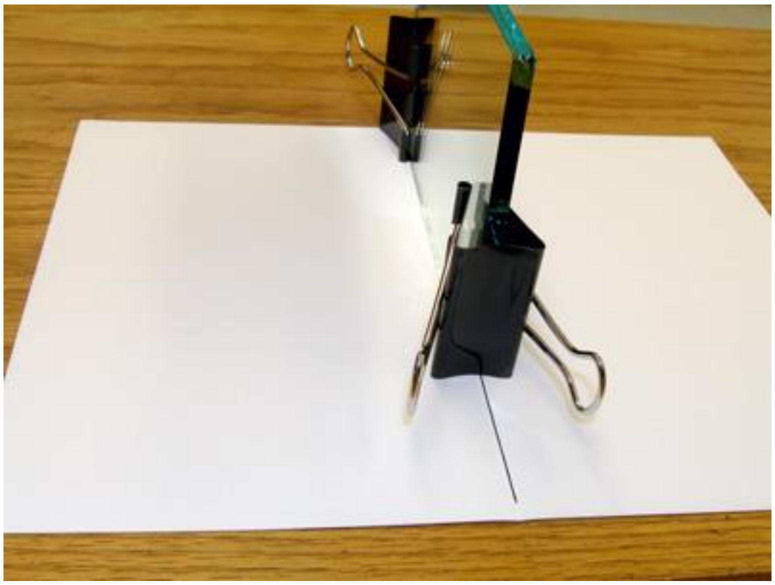
Materials Included:
• A flat mirror, something to make it stand up (clips, clothes pens, block or book)
Materials not Included
• Paper, pen or pencil, 12"ruler with cm tickmarks, protractor, straight pin.

Procedure:
1. Take a sheet of any white 8.5"x11 paper – fold it in half then with a ruler, draw a line across the paper on the fold to divide the paper into two equal halves.

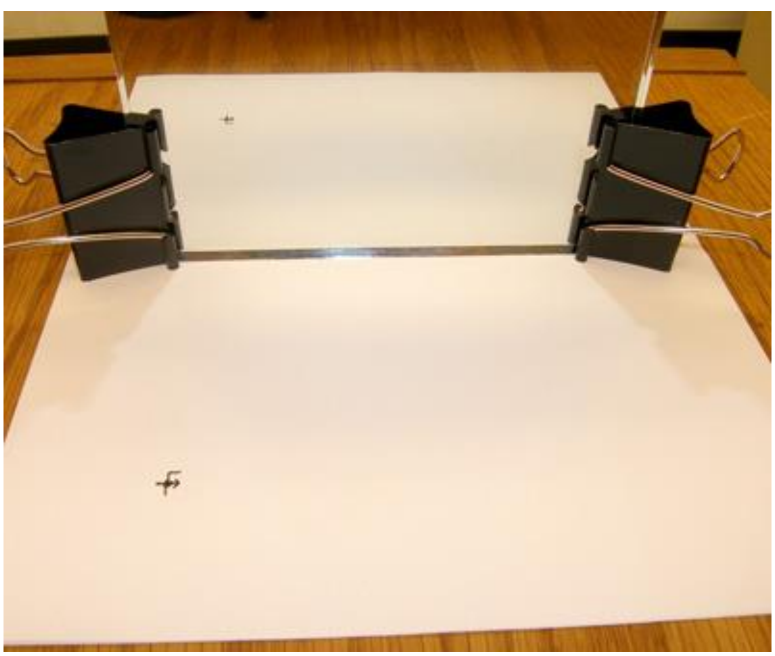


Name____ Date____________________

2. Stand your mirror on the line. Place the silver backing edge of your flat mirror on the line you have drawn. Make sure the mirror stands straight and does not move by using clips as shown (you can also tape or rubber band the mirror to a block, or use clothes pens – what ever is at hand and holds the mirror steady). **It is important that the mirror does not move or change position during this activity**.

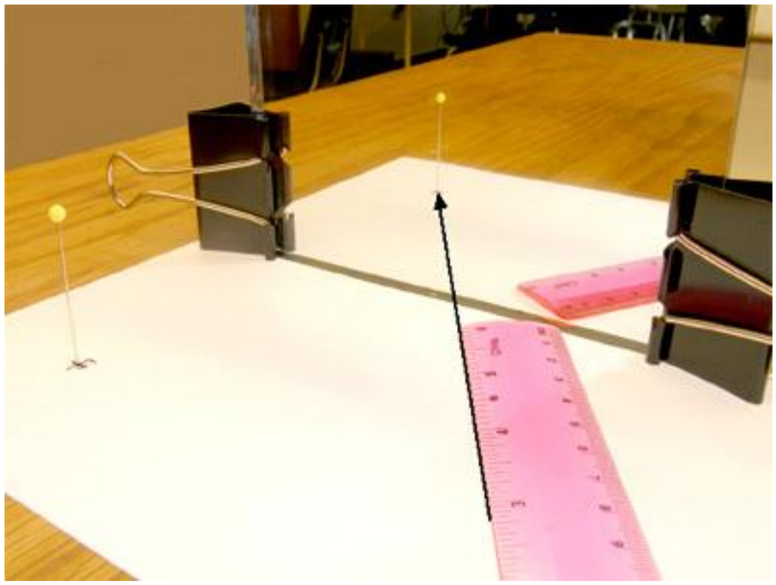


3. Draw an "+" on the paper in front of the mirror (slightly to one side). It helps to put extra marks on the "+" to help identify front/back and left/right while looking at the reflection. Stick a straight pin or needle in the center of the "+" to help line up the reflection in the mirror.

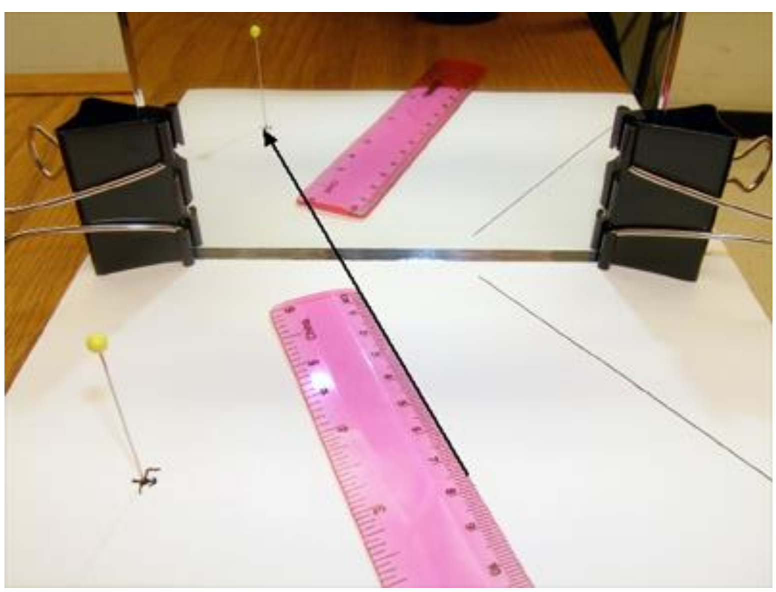


Name____ Date____________________

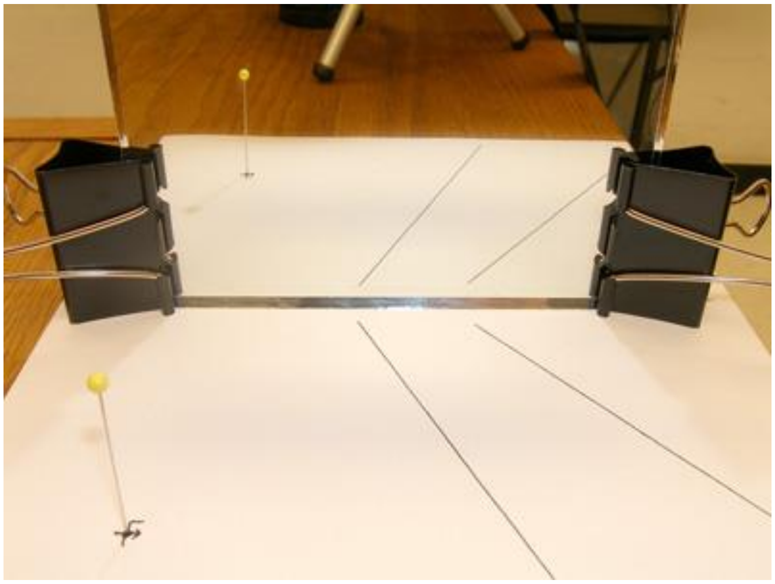
4. Get your eye down to the level of the paper on the table and look at the reflection of the +/pin in the mirror. From the position where your eye sees the reflected image in the mirror – take a ruler and draw a line to where the +/pin appears to be in the mirror. Line the ruler up as if you were making a billiards shot - be careful - draw the line exactly toward the mirror where the image seems to appear.



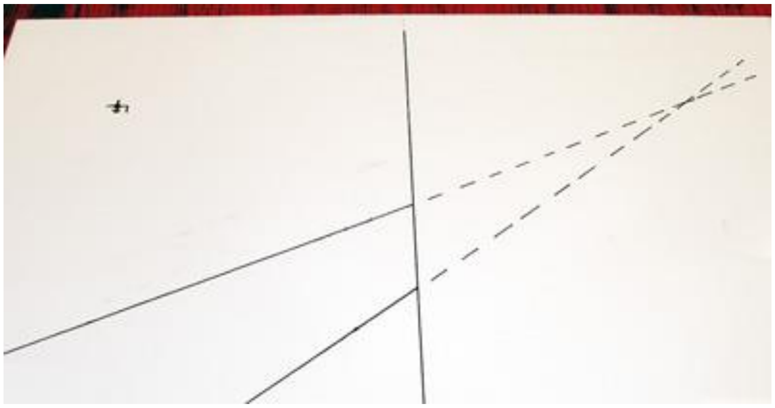
5. Draw another line as above – viewing the object in the mirror from a slightly different angle with your eye.



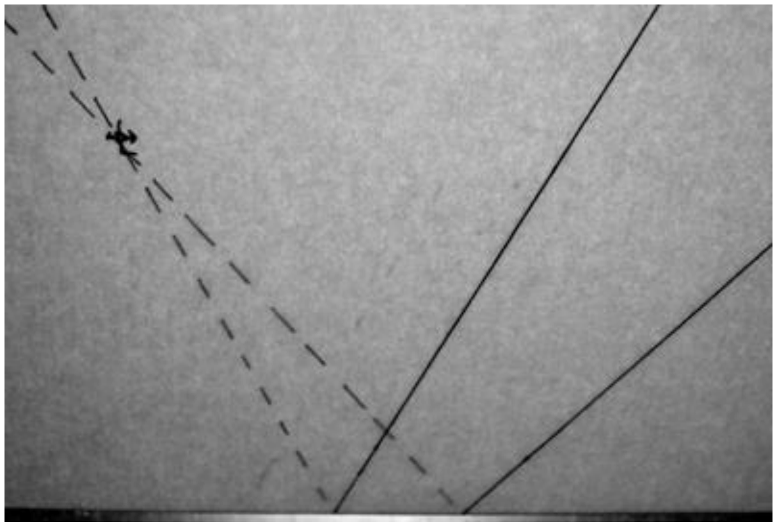
6. You should now have two lines drawn from the two positions where your eye viewed the object toward the mirror. These lines represent the rays of light that are reflected from the object – off the mirror – to your eyes. We will now remove the mirror and finish our light ray diagram.



7. Set the mirror aside - we now have just the two lines on the paper directed toward the line that divided the paper in half (where the mirror was placed). With a ruler, extend your two lines to the mirror and then continue to extent the lines until the lines meet behind the line of the mirror (as shown here). The lines behind the mirror meet at the position where the image appears to be (behind the mirror). Images that appear behind a mirror are known as *virtual images*. You will need to photograph or scan this diagram and submit it with this assignment.

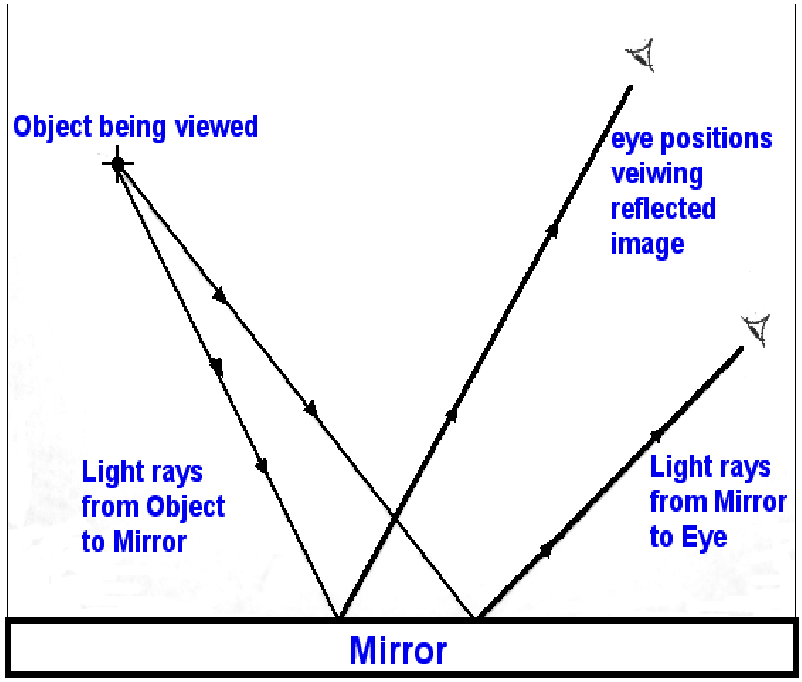


8. Fold your paper in half along the line where the mirror was placed and look through the paper by holding it up to the light (it should look like the picture here). If the lines behind the mirror go through the "+"object – you have done an excellent job drawing your lines.



9. This diagram was made to explain the picture above. The dashed lines on the left are rays of light coming from the object toward the mirror line at bottom of the picture (where you folded the paper). These rays reflect off the mirror exactly to the positions where your eyes viewed the image in the mirror. Note that the angle that rays come to the mirror (angle of incidence) and the angle that the rays are reflected from the mirror (angle of reflection) appear to be the same angles.

Name____ Date____________________


Object being viewed
eye positions
veiwing
reflected
image
Light rays
from Object
to Mirror
Light rays
from Mirror
to Eye
Mirror

Name____ Date___________________

Activity 4 - 2: Making a laser line from a laser spot

Objectives: To make a laser line from a laser spot using a glass rod as a lens

Materials Included:

• Laser pointer, glass rod cylinder,

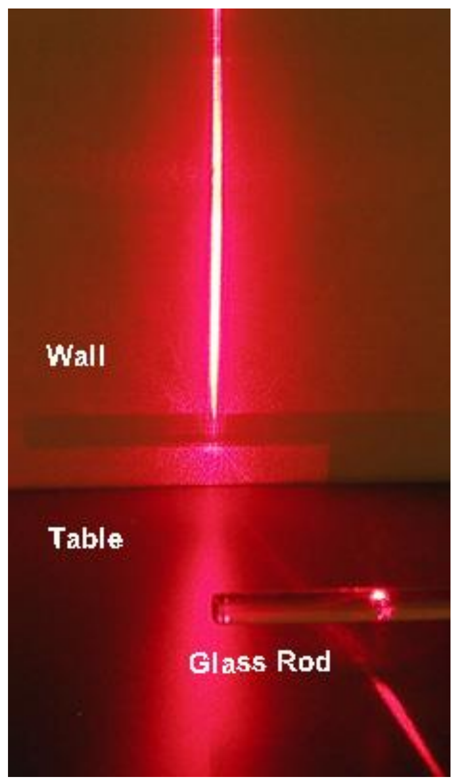
Materials not Provided

• Transparent scotch tape, small metal file, wooden clothespin

Overview:

The laser you use in the following investigations requires an intense line of red light. As seen in the pictures below, directing the Laser light through a cylindrical piece of glass or clear plastic rod can cause this effect. The rod acts as a lens to spread out the Laser light in one direction. Note from the picture- the orientation of the rod compared to the line of light. We will investigate this effect in detail in the Home Lab on Refraction.

Laser pointed at Wall



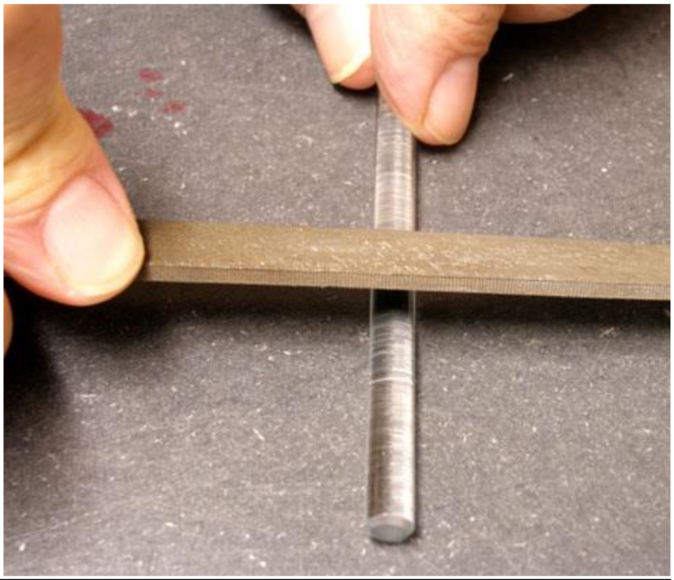
Laser light through a glass rod to Wall

Name____ Date___________________

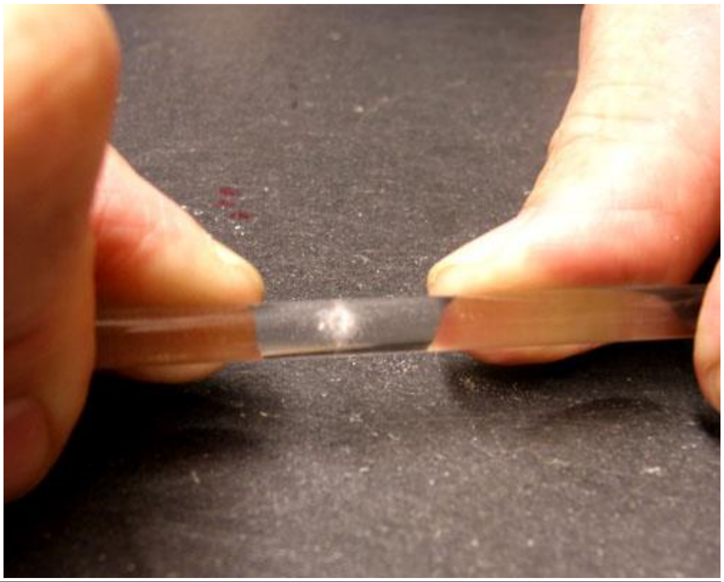
Name____ Date____________________

Procedure:

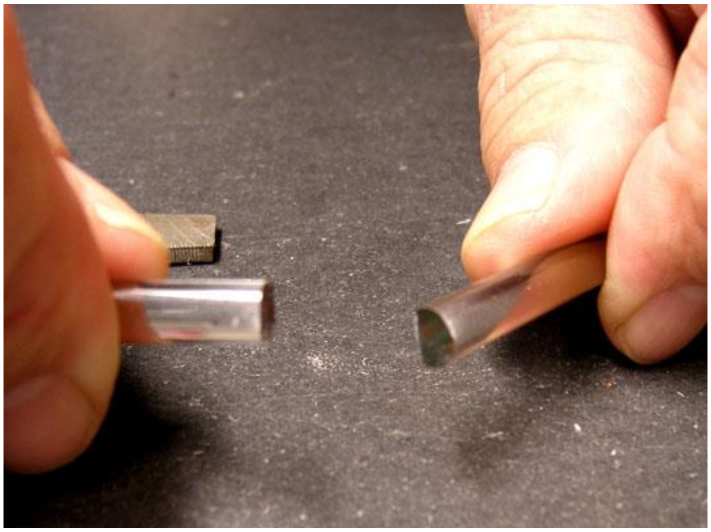
1. Using a small metal file, scribe(cut) a short mark across the glass rod about 1-2 inches from one end of the rod as show in the picture.



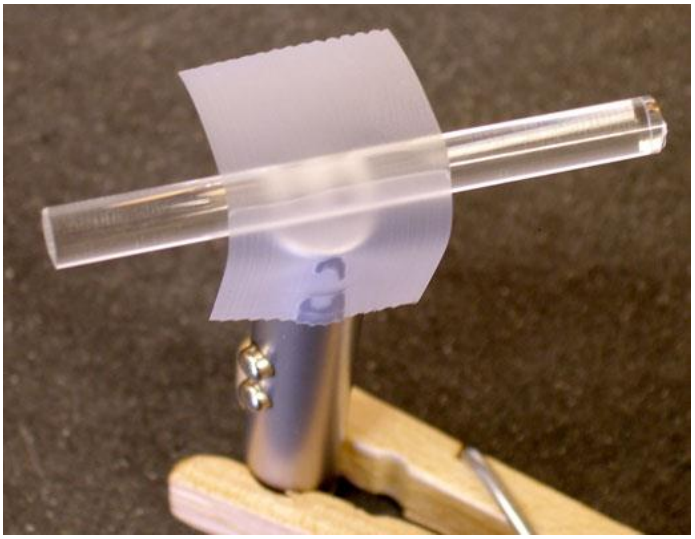
2. Pinch the glass rod at the short end near the scribe mark between thumb and forefinger and do the same on the other side of the mark with your other hand. Do this carefully so you do not cut yourself.



3. Now try to bend the the rod. It will cleanly snap at the scribe mark. The longer the shorter length of rod the easier it is to break.

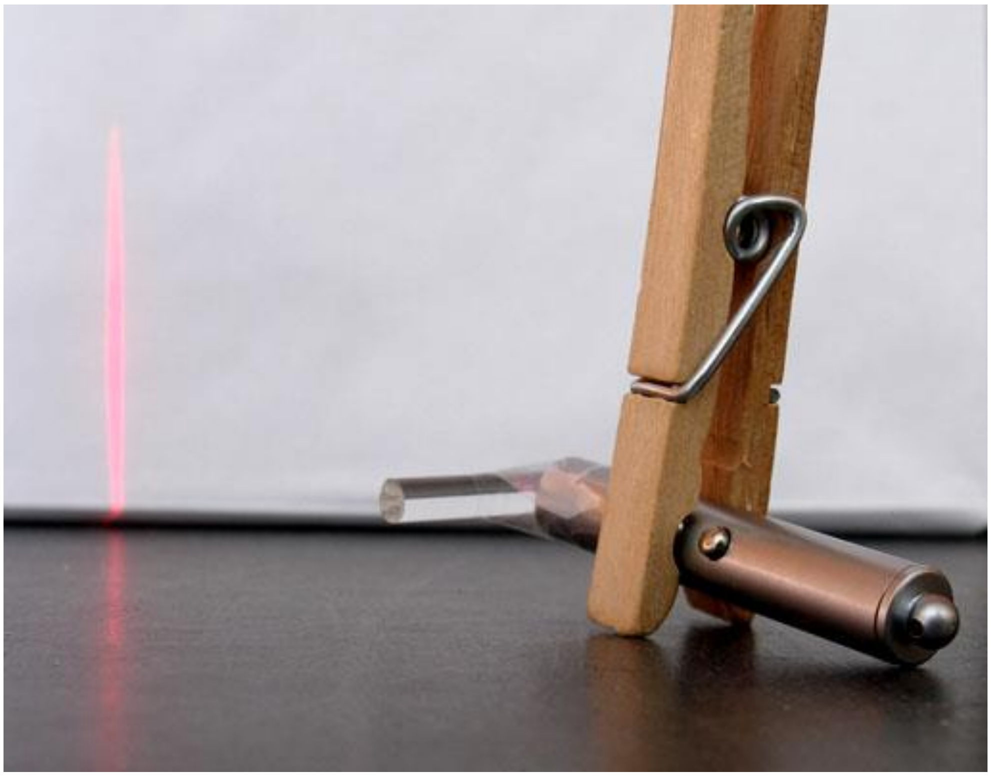


4. Hold the 1-2 inch glass rod next to the laser emission aperature in your laser pointer and tape it securely together. If you use transparent scotch tape the laser beam can go right through the tape without much loss of intensity or emissivity.



Name______________________________________ Date____________________

5. Use a clothespin to hold the laser button on while taking your measurements as shown in the figure below.



You will need to photograph your laser pointer and rod and holder and submit it with this assignment.

6. It is important to shut the laser off while not in use otherwise the batteries will go dead in 30 minutes under continuous operation. After this happens it will take about 15-30 minutes to recharge on their own. When you have to replace the batteries, I recommend to replace all here with silver oxide batteries.

Name____ Date___________________

Activity 4 - 3: Verifying the Law of Reflection

Objectives: To verify and understand the Law of Reflection.

Materials Included:

• Laser pointer, glass rod cylinder, flat mirror, paper protractor on last page

Materials not Provided

• Support for mirror (wooden clothes pen, clamps, etc.), paper, pen or pencil, 12” ruler with cm tick marks

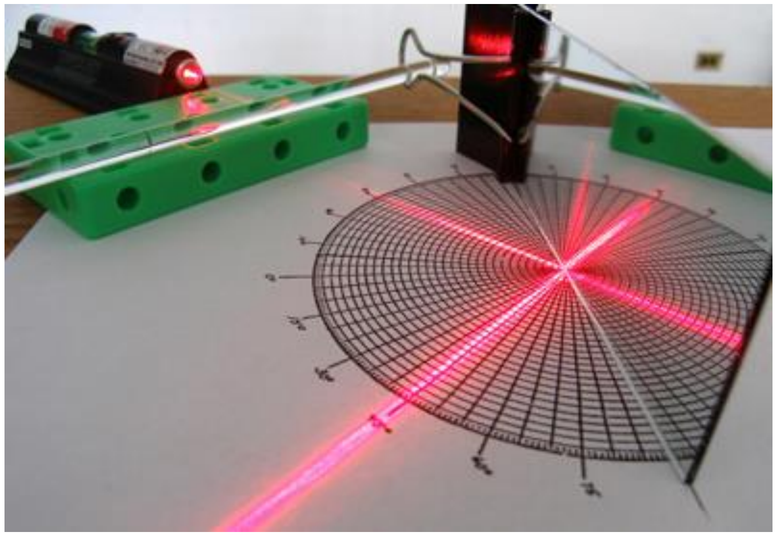
1. From your experience with reflection in Activity 4-1 - describe the direction you think a single beam of light will reflect from the surface of a mirror:

2. Make a prediction - will the angle that the beam of light reflects from the surface of the mirror be smaller, larger, or the same as the angle of the original beam to the surface of the mirror?

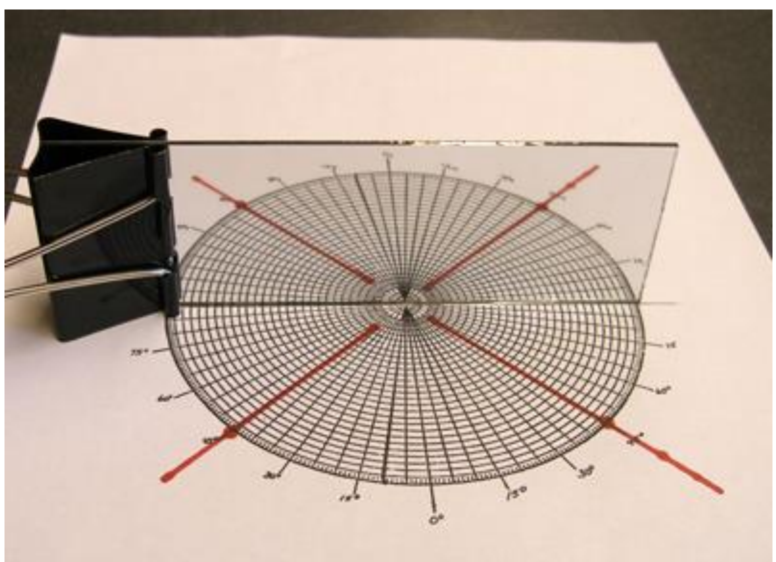
Procedure:

3. On the next to last page of this handout is a picture of a protractor. Print that page and place the page on a table. Place your flat mirror on the straight-line part of the protractor (as shown here). Set-up your Laser pointer and glass cylinder so that the Laser projects a vertical line that hits the mirror at the center point of the protractor. Project this line at a 45-degree angle to the flat surface of the mirror as measured on your protractor. You should see a narrow beam incident on the mirror and a somewhat wider beam reflected from the mirror. When making measurements, try to use the central portion of the beam when reading the protractor. This small difference will lead to some error in your data.

Name____ Date___________________

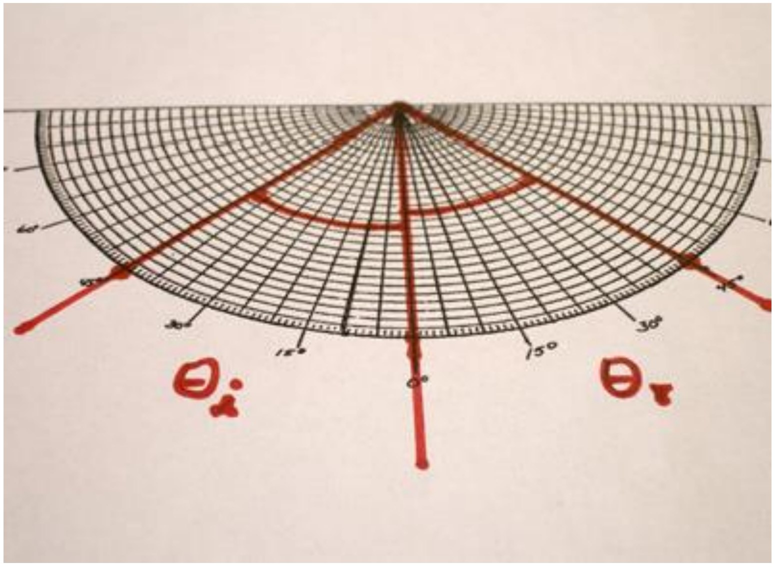


4. Make 2 dots along each projected Laser light line then using a ruler, trace along the projected Laser light line to mark the incident and reflected rays onto the protractor paper (resulting in the picture below when the Laser is turned off). Remove the mirror from the paper then extend the ray lines to the mirror line.



Name____ Date____________________

5. Measure the angle of incidence θ_i and angle of reflection θ_r from the perpendicular (0º) line on your protractor paper. Write down your results in the table below.



6. Repeat steps 3-5 with the Laser pointed at the mirror using angles of incidence of 20 and 60 degrees – fill in your results in the table below.

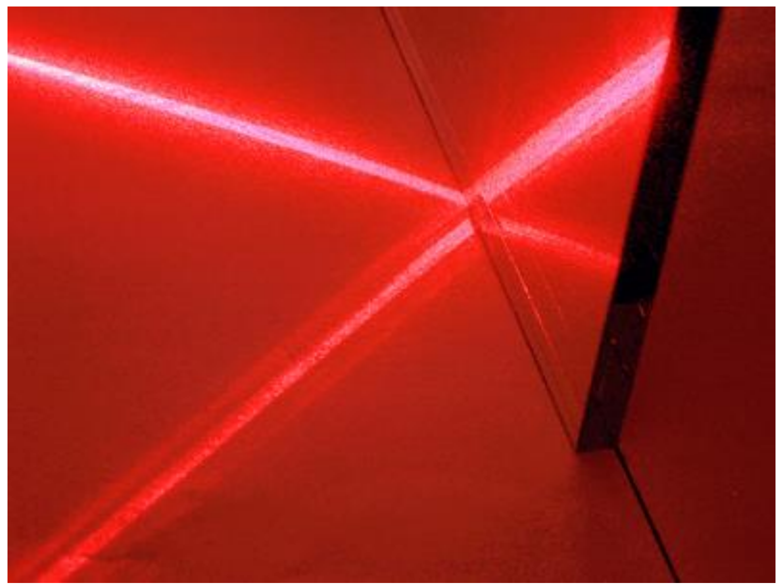
Case #	**Measured Angle of Incidence**	**Measured Angle of Reflection**
Angle 1		
Angle 2		
Angle 3		

7. Based on your observations in the above table, explain the relationship between the measured angle of incidence and measured angle of reflection.

Name____ Date___________________

8. If you use a much thicker mirror (shown below) than what is in the kit, you can barely see three separately reflected beams. The most intense reflected beam is actually reflected from the back of the mirror. The faint beam on the top side is reflected from the front surface and the faint beam on the bottom side is reflected from the back, then front, and then back again. Based on these observations, how would you explain the appearance of your reflected beam from your thinner mirror?

Incident Beam →



Reflected Beam ↗

Name____ Date___________________

Activity 4 - 4: Light Maze Prediction

Objectives:

To demonstrate your understanding of the Law of Reflection - you will direct a path of light around an obstacle course by reflecting it in three different mirrors.

Materials Included:

• Laser pointer, glass rod cylinder, 3 flat mirrors, paper protractor on last page

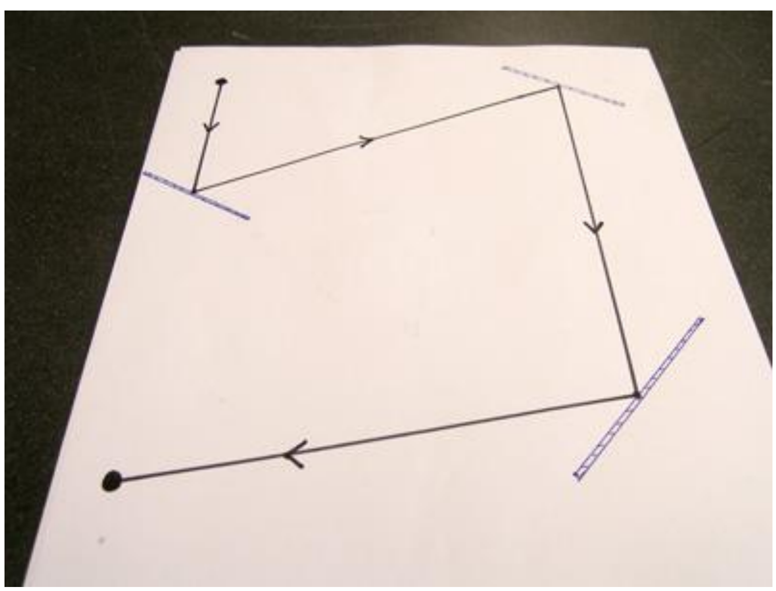
Materials not Provided

• Support for **3** mirrors (wooden clothes pen, clamps, etc.), paper, pen or pencil, 12" ruler with cm tickmarks

Procedure:

1. On the last page of this handout is a page similar to the page shown below – printout the page.

2. From the starting point (in the upper left hand corner) a line goes through 3 changes in direction to finally arrive at the finish point (in the lower left hand corner). It will be your job to set up mirrors to reflect Laser light down these paths to the finish point. In the three places where the lines change directions – draw a short line to represent how you would place mirrors to reflect light to follow the path of lines on the drawing (see completed diagram below).



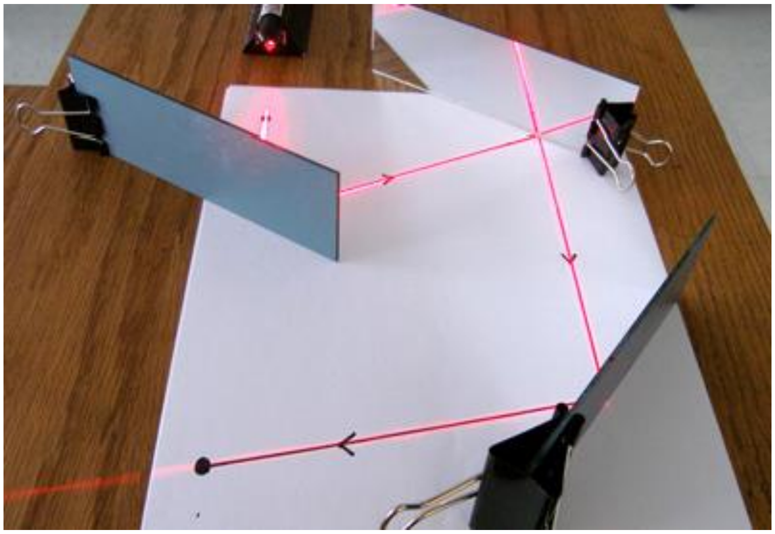
Name____ Date_________________

What is your reason for positioning the lines in this particular manner?

Test your predictions

1. Place mirrors at the 3 locations you have drawn on the page (see picture here).

2. Using the glass cylinder to make a vertical line - direct the Laser Pointer to shine a line through the starting spot, down the first line to the first mirror. The result should cause the light to reflect through the three mirrors to the finish spot at the bottom of the page.



3. How well did you do? Make 2 points along each Laser light line to show where the light projected. Using these points – draw lines where the Laser light projected on your diagram. You will need to photograph or scan yourvdiagram and submit it with this assignment.

4. Try again and see if you can do better.

5. Discuss where your main problems or misconceptions were when you tried this activity the first time:

Name____ Date____________________

Activity 4 - 5: Where to put the mirror

Objective:

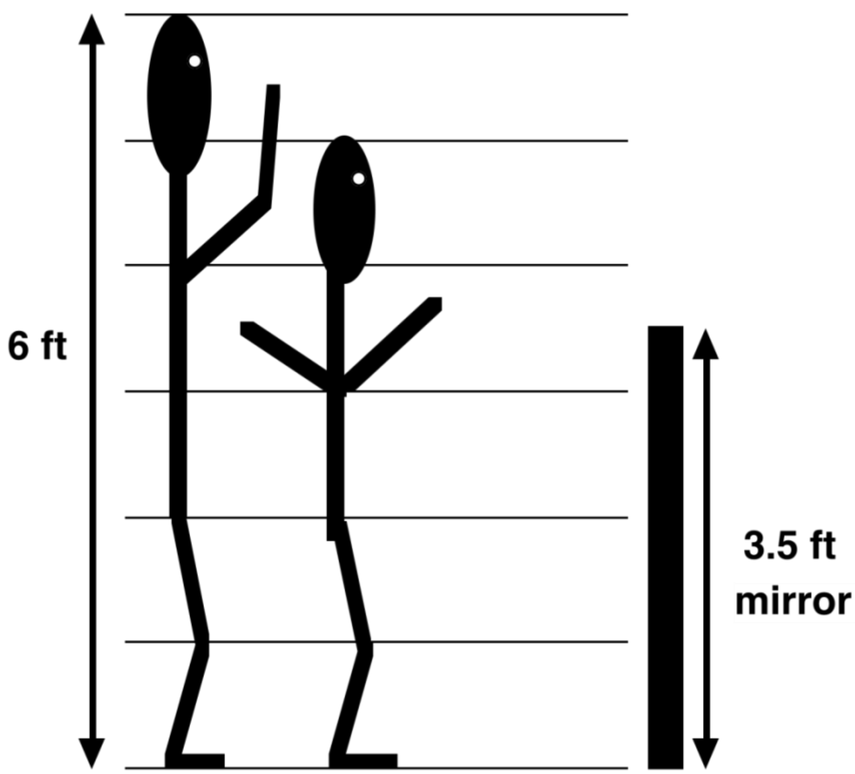
We will use our understanding of reflected light rays to solve a simple household problem.

Materials not provided:

• Paper, pen or pencil, ruler.

<u>Procedure:</u>

1. Please help save my marriage. I am 6 ft tall and my wife is 5 ft tall – my wife always wants to hang the mirror in a low position where I cannot see my head in the mirror without bending over. Your task is to determine the position that we can hang a 3.5 ft mirror vertically on the wall where we can both see our entire body while standing comfortably upright. Assume our eyes are 6 inches below the top of our head.



Name____ Date_________________

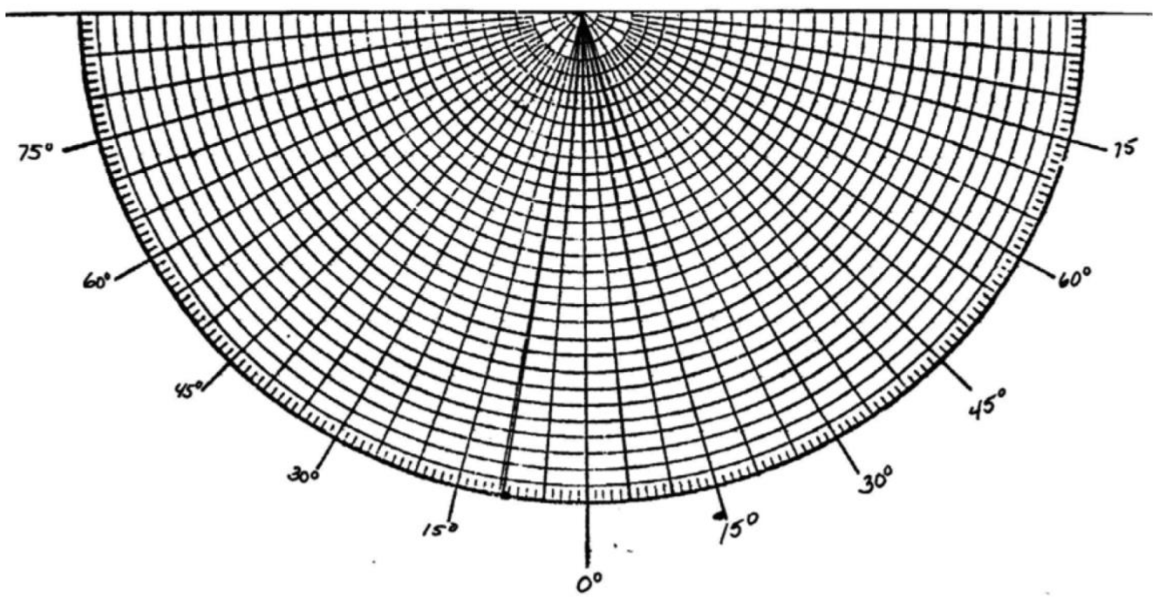
1. On the diagram above place a line that represents the position where the 3.5 ft mirror should be placed vertically so both figures could see their entire body (top of head → to feet).

2.Using a ruler, draw light rays that go from feet → reflect off mirror → to eyes for both figures.

3.Using a ruler, draw light rays that go from top of head → reflect off mirror → to eyes for both figures. You will need to photograph or scan this diagram and submit it with this assignment.

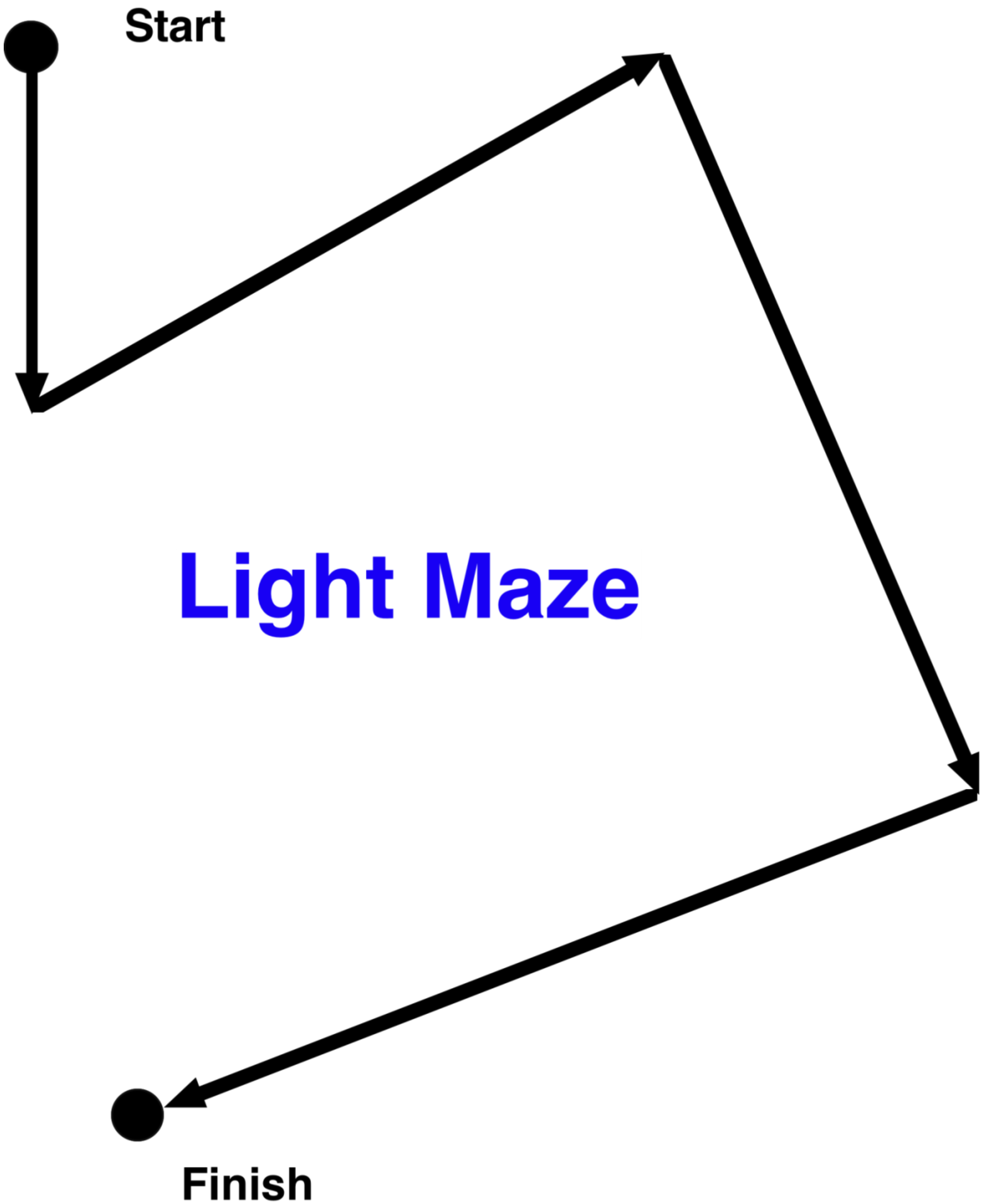
4. By referring to your diagram, write a short statement explaining to my wife where the mirror can be hung vertically so we can both comfortably see ourselves in the mirror without having to bend over to look:

Name____ Date__________________



\

Name____ Date____________________



Name_______________________________ Date____________

Home Lab 5
Refraction of Light

Overview:

In previous experiments we learned that when light falls on certain materials some of the light is reflected back. In many materials, such as glass, plastic, or water, the light also goes through the material or body. For example, I can see my face when light is reflected from the surface of water such as a swimming pool, which means that water reflects light. At the same time, I can see the bottom of the swimming pool, which means light is reflected from the bottom of the pool then transmitted through the water and then into the air to my eye.

Light travels in straight lines until it encounters another material where it is partially reflected and partially transmitted. We learned that the angle of incidence is equal to the angle of reflection and the angles do not depend on the nature of the material. In refraction, we will learn that the angle of the ray when transmitted through the material changes and depends on the speed of light in the two materials.

Many phenomena encountered in our daily lives can be simply explained on the basis of refraction and reflection. Some of these are: why do fish look larger in the water, what causes a spoon to appear bent in a glass of water, why does light travel indefinitely in an optical cable, and, of course, how are rainbows and mirages formed, etc.

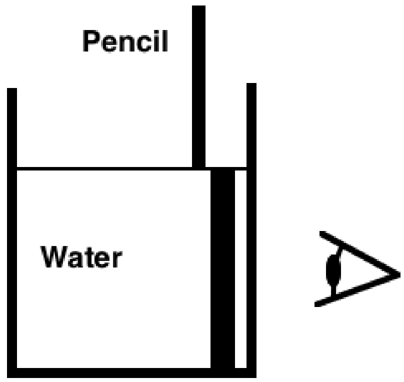
Name________________________________ Date_____________

Activity 5-1: The Broken Pencil

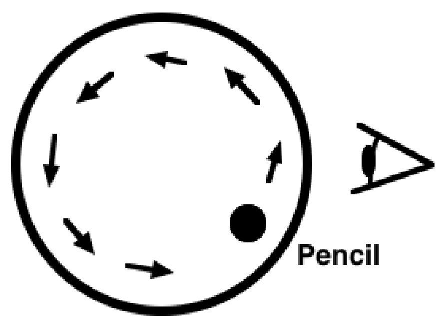
Objective: You will make simple observations of light refracting through and reflecting from water and glass.

Materials Provided by You:
• A clear medium size glass, beaker, or glass jar.
• A pencil, pen, or straw.

Procedure:
Fill the glass about 2/3 full of water. Take the pencil and immerse it vertically in the water. Move the pencil in a circular motion around the inside of the glass while viewing the motion from the side of the glass (as shown in the side view below and top view).



side view



top view

Write your observations and answer questions for each of the following:

1. Briefly describe your observations of the pencil as it moves in a circle inside the glass.

2. Describe where in the circle the pencil in the water appears most like the pencil out of the water.

3. Describe where in the circle the pencil in the water appears most broken from the pencil in the air. (most separated)

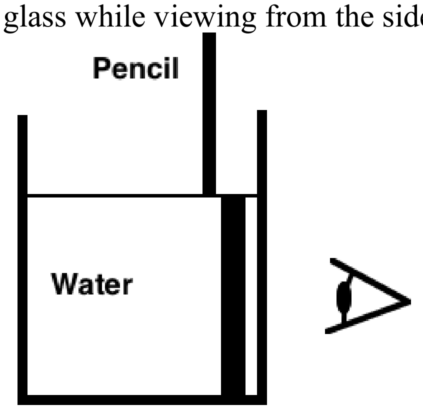
4. Describe where along the length of the pencil the pencil appears to break (in water, air, between the two).

Name______________________________ Date____________

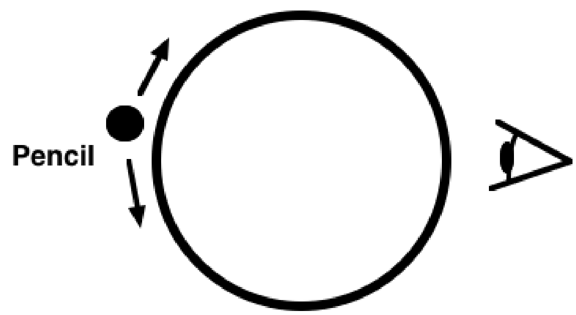
5. Describe where in the circle the pencil in the water appears most magnified.

6. Do you think you would get the same effect with other liquids. Try olive oil. – explain your answer?

Now take the pencil out of the water and move the vertical pencil across the back of the outside of the glass while viewing from the side (as above).



side view



top view

7. Briefly describe your observations of the pencil as it moves across the backside of the glass.

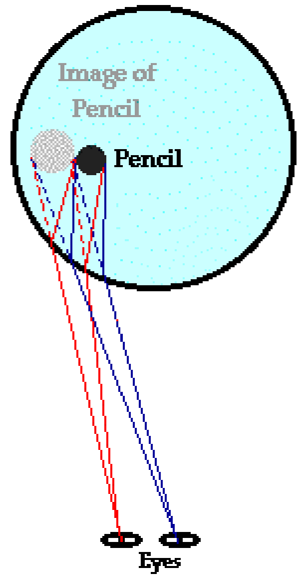
8. Now that the pencil is outside the water does it still appear broken? – explain.

9. Describe where the pencil appears most broken (most separated)?

10. Describe where the pencil appears most magnified as you move it behind the beaker?

Name_______________________________ Date_____________

11. Make an attempt to explain your main observations in terms of your understanding of light rays. What is bending or breaking, where is it taking place, what causes magnification? (Hint: Use the provided image as a guide)



The image of the pencil is located where the refracted rays intersect.

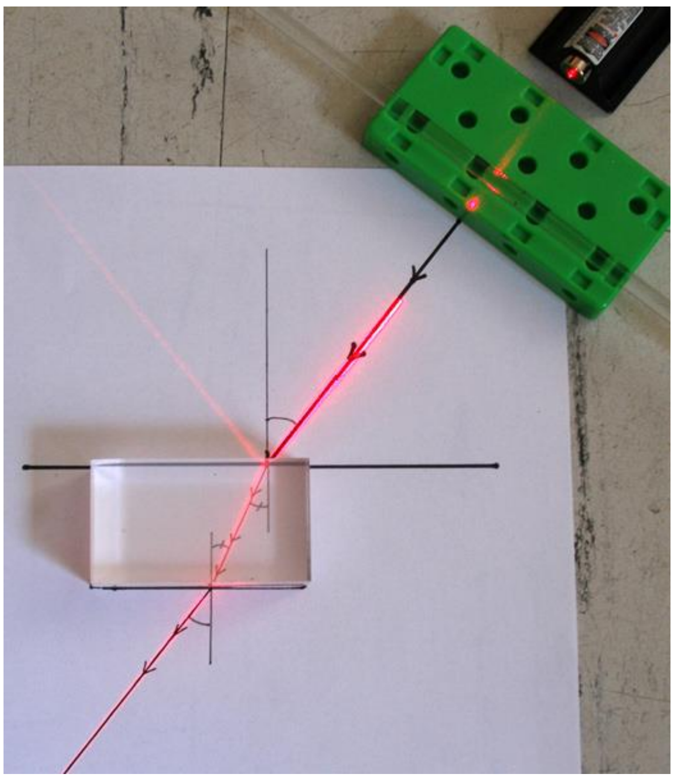
Name______________________________ Date____________

Activity 5-2: Rules of Refraction

Objective: : To explore the rules that predicts refraction in materials.

Materials Included:
• A plastic rectangular block.
• A pencil or pen, ruler, protractor, and paper sheet provided.

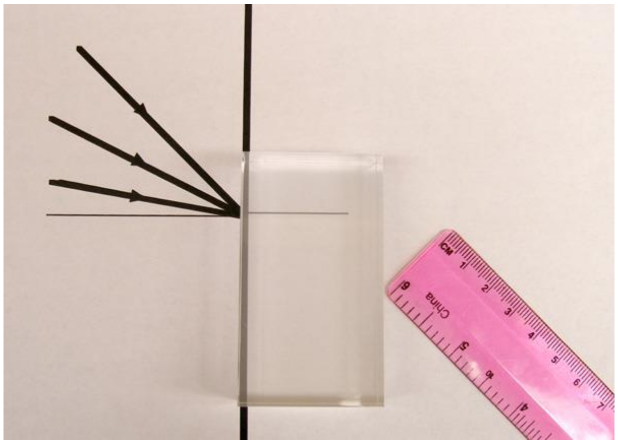
Background:
When a light ray moves from one material into another material its speed will usually be altered, causing the ray of light to change its direction (to bend). In the picture here, it can be seen that the Laser light in the air does not continue in a straight line when moving through a plastic block but bends toward a line drawn perpendicular to the surface where the light entered the block (the normal line). Also, note the slight reflection from the front of the block.

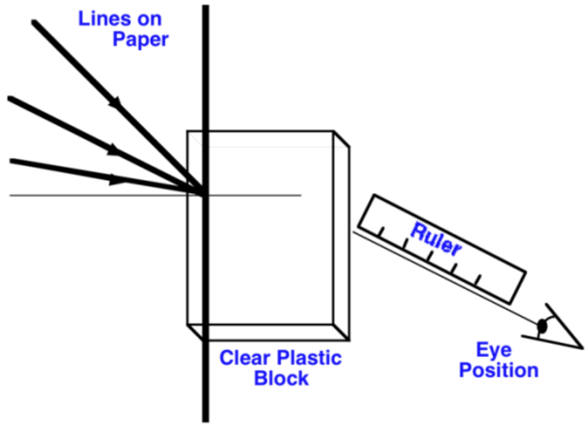


As the light leaves on the other side of the plastic block it bends away from the normal line. The amount of refractive bending of the light caused by the plastic block is an intrinsic property of the material making up the block itself. That is, the material in which the block is made can be identified by how much it bends the light (the ultimate test to determine the authenticity of a diamond is for the jeweler to measure its refractive index in an instrument known as a refractometer). As light enters a more optically dense material (e.g. from air into water or glass) – it will always slowdown and thus, always bend toward the normal line. If light moves into a less dense material – it will always speedup and thus move away from the normal (as we see in the photo above). In this investigation we will determine the amount and direction that light is bent as it moves from one material into another.

Name_______________________________ Date____________

Procedure:

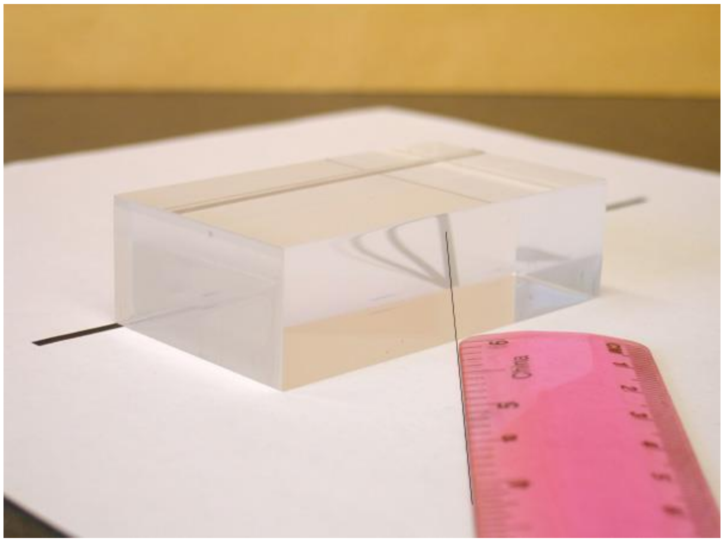




The picture and diagram above represent the same instructions. On the page 21 of this handout you are given a page with 3 diagonal dark lines pointing toward another dark line (as shown above).

• Print out this page and place your block on the line as indicated.

• Get down, so your eye is at table level and view the diagonal lines through the side of your block (it should look like the picture below).

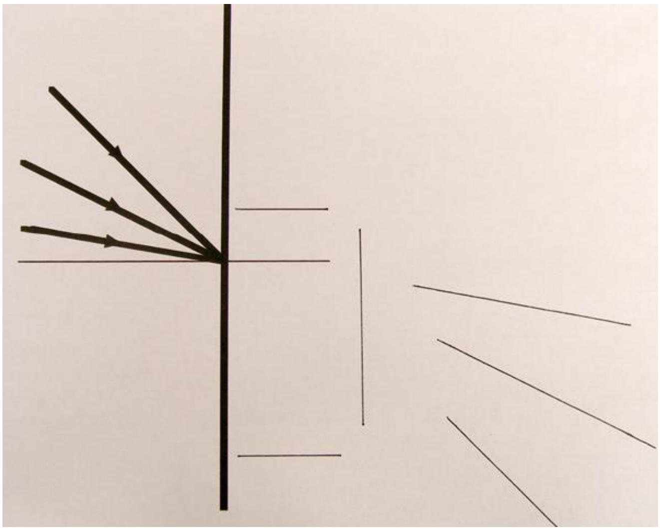


• Draw lines around the edge of the block so you will know the placement of the block.

• Line up a ruler with where the diagonal lines appear to project when looking through the side of the block – draw 3 lines to where these lines would continue as seen through your side of the block. Label your lines so we know which are yours.

• Remove the block from the paper and you should have a diagram much like the picture below.

Name_______________________________ Date_____________

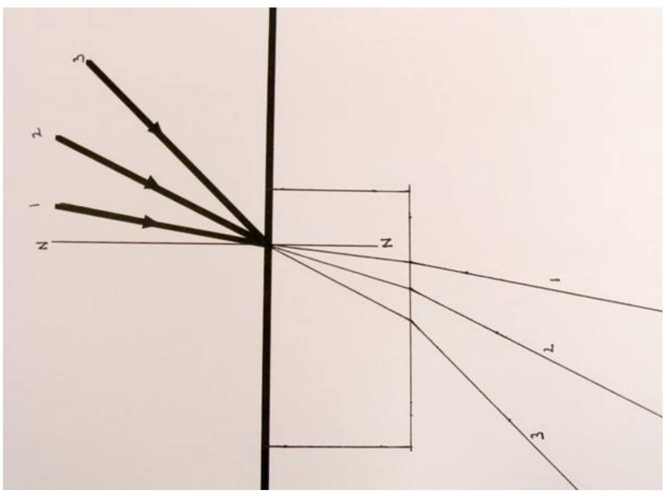


• Connect the lines that outline the edge of your block (to make the rectangle).

• Continue your sight lines to the line that represents the edge of the block you were viewing through (see diagram below).

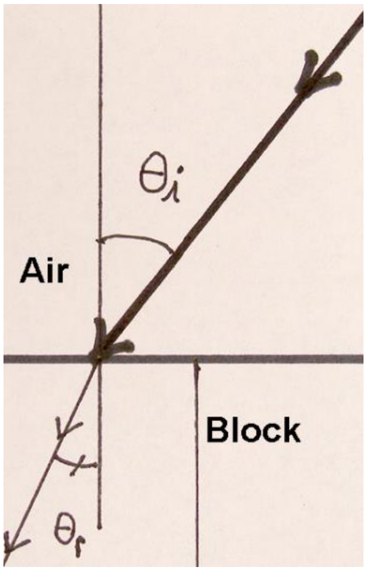
• Finally, connect your sight lines <u>through the rectangle</u> (that represents the position of the block) to where the diagonal lines all meet normal to the surface on the other side of the block. Label the line zz as the Normal. All angles are measured relative to the Normal. The Normal is a line drawn perpendicular to the surface when the light ray hits the surface.

Your drawing should look something like the picture below:



You now have a diagram of 3 different light rays passing from the air on one side of the block – into and through the plastic block – and finally out of the block through the air to where you observed them with your eyes. Compare this drawing with the first diagram above, if you are confused. We will now make angle measurements from this drawing.

Name________________________________ Date_____________



• With a protractor, measure the incoming, incident ray θ_i and the angle of the refracted light ray θ_r - both measured from the normal line (see diagram here for angles).

• Measure these angles for the other rays and write your data for all 3 light rays in the table below.

Raw Data:

Line	q_i (deg)	q_r (deg)	Change in angle (deg) (θ_i - θ_r)
1			
2			
3			

Based on your observations during this activity answer the following questions:

1. What direction were the straight light rays bent as they moved from the air (outside the block) into the plastic block:

2. What direction did the straight light rays bend as they moved from inside the plastic block back into the air:

3. Were all the light rays bent by the same amount or did some bend more? – explain.

4. From your observations - conclude a rule about the direction light rays will bend when moving from materials of a lower optical density (for example air) to a higher optical density (e.g. plastic):

5. From your observations - conclude a rule about the direction light rays will bend when moving from materials of a higher optical density to one of a lower optical density. (example: plastic to air):

Name______________________________ Date____________

6. As light moves through a material with a high density – describe how does its speed of that light compares to the speed of light in a vacuum.

7. If you need to wear glasses to see properly, light does not come to focus at the right place on your retina. From what you have learned in this activity – explain the function of the plastic in the lenses of your glasses:

8. Briefly describe the process of refraction in terms of the speed of light and the changing direction of light rays:

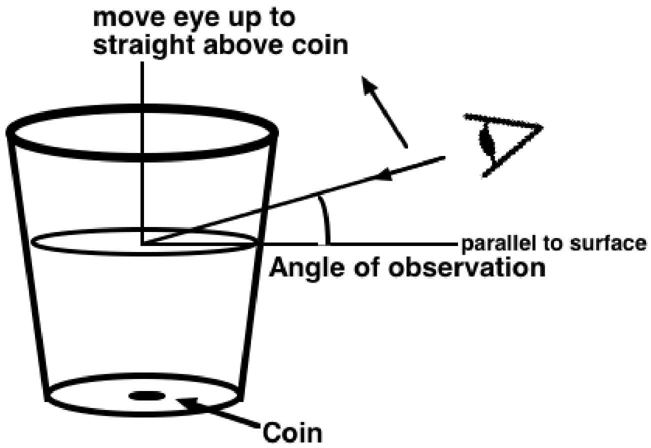
Name______________________________ Date____________

Activity 5-3: Where's my money

Objective: You will make simple observations of light refracting through and reflecting from water and glass.

Materials not Included:
• A clear, medium size glass beaker, or glass jar that will fit inside a larger size clear glass beaker, etc.
• A coin (penny, nickel, dime, etc.)

Procedure A:
You will make simple observations of light refracting through and reflecting from different materials. Place a coin in the center of the bottom of the smaller glass. Fill the glass so there is about 3 inches of water in it (it is important that there is enough water in the glass). Set the glass on a table. Move your eye so that it is parallel (even) with the surface of the water in the glass. Now while looking at the surface of the water, slowly change your angle of observation of the surface from parallel to the surface to looking straight above the coin in the glass (see diagram below).



Write your observations and answer questions for each of the following:

1. Briefly describe your observations of the surface of the water as you moved your eye from the side to straight above the glass:

2. How many coins do you see on the surface when you began looking parallel to the surface?

Name________________________________ Date____________

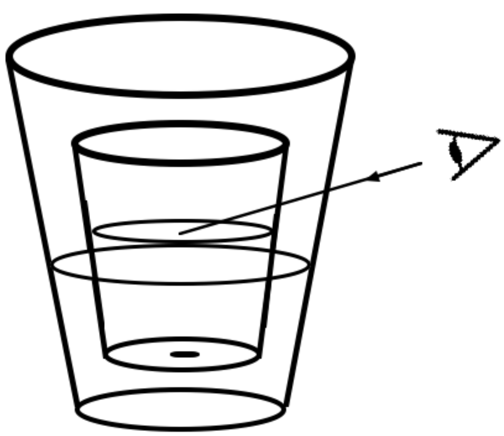
3. Was there any point where you could see a coin while viewing the surface from an increasing angle? Describe when this happened. What was the approximate angle of observation from the surface?

4. Is there a position where you could see more than one coin while viewing the surface? Describe when this happened. What was the approximate angle of observation from the surface?

5. Briefly describe what the coins look like – is either coin inverted (upside-down)?

6. As you viewed the multiple coins – explain where reflection is occurring? Where is refraction occurring? Is reflection and refraction occurring both for the same image?

Procedure B:
Take the larger glass and fill it with a few inches of water. Now while holding your eye in the position where you can see two coins on the surface of the water in the smaller glass – slowly immerse the smaller glass into the larger glass (see diagram). As you lower the smaller glass into the larger glass the water level in the large glass will rise (be careful that it does not overflow onto the table). Lower the small glass so that the level of the water in both glasses is about even. Watch the coin images on the surface of the water of the smaller glass as you lower it into the water of the larger glass.



Name______________________________ Date____________

7. Briefly describe what happens to the images of the two coins as you lower the smaller glass into the water. Hint does one of the images disappear or both disappear?

8. Briefly attempt to explain this effect using your understanding of reflection and refraction (hint: remember that refraction and reflection occurs between two different materials).

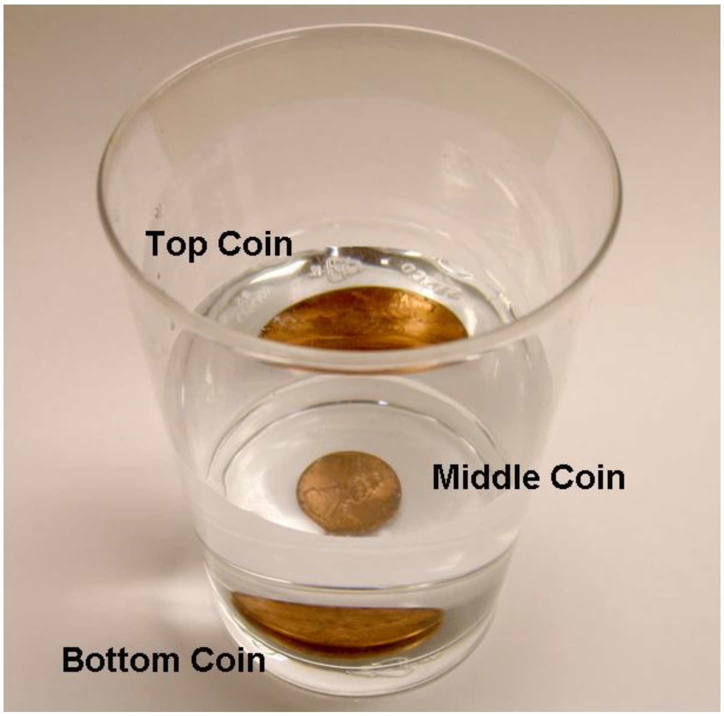
Name________________________________ Date____________

Activity 5-4: Seeing Multiples

Objective: To determine the light ray paths for several images of a penny and stick in a beaker of water.

Materials: Same as Activity 5-1

Procedure:



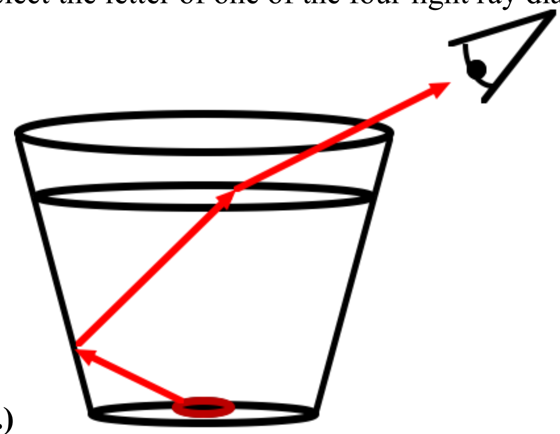
In the photograph to the left – one can see 3 separate images of the same penny sitting at the bottom of a cup filled with water. In this exercise – you will select the path of light from the penny to your eye.

Below, you will match one light ray diagrams to the image of the penny that it forms.

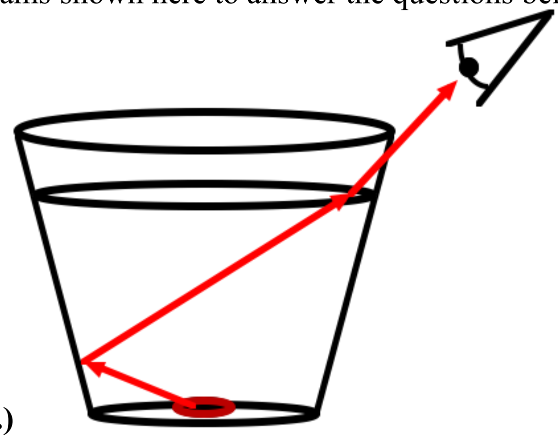
Fig. 5-5-1. In the figure one can see 3 images of a penny.

Name______________________________ Date____________

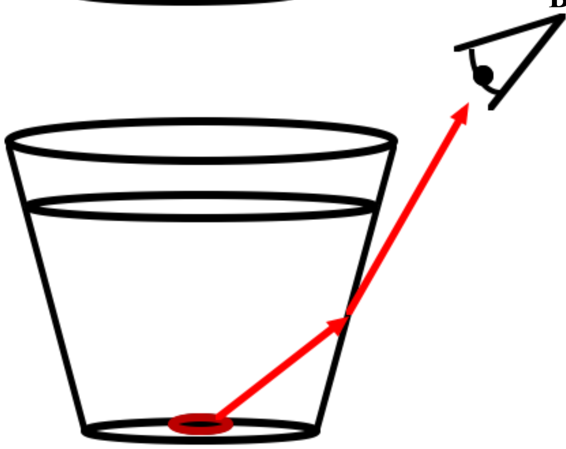
Select the letter of one of the four light ray diagrams shown here to answer the questions below.



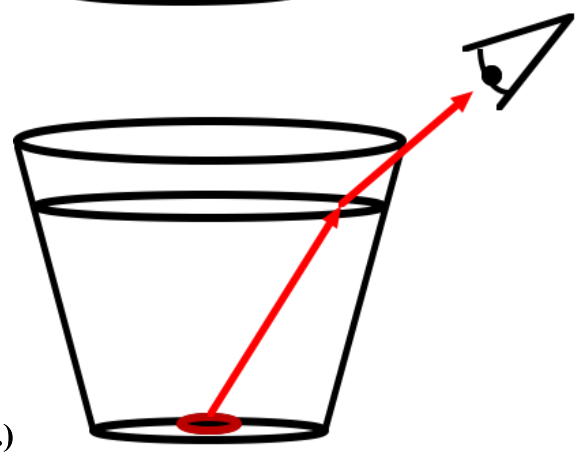
A.)



B.)



C.)



D.)

1.) Write the letter of the diagram that best represents the path of light of the Top Coin:

2.) Write the letter of the diagram that best represents the path of light of the Middle Coin:

3.) Write the letter of the diagram that best represents the path of light of the Bottom Coin:

4.) From your understanding of the properties of refraction – explain which of the four diagrams is not possible and why:

Name_______________________________ Date____________

Activity 5-5: Thick Lenses and Beam Spreaders

Objective: To observe and demonstrate how a beaker of water can act as a thick lens to focus parallel rays of light

Background:

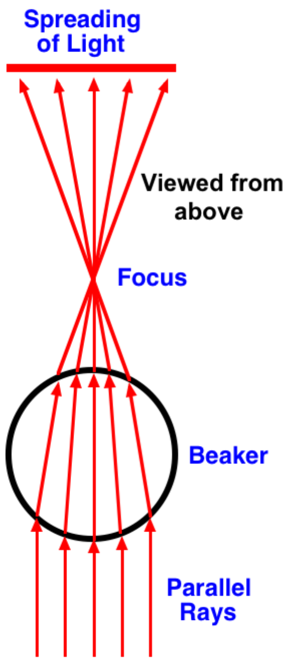


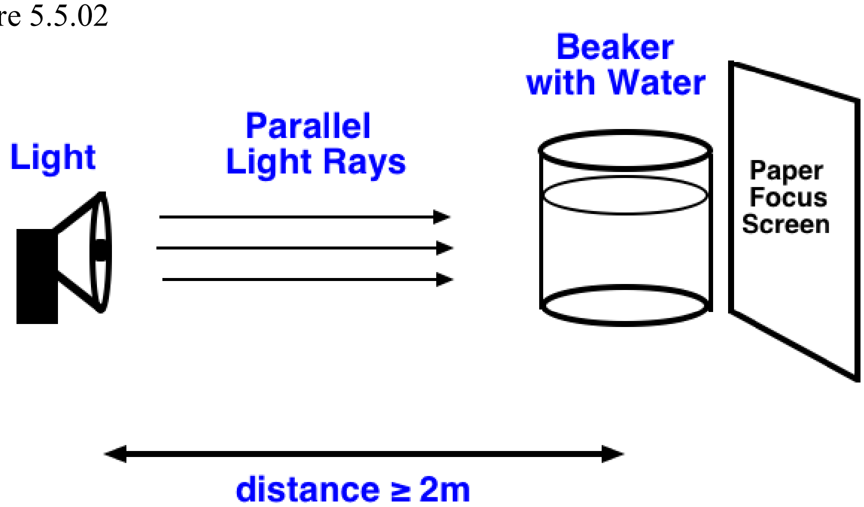
Figure 5.5.01 Viewing beaker from above

Looking through a glass full of water, you can easily view a distorted image of objects on the other side of the glass. The objects may appear blurry or magnified depending where they are in relation to the glass. In this case, the water in the glass is acting like a very thick lens. Since this lens is a cylinder (shaped like a tin can) and is not symmetrical and round like the lens in a magnifying lens - parallel light rays passing through the glass and water will focus to a line (not a single point as with a magnifying lens). The diagram 5-5-01 shows how parallel rays of light pass through the water in a beaker and come together to focus on the outside of the beaker. These rays then continue to move in a straight line through the air and spread out as they move further from the beaker. In this exercise, instead of viewing objects through a lens - we will investigate this lensing effect by focusing and spreading out of light rays with a simple beaker of water.

Materials Included:

- 2 different beakers whose diameters differ by roughly a factor of 2 (or round drinking glasses with vertical sides). The height does not matter.
- Lamp or flashlight.Lamp and bulb
- A few sheets of standard white paper, ruler, pen, and simple calculator.

Set Up: Figure 5.5.02



Name______________________________ Date____________

Procedure:

• Make a "+" in the center of a standard sheet of white 8.5 x 11 paper and center the small beaker (filled with water) on the spot marked "+".

• Draw a circle around the bottom of your beaker with a pen so you will know its position.

• Direct light from your lamp toward the beaker from at least 2 meters away (at this distance all the rays of light will approach the beaker almost parallel) - darken the room.

• Use a flat sheet of white paper as a focus screen to view the image behind the beaker. You will need to move the paper away from the light source to find the best focused line (see Figure 5.5.02).

• At some specific distance from the back of the beaker a sharp line should come into focus on the paper. Move the paper back and forth until you find the exact spot the line comes into sharp focus (see pictures in Figure 5.5.03).

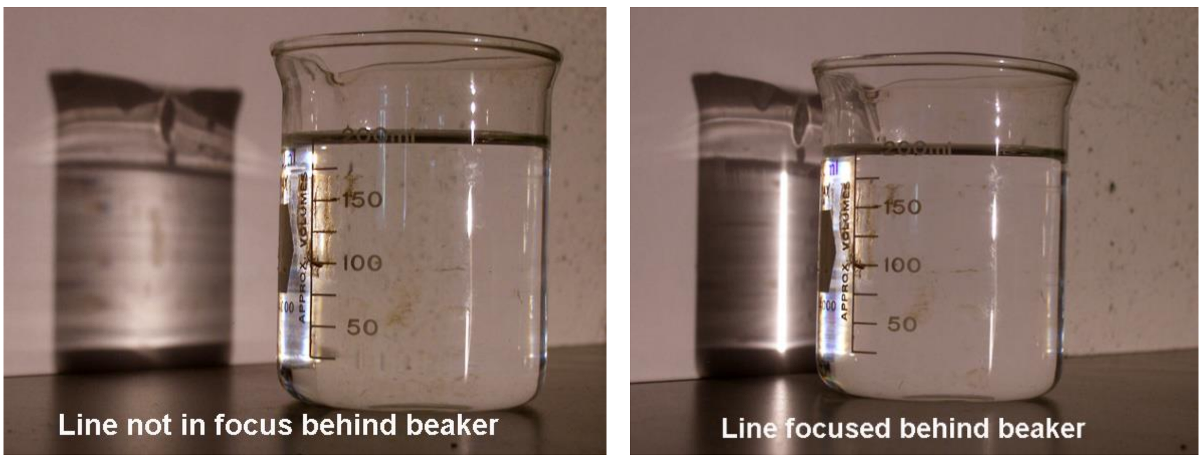


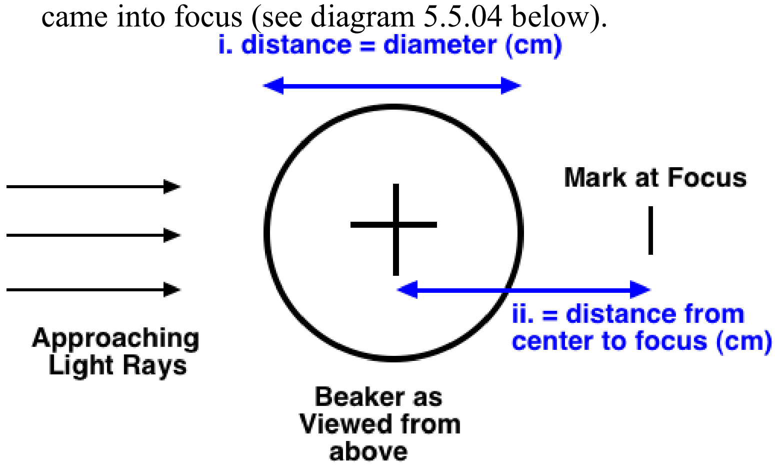
Figure 5.5.03

• On the paper in which the beaker is sitting (the paper with the "+") make a mark at the distance where the light comes into focus.

• Remove the beaker with water. Using your sheet of paper, measure:

i. the diameter of the beaker (the distance across the circle drawn at the bottom of the beaker and

ii. the distance from the center of the beaker at "+" to the mark you made where the line came into focus (see diagram 5.5.04 below).



Name______________________________ Date____________

- Write your data in the table below and divide the diameter by the focus distance.
- Do all of above for the other larger beaker.

	dist i. **diameter (cm)**	dist ii. **dist to focus (cm)**	**dist i./dist ii. (no units)**
Beaker 1			
Beaker 2			

Based on your observations during this activity answer the following questions:

1. When we say, "the light comes into focus at one spot"- describe what this means in terms of the path of different light rays.

2. Describe the path of rays that proceed through the center of the beaker to a point of focus behind the beaker – noting any places the light might bend:

3. Describe the path that parallel rays of light that pass through the outer part of the beaker must take to come to the focus point – noting any places the light might bend:

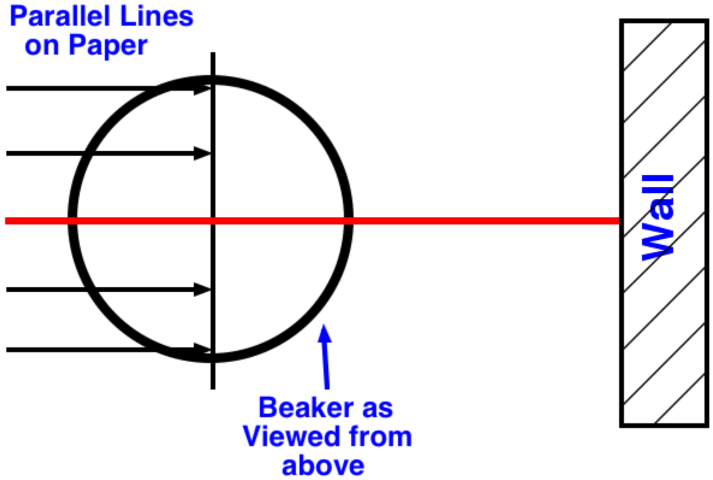
4. The water in the beaker acts as a thick lens. There is a mathematical relationship between the thickness of a lens & the place where parallel rays come into focus behind the lens (the focal point of the lens). From your diameter and focal length data table – discuss any pattern in your data that might hint at this relationship for a round lens:

5. If you -were to have a beaker whose diameter was 10 cm across –predict the distance from its center to focal point:

Name________________________________ Date____________

Activity 5-6: The focusing and spreading out of parallel rays of light

Objective: To observe and demonstrate how a beaker of water can act as a thick lens to focus parallel rays of light from a laser pointer



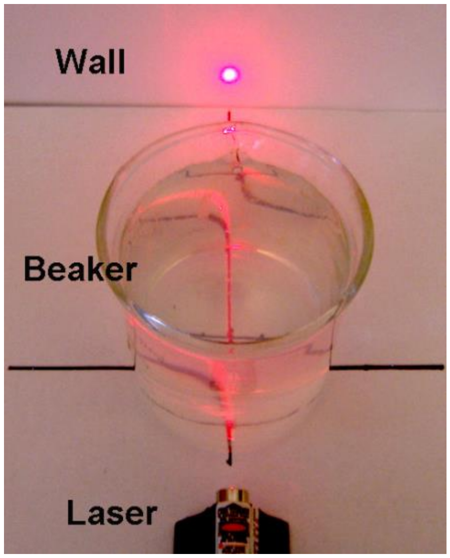


Figure 5.6.01

Materials Included:
- A beaker (or round drinking glasses with vertical sides).
- Small amount of milk or milk powder.
- Laser-pointer.
- Page of paper with lines (provided on the last page of this handout)
- Ruler and pen.

Procedure:

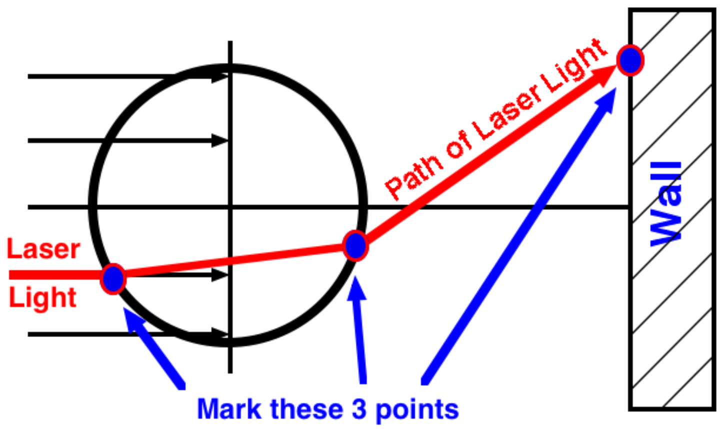
At the end of this activity you will have made a ray diagram similar to Figure 5.5.01 (the completed diagram from this activity will need to be scanned or photographed and electronically submitted with your answers).

- On the page 22 of the handout there is a page with many parallel lines – printout this page.
- Place the larger beaker filled water on this page and center it as shown in the diagram 5.5.06 below. Make sure the distance between the wall and the beaker is greater than the diameter of the beaker.
- Put a very small amount (less than ½ teaspoon in 200mL of water) of milk in the water - darken the room.
- Place the laser-pointer so that it points directly down the centerline through the beaker and strikes the wall just above where the centerline reaches the wall (see above picture & diagram).

Name_______________________________ Date____________

• Note that you should be able to see the path of the laser light through the water because of the reflection from the milk particles in solution. If you cannot see the path of the laser through the solution → add slightly more milk. If the laser light is too diffuse and does not make a clear spot on the wall → dilute the solution by pouring out half the solution and add more water in the beaker.

• On the sheet of paper draw a circle around the bottom of the beaker to clearly identify its position.



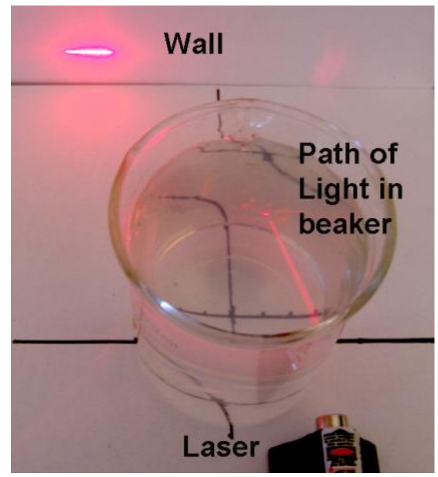


Figure 5.5.06

• On the sheet of paper – you need to mark 3 points:
1. the point on the circle where the laser light enters the beaker,
2. the point on the circle where the laser light leaves the beaker, and
3. the point where the laser light is projected to the wall. This first case should be simple since the light was set up to move in a straight line through the beaker to the wall beyond.

• Now move the laser pointer to the side of the center line, so that it points directly down one of the parallel lines drawn on the paper in the direction of the beaker (as shown in Figure 5.5.06 above).

• Again, mark the 3 points mentioned above on the paper (in this case the laser light should be bent slightly as it enters and leaves the surface of the beaker).

• Repeat this procedure to make 5 lines in total. The centerline and two lines on each side of the center line.

• Once the five light paths have been marked – remove the beaker and connect the marked points to show the each of the 5 paths of the light through the beaker to the wall (much like *Figure 5.5.01*). Scan or photograph this diagram and embed it as the last page of this document – you will submit it as part of this assignment.

Name_______________________________ Date_____________

Based on your observations during this activity answer the following questions:

1. Describe the path the laser light takes moving through the center line of the beaker to the wall.

2. Describe the path the laser light takes moving through the beaker to the wall – if the light enters the beaker off the centerline.

3. Most lenses have a position where parallel rays of light come into focus (known as the focal point)
    i. Describe the place on your diagram that represents the focal point of your beaker lens.

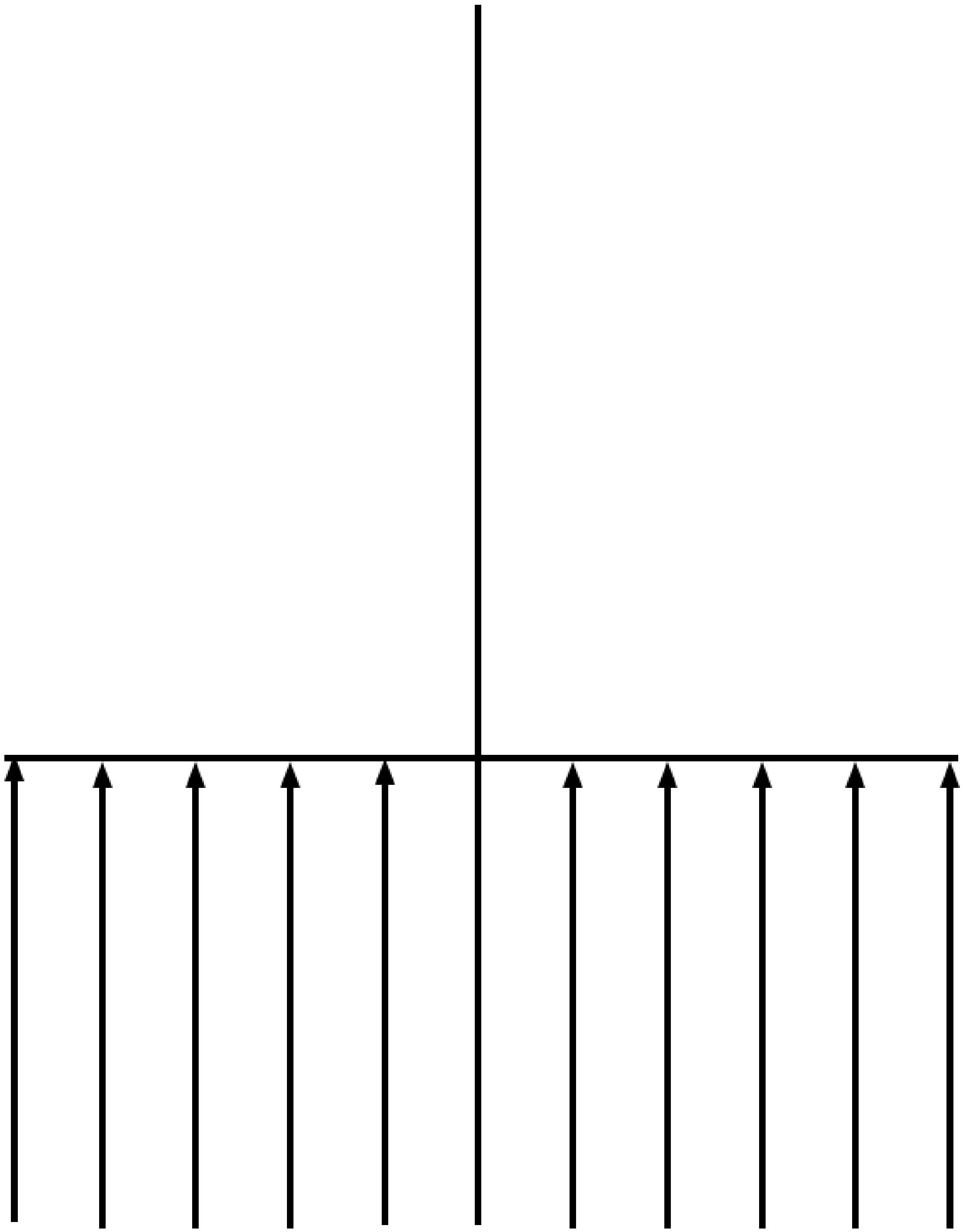
    ii. Discuss what we mean when we say “focus”.

4. Previously in our reflection lab you used a small glass cylinder to spread-out our laser beam to make a line – explain where on your diagram would this “spreading-out” occur.

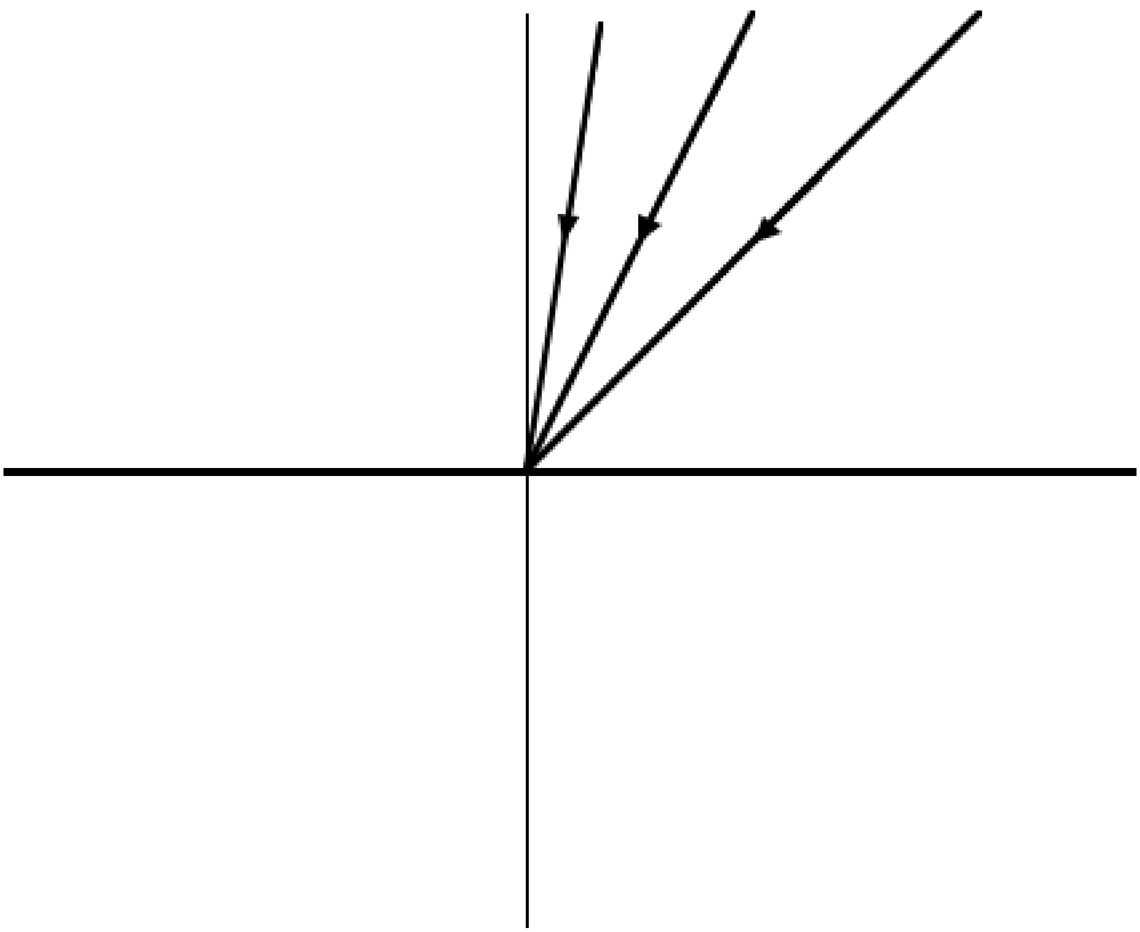
5. Explain how you would relate this diagram to our previous investigation (5.5) – where on the sheet of paper did the lines come to a focus? Does the same relationship hold between the thickness (diameter) of the beaker and the focal point?

Embed your picture for activity 5-6 here.

Name________________________________ Date_____________



Name________________________________ Date_____________



Name________________________________ Date_____________

Home Lab 6
Color, Waves, and Dispersion

Overview:

Visible light is light that can be perceived by the human eye. When you look at the visible light of the sun, it appears to be **colorless**, which we call **white**. And although we can see this light, white is not considered to be part of the visible spectrum (Figure 4). This is because white light is not the light of a single color, or frequency. Instead, it is made up of many color frequencies. When sunlight passes through a glass of water to land on a wall, we see a rainbow on the wall. This would not happen unless white light were a mixture of all of the colors of the visible spectrum. **Isaac Newton** was the first person to demonstrate this. Newton passed sunlight through a glass prism to separate the colors into a rainbow spectrum. He then passed sunlight through a second glass prism and combined the two rainbows. The combination produced white light. This proved conclusively that white light is a mixture of colors, or a mixture of light of different frequencies. The breaking up of white light into wavelengths of different colors is called dispersion.

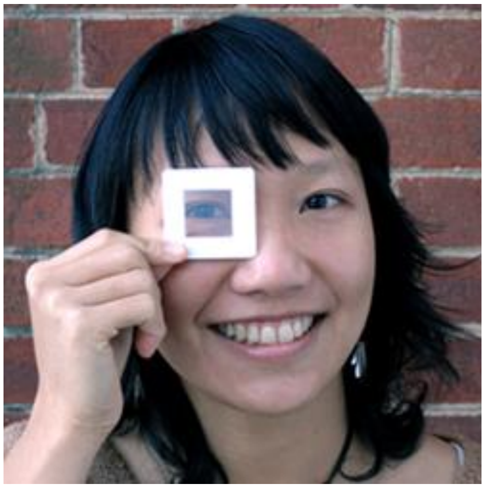
Activity 6-1: Observing a Spectrum of Light using a Diffraction Grating

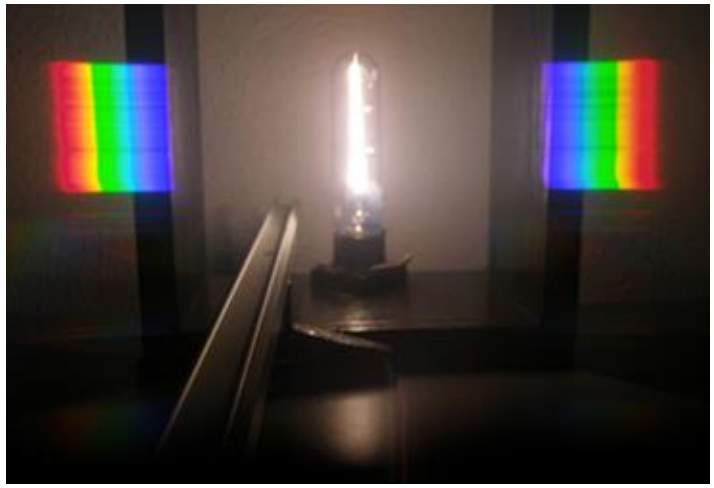
Overview:

A diffraction grating is made up of a multitude of closely spaced slits and is used to disperse light into colors via the interference of diffracted light waves. Diffraction is the bending of light around an obstacle or through a narrow opening, causing the light to spread and produce light and dark fringes. More on diffraction will be covered in a later lab. It is only used is this activity because it makes it easy to observe the dispersion of light.

Objective: To understand and view that white light is made up of colored light using a diffraction grating.

Name________________________________ Date_____________





Material Included:

- Diffraction grating
- Red, blue, green, yellow, magenta, and cyan colored filters

Material Not Included:

White light source

Standard unfrosted 60-100 watt bulb or bulb similar in shape to that shown in above picture, White LED light on Maglite from Lowes or any hardware store

- **Procedure:**

1. Darken room
2. Look at the white light source through the diffraction grating (you can do so by holding the diffraction grating up close to your eye as shown in the picture, or hold it a distance away and adjust your sight until you see clear color patterns). If you notice colors top and bottom, rotate the grating 90 degrees so the colors will be left and right.
3. Do you see the visible spectrum (ROYGBIV)? _____Are these colors separated by dark spaces or continuous? ____________________
4. What is the order of the colors from left to right (from the white light)? ____
5. Now shine the light through the diffraction grating onto a white wall. You will need to be close to the wall and see if you can again see the spectrum.
6. What is the order of these colors? ____
7. A typical diffraction grating has over 10,000 grooves per inch. Make a reasonable guess for the ordering of the colors?

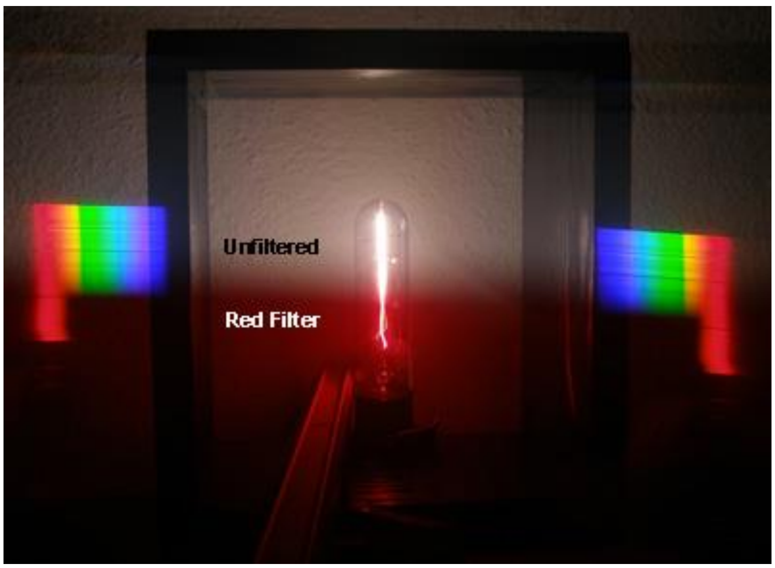
   ____

Activity 6-2: Evaluation of color light filters

Overview:

When white light shines on a transparent colored filter, it is assumed that the transmitted light is the color of the filter, but in fact most filters also transmit other colors as well. A diffraction grating that separates white light into the spectrum is very sensitive to observing different wavelengths of light. It can be useful to evaluate how well the filter transmits a particular color. If a particular color or wavelength is truly absorbed by the filter, then it should be absent when viewing the transmitted light through a diffraction grating. When you viewing the light through a filter using the diffraction grating, you will see some wavelengths weakly and some strongly. The strongest appearing color in terms of its brightness or intensity should correspond to the color of the filter.

Objective: To understand and view the limited filtering capabilities of certain color filters.



Materials Included:

- Diffraction grating
- Red, blue, green, yellow, magenta, and cyan colored filters

- **Material Not Included:**
- White light source

  Standard unfrosted 60-100 watt bulb or bulb similar in shape to that shown in above picture, White LED light on Maglite from Lowes or any hardware store

Name______________________________ Date____________

Procedure:

1. Darken room.
2. Turn on white light source and hold diffraction grating up to your eye. Rotate grating until spectrum is sideways not up and down.
3. Cover the bottom half of the diffraction grating with a red filter. Hold grating filter combination close to your eye and look at light above the red filter. Then raise the grating/filter slightly, so you are observing light through red filter. It does not matter if you place the filter before the grating or after.
4. When you look through the grating you will see the entire spectrum but when you look through red filter the brightness of the colors will be limited as you see above with red filter.
5. What color(s) is(are) strongly transmitted through the red filter to your eye? ____

Filter	Transmission	Red	Orange	Yellow	Green	Blue	Violet
Red	Strongly						
	Weakly						

6. What color(s) are weakly transmitted through the red filter to your eye? ______________________________
7. What color(s) are unable to pass through the red filter? ______________________________
8. Replace the red filter with 5 different colored filters and complete table.

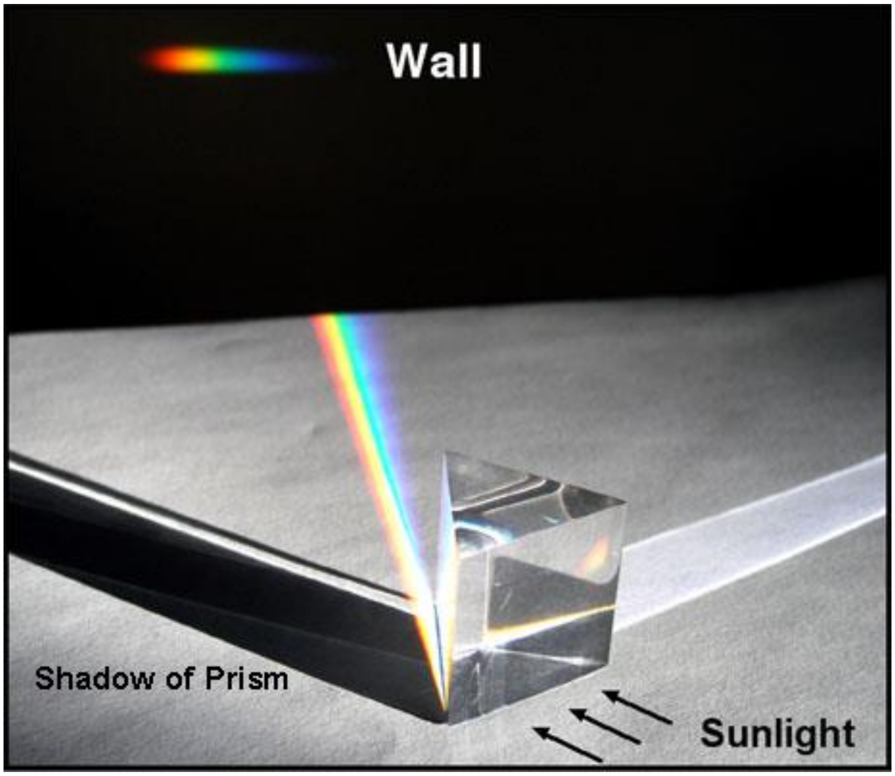
Name________________________________ Date_____________

	Zero						
Blue	**Strongly**						
	Weakly						
	Zero						
Green	**Strongly**						
	Weakly						
	Zero						
Yellow	**Strongly**						
	Weakly						
	Zero						
Magenta	**Strongly**						
	Weakly						
	Zero						
Cyan	**Strongly**						
	Weakly						
	Zero						

Name________________________________ Date_____________

Activity 6-3: Dispersion of Sunlight from a Prism

Objective: To illustrate that white light is made up of different colors by dispersing it through an equilateral prism.



Materials Included:

- Equilateral Prism

Materials not included

- Bright sunlight
- Flat white vertical surface or wall or screen

Procedure:

1. Locate the bright sun in the sky preferably in the early morning or late afternoon where it is lower in the sky and almost horizontal rays are obtained.
2 The sun is a good source of light for illustrating dispersion because the rays are parallel and each ray strikes the prism at the same angle.
3. Place the prism on the template as shown in the photo in the above Figure so that the light beam enters one side of the prism and exits the opposite side and refracts through the largest possible angle.
4. Place a vertical white screen about 50 cm to 100 cm behind the prism such that the sunlight beam strikes the screen after passing through the prism. You need some distance to allow the

colors to spread out.
5. Slowly rotate the prism until you are able to observe a bright spectrum of light on the screen and template. Success is being able distinguish the individual colors. See the geometry in the above figure.
6. The **amount of refraction or angular deflection from the light beams original direction** depends inversely on the wavelength. Red has the longest wavelength in the visible spectrum and it bends the least. Violet has the shortest wavelength and it bends the most from the original path of white light. Record the colors you see from top (pointed end of prism) to bottom and look up the wavelength of each color in nanometers.

Color	Wavelength in nanometers
Red	
Orange	
Yellow	
Green	
Blue	
Violet	

Questions
1. Explain why the light has to be parallel to observe a colorful spectrum.

2. If the light were not parallel such as that emitted from a point source, what do you think you would observe. To answer this question use the white light from from your laser pointer.

Name________________________________ Date_____________

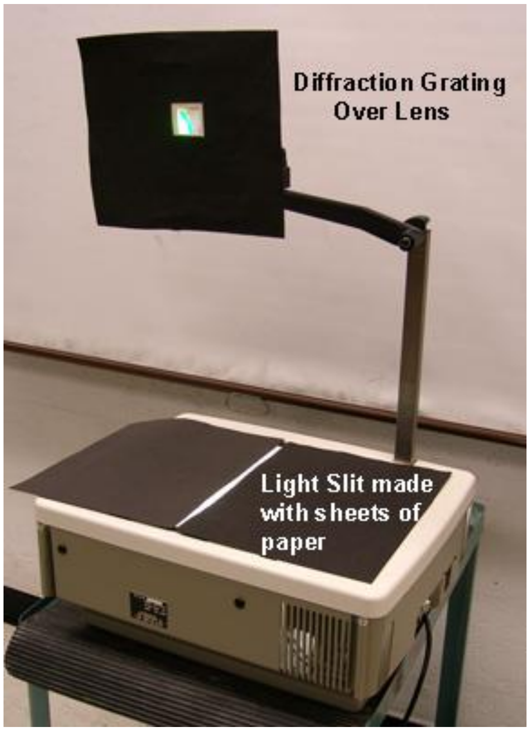
Activity 6-4: Spectrum of light from overhead projector using a slit and diffraction grating

Overview:
A diffraction grating is used is this activity to observe the dispersion of light from an overhead projector. A diffraction grating will spread the white light passing through the slit into a spectrum from red through green to blue. The angular spread is proportional to the wavelength of light.

Material Included:
- A holographic diffraction grating
- Red, blue, and green filters.

Material Not Included:
- An overhead projector and white screen or wall
- Thin opaque cardboard or black construction paper larger than the diffraction grating in which to mount the diffraction grating plus some sticky tape.
- Thin opaque cardboard or black construction paper large enough to cover the lens of the overhead projector.
- Meter stick

.
Procedure:
In the steps described below refer to the following figure.



1. Cut a hole in the cardboard slightly smaller than the diffraction grating.

2. Tape the diffraction grating over the hole.

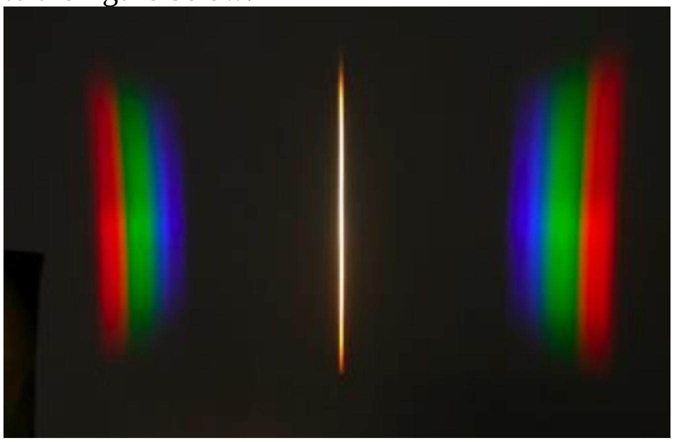
3. In the other piece of cardboard or black paper , cut a slit 10 mm to 20 mm wide (1/2 to 1 inch) wide and 10 – 20 cm long. Cut the slit out in one piece using a razor and keep the cutout construction paper in one piece for Actvity 5.

4. Place the cardboard or black paper with the slit in it on the overhead projector so that the slit is projected as a vertical line on the screen. Cover the entire overhead projector with cardboard or black paper so that no light gets out except the light that comes through the **slit.** Focus the image of the slit.

5. Hold the cardboard-mounted diffraction grating over the exiting light from the overhead projector after the focusing lens. Rotate it until two spectra of light appear to the right and left of the slit of light. Tape it in place. In this orientation the lines on the diffraction grating will be vertical. Rotate the overhead projector, or move the screen until the spectrum appears on the screen and the white image of the slit too. Wider slits will produce a brighter spectrum, narrower slits will produce a sharper yet dimmer spectrum. I suggest you start with slits about 10 mm (1/2 inch) wide.

6. Notice the slit still appears white even after the diffraction grating is in-place, this is called the zero'th order diffraction. Spectra of light appear on both sides of the slit, these are the first-order spectra. A second more widely spread spectrum may appear beyond the first, this is the second

order spectrum. Ignore the second order for this activity. You should observe something similar to the figure below.



7. In both first order spectra, blue light is near the white slit and red is farthest away.
Notice the colors that appear between blue and red. Children will often have heard the word ROYGBIV as a way to remember the colors in order. Red Orange Yellow Green Blue Indigo and Violet.

8. Cover the top half of the slit with a red filter (it could be any color). The full spectrum of the white light from the bottom of the slit appears to the side. Only the light colors which get through the filter appear to each side of the colored part of the slit. A yellow plastic filter will usually transmit red and green while blocking the blue. A magenta filter will pass both red and blue while blocking green, and a cyan filter will pass through green and blue while blocking red.

What's Going On?

a. When light passes through a diffraction grating some is bent to the side. Each color of light is bent through a different angle: red light is bent through the largest angle while blue light is bent through the smallest. Each position in the spectrum corresponds to a wavelength of light. So each color in the spectrum is a human perception of a single wavelength of light.

b. Transparent plastic filters absorb a wide range of wavelengths of light and allow other wavelengths to pass through. Yellow filters absorb blue and allow green and red to pass through. Human eyes perceive the resulting sum of green and red as the color yellow. The energy of the light absorbed by the filter, warms the filter.

9. Measure the wavelength of the light on the different colors of light using the following formula and fill out the table. The wavelength is given by : $\lambda = 2000nm\sin\theta$ where the

Name________________________________ Date_____________

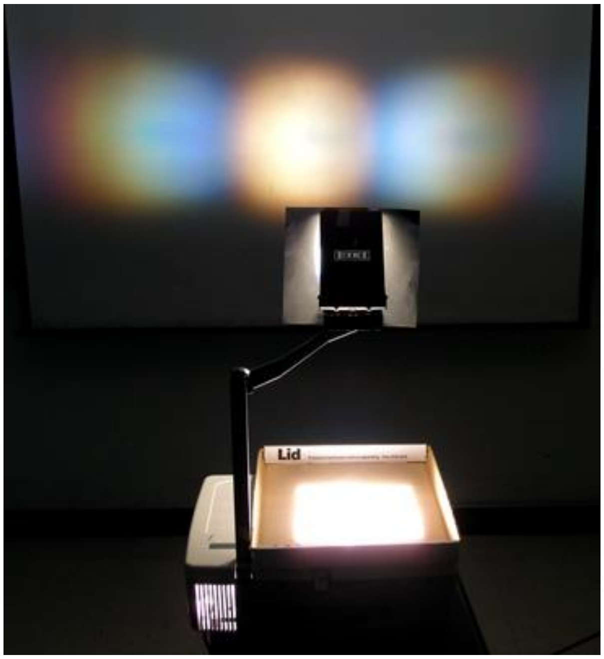
constant 2000 nm depends on the particular diffraction grating. θ is the angle of a particular ray that is bent away from the original direction

Color	θ	sinθ	Measured λ	Expected λ
			nm	nm
Red				
Orange				
Yellow				
Green				
Blue				
Violet				

$$\sin q = \frac{x}{\sqrt{d^2 + x^2}}$$

where x is the straight horizontal distance from the zero’th order white light on the screen to the red light
and d is the perpendicular distance from the diffraction grating mounted on the projector to the screen.

10. Remove all the paper from the overhead projector and observe the spectrum on the wall from the entire overhead projector. You should observe something similar to:



Explain why you see on each side of the bright white central pattern first bluish light then some white light, some yellow, and then red on the end. Clearly it looks different from the slit but still there is a kind of spectrum.

Name________________________________ Date_____________

Activity 6-5: Spectrum of subtractive light from overhead projector using an anti-slit and diffraction grating

Objective: To observe the complementary spectrum of subtractive light from an anti-slit.

Material
Same as Activity 6-3

Procedure:

1. Put the cardboard-mounted diffraction grating over the exiting light from the overhead projector after the focusing lens as in Activity 6-4.

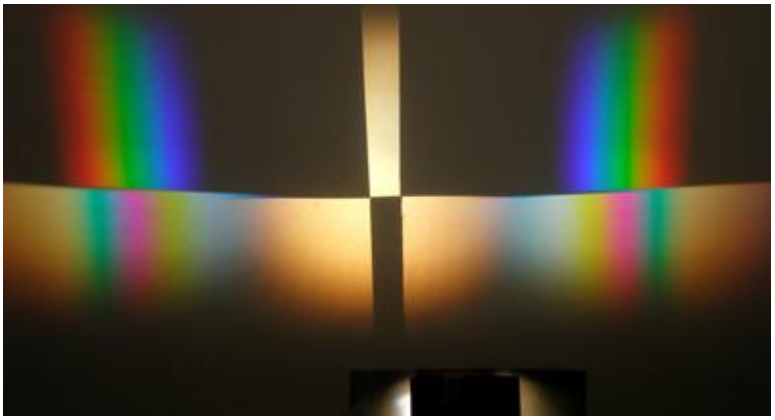
2. Replace the slit with the anti-slit or cut out strip from Activity 6-4.

3. Notice the strange "spectrum" of light that appears on the screen.

The colors range from cyan through magenta to yellow. What is going on? Each wavelength of light in the white light from the slit is bent through a unique angle so that the wavelength we see as red light appears at one point on the screen, and the wavelengths for green and blue at other places. The anti slit does not let light through, so at the position where red light would go from the slit, there is no red light with the anti-slit. The light at that position will be white minus red which is cyan. W - R = C. In the position of green will be white minus green or magenta, W - G = M and in the position for blue will be white minus blue or yellow. W - B = Y. The anti-slit removes one wavelength at a time from white light. Thus we see the spectrum of subtractive colors.

Name______________________________ Date____________

4. Below is a spectrum from both the slit and the anti-slit placed on the projector at the same time with the black anti-slit placed below the slit defined the black paper. Explain how this demonstrates the explanation in Step 3 above.



Name_______________________________ Date_____________

Home Lab 7
Refraction and Snell's Law

Activity 7-1: Snell's Law $n_1 \sin \theta_1 = n_2 \sin \theta_2$

Objective:
- Verify Snell's law

Materials Included:
- Laser pointer
- Cylindrical glass rod
- Parallel-sided plastic rectangular prism

Materials Provided by You:
- White paper
- Protractor
- Scotch tape

Procedure:
1. Use transparent scotch tape to attach the plastic rod to the laser pointer so that the laser pointer makes a horizontal laser line. Place the laser beam spreader attachment on the white paper.

2. Draw a straight line on a sheet of paper. Draw a 90° angle to the surface of the parallel-sided plastic rectangular prism at some convenient location.

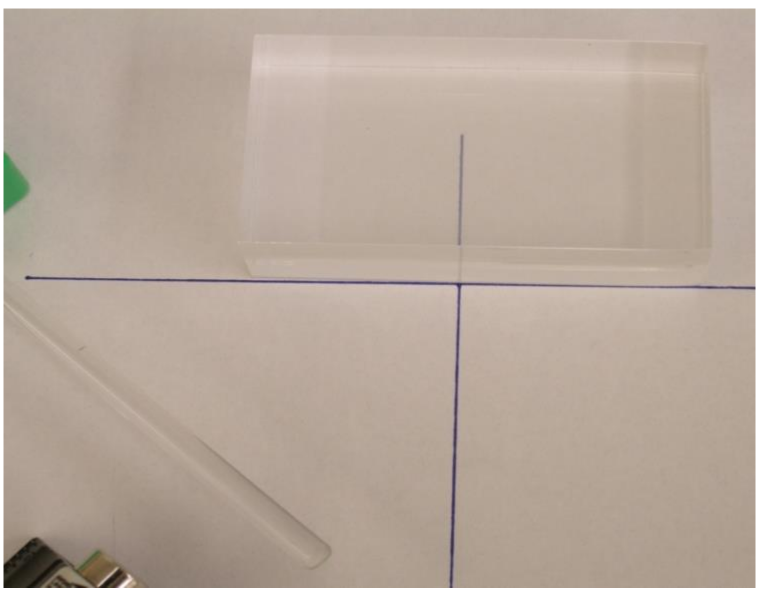


Figure 7-01

3. Place the plastic parallel sided rectangular prism on the sheet of paper with one side of the prism on the line you have drawn. Trace the prism with your pencil and direct the laser at the prism vertex of the 90° angle that you have drawn. Set the angle of incidence

to 10°.

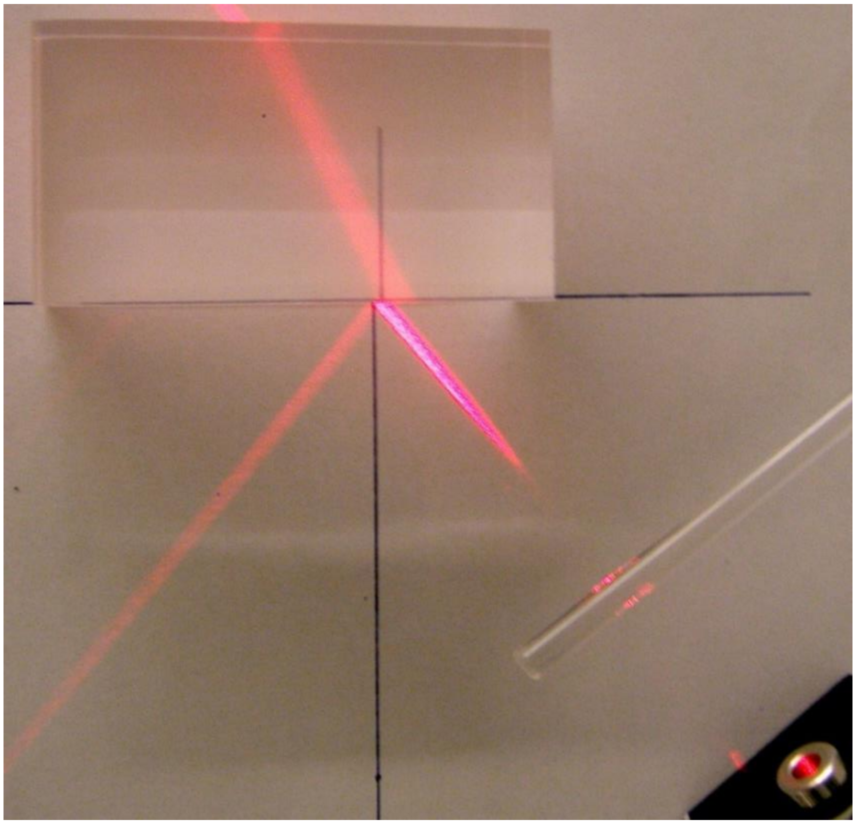


Figure 7-02

*Note: The camera causes a shift in the perpendicular line due to the angle at which the picture is taken.

4. Observe the ray tracks, and mark the paper where the laser beam strikes the prism and where the laser beam exits the prism.

5. Trace the path of the laser beam on your sheet of paper by connecting those marks.

6. Measure the angles at which the laser beam strikes the front of the prism, and the angle at which the laser beam travels into the prism. Record the values of the angle of incidence and the angle of refraction. Measure the angles to the nearest 1° or as close as possible.

7. Repeat the process for 20°, 30°, 40°, and 50°. Results will improve for steeper angles of incidence. Record the data in **Table 7-01**. Calculate the sine of the angle in degrees and record your values of sin θ_1 and sin θ_2 to 3 decimal places.

Name________________________________

Table 7-01

Snell's Law

Angle of incidence θ_1	Angle of Refraction θ_2	sin θ_1	sin θ_2	n_2
10				
20				
30				
40				
50				

8. Make a plot of sin θ_1 versus sin θ_2 with sin θ_1 on the y axis using the chart option in Excel. Include a scale on your graph, and properly label the axis. Use the trend line option in Excel to draw a best-fit straight line to the data. Do not expect the line to exactly go through all the data points. Cut and paste the Excel chart here.

8. Record the slope from Excel here. Slope = _____________. Now calculate the slope by hand as a check of the trend line option and record it here____________________.

9. What is value of n_1, the index of refraction for medium 1, air? Record your value to three decimal places. Look it up in a textbook or google it.
n_1 = ________________

10. Determine the value for n_2 from Snell's law, the index of refraction for medium 2 the plastic prism for all your trials. Record the values in **Table 7-01**. Determine the average value of n_2.
$n_{2\ average}$ = ________________

Compare the average value of n_2 to the accepted value of the index of refraction for the plastic prism. Take n=1.500 as the accepted value. Use the formula:

$$percent\ difference = \frac{|\,your\ value - accepted\ value\,|}{accepted\ value} * 100\%$$

. Comment on what part or parts of your experiment contributes the most to the error in the determination of the index of refraction of the prism

Name________________________________

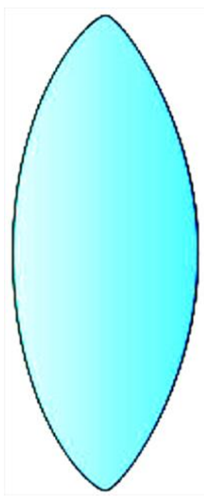
Activity 7-2: Model of a Lens

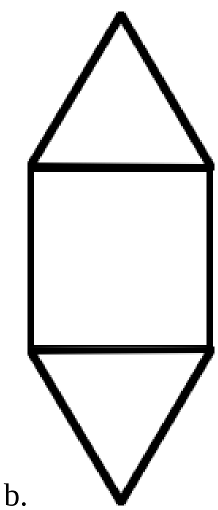
Objective:
To find the approximate focus of a model of a lens

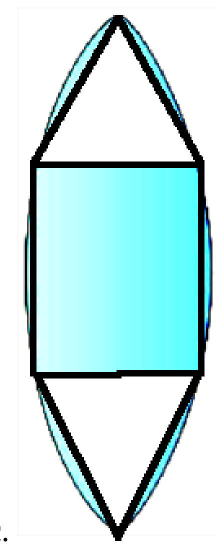
Materials Provided by You:

- White paper
- Protractor
- Pencil

Procedure:
It can be seen from the diagram below that simple geometric shapes can be used to approximate a converging lens. Using these geometric forms, we can explore how refraction causes light to bend through simple lenses. a. side view of converging lens, b. equilateral triangles and square shapes, c. shapes approximating a converging lens


a.


b.

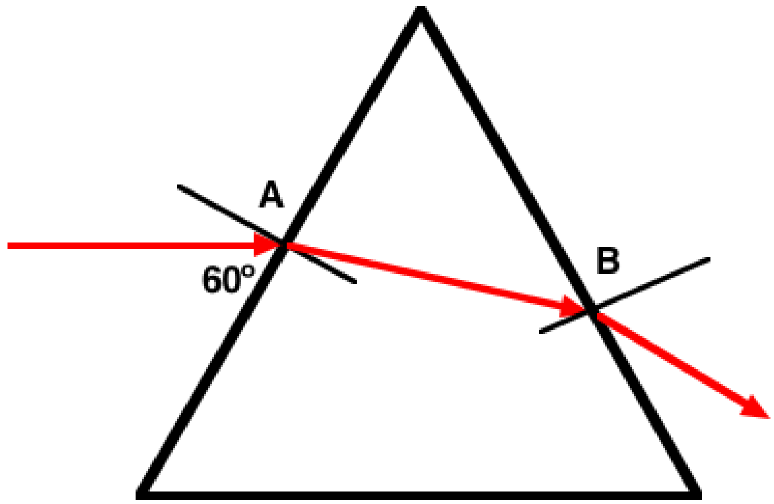

c.

Red light enters and passes through a glass (n = 1.5) equilateral prism (all angles = 60º).

1 .Using Snell's Law (and a little geometry) determine the incident and refractive angles at points A & B, enter the calculated angles in the table below.

Home Lab – Lab 7 Refraction and Snell's Law

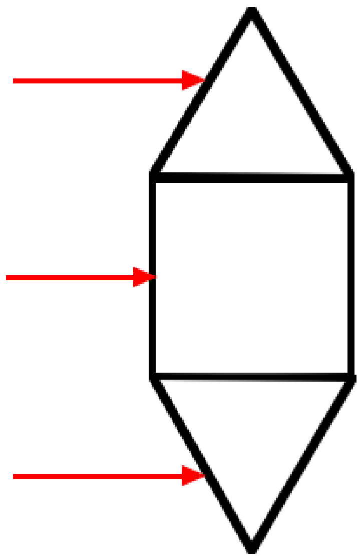
Name_________________________________ Date______________



A		B	
θ incidence	***θ refraction***	***θ incidence***	***θ refraction***

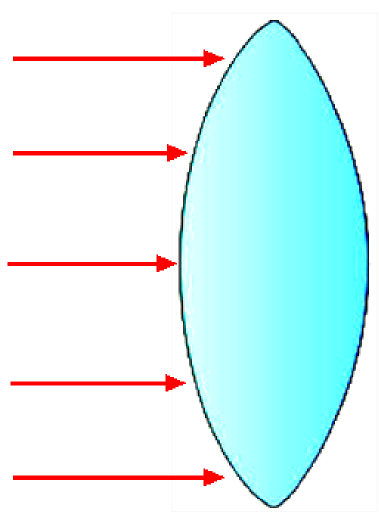
2. Use the angles calculated above to draw the rays of light through the indicated forms in the diagrams below. Sketch the normal lines to help you identify the angles (be as precise as possible).

3. Extend the light rays to the far right hand side of the page. Where do they meet? Explain.



The point where light rays converge behind the lens is called the "focal point," or simply the "focus" of the lens.

4. Repeat the steps for the converging lens below. Find the focal point for the lens and determine if additional light rays towards the top and bottom of the lens also converge at the focal point. Do they converge to a point? Explain your answer.



Name________________________________ Date_____________

5. Compare your results for the simple lens made of three geometric shapes and the regular c onverging lens. How are they similar and different?
6. Use Snell's law and simple geometry to justify your answer. After you have finished your ray diagrams above, scan or photograph this page and submit the page at the end of this assignment in your word.doc.

Name________________________________Date_____________

Home Lab 8
Curved Mirrors, Ray Diagrams, and Simulations

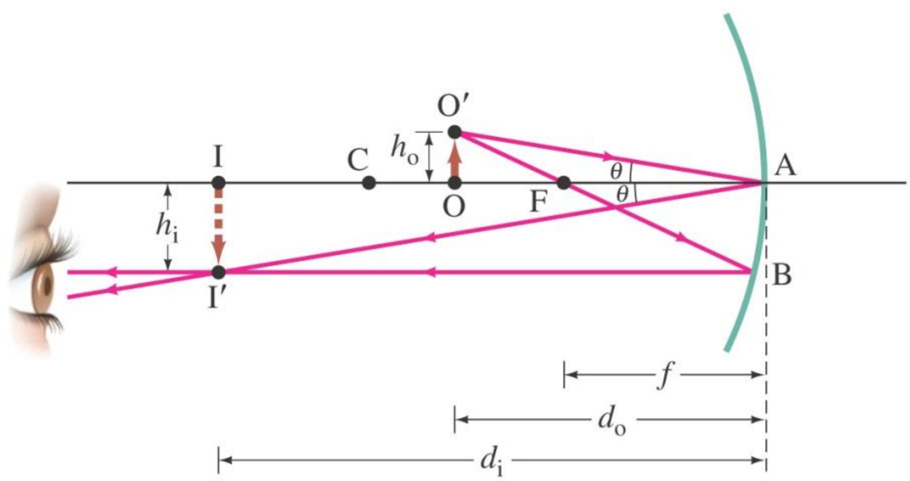
Background Information

Spherical mirrors may be concave or convex. Concave mirrors have the focal point (*f*) in front of the mirror, and convex mirrors have the focal point behind the mirror. In this equation, the symbols d_o and d_i represent the distances from the mirror to the **o**bject and to the **i**mage.

The mirror equation used in this activity: $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

The sign convention for mirrors is described below:

d_o	positive	when the object is "in front of the mirror"
d_i	positive	real images (inverted - "in front of the mirror")
d_i	negative	virtual images (upright - "behind the mirror")
f	positive	converging (concave) mirrors
f	negative	diverging (convex) mirrors



Name________________________________Date_____________

Activity 8 – 1: Focal Length of a Concave Mirror using Parallel Rays - Method I

Objective:

- Determine the focal length of a concave mirror – quickly with a minimum of materials.
- For a spherical concave mirror – parallel rays of light focus to a point. The distance from the mirror to the focused point image is the focal length of the mirror.

Materials Included:

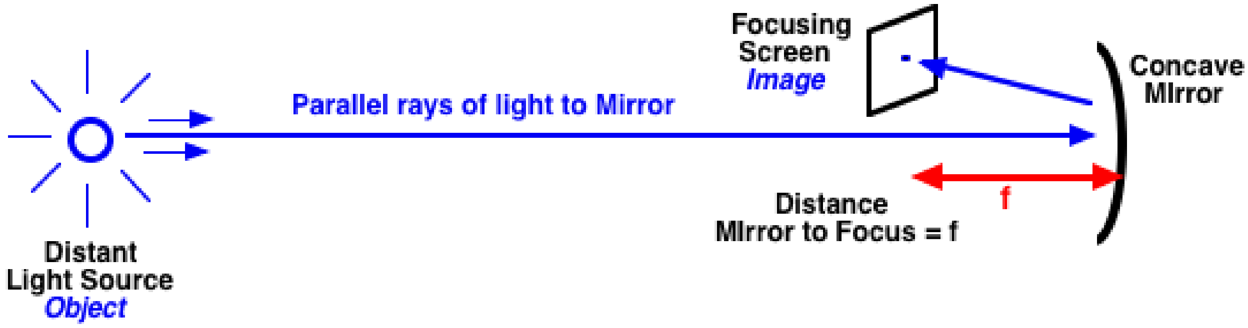
- Economy Optical Bench (Optional)
- 10 cm focal length concave mirror

Materials Provided by You:

- Incandescent Frosted 60 Watt bulb with an F drawn on it (Optional)
- A Ruler and a sheet of paper (for focusing screen)
- Permanent ink (Sharpie) Pen

Procedure:

1. Aim your mirror at a distant light source greater than 6 meters away in a darkened room. You can use the sun outdoors or even inside through a window.
2. Place a sheet of paper (focusing screen) between the mirror and light source so that light can strike the mirror and reflect back to the paper (see diagram below).
3. Move the paper toward and away for the mirror to find the position where the reflected light forms the image of a small spot on the paper.
4. Measure the distance between the mirror and the image on the spot with a ruler
5. **Focal Length of Mirror using Method I: ______________ cm**



Name________________________________Date_____________

Activity 8 – 2: Focal Length of a Concave Mirror using Equidistance - Method II

Objective:

- To determine the focal length of a concave mirror.
- $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \quad if \;\; d_o = d_i \;\; \Rightarrow \;\; \frac{1}{f} = \frac{2}{d} \;\; \Rightarrow \;\; f = \frac{d}{2}$ $\quad f$ is half the distance to the mirror

Materials Included:

- Economy Optical Bench
- 10 cm focal length concave mirror

Materials Provided by You:

- Incandescent Frosted 60 Watt bulb with an F drawn on it
- A Ruler and a sheet of paper (for focusing screen)
- Permanent ink (Sharpie) Pen
- Paper clip and scotch tape (Optional)

Name________________________________Date_____________

Procedure:

1. With a Sharpie pen, draw the letter "F" at least 3 cm tall on the bulb facing the direction of the mirror (this will allow you to distinguish up/down or left/right on the image). Place the front of the light source at the zero meter end of the optical bench (as shown below).

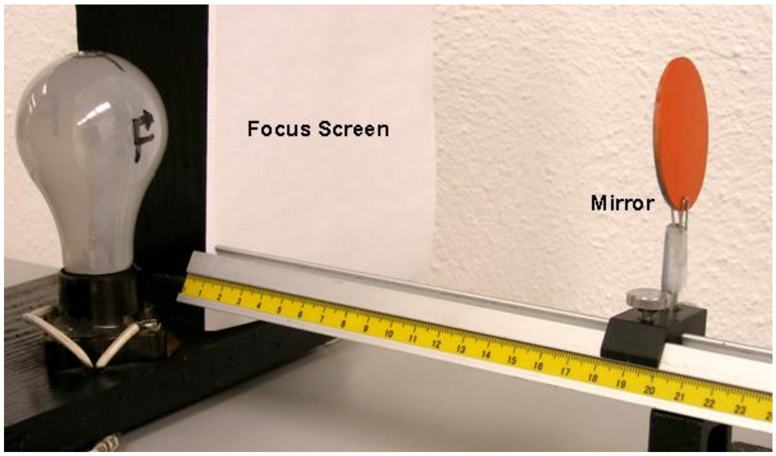


Figure 8 - 1

2. Place a concave mirror facing the bulb in a sliding holder on the optical bench.

3. Fold a sheet of white paper in half to make a focusing screen and place it slightly to the left or right of the light source → so that the front of the bulb and the paper focusing screen are equal distance from the mirror. See Figure 8-1.

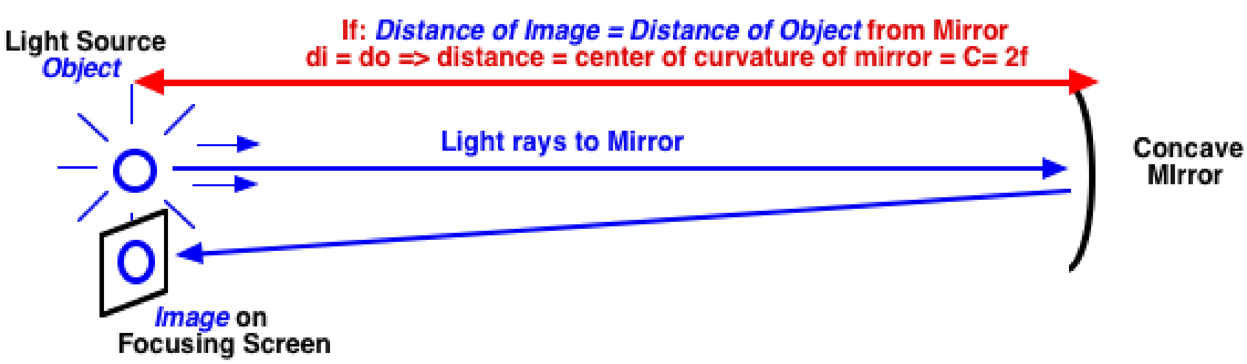


Figure 8-2

4. Adjust the position of the mirror, back and forth, along the bench until you have the clearest image of the "F" (on the bulb) on the focusing screen. You will have to also

rotate the mirror slightly to get the image on the paper. Record the location of the mirror along the bench in centimeters:

____________________ cm

5. What is the orientation of the image with regards to up/down and left/right compared to the original lamp?

6. How does the size of the image compare to the object?

7. What is the image distance ________________ cm?
8. What is the object distance ________________ cm?

9. Use the mirror equation to determine the focal length f of the mirror from your information in step 6. Focal length for the concave mirror = ______________________ cm.

10. Compare your calculated value of ***f*** to the suggested value for focal length of the mirror given by the lens company?

Activity 8 – 3: Focal Length of a Concave Mirror using Graphical Analysis-Method III

Objective:

- Accurately determine the focal length of a concave mirror.

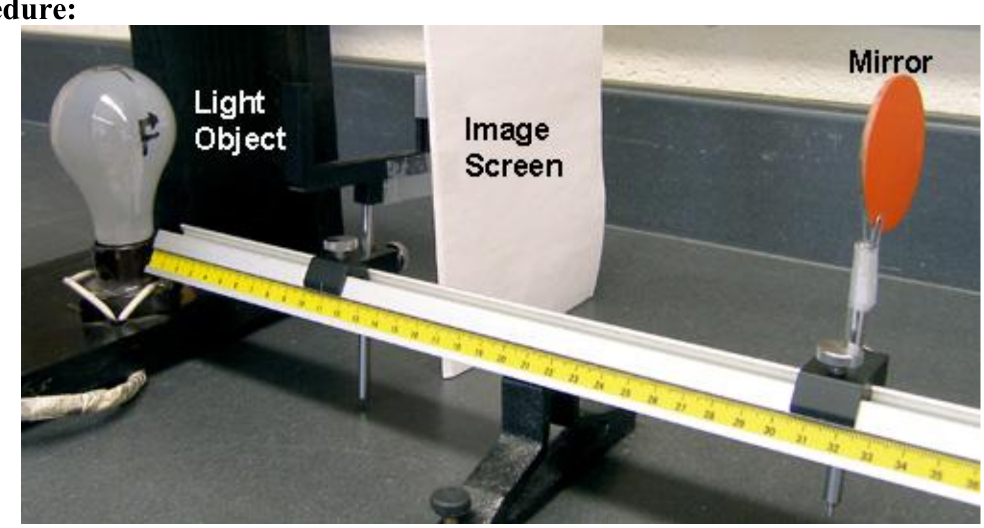
Materials Included:

- Economy Optical Bench
- 10 cm focal length concave mirror

Materials Provided by You:

- Incandescent Frosted 60 Watt bulb with an F drawn on it
- A sheet of paper (for focusing screen)
- Permanent ink (Sharpie) Pen
- Paper clip and scotch tape (Optional)

Procedure:



1. Use the light source and mirror used in activity 8-1. Connect the light source and place the light source at the zero end of the optical bench.

2. Place the mirror at the 80 cm mark on the bench. Put the white focusing screen between the mirror and the light source (slightly to the side). Adjust the location of the screen until you see an image on the screen of your light bulb. You may have to tilt the mirror slightly to form an image on the screen.

3. Record the distance from the lamp to the mirror as $\boldsymbol{d_o}$, and the distance from the mirror to the screen as $\boldsymbol{d_i}$. Record these distances to the nearest 0.1 cm in **Table 8-1**.

4. Is the image erect or inverted? Is the image real or virtual? Record this information in **Table 8-1**. (hint: there may not be a clear "real" image at all (d_o) distances.)

Table 8-1
Concave Mirror

Trial #	Light to Mirror d_o (cm)	Image to Mirror d_i (cm)	$\frac{1}{d_o}$	$\frac{1}{d_i}$	Image Orientation Erect/Inverted	Type of Image (real/virtual/none)	Image height (cm)
1	80	?	?	?	?	?	
2	70	?	?	?	?	?	
3	60	?	?	?	?	?	
4	50	?	?	?	?	?	
5	40	?	?	?	?	?	
6	30	?	?	?	?	?	
7	20	?	?	?	?	?	
	15						
8	10 5	?	?	?	?	?	

5. Decrease the distance between the lamp and mirror and record your results in the above data table. Continue to decrease the object distance until you have reached an object distance of 5 cm.

6. Discuss the orientation and height of the various types of images formed in relation to the perceived focal length of the lens (f found in previous activities).

6. We will now determine the focal length of the mirror using two different graphical methods taking advantage of the equation:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$ → → *using a little algebra*

Name________________________________Date_____________

first from: $\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$ we will plot: $\frac{1}{d_o}$ (as x), $\frac{1}{d_i}$ (as y) to find $\frac{1}{f}$, thus ***f***

7. Make a plot of: $\frac{1}{d_o}$ (as x) vs. $\frac{1}{d_i}$ (as y) using the chart option in Excel.

   Properly scale and label the axis of the graph. Draw a best-fit straight line using the "trend-line" option under chart (also select to display the equation of the trend-line). The trend-line may not go exactly through all the data points.
   Cut and paste the Excel chart here.

8. If the equation for this graph is: $\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$,how can you determine the value of $\frac{1}{f}$ from the graph? Explain your reasoning here:

The values you determined from your graph:

$\frac{1}{f}$ = _____________ f = _____________

Name_______________________________Date____________

9. How do your values of ***f*** compare for the same lens? Fill in the table below.

Methods	***f value (cm)***
Method Activity I	?
Method Activity II	?
Graphical Method I	?
Manufacture's Value	?

10. State which of the ***f*** values you think is most accurate? Justify your reasoning. Briefly explain how you would determine ***f*** for this mirror - if accuracy of the ***f*** value were very critical.

Name_______________________________Date_____________

Activity 8 – 4: Computer Simulation Illustrating Graphical Analysis

Objectives:

- To graphically analyze more difficult optical phenomenon using computer simulations.

Materials Provided by You:

- Internet access

Procedure:

1. We will use the mirror simulation program located at http://webphysics.davidson.edu/Applets/optics/intro.html. You will use this applet again later in the course. Bookmark this location.

2. Click your mouse on the "**Mirror**" button. The text becomes colored, showing that it is active. Click on the diagram and you will notice a "**+**" on the screen. Note that as you move the "+" a small yellow box in the corner of the diagram indicates its x, y position (left edge = x = 0, yellow line = y = 0).

3. Move your cursor to about 1/4 of the way from the right side, near the yellow line. When you click your mouse, a concave curved mirror appears. The location of the center of the mirror is given on the screen. Move the mirror to a convenient location (such as x = 4.0) by dragging the mirror left or right. This is labeled on the screen as "**x**" and is near the center of the mirror. The focal length of the mirror is labeled "**fl**".

4. Click the "**Object**" button. Click about 1/4 of the way from the left side, above the yellow line. An arrow will appear as our object. As object will appears, three light rays come from the point of the arrow to strike the mirror and reflect back. You can change the height of the arrow or its distance from the mirror by putting the hand icon at the top of the arrow and dragging it around the diagram. Note also that the three reflected rays converge to a point on the screen that represents the arrow point of the image.

5. Click on the focal point on the left side of the mirror and slowly drag it to the far left of the screen.
   - What effect does this have on the shape of the mirror?
   - How do the "fl" numbers change?
   - What effect does this have on the image arrow?

6. Return the focal point to its original position. Now, click on the left focal point and drag it slowly to the right of the mirror.
   - What effect does this have on the shape of the mirror?
   - How do the "fl" numbers change?
   - What effect does this have on the image arrow?

7. Changes can be easily corrected by clicking on the object you want to change then selecting the "**Clear Active**" button. If you want to restart the applet from the beginning, click on the "**Clear All**" button.

8. Select the "**Beam**" button then click on the screen. Describe what this option does.

9. Leave the "**Beam**" on, and now use the "**Aperture**" option. Play with it and describe what this option does.

Practice with the various options until you feel comfortable changing the size and location of the object, changing the location of the mirror, changing the type of mirror, adding and deleting the beam, changing the location of the beam. The more practice you have for this activity, the more time you will save in the later activities.

Name_______________________________Date_____________

Activity 8–5: Ray Diagrams for Concave Mirrors

Objective:

- Draw a ray diagrams for a mirror to quickly locate the image.

Materials Provided by You:

- Ruler
- Paper

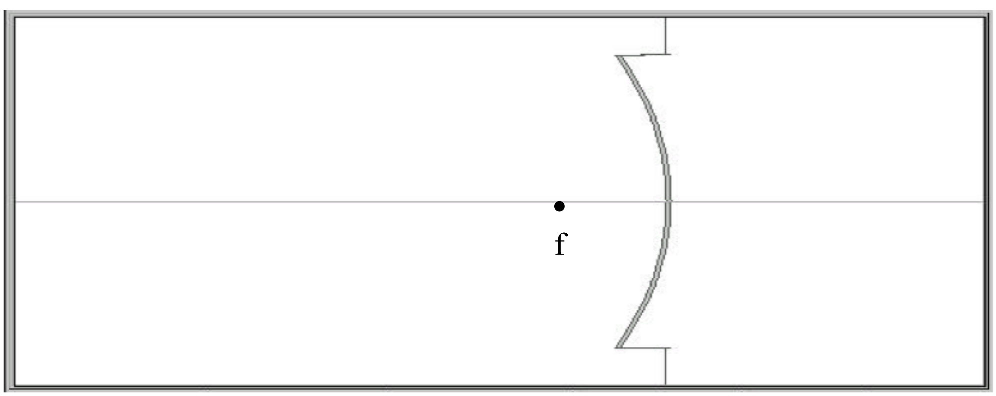
Procedure:

1. We will make our ray diagrams by using three rays. Use a vertical arrow for the object. All light rays start at the tip of the arrow. Make an object that is 1 cm high. Locate the object at a distance that is between f and 2f.

2. One ray goes parallel to the principal axis from the tip of the arrow to the mirror. When it strikes the front of the mirror, it reflects and goes back through the focal point ***f***.

3. One ray goes from the tip of the arrow through ***f*** to the mirror. After it strikes the mirror, it is reflected back on the same side of the object parallel to the principal axis.

4. One ray goes to the center of the mirror and is reflected back at the same angle. The three reflected rays should intersect at the same location. Make your rays on the diagram below.



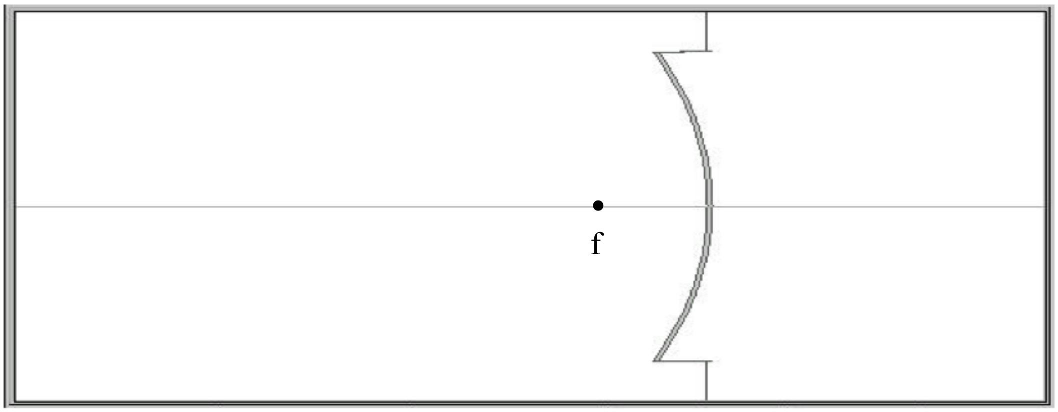
5. Measure d_o, d_i. Measure the height of the image. Record your answers to the nearest 0.1 cm. Record units on your measurements.

d_o = d_i =

Height of image = Type of image =

Name________________________________Date_____________

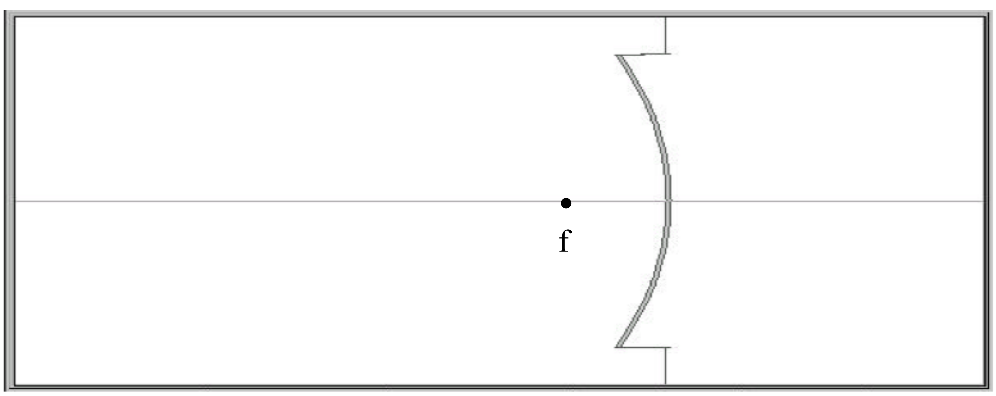
6. Place your object at *2f*. Make your ray diagram on the diagram below.



7. Measure d_o, d_i. Measure the height of the image. Record your answers to the nearest 0.1 cm. Record units on your measurements.
   d_o = d_i =

   Height of image =   Type of image =

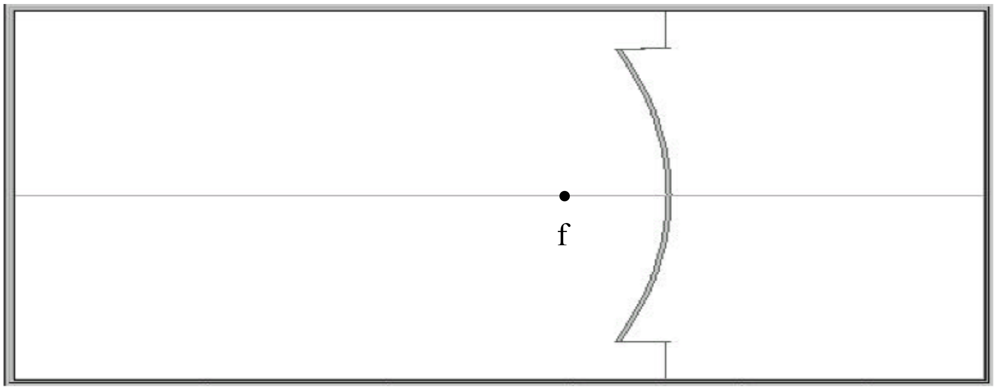
8. Place your object at a distance that is greater than *2f*. Make your ray diagram on the diagram below.



9. Measure d_o, d_i. Measure the height of the image. Record your answers to the nearest 0.1 cm. Record units on your measurements.
   d_o = d_i =

   Height of image =   Type of image =

10. Place your object at a distance that is at 0.5*f*. Make your ray diagram on the diagram below.



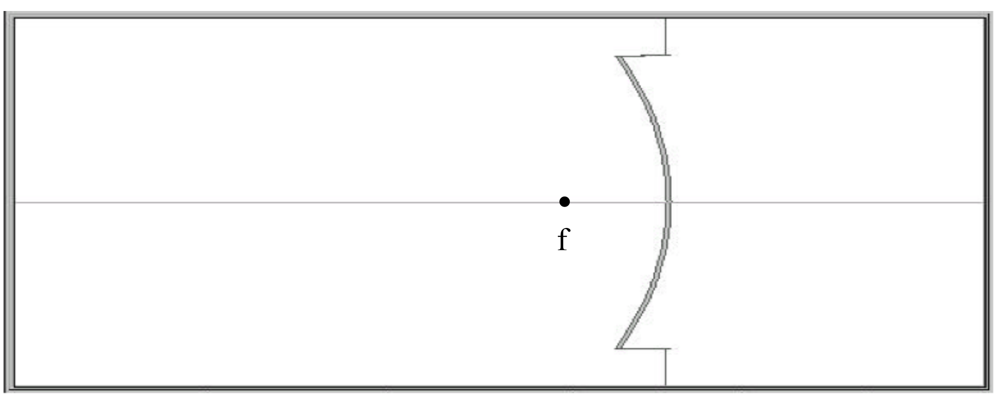
11. Did your rays intersect on the left side of the mirror? If not, extend the reflected rays. Make them dashed when you extend the lines.

12. Measure d_o, d_i. Measure the height of the image. Record your answers to the nearest 0.1 cm. Record units on your measurements.

d_o = d_i =

Height of image = Type of image =

13. Place your object at a distance that is equal to *f*. Make your ray diagram on the diagram below.



14. Did your rays intersect on the left side of the mirror? If not, extend the reflected rays. Make them dashed when you extend the lines.

15. Measure d_o, d_i. Measure the height of the image. Record your answers to the nearest 0.1 cm. Record units on your measurements.
    d_o = d_i =

    Height of image = Type of image =

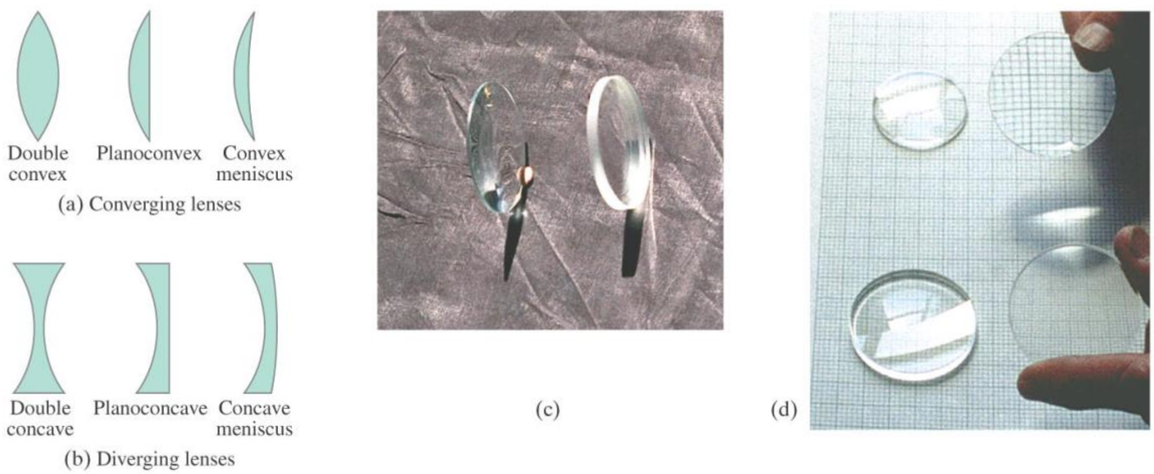
16. Summarize your ray diagrams for a concave mirrors.

Name________________________________ Date_____________

Home Lab 9
Lenses, Lens Equation, and Simulations

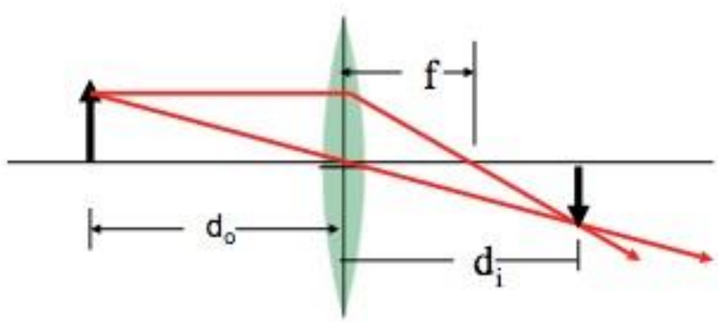
Background Information

Thin lenses are those whose thickness is small compared to their radius of curvature. They may be either converging (a) or diverging (b) or double convex or double concave or in between.



In this Lab we will study the properties of convex and concave lenses using the Lens equation which relates the focal length f to the object distance d_o and the image distance d_i .

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$



Name_______________________________ Date_____________

The sign convention for lenses is:

1. The focal length is positive for converging lenses and negative for diverging.
2. The object distance is positive when the object is on the same side as the light entering the lens (not an issue except in compound systems); otherwise it is negative.
3. The image distance is positive if the image is on the opposite side from the light entering the lens; otherwise it is negative.
4. The height of the image is positive if the image is upright and negative otherwise.

Activity 9-1: Focal length of a convex lens

Objective:

- Determine the focal length of two different convex lenses.

Materials Included:

- 30 mm Diameter Double Convex Lens (Convex Lens 1)
- 50 mm Diameter Plano-Convex Lens (Convex Lens 2)

Materials Provided by You:

- Incandescent Frosted 60 Watt Light Bulb
- Ruler

Procedure:

1. With any bright light source located at any large distance (2 meters or more) from a wall of a room or ceiling, place convex lens 1 at the wall and move it with your hand towards the light source until you see a sharply focused imaged of the light on the wall. To make the image clearer you might hold a piece of white paper against the wall. Measure the distance between the center of the convex lens 1 and the wall to the nearest 0.1 cm and record this value as focal length of convex lens 1.
   f_{30mm} ____________________ ± 0.1 cm

   This is not exact but a very good approximation of the focal length of lens 1. If the light source were at infinity then it would be the exact focal length. More on this later.

2. Repeat the step above for convex lens 2. Measure the distance between the center of the convex lenses and the wall to the nearest 0.1 cm and record this value as focal length of convex lens 2.
   $f_{50\ mm}$ ____________________ ± 0.1 cm

This is a very good approximation of the focal length of lens 2.

Name________________________________ Date_____________

Activity 9-2: Size and brightness of the image from a convex lens

Objective:

- Find a relationship between the size of the object and the size of the image.

Materials Included:

- Economy Optical Bench, light source, white screen, insert poles, and slide blocks
- 30 mm diameter Double Convex lens

Materials Provided by You:

- Same as Activity 9-1

Procedure:

1. Draw an arrow (or an F) on the light source and place the light source next to the 0 m end of the optical bench. It will serve as your object for the convex lens. See Figure 9-1.

2. Screw the small pole into the 30 mm double convex lens holder and place it at 20 cm from the light source. Use one of the small clamps to hold the pole to the optical bench. See Figure 9-1.

3. Place the white screen in the holder at about 50 cm on the optical bench.

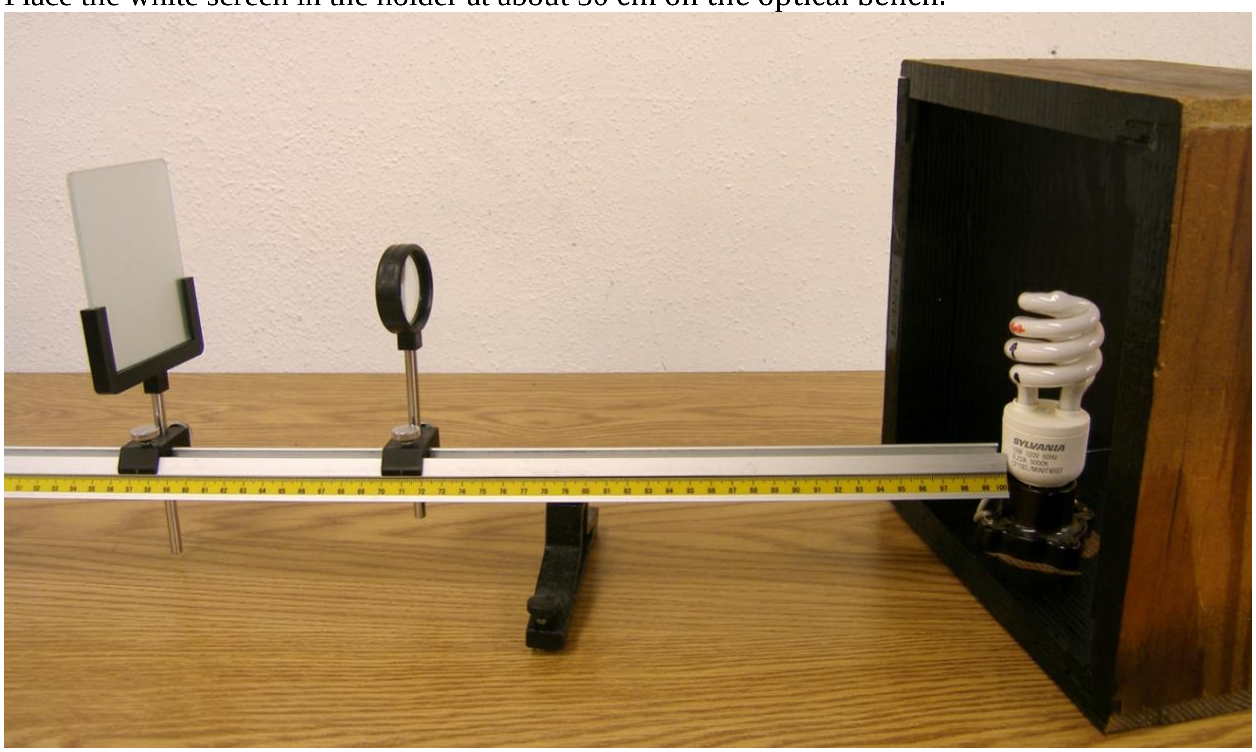


Figure 9 - 1

3. Move the screen back and forth until you find a clear and sharply focused image of the light source. You may have to move it back and forth several times to get the location to about 0.1 to 0.2 cm in error. You may have to reduce the lighting in the room for best results.

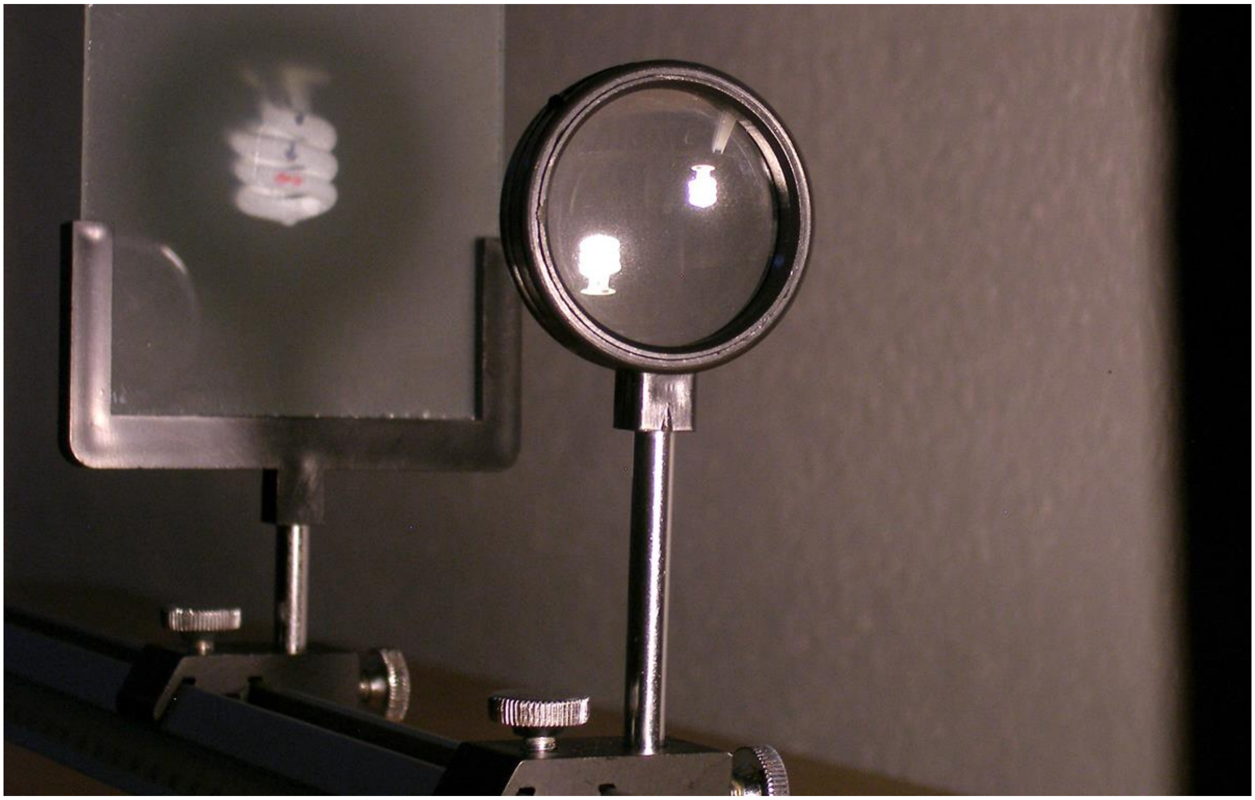


Figure 9 - 2 (Note the multiple images in the lens)

4. Measure the height and width of the object (light source) and the image on the screen and record below:

Object Height __________________ cm, width ________________ _ cm
Image Height __________________ cm, width _________________ cm

5. Divide the height of the image by the height of the original object. Divide the width of the image by the width of the original object. Measure to the nearest 0.1 cm.

Height of image ÷ height of original object________________

Width of image ÷ width of original object _________________

What is the magnification of the image? ____________________
(See pages 12-13__in Lecture Notes for definition of magnification)

What is the orientation of the image? inverted /erect (circle one)

Name________________________________ Date_____________

6. Next we are going to investigate the effect on the image when the light rays strike the upper half of the lens only and then the lower half. You can do this by covering the upper/lower half of the lens with a piece of black paper. Before you begin, predict what will happen to the image and explain your reasoning. Then, carry out the procedure and record the actual result. Use what you have learned about light and lenses to explain the result you observe. Fill in your answers in the table below.

Action	Covering the top half of the lens	Covering the bottom half of the lens
Prediction		
Reasoning for your prediction		
Actual Result		
Explanation of the actual result		

7. Discuss any discrepancies between your prediction and the actual result. Did you have any misconceptions before you started the procedure?

Name________________________________ Date_____________

Activity 9-3: Relationship between Object Distance and Image Distance for a Convex Lens

Objective:

- Verify the well known lens equation 1/o +1/i = 1/f
    - Determine the focal length by averaging all values of f in **Table 9-2**

Materials Included:

- Economy Optical Bench and accessories
- 30 mm Double Convex Lens

Materials Provided by You:

- 13 Watt Fluorescent Light source or 100 Watt Light Bulb with an F drawn on it
- Ruler
- Excel

<u>Procedure</u>:

1. Set up the optical bench in the order similar to that in Activity 9-2. The light source should be at the zero-end of the optical bench, then the lens, and finally the screen at the far end of the optical bench.

2. Locate the 30 mm Double Convex Lens at the 6.0 cm mark. Adjust the screen until you get a sharply focused image of the arrow on the screen.

3. Note the sign convention for the lens equation:

o, object distance	positive, +	when the object is placed "in front of the lens"
i, image distance	positive, +	for real images (inverted, on the other side of the lens opposite the object)
	negative, -	for virtual images (erect, on the same side of the lens as the object)
f, focal length	positive, +	for convex (converging) lenses
	negative, -	for concave (diverging) lenses

4. Record the distance between the lens and the object to the nearest 0.1 cm. This is called o – object distance.
   o = ___________________ ± <u>0.1</u> cm

5. Record the distance between the lens and the image to the nearest 0.1 cm. This is called i – image distance.

i = ______________________ ± 0.1 cm

6. Increase the distance between the lens and the object by at least 1 cm, and repeat steps 2 - 4 for 5 more trials. Organize the data in **Table 9-1**.

Table 9-1

Trial	i	Uncertainty	o	Uncertainty
#	cm	cm	cm	cm
		0.1		0.1
		0.1		0.1
		0.1		0.1
		0.1		0.1
		0.1		0.1
		0.1		0.1

7. Now we will analyze the data to determine any relationship that may exist. Fill in the columns in **Table 9-2**:

Table 9-2

Trial	i	o	1/o	1/i	1/i + 1/o	f
#	cm	cm	cm^{-1}	cm^{-1}	cm^{-1}	cm

Most of your data should have 3 significant figures, so every calculated value should also have 3 significant figures.

8. Is 1/o + 1/ i a constant within the uncertainty of your measurements? If so, what is the significance of this constant?

Name________________________________ Date_____________

9. Average all values of f in Table-2 and compare the averaged value with that determined in Activity 1. Determine the percentage difference assuming the accepted value is the value found in Activity 1.

 Ave value of focal length =___________________

Percentage difference =___________________%_

Name_______________________________ Date_____________

Activity 9-4: Size of the Lens and Intensity Relationship

Objective:
- Determine a relationship between the diameter of the lens and the intensity of the light on the image.

Materials Provided by You:
- Internet access
- Excel

Procedure:
1. Go to http://phet.colorado.edu/simulations/sims.php?sim=Geometric_Optics . Click on the "Run Now" button so that you can run the simulation.
2. Click on "**Change Object**" to change the object to an arrow and move it so that the base of the arrow is on the Principal Axis.
3. Change the "**Diameter**" to the maximum value of 1.3 for the lens you will use.
4. Change to "**Marginal Rays**".
5. Move the object so that it is somewhere between distance "f" and "2f" from the lens. The focal length "f" is marked by an "**X**" on the principal axis. You only need to estimate this distance.
6. Gradually decrease the diameter of the lens and observe the change in i, the image distance, and the intensity of the image.
7. Based on your observation, what can you conclude about the relationship between lens diameter and image distanced?
8. Why do you think this is the case?

Name_______________________________ Date_____________

9. Based on your observation, what can you conclude about the relationship between lens diameter and image intensity?

10. Why do you think this is the case?

Name_______________________________ Date_____________

Activity 9-5: The Effect of Changing the Index of Refraction of the Lens

Objective:

- To explore a relationship between the index of refraction and the focal length of the lens.

Materials Provided by You:

- Internet access

Procedure:

1. We will use the same computer simulation in Activity 9-4 that is located at: http://phet.colorado.edu/simulations/sims.php?sim=Geometric_Optics

2. Comment on what happens to the focal length of the convex-convex lens and the image position as you vary the "**index of refraction using the slider**.

3. Why do you think the focal length changes this way in response to the change in lens index of refraction?

Name______________________________ Date____________

Home Lab 10
Using Multiple Lenses

Activity 10-1: Focal Length of a Concave Lens (Simulation)

Overview:

The focal length of a concave lens cannot be determined using the methods similar to those used for the convex lens because no real image is formed. You will use a method called simulation where a concave lens focal length is assumed. You will place the object at various distances using a computer program that utilizes the lens equation to calculate the image locations. You will record the image distances and objects distances. Using the lens equation you will now calculate the focal length for each object and image setting. You should get agreement with the assumed focal length you started with.

Objective:

- Determine the focal length of a concave lens using a computer simulation program.

Materials Provided by You:

- Internet access
- Excel or similar spreadsheet application program.

Procedure:

1. We will use the computer simulation that we used in Activity–8 - 4. The website is http://webphysics.davidson.edu/Applets/optics/intro.html.

2. Click on "**Lens**" to make a lens. Move the "+" to the middle of the screen and right click. You should get a convex lens. You can change the location on the principal axis by getting a hand icon, left clicking and dragging the lens right or left.

3. Change the lens to a concave lens by locating a focal point of the convex lens, and dragging the focal point through the convex lens to the other side of the lens. Set the focal length to - 0.5.

4. Record the focal length and position of the concave lens (**fl** and **x**) in the upper left in **Table 10-1**.

5.

Table 10-1

Concave Lens								
fl								
X								
Object location (in terms of **f**)	Object coordinates (white)		Image coordinates (Yellow)		Image Type (Real/Virtual)	Object Distance	Image Distance	Focal length
x	X_o	Y_o	X_i	Y_i		o	i	
3fl								
2fl								
2fl – fl								
fl – 0.5fl								
0.5fl – the lens								

6. Click on the "**Object**" to generate an object. Move the object to 3*fl. Record the values for x and y in the proper columns. Record the x, and y location of the image in **Table 10-1**. Those values are in yellow.

7. Move the "**Object**" to the following locations: 2**fl**, between 2**fl** and fl, at **fl**, between **fl** and 0.5***fl**, and finally between 0.5***fl** and the lens. Record the values in **Table 10-1**.

8. Comment on the sizes of the image formed in the above cases. In which of the cases was the image larger than the size of the object? Smaller? The same?

9. Calculate the object distance and the image distance by subtracting the values of the x coordinate. Pay special attention to the sign convention as outlined in Lab09. Record the values in **Table 10-1.**

10. Calculate the focal length of the concave lens using the lens equation. Enter this information in **Table 10-1**.

Name_______________________________ Date_____________

11. Calculate the magnification of your image. Relate the calculated magnification to your observations on the image size made earlier in activity.

12. Determine the type of image formed for each object location and record your answers in **Table 10-1**. How did you determine if the image is real or virtual?

Name________________________________ Date_____________

Activity 10 – 2: Back-to-Back Double Convex Lens and Plano-Convex Lens

Objective: To determine the focal length of a combined system of convex lenses.

Materials Included:

- Economy Optical Bench and Accessories
- 40 mm diameter Double Convex lens
- 50 mm diameter Plano-Convex Lens

Materials Provided by You:

- 60 Watt Standard Light Bulb with F drawn on it
- Ruler

Procedure:

1. Measure the focal lengths of the 40 mm lens using the method in Activity 9-1. Record the focal lengths of the 40 mm lens and the 50 mm lens that you determined in an earlier activity below.
   $f_{50\ mm}$ _________________ ± _____ cm
   $f_{40\ mm}$ _________________ ± _____ cm

2. Place both convex lenses as close as possible to each other on the optical bench.

3. Place the light source at the zero end of the optical bench.

4. Measure the focal length of the combined system. You have previously learned in earlier labs several ways to determine the focal length of a lens. The most economical method is to use an object as far away as possible to focus on the screen. You will have to vary the distance from the screen to the lens until the image most sharply observed. Usually this is when the image is smallest. The focal length will be the distance between the front of your screen and the midpoint between the two lenses. Record the focal length as
   $f_{combined}$ _________________±_____________ cm

Name________________________________ Date_____________

5. Review your Lecture Notes (See page 6) and study the concepts behind the derivation of the formula for the combined focal length of a two-lens system. The focal length of the combined back to back lenses is given by :

$$\frac{1}{f_{combined}} = \frac{1}{f_1} + \frac{1}{f_2}$$

This expression assumes that the thin lens formula is valid and there is no separation distance between the two lenses. Note that the formula is similar to how resistors add when in parallel. The focal length can be written as:

$$f_{combined} = \frac{f_1 f_2}{f_1 + f_2}$$

Calculate the focal length of the combined system using the above formula and record it here____.

6. How does your measured $f_{combined}$ in step 4 compare to the $f_{combined}$ calculated from the formula in step 5? Calculate the percentage difference of $f_{combined}$ determined from step 4 and step 5.

7. Why won't the two results agree exactly even if you made perfect measurements?

Name______________________________ Date____________

Activity 10-3: Back-to-Back Double Convex Lens and Double-Concave Lens

Overview: The focal length of a concave lens cannot be determined using the methods similar to those used for the convex lens because no real image is formed. Here we will combine a convex lens with a known focal length with a concave lens of unknown focal length to produce a real image. Using the formula for the focal length of the combined system we can calculate from the measurements the focal length of the concave lens.

Objective:

- Determine the focal length of a back-to-back convex lens and a concave lens**.**

Materials Included:

- Economy Optical Bench and Accessories
- 30 mm Diameter Double-Convex Lens
- 30 mm Diameter Double-Concave Lens

Materials Provided by You:

- 60 Watt Standard Light Bulb with F drawn on it
- Ruler

Procedure:

1. Record the focal length of both lenses below: Take the value of the double-concave lens from the specification sheet that came with the optical bench.
   $f_{30\text{ mm double convex}}$ ____________________ cm
   $f_{30\text{ mm double concave}}$ ____________________ cm

2. Think back to the properties of convex and concave lenses. Do you think the combined focal length will be longer/shorter than the focal length of the convex lens? Briefly describe your reasoning.

3. Place the convex lens as close as possible with the concave lens on the optical bench with the concave lens on the side towards the light. Measure the focal length of the combined system using the previous method in Activity 10-2. Record the focal length as
   $f_{combined}$ ______________________ ± ________________ cm.

Name______________________________ Date____________

4. Is your measured focal length of the combined lenses longer or shorter than that of the convex lens? Justify your answer.

5. How does your measured focal length in step 4 differ from your prediction in step 2? Discuss any misconceptions you might have had.

6. Using the formula previously used in step 5 in Activity 10-2,

$$f_{combined} = \frac{f_1 f_2}{f_1 + f_2}$$

, caluculate your best value of the convex lens focal length, and the measured value of the combined focal length, solve for the focal length of the concave lens. Record the value $f_{concave}$ ____________________ cm. Include the proper sign in your answer.

7. Compare your experimental value for the focal length of the concave lens to the value of the concave lens on the specification sheet. (Note that the sign is not given on the spec sheet). Calculate the percentage difference and explain why there may be differences.

Name______________________________ Date____________

Activity 10–4: Magnification Properties of Lenses

Objective:

- Determine which type of lens would make the best magnifying glass.

Materials Included:

- 30 mm diameter Double-Convex lens
- 30 mm diameter Double-Concave lens
- 50 mm diameter Plano-Convex lens

Procedure:

1. Record your measured focal length for each of the lens in **Table 10-4.1**.

2. Hold each lens close to less than 2 cm from your eye. Look at an object at a great distance away. How does the size and clarity of the image compare to the object? Record your answers in **Table 10-4.1.**

Table 10-4.1

Lens Type	Focal Length (cm)	Image Description (as compared to the object)
30 mm Double Convex Lens		
50 mm Plano-Convex Lens		
30 mm Double-Concave Lens		

.

Name______________________________ Date____________

3. Hold each lens close to your eye and look at an object 2-8 cm away such as words in your textbook. Move the lens until the object is focused. How does the size and clarity of the image compare to the object? Record your answers in **Table 10-4.2.**

Table 10-4.2

Lens Type	Focal Length (cm)	Image Description (as compared to the object)
30 mm Double Convex Lens		
50 mm Plano-Convex Lens		
30 mm Double-Concave Lens		

4. From your observations, which type of lens would you use as a magnifying glass – large or small focal length lens, convex or concave lens? Explain.

5. Now hold each lens at arm's length. Look at some object, and slowly walk toward the object. Start at 2 meters away from the object, and gradually decrease distance to 1 cm between the object and the lens (object distance decreasing) while keeping the lens at arm's length from your eyes. Pay attention to the size and the orientation of the image as you walk toward the object and record your observations in **Table 10-4.3.**

Table 10-4.3

Lens Type	Focal Length	Object Distance (Give two ranges) e.g. (0 - 0.5 m) (0.5 – 2.0 m)	Change in Image Size (increasing/decreasing)	Image Orientation (upright/inverted)
30 mm Double Convex Lens				
50 mm Plano-Convex Lens				
30 mm Double-Concave Lens				

Name______________________________ Date____________

6. At some point the images of the convex lenses get very blurry. Find that distance for both lenses and record the information in the table below.
   Large focal length lens. Distance at which there is no image: _________±________ cm.

   Small focal length lens. Distance at which there is no image: _________±________ cm.

7. What is the connection between the focal length and the distances above?

Name______________________________ Date____________

Activity 10-5: Image Formation From a Convex and Concave Lens (Ray Diagrams)

Objective:

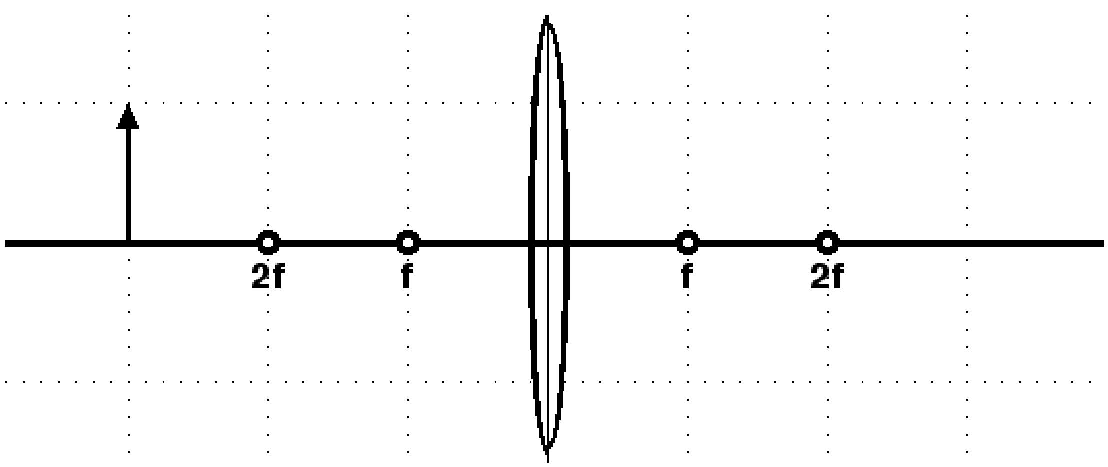
- Determine the type of image given by a convex and concave lens.
- Make observations about image formation from convex and concave lens.

Materials Provided by You:

- Paper, sharp pencil, ruler

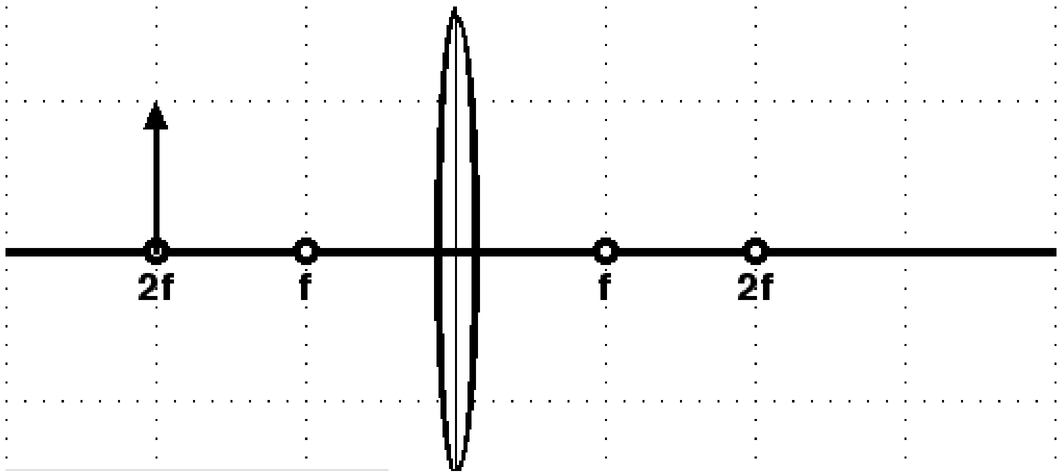
Procedure: Just as with curved mirrors, the relationship between the an object's and image's position, size, and orientation can be quickly determined using ray diagrams. In this exercise you need to first – print the next 3 pages of diagrams. Draw the 3 primary rays: i) parallel→f, ii) f→parallel, iii) through center of the lens (if possible); then locate and draw the image. Digitally copy the diagrams and add them to the end of this document.

Convex (converging) Lens with object outside 2f:

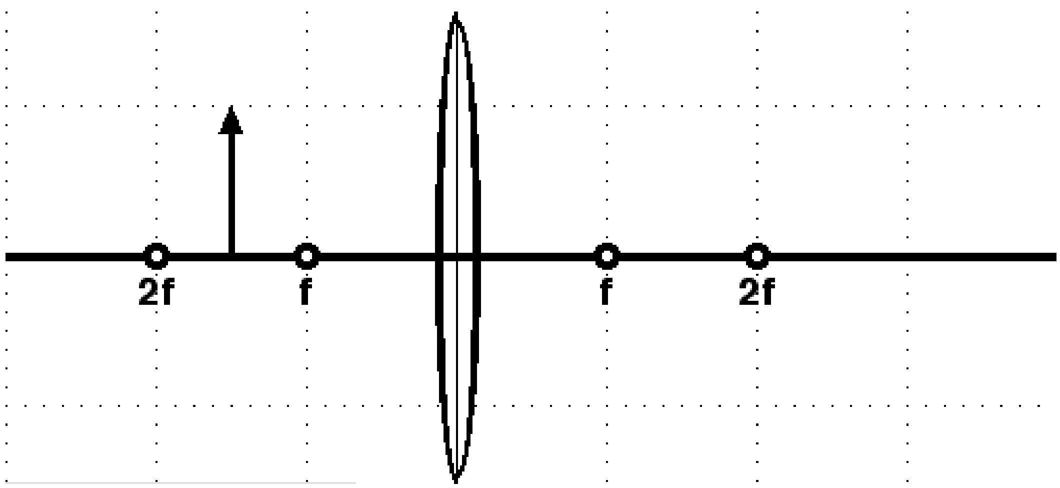


Name_______________________________ Date_____________

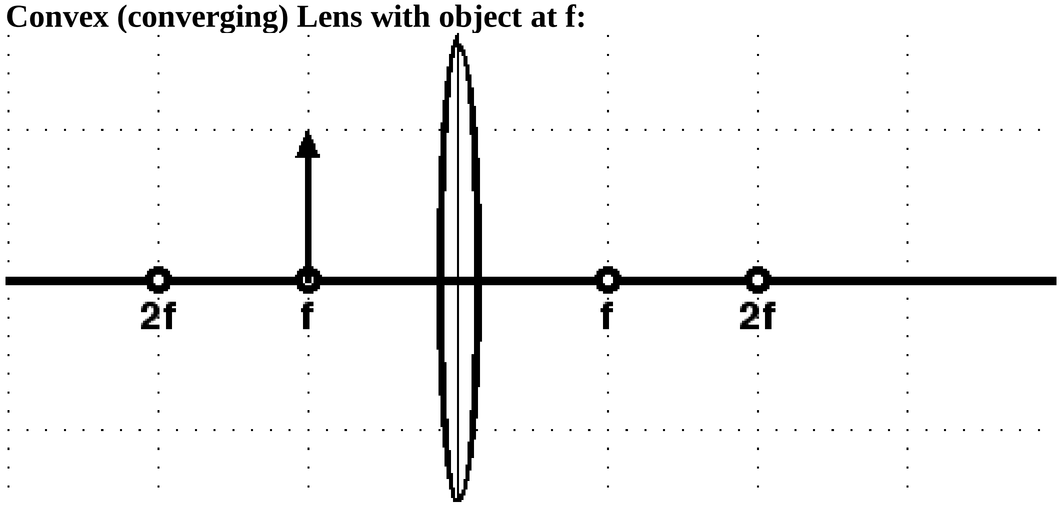
Convex (converging) Lens with object at 2f:



Convex (converging) Lens with object between 2f and f:

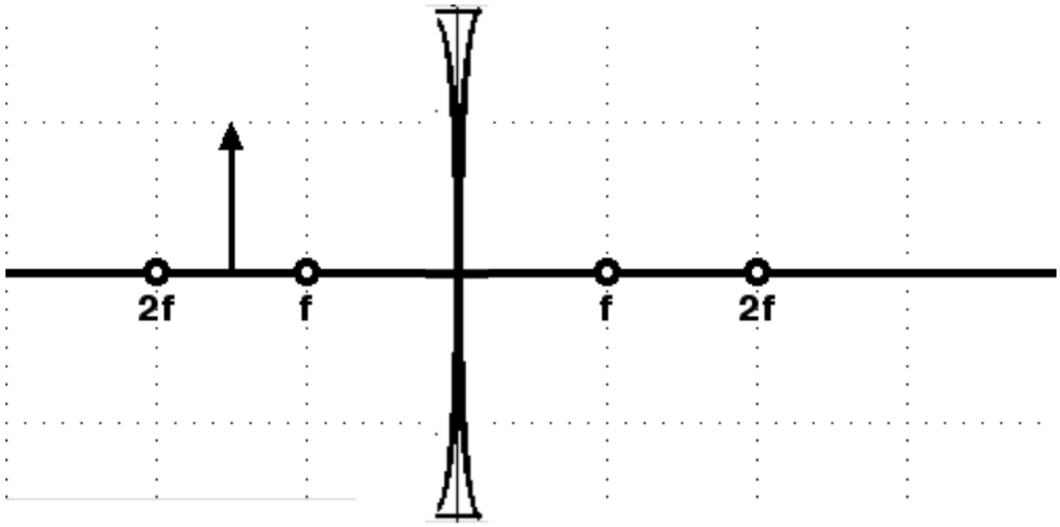


Convex (converging) Lens with object at f:

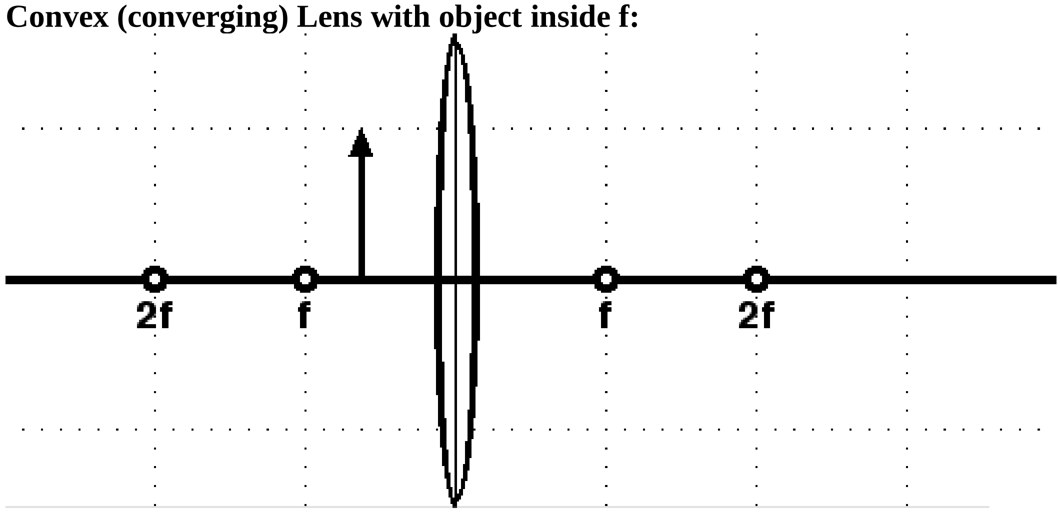


Name________________________________ Date_____________

Concave (diverging) Lens with object between 2f and f:



Convex (converging) Lens with object inside f:



Name________________________________ Date_____________

Home Lab 11
Optical Instruments

Activity 11 – 1: A Simple Magnifier

Objective: To make a simple magnifier using three converging lenses of different diameters and measure their magnification and compare them.

Materials Included:

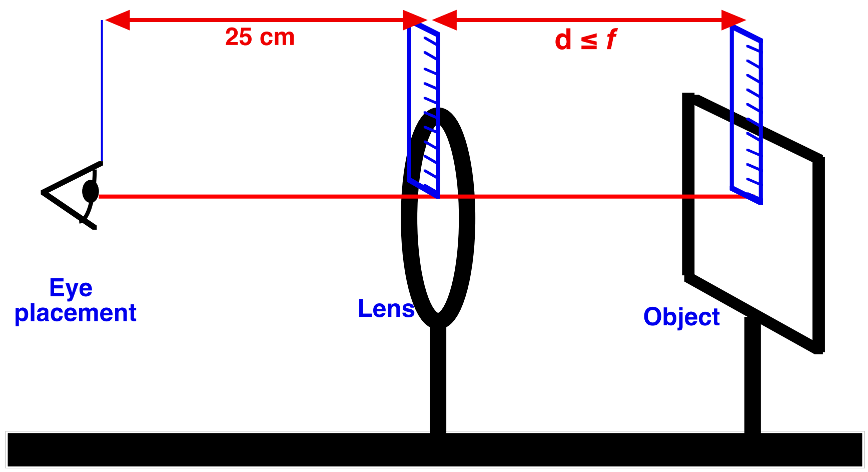
- 30 mm Diameter Double Convex lens
- 40 mm Diameter Double-Convex Lens
- 50 mm Diameter Plano-Convex Lens
- Economy Optical Bench and accessory kit

Procedure:

1. Place the white screen at a known place on the optical bench such as at the 50 cm mark.
2. Scotch tape your ruler across the middle of the screen.
3. Place the first lens (30 mm) on the optical bench so that the ruler which is the objective is located at a distance that is about 1-2 mm less than the focal length of the lens.
4. Now tape another ruler to the lens on the side furthest away from the first ruler taped to the white screen. A clear plastic ruler works best. Your setup should something like our setup in the photo below.

Name________________________________ Date_____________

Now with your eye at about 25 cm behind the lens look through the lens so that you see a magnified image of the ruler. You may have to move your eye back and forth a little to see the clearest image. The figure below shows the relative orientation. The rulers are vertical instead of horizontal in the figure below.



5. Look through the lens and use the ruler on the lens to measure the width in mm of 1 mm on the ruler on the screen. The width is______________________ mm.
6. The magnification is the width you measure in mm divided by 1 mm. The magnification M= ________________.
7. Repeat this process for the 40 mm lens. The magnification M= ________________.
8. Repeat this process for the 50 mm lens. The magnification M= ________________.
9. Now make a table of focal length and magnification for the three lenses.

Kind of Lens	Diameter of Lens mm	Focal Length f mm	Magnification M Measured	Magnification M Expected
Convex-convex	30			
Convex-convex	40			
Plano-convex	50			

10. Using excel make a plot of the focal length vs the measured magnification and also on the same graph make a plot of the focal length vs the expected magnification where the expected magnification is given by M=250 / f (mm)
11. Make a comment on the agreement or disagreement of the two plots.

____

Name________________________________ Date____________

Activity 11 – 2: Galilean Telescope

Objective:

To build two Galilean telescopes one with a 50 mm convex-plano objective lens and a 30 mm concave-plano eyepiece and one with a 30 mm convex-convex objective lens and a 30 mm concave-concave eyepiece and compare their magnifications.

.

Materials Included:

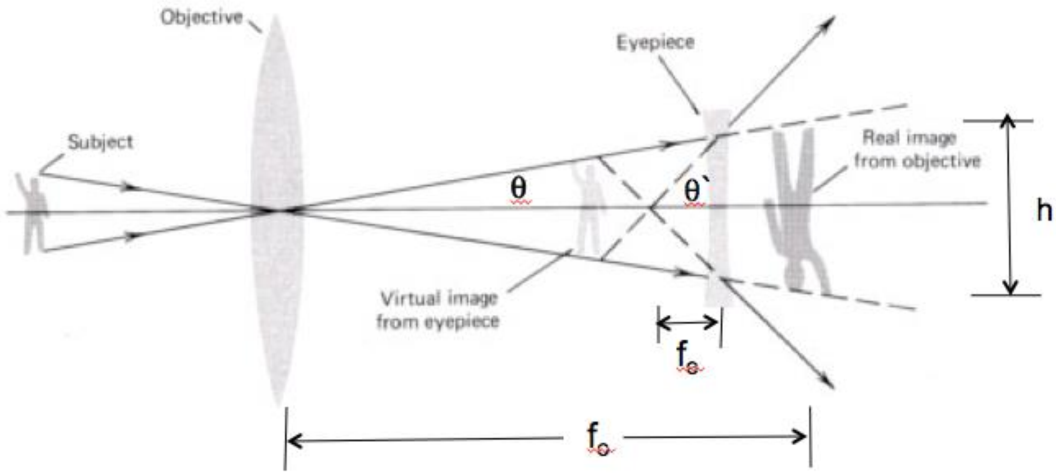
- 40 mm Diameter Double Convex lens
- 30 mm Diameter Double Concave lens
- 50 mm diameter Plano-Convex Lens
- Economy Optical Bench and accessory kit
- Ruler

Procedure:

1. Record the focal lengths of the three lenses from your previous measurements.
   $f_{50\text{ mm-convex}}$ __________±_________ cm.
   $f_{40\text{ mm-convex}}$ __________±_________ cm.
   $f_{30\text{ mm-concave}}$ __________±_________ cm.

2. Mount the **50 mm diameter plano convex lens** at about the 50 cm tick mark on the optical bench
3. Mount the **30 mm diameter double concave lens** at a distance from the convex lens equal to the difference in the focal length of the objective lens and the eyepiece lens.

4. Slightly adjust the distance between the lenses by trial and error, so that you form a large clear image when you view a distant object when you look through the eyepiece.



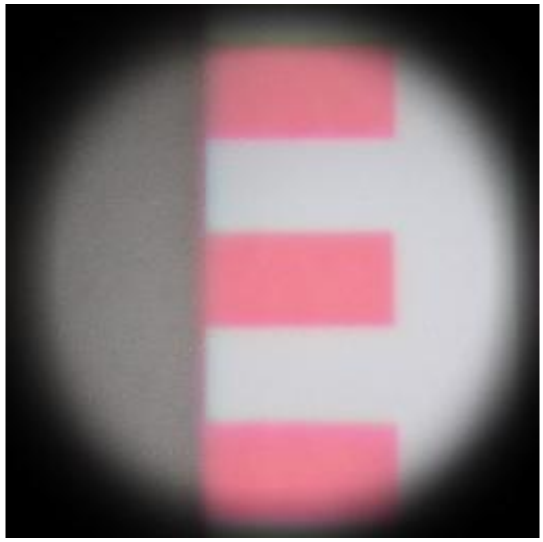
5. Which of the two lenses is the eyepiece?_____________________________________
6. Which of the two lenses is the objective?_____________________________________
7. Record the final distance between the two lenses. Distance = __________±_________ cm.
8. How is the distance between the two lenses related to the focal length of the lenses?

____

9. Measure the magnification of the telescope using the following procedure. You cannot use the exact same procedure described in Activity I. Here are 2 methods.

   Method 1
   In the figure below the grid of pink horizontal bars represent a meter stick on a wall that you can see with the naked eye. The target stick consist of equally wide alternating peak and white bars. It could be a simple meter stick using the cm scale if you could see it.

The figure below is the same target meter stick viewed through the telescope you want to measure the magnification.

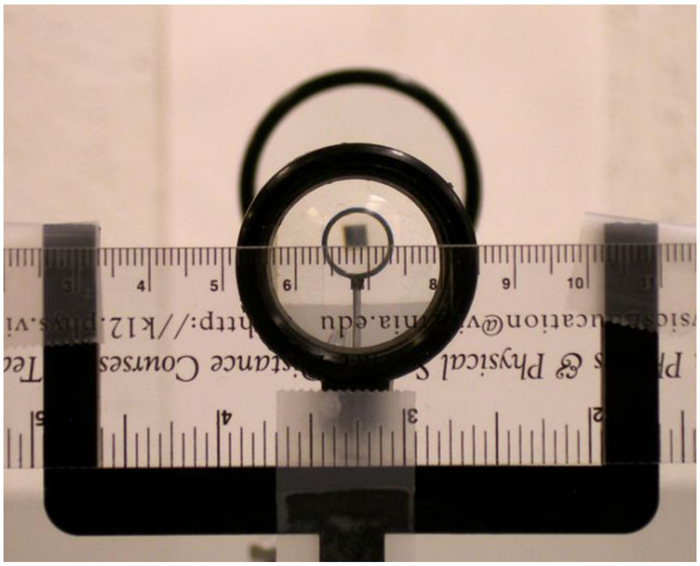


The figure below shows the two figures superimposed. The magnification is the number of pink and white bars in the picture viewed with the naked eye that overlap with one magnified pink bar. In the picture the magnification is 16 because there are 8 pink bars and 8 white bars.

Name________________________________ Date____________

Method 2

If you don't want to do all this camera work, you can use the scale or small ruler mounted on the eyepiece in Activity 1. Simultaneously view the scale and the image through the telescope and measure the width or height of the image that you view through the telescope. Remove the scale from the eyepiece and use it to measure the width of the object without looking through the telescope. The ratio of the two measurements is the magnification. You will have some problem holding the ruler steady and making this measurement. The magnification is____.



10. Is the final image real or virtual erect or inverted?__________________________
11. How does it compare with the expected magnification?___________________________

For a telescope it is the angular magnification that is important. You can find a formula for the expected magnification in Chapter 6 in the textbook.

12. Try to repeat steps 1-11 using the **<u>40 mm diameter double convex lens</u>** and the same **<u>30 mm double concave</u>** <u>lens</u>. What problems do you have?__________________________

13. Fill out the Table below and what Galilean telescope has the greatest magnification?

Galileo Telescope	Objective Lens Diameter mm	Eyepiece Lens Diameter mm	Magnification M Measured	Magnification $M = -f_o/f_e$
Convex-plano/ Concave-concave	50	30		
Convex-convex/ Concave-concave	40	30		

Name________________________________ Date____________

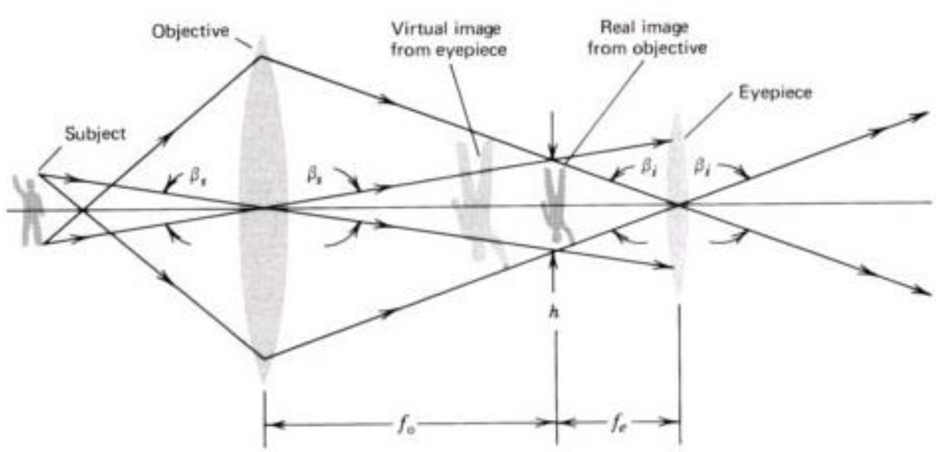
Activity 11-3: Keplerian Telescope

Objective:
To build two Keplerian telescopes one with a 50 mm convex-plano objective lens and a 30 mm convex – convex eyepiece and one with a 30 mm convex-convex objective lens and a 30 mm convex - convex eyepiece and compare their magnifications.

Materials Included:
- 30 mm Diameter Double Convex Lens
- 40 mm Diameter Double Convex Lens
- 50 mm diameter Plano-Convex Lens
- Economy Optical Bench and accessory kit

Procedure:
1. Record the focal lengths of the three lenses from your previous measurements.
2. $f_{50\ mm\text{-}convex}$ __________±_________ cm.
3. $f_{40\ mm\text{-}convex}$ __________±_________ cm.
4. $f_{30\ mm\text{-}convex}$__________±_________ cm.

5. Mount the **<u>50 mm diameter plano convex lens</u>** at about the 50 cm tick mark on the optical bench
6. Mount the **<u>30 mm diameter double convex lens</u>** at a distance from the convex lens equal to the sum of the focal length of the objective lens and the focal length of the eyepiece lens.
7. Slightly adjust the distance between the lenses by trial and error, so that you form a large clear image when you view a distant object when you look through the eyepiece.



8. Which of the two lenses is the eyepiece?____
9. Which of the two lenses is the objective?____
10. Record the final distance between the two lenses. Distance = __________±_________ cm.
11. How is the distance between the two lenses related to the focal length of the lenses?____

Name_____________________________ Date____________

12. Measure the magnification of the telescope using the procedure described in Activity 2.
13. Is the final image real or virtual erect or inverted?_________________________________
14. How does it compare with the expected magnification, which is given by $M= - f_o/f_e$, ______________________________?

15. Repeat steps 1-11 the using the **30 mm diameter double convex lens** and the **40 mm double convex** lens.

16. Fill out the Table below and which Keplerian telescope has the greatest magnification?

17. Describe any differences in the images formed from the Keplerian Telescope compared to the Galilean Telescope? _______________________________________

18. Describe any differences in the field of view from the Keplerian Telescope compared to the Galilean Telescope? _______________________________________

19. Describe any differences in the magnification from the Keplerian Telescope compared to the Galilean Telescope? _______________________________________

Keplerian Telescope	Objective Lens Diameter mm	Eyepiece Lens Diameter mm	Magnification M Measured	Magnification $M= - f_o/f_e$
Convex-plano/ Convex-convex	50	30		
Convex-convex/ Convex-convex	40	30		

Name_______________________________ Date_____________

Home Lab 12
Polarization

Overview

Activity 12 – 1: Determine the Axis of Polarization of a Piece of Polaroid

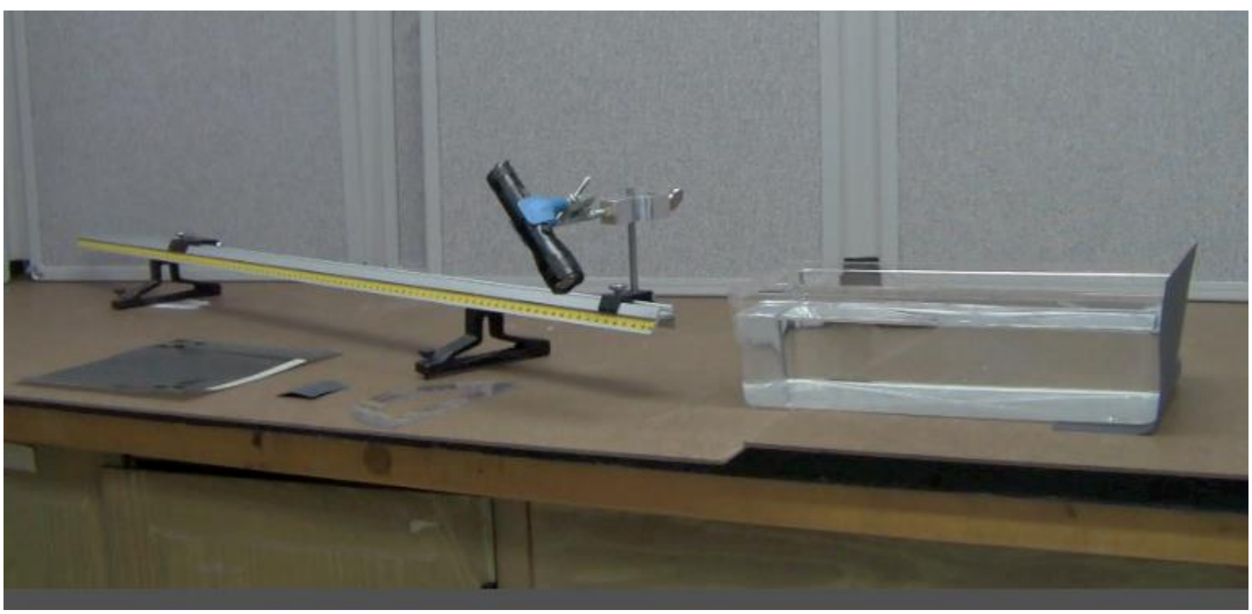
Objective: To find the axis of polarization of the Polaroid sheet

Materials :

- **Red laser pointer**
- **Flashlight or White LED light source (Maglight)**
- **Small tray or glass of water**
- **1 Large Sheet of Polaroid**
- **Protractor**
- **Masking tape**

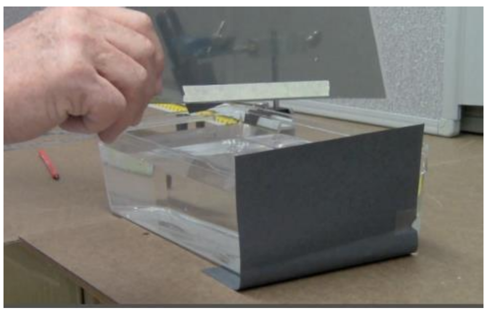
Procedure:

1. Fill up a plastic or glass tray with water almost to the top. Shine the red laser beam at an incidence angle of about 50 degrees to the water. When light is reflected from the surface some of it will be polarized in the plane of the surface. See the lecture notes. You will have to use your ingenuity to hold the laser pointer at the given angle.



Name______________________________ Date____________

2. Now observe the reflected light through your Polaroid sheet. Hold the sheet so that the reflected light is perpendicular to the sheet. Rotate the Polaroid about an axis parallel to the incident laser beam on the Polaroid and look thorough the back of the sheet and observe the red laser light spot on the sheet. It will vary from dark to bright as you rotate the sheet. The light will be brightest when the optic axis or polarization axis of the sheet is parallel to the plane of the water surface. Tape a piece of masking tape along the edge of the Polaroid so it is parallel to the optic axis. Tape a similar piece along the opposite side of the sheet. This now indicates the direction of the optic axis of the Polaroid. Describe your specific observations about the intensity of the light as you rotated the Polaroid sheet.



3. Now cut the Polaroid sheet up into 4 equal squares in such a way that each sheet will have a piece of masking tape on it to indicate the polarization direction.
4. As a check that you did everything right shine the laser beam off the water surface again and make sure the tape is parallel to the proper axis.
5. Now reflect the laser light off the rectangular prism block and again check that the tape on each piece of Polaroid is parallel to the plane of the surface of the block for maximum transmission through the Polaroid.
6. Repeat 1-6 with white LED or flashlight as the source of light. Describe any differences or similarities in sensitivity of locating the optic axis using white light point source versus red laser light.
7. Observe the sky through a piece of your Polaroid and describe the direction of polarization of the light from the sky.
8. Your laptop displays emits polarized light with the axis of polarized light along a diagonal. Observe your laptop computer screen through a piece of your Polaroid and describe which diagonal is the direction of polarization.

Name_______________________________ Date_____________

Activity 12-2 Polarization by Absorption

Objective: To use Polaroid sheets as an analyzer and polarizer to test Malus's Law.

Materials:

- **Red laser pointer**
- **Flashlight or White LED light source (Maglight) or 60 watt bulb**
- **Optical Bench**
- **2 Sheets of Polaroid**
- **Protractor**

Procedure:

1. It will be convenient to use the optical bench for this activity.
2. Position your light source on the optical bench at 0 meters. You may use any of the suggested light sources.
3. Clamp or tape a piece of Polaroid sheet with the optic axis along the vertical onto one of the rods clamped to the optical bench or onto the black u-shaped holder that threads into a rod and secure it on the optical bench about 5 cm from the light source. This is used to polarize the light along the optic axis (along the long direction of the masking tape that you found in Activity 1) and is called the polarizer. The optic axis is also called the transmission axis.

4. Now take another piece of Polaroid sheet and hold it at about 10 cm on the optical bench which would be 5 cm from the polarizer. This is called the analyzer. You may hold it with your hand in position so you can rotate it as you look through it.

5. Look with your eye through the analyzer and view the light source. Rotate the analyzer as you view the light source. Describe your observations here.
6. What is the relative orientation of the optic axis of the two pieces of Polaroid when the light appears brightest? Is the masking tape parallel to each other or perpendicular?

Name_______________________________ Date_____________

7. What is the relative orientation of the optic axis of the two pieces of Polaroid when the light appears dimmest? Is the masking tape parallel to each other or perpendicular?
8. Repeat steps 1-7 with the white LED light source and describe and difference and similarities in using the two different light sources

Name______________________________ Date____________

Activity 12-3 Polarization by Reflection of White Light

Objective: To find the reflection angle that gives you the angle for 100% polarization and compare with the prediction of Brewsters Law.

Materials:

- **Red laser pointer**
- **Flashlight or white LED light source (Maglight)**
- **Rectangular prism**
- **Sheet of Polaroid**
- **Protractor**

Procedure:

1. Place the rectangular prism on a flat surface. Shine the light at some small angle to the surface of the block. When light is reflected from the surface some of it will be polarized in the plane of the surface.
2. Now rotate the Polaroid about an axis parallel to the incident light on the Polaroid. The reflected light on the sheet will vary from dark to bright. The light will be brightest when the optic axis or polarization axis of the sheet is parallel to the plane of the surface and dimmest when the polarization axis is perpendicular. You will be more sensitive to finding the angle when you try to look for where the light is dimmest.
3. After you have the optic axis aligned with the surface, now very the incident angle a little as you view the reflected light through the Polaroid sheet. This is to make sure you have the angle when the light is the dimmest. When you reach a reflection angle where the brightness is a maximum or the dimmest when the axis is perpendicular, that reflection angle will be Brewsters angle.
4. Do your best to measure the angle using your protractor. You will have to improvise here to actually get a good measurement. You might need some assistance to hold the Polaroid and have someone else hold the protractor to read it. Describe your observations in step 3.

5. Calculate Brewsters angle for the prism assuming n=1.5.

6. Calculate the percentage difference between the measured value and the calculated value.

Name________________________________ Date____________

Activity 12-4: Polarization by Scattering of White Light, Part I

Objective: To observe the polarization effect by Rayleigh scattering.

Materials:

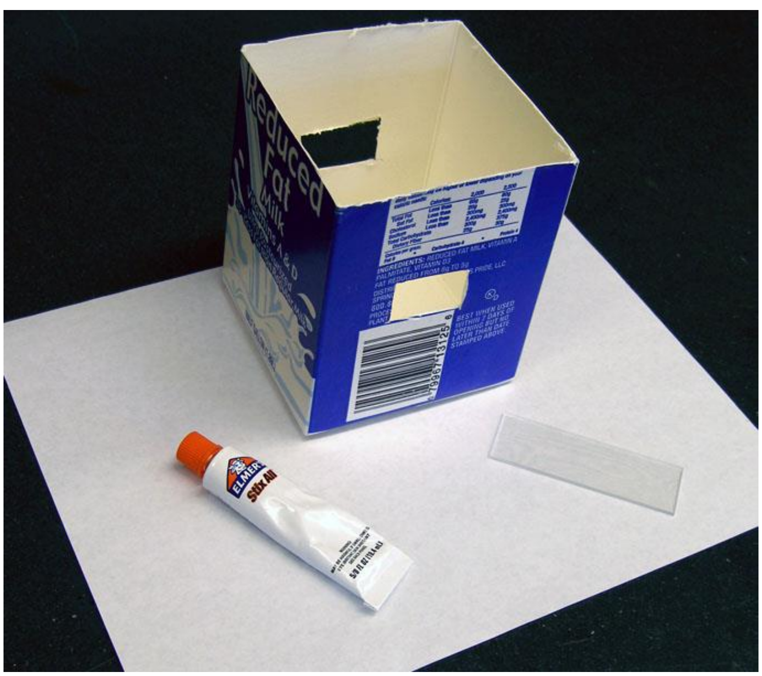
- A cardboard milk carton
- A pair of scissors or a razor
- Two glass slides
- RTV waterproof glue (silicon glue or aquarium glue; do not use superglue)
- A flashlight
- Milk
- An eye dropper
- Marker

The Setup:

1. Wash the milk carton clean and cut the top of the carton at an even height of about 6 inches from its base.

2. Draw a rectangle on one side of the carton 2 inches from the top of the carton. The width of the rectangle should not exceed the width of the glass slide.

3. Make a window by cutting along the rectangle with a pair of scissors or a razor.



4. Repeat step 2 and 3 on the opposite side of the milk carton. Measure the distance of the first window to the left and right edges of the carton and use your results to determine the position of the other window on the opposite side. The two windows must be aligned so that the light passing through the first window will exit through the second window.

5. Glue one glass slide to each window. You should seal the edge completely between the glass slide and the carton so that water in the carton does not leak in the later steps. Be careful on the amount of glue used; excessive amount of glue will overflow and taint the glass when you press the glass slide against the carton.

6. Let the carton sit and wait for the glue to dry overnight preferably.

The Procedures:

1. Fill the carton with water to about 1 inch from the top.

2. Turn off the lights in the room. Shine the flashlight through one window such that it exits from the other. Observe the light by looking from the top of the carton and through the exit window. Do you see the light path as the it travels in water? What is the color of light viewed from the top and through the exit window? Record your observation in **Table 12-4**.

3. Add a couple drops of milk in the water. The exact number of drops will depend on the fat content of milk (2%) used and the size of the droplets. In general, the amount of milk should not exceed 1/2 of a regular teaspoon. If you put in too much milk, then light will not make it through the exit window Stir the milk-water mixture. Shine the flashlight through one window such that it exits from the other and observe the light from the top and through the exit window. What do you see that is different from your previous observations in step 2? Record your observation in **Table 12-4**.

Name_______________________________ Date_____________

Table 12-4

Condition	Top View		Exit Window View	
	Categories	**Observations**	**Categories**	**Observations**
Water only	Color of Light Glow		Color of Light	
	Light Path		Other Observations	
Water with a few milk drops	Color of Light Glow		Color of Light	
	Light Path		Other Observations	

4. Summarize the relation between the amount of milk added and your observation of the color of the light when viewed from the two different directions.

5. Determine if the light is polarized when viewed through the top and if polarized when viewed through the exit window on the side of the milk carton. How much do you think it is polarized? 100%, 50%, 0%. Explain your answer.

6. Knowing that white light is comprised of light of different wavelengths that result in different colors of light, how can you explain the different color you observed when viewing from the top of the carton versus the exit window?

Name_______________________________ Date_____________

Activity 12-5: Polarization by Scattering of Red Laser Light, Part II

Objective: To investigate the polarization effect by scattering.

Materials: Same as in Activity 12-4

Setup: Same as in Activity 12-4

Procedures:

1. Fill the carton with water and a few drops of milk as described in the step 4 in the procedures from Activity 12-4.

2. Shine the red laser beam into the carton through the windows. Look down from the top of the carton through a polarizer with a marked axis of transmission. Rotate the polarizer until the transmitted light is maximal. What is the polarization of the scattered light?

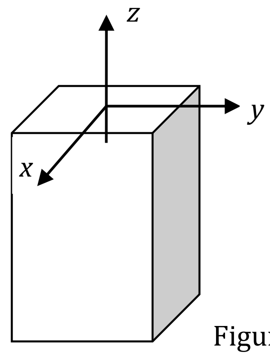


Figure 12-5

Polarization of the scattered light: ______________________ (x-axis/y-axis/z-axis)

3. In the next step, we are going to put a polarizer in front of the laser beam before the light enters the window. Based on your answer to the previous question, predict what orientation of the polarizer will produce the maximal scattering light (x-axis/y-axis/z-axis). Explain your reasoning.

4. Put the polarizer in front of the laser beam before the light enters the window. Rotate the polarizer. Observe the intensity of the scattered light by viewing from the top of the carton.

   4a. How many times has the light you observed from the top of the carton been polarized in this setup? Describe the polarizing mechanism for each polarization process.

   4b. At what orientation of the polarizer do you see the maximal scattering light? ____________________(x-axis/y-axis/z-axis)

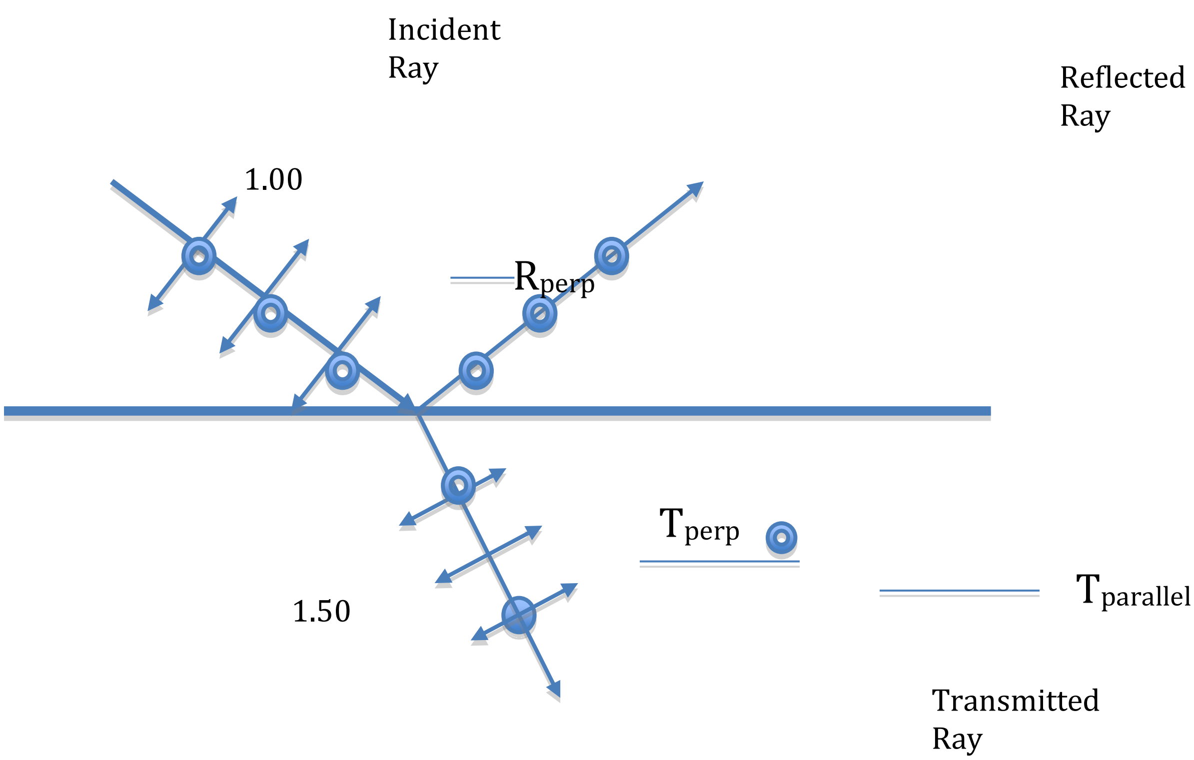
   4c. At what orientation of the polarizaer do you see the minimal scattering light? ____________________(x-axis/y-axis/z-axis)

5. Explain how your results in step 4 relates to the polarization of the scattered light that you found in step 2. (*Hint*: Think about Malus' Law .)

6. Do your results agree with your prediction in step 3? Discuss any misconceptions you might have had.

Name_______________________________ Date_____________

Double Arrow is parallel component of the electric vector
Circle is the perpendicular component of the electric vector



$$q = \tan^{-1} 1.5 = \text{Brewster's angle} = 56 \text{ Degrees}$$

Name________________________________ Date_____________

Home Lab 13
Interference

Activity 13 – 1: Thin film interference of reflected light from air and glass interfaces

Objective: To observe and describe interference phenomena

Materials Provided by You:
- **Two Microscope Slides**
- **An Incandescent Light Bulb**
- **A Fluorescent Light Bulb**

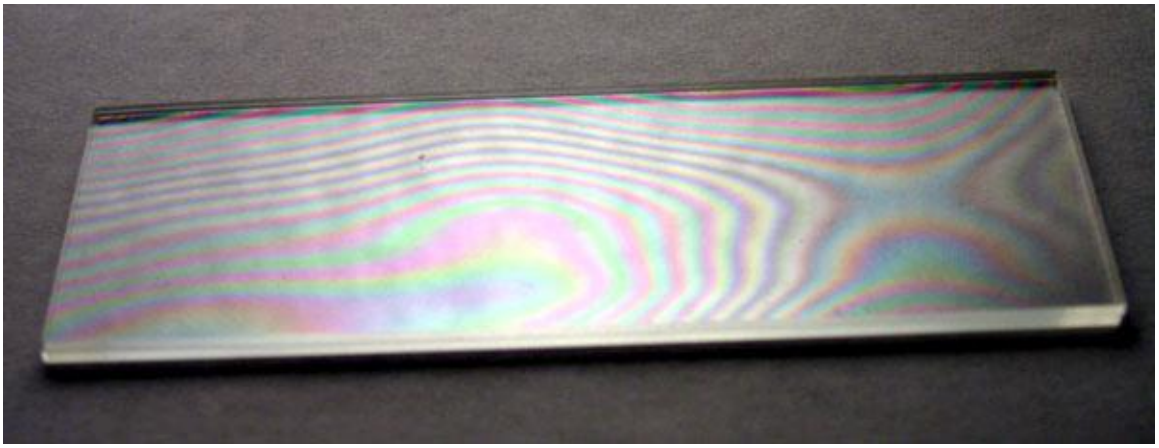
Procedure:
1. Wash the two microscope slides clean and dry them with a lint-free cloth (paper towels will do).
2. Put one slide on top of the other. Press and slide the top slide left and right to get any excess air out in between. The two microscope slides should be tightly sealed.
3. Hold the slides against an incandescent light bulb and observe the interference pattern. Record your observations in Table 13-1. Include a photograph of your result.
4. Hold the slides against a fluorescent light bulb and observe the interference pattern. Record your observations in Table 13-1. How does the amount of fringes differ from last time? Include a photograph of your result.

Table 13-1

	Against Incandescent Light	Against Fluorescent Light
Interference Pattern		
Color Pattern		
Amount of Fringes (More/Less)		

An example of the interference pattern with a fluorescent light:

Name________________________________ Date_____________



5. Press on the slides with your two fingers and observe the change in the interference pattern against the fluorescent light.

   5a. What part of the two microscope slides setup have you changed by applying pressure to the slides?

   5b. How does the interference color pattern change in response to the change you identified in 5a?

6. What are the repeated colors you observe in the interference pattern?

7. How do these colors relate to the primary colors of light (red, blue, and green)? (*Hint*: Refer back to the previous color addition/subtraction lab)

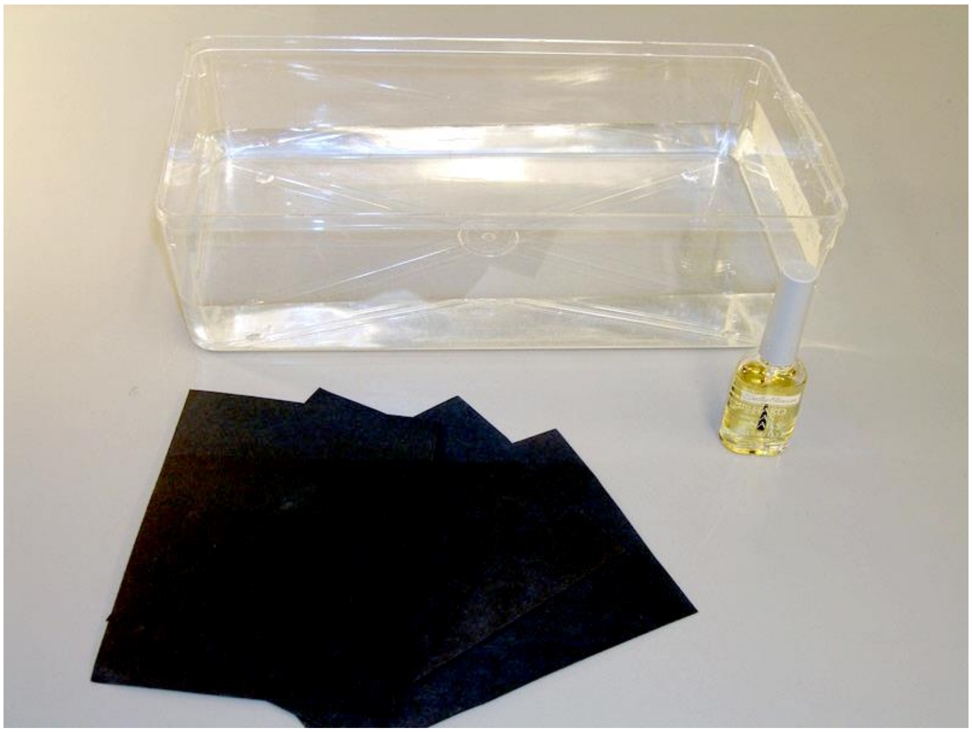
8. Based on your understanding on how interference is related to the wavelengths, explain why you observe these particular colors from the interference fringes when shining a white light through the two microscope slides.

Activity 13 – 2: Thin film interference of reflected light from chemical – water interfaces

Home Lab – Lab 13 Interference
Name________________________________ Date_____________

Objective: To observe the thin film interference pattern formed by the nail polish

Materials Provided by You:
• A Large Bowl or Tray of Water
• Clear Nail polish
• Black Construction Paper



Procedure:

1. Take a standard size sheet of black construction paper and cut it into quarters (about 6x4 inches).

2. Fill your tray a few inches deep with water.

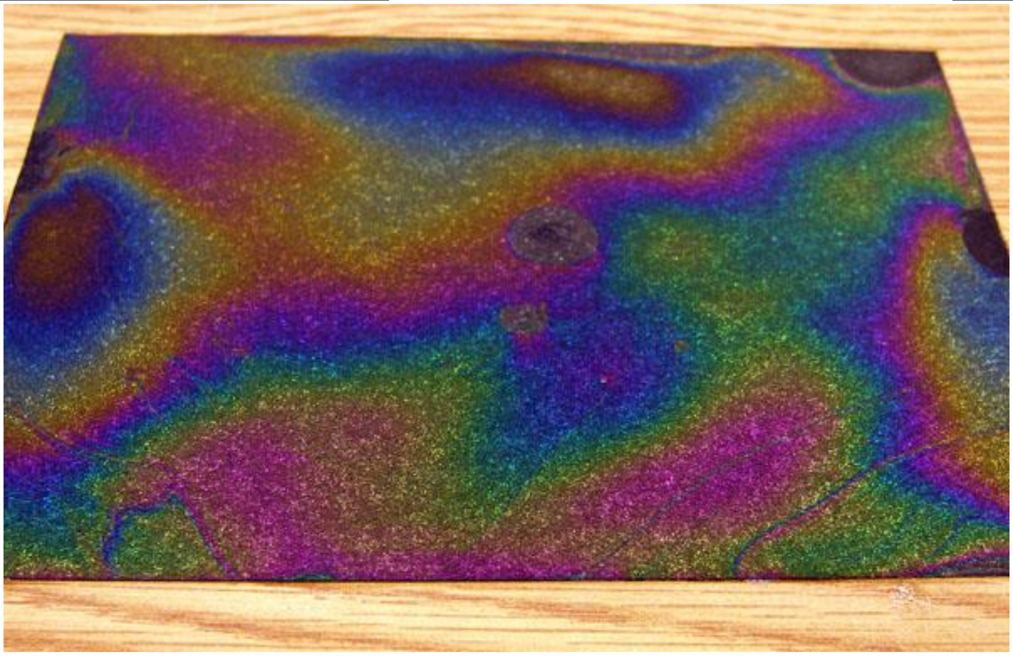
3. Completely submerge one of the pieces of black paper in the water (so no part of the paper is touching the surface of the water).

4. Pour a few drops of nail polish onto the surface of the water (it will disperse over the surface as a thin invisible film).

5. Reach into the water, grab the paper by two corners, and pull the sheet of paper through the film on the surface with one edge of the paper slightly lower to allow the water to drain off.

6. Set the wet paper aside on a flat / dry surface to dry.

Example of finished product:



7. Compare the interfaces for the nail polish activity to those for the previous activity using microscope slides. Include a photograph of your result.
Sketch and label the interfaces for each activity below and indicate the layer that functions as the thin film in producing the interference patterns.

Activity 13-1: Microscope Slides	Activity 13-2: Nail Polish

Activity 13 – 3: Thin film interference of reflected light from soap bubbles

Objective: To observe the thin film interference from the soap bubbles

Name______________________________ Date____________

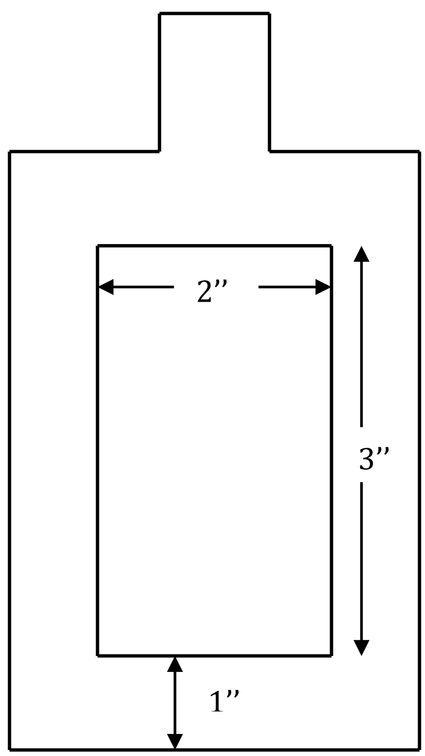
Materials Provided by You:

- **25 ml of Glycerin (Not necessary but improves stability)**
- **25 ml of Dawn or Joy Dish Soap**
- **200 ml of Water (preferably distilled)**
- **A Container (to mix the soap bubble solution)**
- **A Piece of Heavy-Duty Paper (index cards or milk cartons, for example)**
- **A Clothe Pin, Paper Clip, or Binder Clip**
- **A Fluorescent Light Source**
- **A Pair of Scissors**
- **A Razor**

Procedure:

1. Make the soap solution by mixing together glycerin, dish soap, and water in the container.

2. Sketch the soap bubble frame (see below for the shape) on the heavy-duty paper. The hollow rectangle inside should have dimensions 2''x 3'' and the width of the side should be around 1'' to prevent the frame from breaking apart.

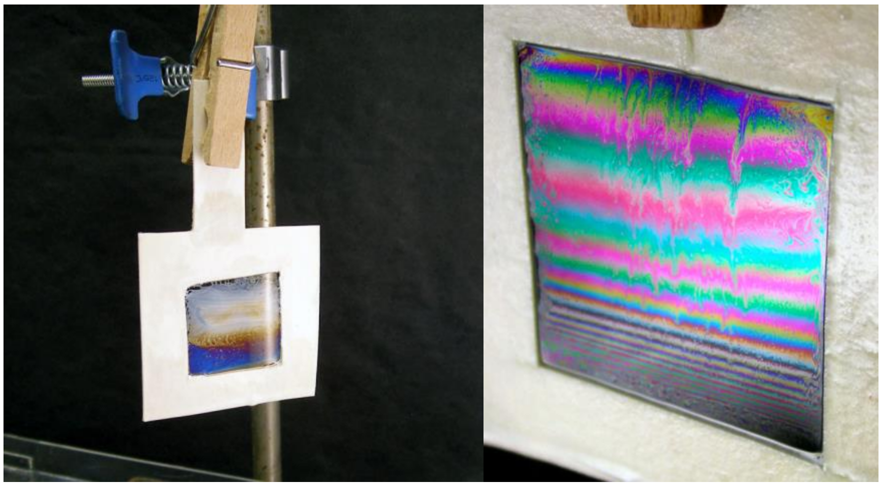


3. Use a pair of scissors and a razor to cut out the soap bubble frame.

Name______________________________ Date____________

4. Place the bubble frame in the soap bubble solution briefly and then carefully take it out of the solution. You will see a thin soap bubble film formed in the rectangle area.

5. Use the clothespin/paper clip/binder clip to hang the soap bubble frame up steady. See Fig 13-1.1 below. The enlarged soap film on the right shows the correct behavior.



6. Place the fluorescent light between you and the soap bubble frame and observe the interference pattern on the soap bubble film. You may have to move around to find the best observational angle.

Questions:

1. Observe the initial interference pattern of the soap bubble. Record your observations for the interference pattern, color, and color boundary under the "Initial Observation" column in **Table 13-3.** Include a photograph of your result.

2. Wait for a minute or two and observe the interference pattern again. Does the interference pattern change? Do new additional colors appear? Record your observations for the interference pattern, color, and color boundary under the "Later Observation" column in **Table 13-3.**

Table 13-3

	Initial Observation	Later Observation

Name______________________________ Date____________

Interference Pattern		
Color		
Color Boundary (distinct/blurry)		
Film Thickness (continuous/discontinuous)		

3. We know that the thin film interference arises because of the different thicknesses of the film. How does the thickness of the film vary in the case of our soap bubble?

4. What can we infer about the continuity/discontinuity of the thickness of the soap bubbles from the color boundaries we observe in the interference pattern? Record your answers in **Table 13-3**.

5. Which part of the rectangle soap bubble film does the change in the interference pattern first appear?

6. From 5, how does the change relate to the thickness of the soap bubble film?

7. From 5 and 6, how can you use the thickness of the soap bubble film to explain the interference color pattern in your later observation?

Name_______________________________ Date____________

Home Lab 14
Diffraction

Activity 14 – 1: Diffraction of red laser light from a slit

Objective: To measure the width of a small slit using diffraction of laser light of known wavelength

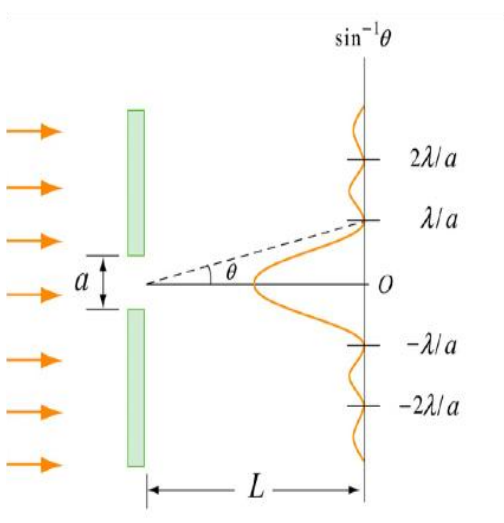
Materials Included:
- Laser pointer with red laser light (Wavelength of light is about 660 nm)
- Optical bench and accessories

Materials Provided by You:
- Two single edges razor blades
- Sticky tape(Scotch tape)
- Wooden platform with nail to hold laser pointer
- Camera (optional)

Background:

When a parallel beam of light is incident on a small aperture whose width is of the order of the wavelength of light, a phenomena known as diffraction takes place. One sees an alternating pattern of bright and dark light or fringes along a screen perpendicular to the axis. Even when you are outside the range of the penumbra shadow you will observe light as show in Fig. 14-1.1.

Fig. 14-1.1



Name_______________________________ Date____________

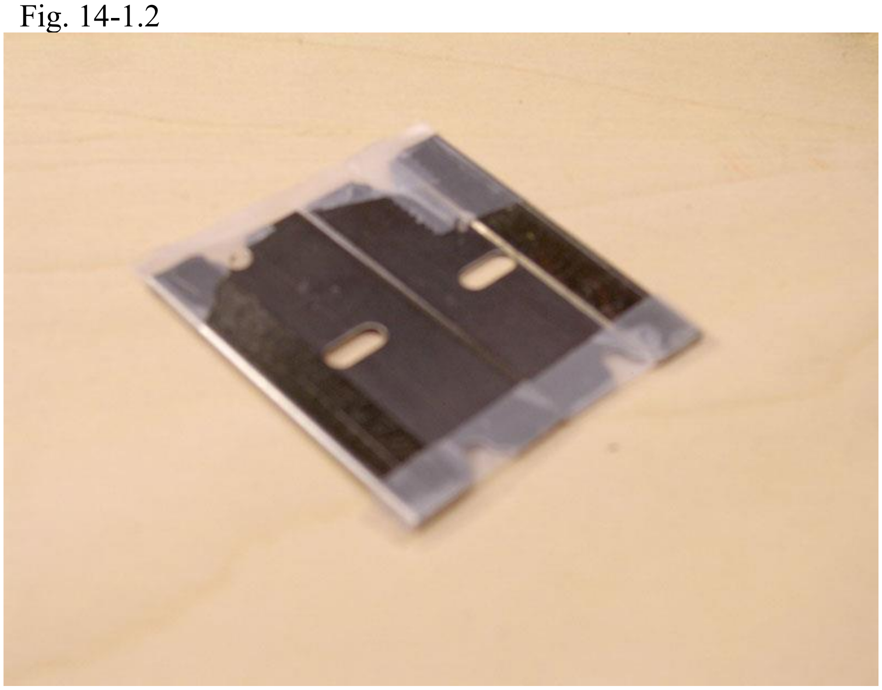
This is a wave property of light and is quite different when light is viewed strictly as a ray of light as we did in the early labs. There is no umbra or penumbra here. The effect is caused by the secondary wavelets produced in the aperture having different path lengths to the screen. Some path lengths give constructive interference and others give destructive interference to give the pattern shown above.

Procedure:

1. Obtain two single edge razor blades or two double edge razor blades. The single edge blades are preferable and will be sturdier and you will be less likely to cut your self.

2. Make the slit by scotch taping two sharp edges together in the same plane with the spacing a one end almost touching and a few tenths of a mm at the other end. See the Fig. 14-1.2 below. This will give you a variable slit width and you can aim the beam at various positions along the slit. The width will be relatively constant over the size of the beam. Once you position the beam on the slit do not move it since the width varies along the razor blade separation and it will change your results.

Fig. 14-1.2



3. Mount the razor blade slit in the U-shaped black holder that comes with the optical bench and place it at about 10 cm from one end of the bench. You may also use a clothespin to hold it to the black u-shaped holder. The slit should be vertical to make the diffraction pattern spread horizontally on a wall about 3 meters away from the slit.

4. Mount the laser pointer on the wooden platform on the optical bench a few cm behind the slit. Use the clothespin to clamp the laser button to the on position.

5. Adjust the laser so it produces a beam of red laser light parallel to the axis of the optical bench and illuminates the slit in the middle of it. The complete setup is shown below in the Fig 14-1.3.

6. Observe the diffracted light on a smooth wall at about a distance of about 3 meters from the slit. The distance from the center of the central maximum to the first minimum should be about 0.2 cm to 0.8 cm depending on the slit width and the distance between the slit and the wall.

7. Measure the distance from the slit to the wall including an estimate of the error and record it here_________________.

8. Measure the distance between the first minimum to the left of the central maximum and the first minimum to the right of the central maximum including an estimate of the error and record it here___________________________________.

9. Divide the distance and error by 2 and record it here ______________________________.

10. The width of the slit, a, is given by the formula $a = \frac{660}{q} nm = \frac{660}{y_1 / L} nm = 660 \frac{L}{y_1} nm$ where nm stands for nanometers or 10^{-9} meters. Calculate and record its value here including the estimate of the error_______________________________________.

11. Now measure the diameter of the slit using one of your lenses as a magnifying glass. First measure the magnification of the magnifying glass as you did once before in Activity Lab11-1. Replace the ruler behind the lens with the razor blades. Record the value of the measured width using the ruler here and record the value after you divide by the magnification of the lens. Include an estimate of the error_____________________.

12. Comment on the agreement or disagreement of the two results as to which one is more accurate.____.

13. Repeat steps 7-12 for a different position along the slit say about 1 cm away from the first position. Choose a position where the slit width is different and comment on how you expect the spacing between minima to vary with slit width_____________________

Activity 14 – 2: Diffraction of red laser light from a single strand of hair.

Name______________________________ Date____________

Objective: To measure the diameter of a strand of hair using diffraction and compare your result with a magnifying glass to measure the diameter.

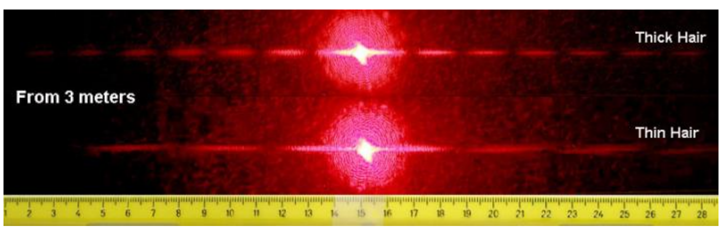
Materials Included:
- Laser pointer with red laser light (Wavelength of light is about 660 nm)
- Optical bench and accessories

Materials Provided by You:
- Strand of hair
- Thin piece of cardboard
- Wooden platform with nail to hold laser pointer
- Camera (optional)

Background:

The diffraction pattern from a single strand of hair is the similar to that from a slit whose width corresponds to the diameter of the hair. This can be understood from Babinet's principle which you can read about in the text. It is not exact because the hair is cylindrical and not flat like a perfect anti-slit would be. Using the same relationships describing the location of minima and maxima on the screen and replacing the width of the slit with the diameter of a hair, you can measure the diameter of your hair. Below in Fig 14-2.1 is a photograph of the diffraction pattern from a single strand of hair.

Fig. 14-2.1



Name________________________________ Date_____________

Experiment to measure diameter of a strand of hair using first diffraction minimum.

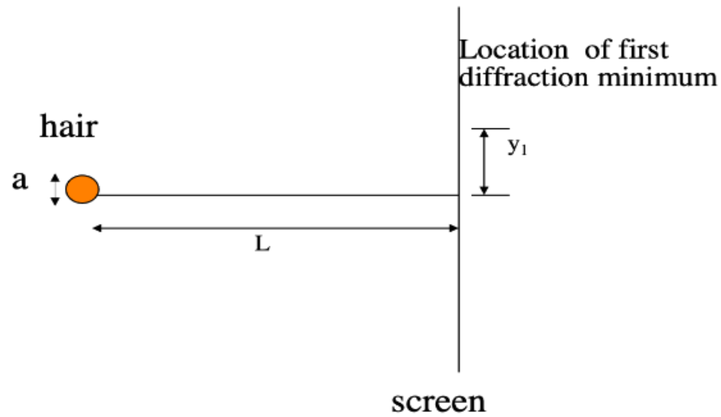
$a\sin\theta = \lambda$ for the first diffraction minimum

$$a = \frac{\lambda}{\sin\theta}$$

$$\sin\theta \approx \tan\theta = \frac{y_1}{L}$$

$$a = \frac{\lambda L}{y_1}$$

$$a = 660\ nm\left(\frac{L}{y_1}\right)$$

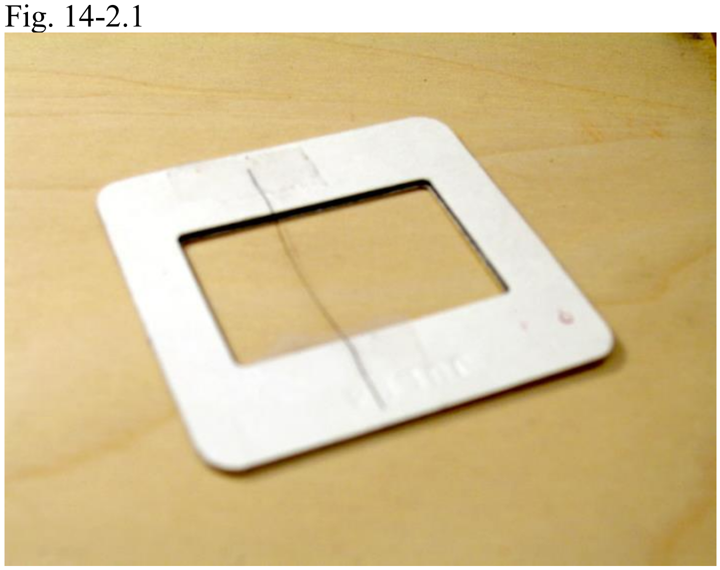


Procedure:

1. Pull a strand of hair typically 0.02 to 0.07 mm in diameter from your head or from some other convenient source.

2. From a piece of stiff cardboard about 1-2 mm thick cut out a 4 cm x 4 cm picture frame with a 2 cm x 2 cm hole in it. Tape the hair across the center of the frame with sticky tape (Scotch tape) as shown in Fig. 14-2.2. Keep the hair taught as you tape it so it makes a nice straight line. The hair is not quite straight enough in the figure below.

Fig. 14-2.1



Name______________________________ Date____________

3. Mount the cardboard with hair in the U-shaped black holder that comes with the optical bench and place it at about 10 cm from one end of the bench. You may also use a clothespin to hold the cardboard to the black u-shaped holder. The hair should be vertical to make the diffraction pattern spread horizontally on a wall about 3 meters away from the hair.

4. Mount the laser pointer on the wooden platform on the optical bench a few cm behind the hair. Use the clothespin to clamp the laser button to the on position.

5. Adjust the laser so it produces a beam of red laser light parallel to the axis of the optical bench and illuminates the hair in the middle of it.

6. Observe the diffracted light on a smooth wall at about a distance of about 3 meters from the hair. The distance from the center of the central maximum to the first minimum should be about 0.2 cm to 0.8 cm depending on the hair diameter and the distance between the hair and the wall.

7. Measure the distance from the hair to the wall including an estimate of the error in the distance and record it here_______________.

8. Measure the distance between the first minimum to the left of the central maximum and the first minimum to the right of the central maximum including an estimate of the error and record it here________________________________.

9. Divide the distance and error by 2 and record it here _________________________________. This will give you a better result that trying to measure the distance between the midpoint of the central maximum and the minimum.

10. The diameter of the hair, a, is given by the formula $a = 660\frac{L}{y_1}nm$ where nm stands for nanometers or 10^{-9} meters. Calculate and record its value here including the estimate of the error___________________________________.

14. Now measure the diameter of the hair using one of your lenses as a magnifying. First measure the magnification of the magnifying glass as you did once before in Activity Lab11-1. Replace the ruler behind the lens with the hair. Record the value of the measured diameter of the hair using the ruler here and record the value after you divide by the magnification of the lens. Include an estimate of the error___________________.

11. Comment on the agreement or disagreement of the two results. Which one is more accurate?____.

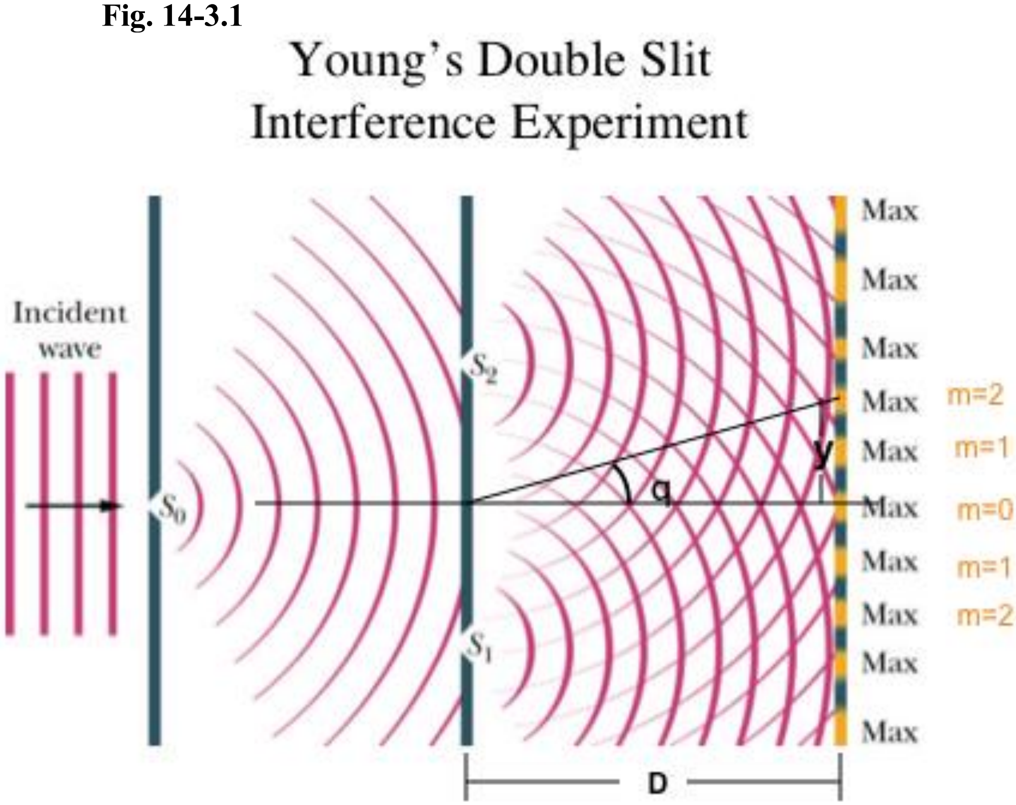
Name______________________________ Date____________

Activity 14 – 3: Diffraction and Interference from 2 stands of hair

Objective: To determine the distance between two closely spaced hairs using diffraction and interference. The main idea

Background: The historical background and the idea behind Young's double slit experiment is described in your textbook. The main idea is that when a beam of monochromatic and coherent light is incident upon two narrow slits as shown in Fig. 14-3.1 an interference pattern is produced on a screen a distance D away from the slits. The distance D should be of the order of a meter and the slits widths and separation are of the order of a wavelength of light. The interference of light emanating from the slits produce bright (max) and dark fringes (min) on the screen as shown below. The angle θ is shown as q and y is the distance from the m=0 fringe to a higher order fringe characterized by m.

Fig. 14-3.1



Name________________________________ Date____________

Materials Included:
- The Optical Bench

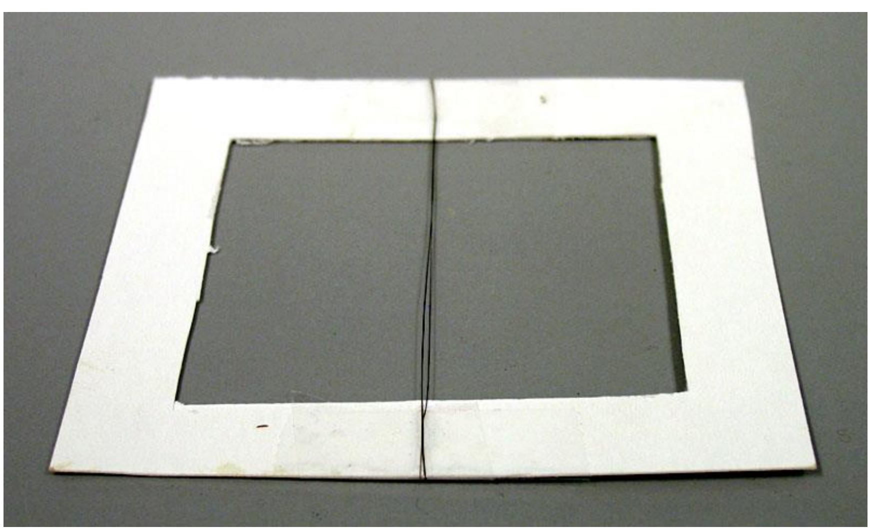
Materials Provided by You:
- A Sheet of Cardboard paper
- Two Hairs
- Sticky Tape
- Wooden Platform with Nails to Hold the Laser Pointer
- A Pair of Scissors
- Meter Sticks

Procedures:

1. From a piece of stiff cardboard about 1-2 mm thick cut out a 4 cm x 4 cm square picture frame with a 2 cm x 2 cm hole in it.

2. Extract two hairs hopefully of the same diameter from your scalp. Carefully tape one hair across the picture frame as you did in the Lab13. Tape the second hair parallel to the first hair with a separation distance of about 3-5 hair diameters. Keep the hairs taught as you tape them to the frame. Make sure none of the tape is on the inside of the frame avoiding any chance that the laser beam may strike it causing stray interference or distortion. **Fig. 14-1.2** shows a finished product. The hairs will serve as double anti-slits to produce a diffraction and interference pattern. From Babinets principle the pattern viewed on the screen will be the same as that from two apertures.

Fig. 14-1.2



Name______________________________ Date____________

3. Mount the rectangular cardboard square with the hairs on the U-shaped black holder included in the optical bench set. You may also use a clothespin to hold the cardboard upright and up against the black u-shaped holder. The hairs should be vertical to make the diffraction pattern spread horizontally on a wall about 3 meters away from the hairs. Measure the distance from the two hairs to the wall.

   Distance from the two hairs to the wall: ___________________________

4. Mount the laser pointer on the wooden platform on the optical bench a few centimeters behind the hairs. Use the clothespin to clamp the laser button to the "on" position and a second clothespin to help position and stabilize the laser pointer on the platform. Adjust the position of the laser pointer so it produces a beam parallel to the axis of the optical bench and illuminates the two hairs uniformly. The complete setup is shown in **Figure 14-3.3.**

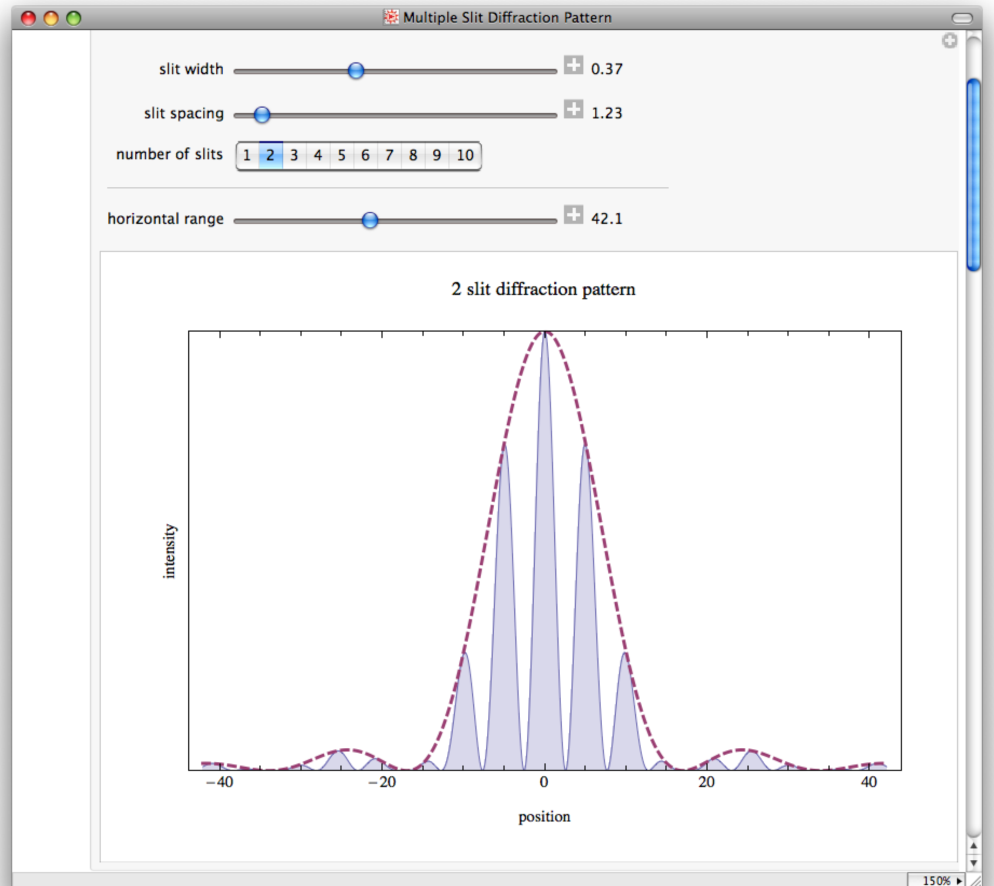
Fig 14-3.3

6. You will see small fringes caused by interference between the two hairs modulated by the diffraction pattern that resembles the single slit diffraction.

7. Measure the distance between the first minimum on the left of the central maximum in the envelope to the first minimum on the right of the central maximum in the envelope. Essentially, you are measuring the distance from m = 1 to m = -1. In the example

diffraction pattern in **Figure 14-3.4** below, this is the distance from -17.50 to +17.50 on the position axis. Record your distance here: ______________________________________.

Figure 14-3.4



Source:
http://www.jca.umbc.edu/~george/html/courses/phys224/2009spg/lectures/lect38/lect38.shtml

8. Divide your distance by 2 and record your result here: __________________________

This gives you the average distance from m = 0 to the m= +1 minimum and from the m=0 to the m=-1 minimum.

9. Our goal now is to express the separation distance between the two hairs in terms of the n^{th} order of the interference fringe and the diameter of the hair. From the single slit equation, we know that $a \sin\theta = m\lambda$ where λ the wavelength is given by 660 nm. Taking m = 1 for the first minimum we get $\sin\theta = \frac{\lambda}{a}$.

Name_______________________________ Date_____________

10. We know the distance d between the two hairs is related to n by the equation $d\sin\theta = n\lambda$, where n is the number of small fringes from the center of the central maximum out to the first minimum of the diffraction minimum. Solving for sin θ, we get $\sin\theta = \frac{n\lambda}{d}$.

Setting $\frac{\lambda}{a} = \frac{n\lambda}{d}$ and then eliminating λ, we get n = d/a. Therefore, the number of small fringes is d/a.

11. How many fringes do you observe between the central maximum and the first minimum?. Record the number here____________________. An example of what you expect to see is shown in the photo in Fig. 14-3.4

12. Given that one can approximate sin θ with tan θ, determine the value of a from the position of the first minimum. Record the value here: a=___________________.

13. Calculate the value of *d* using *n* found in step 11 and *a* found in step 12.

d = _________________________

14. Measure the distance between the hairs, *d*, and the diameter of each hair a using one of your lenses as a magnifying glass as you did in the previous lab. Record the value for *d* and a here. *d* = ___________________ and a_1=___________ and a_2 =______________.

15. Compare your results for a and *d* obtained in step 12, 13, and 14 and comment on the agreement or disagreement. Compare a to the average of a_1 and a_2 .