Reflection

Physics 102 **Workshop #7** **Feb. 25 – Feb. 29, 2008**

Name: _______________________________ Instructor: ____________
Lab Partner(s): ________________________ Time of Workshop: _____

General Instructions

- Workshop exercises are to be carried out in **groups of three.**
- **One report per group** is due by the end of the class.
- Each week's workshop session would typically contain **three sections**. The first two sections must be completed in class. The third section should be attempted if there is time.
    1. A pre-lab reading and assignment section
    2. Experiment section
    3. Practice questions and problems

Lab sessions so far have dealt with light as a wave (wave optics). The next few labs would be dealing with ray optics. This lab session is devoted to Reflection. This lab is divided into three sections i) Reflection and its importance, ii) Image formation by plane mirrors, and iii) Concave Mirrors.

You would need a ruler, pencil and protractor for this lab. Please make all distance measurements in centimeters and angle measurements in degrees.

Part I: Reflection and its importance

The importance of light

"Without light there is no sight". The visual ability of humans and other animals is the result of the complex interaction of light, eyes and brain. We are able to see because light from an object can move through space and reach our eyes. Once light reaches our eyes, signals are sent to our brain, and our brain deciphers the information in order to detect the appearance, location and movement of the objects we are sighting at. Objects present around us generate or reflect light. Objects that generate light are called **luminous objects**. Objects that reflect light are called **illuminated objects**. For example, Sun is a luminous object and the Moon is an illuminated object.

Line of Sight

Everything that can be seen is seen only when light from that object travels to our eyes. Whether it be a luminous object or an illuminated object, you can only view the object when light from that object travels to your eye. The object has to be in line with the eyes for us to see it. This directing of our sight in a specific direction is sometimes referred to as the **line of sight**.

> **In order to view an object, you must sight along a line at that object; and when you do light will come from that object to your eye along the line of sight.**

A luminous object emits light in all possible directions; and an illuminated object reflects light in all possible directions. Although this light diverges from the object in a variety of directions, your eye only sees the very small diverging cone of rays that is coming towards it. If you are viewing this object from a different location, then you would see a different cone of rays. Regardless of the eye location, you will still need to sight along a line in a specific direction in order to view the object.

While simple, this concept of the line of sight is also profound! This very principle of the line of sight will assist us in understanding the formation of images in both this lab (reflection) and the next lab (refraction).

A light source emits light rays in all possible directions. A fraction of these rays strike the surface of the object. We are able to see objects because a fraction of the rays leaving the object are in our line of sight.

In the case of reflection, a fraction of light rays leaving the illuminated object strikes the mirror surface. Some of the rays that strike the mirror surface are directed towards our eye (lie in the line of sight). Hence we are able to see the reflection of the object. The ray of light that travels from the object to the mirror's surface is called the **incident ray**.The ray that reflects off the surface of the mirror into the eye is called the **reflected ray**. The figure below shows plane mirror reflection.

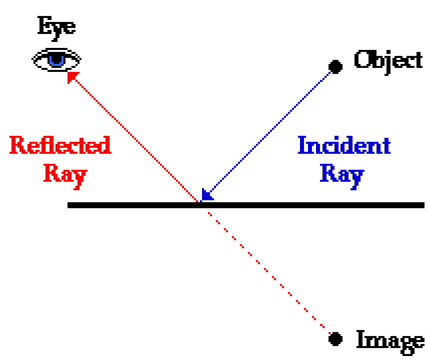


Figure1: Reflection by plane mirror

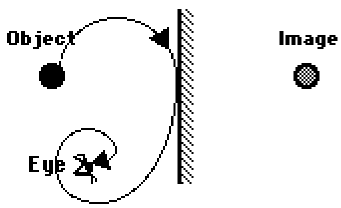
So the manner in which light travels to your eye as you view the image of an object in a mirror can be summarized as follows.

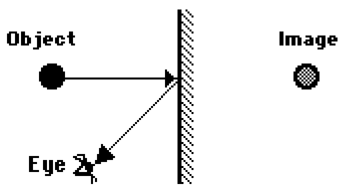
> **To view the image of an object in a mirror, you must sight along a line at the image. One of the many rays of light from the object will approach the mirror and reflect along your line of sight to your eye.**

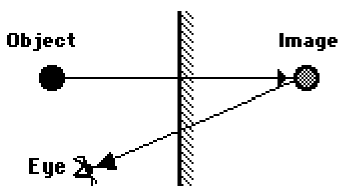
Observe in fig. 1 that the image is positioned directly across the mirror along a line which runs perpendicular to the mirror. The distance from the mirror to the object (known as the object distance) is equal to the distance from the mirror to the image (known as the image distance). For all plane mirrors, this equality holds true:

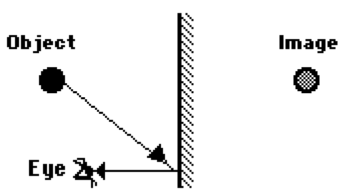
Object distance = Image distance

The following diagrams depict some ideas about how light might travel from an object location to an eye location when viewed the image of the object is viewed in a mirror. Comment on the incorrectness of the following diagrams. Discuss what makes them incorrect.









The Law of Reflection

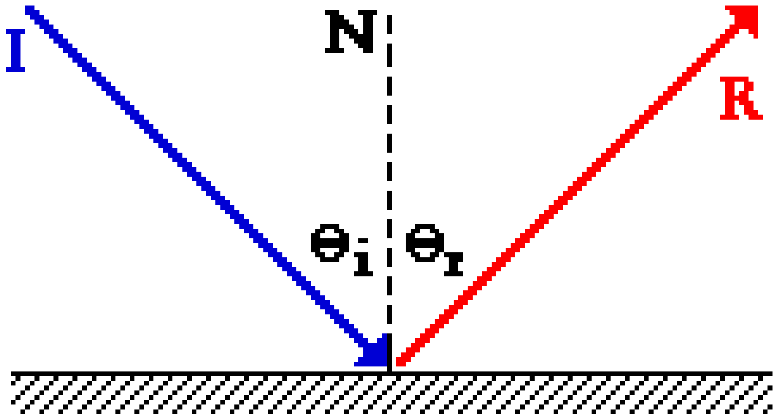


Figure 2: Laws of reflection

In Fig. 2, the ray of light approaching the mirror is known as the **incident ray** (labeled I). The ray of light which leaves the mirror is known as the **reflected ray** (labeled R). At the point of incidence where the ray strikes the mirror, a line can be drawn perpendicular to the surface of the mirror; this line is known as a **normal line** (labeled N). **The normal line divides the angle between the incident ray and the reflected ray into two equal angles.** The angle between the incident ray and the normal is known as the **angle of incidence**. The angle between the reflected ray and the normal is known as the **angle of reflection**.

The law of reflection states that when a ray of light reflects off a surface, the angle of incidence is equal to the angle of reflection.

Now let us consider the case where the reflection of the object is being viewed. Figure 3 shows us how we are able to see reflection of an object in the mirror.

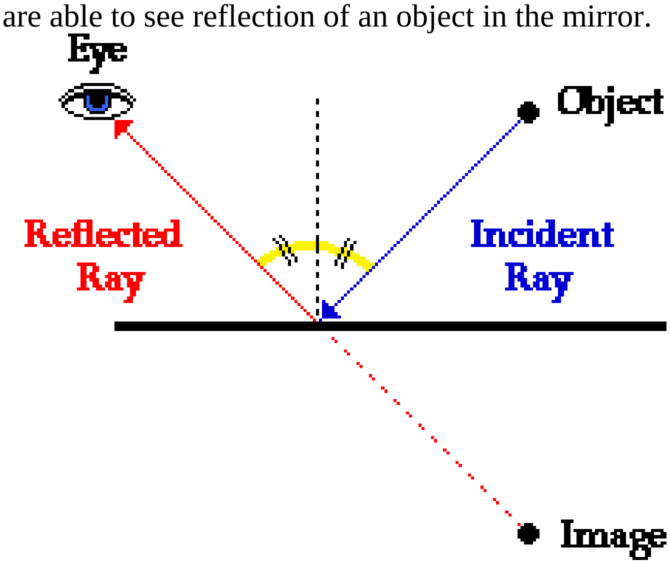


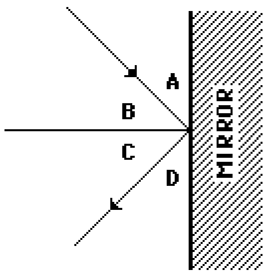
Figure 3: Reflection of an object

The incident ray from the object reflects off the surface of the mirror. The reflected ray is in our line of sight and hence we are able to see the object. From the law of reflection, we know that the angle of incidence is equal to the angle of reflection. **The distance of the image from the mirror's surface is the same as the distance of the object from the**

mirror's surface. If we were to stand in different positions (different angles of incidence) we would still view the image at the same location. This is known as parallax.

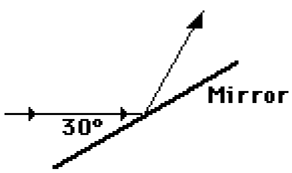
Review Questions

Consider the diagram at the right. Which one of the angles (A, B, C, or D) is the angle of incidence? Which one of the angles is the angle of reflection?



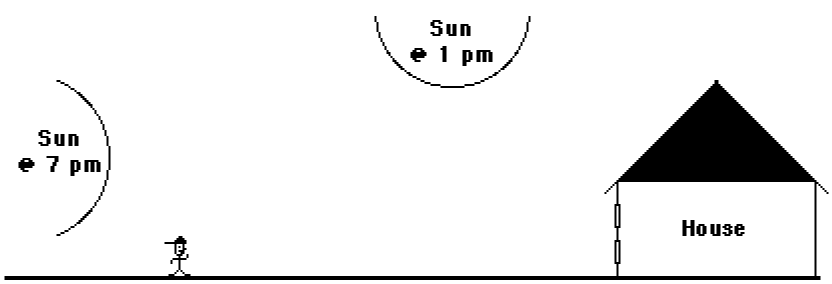
ANSWER: ____________

A ray of light is incident towards a plane mirror at an angle of 30-degrees with the mirror surface. What will be the angle of reflection?

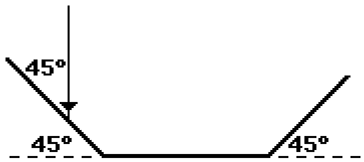


ANSWER: ______________

Why do windows of distant houses appear to reflect the sun only when rising or setting? Use the diagram below to explain, drawing appropriate light rays on the diagram.



A ray of light is approaching a set of three mirrors as shown in the diagram. The light ray is approaching the first mirror at an angle of 45-degrees with the mirror surface. Trace the path of the light ray as it bounces off the mirror; continue tracing the ray until it finally exits from the mirror system. How many times will the ray reflect before it finally exits?



Specular Vs Diffuse Reflection

Laws of reflection always apply no matter the type of surface. Reflections of standard surfaces are easy to predict. If we draw a Normal line at the point of incidence, we can estimate the reflected ray using the law of reflection. Reflection is also dependent on the nature of surfaces off which they are reflected. Reflections off smooth surfaces like mirrors, still surface of water,… are classified as **specular reflection**. Reflections off rough surfaces like paper, asphalt roads,… are classified as **diffuse reflection**. Figure 4 summarizes this idea.

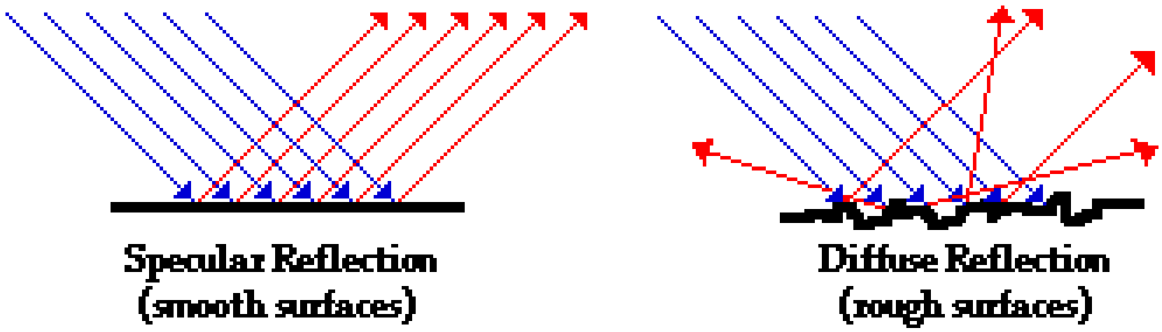


Figure 4: Diffuse and specular reflection

PART II: IMAGE FORMATION IN PLANE MIRRORS

We will explore image the formation phenomenon in plane mirrors in this section. Figure 5 below summarizes the concepts covered in the previous part.

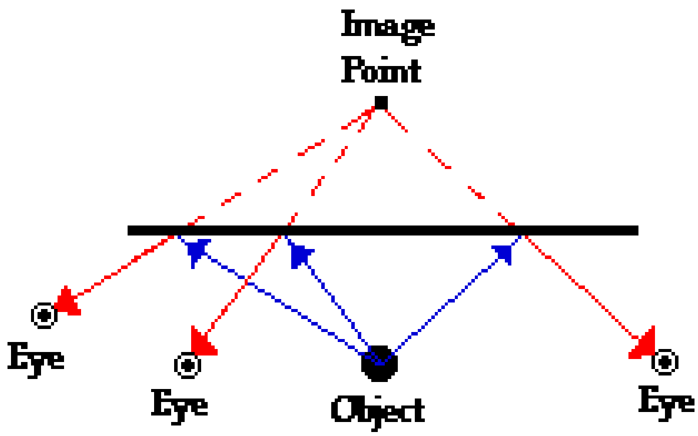


Figure 5: Image formation in mirrors

The image location is located at that position where observers are sighting when viewing the image of an object. It is the location behind the mirror where all the light appears to diverge from. In fig. 5, three individuals are sighting at the image of an object along three different lines of sight. Each person sees the image due to the reflection of light off the mirror in accordance with the law of reflection. When each line of sight is extended backwards, each line will intersect at the same point. This point is the image point of the object.

Images

An **image** is a position in space where all the reflected light appears to diverge from. Since light from the object appears to diverge from this location, a person who sights along a line at this location will perceive a replica or reproduction of the actual object. In the case of plane mirrors, the image is said to be a **virtual image**. Virtual images are images which are formed in locations where light does not actually reach. Light does not actually pass through the location on the other side of the mirror; it only appears to an observer as though the light were coming from this position. Whenever a mirror creates a virtual image, it will be located behind the mirror where light does not really pass.

The next two parts will deal with instances in which images are formed by curved mirrors. Such images are called **real images**. Such images are formed on the same side of the mirror as the object and light passes through the actual image location. Real images can be captured on a screen unlike virtual images.

Another important characteristic worth mentioning is the orientation of the image. Virtual images are usually **right-left reversed**. If you observe your image in the mirror, this would be obvious. Real images are usually **inverted**.

The third important characteristic is the relation between image distance and object distance from the mirror. For plane mirrors, the object distance (often represented by the symbol d_o) is equal to the image distance (often represented by the symbol d_i). That is the image is the same distance behind the mirror as the object is in front of the mirror.

A fourth and final characteristic of plane mirror images is that the dimensions of the image are the same as the dimensions of the object. The ratio of the image dimensions to the object dimensions is termed the **magnification**. Plane mirrors produce images which have a magnification of 1.

Ray diagrams

Ray diagrams are important tools in understanding image formation. A ray diagram is a diagram which traces the path which light takes in order for a person to view a point on the image of an object. Rays (lines with arrows) are drawn for the incident ray and the reflected ray. Complex objects such as people are often represented by stick figures or arrows; in such cases it is customary to draw rays for the extreme positions on such objects.

Ask your TA to explain how ray diagrams are drawn for plane mirrors. Rays are drawn from each end of the object to the mirror surface. The reflected rays converge at the eye. Figure 6 illustrated a simple ray diagram from a plane mirror.

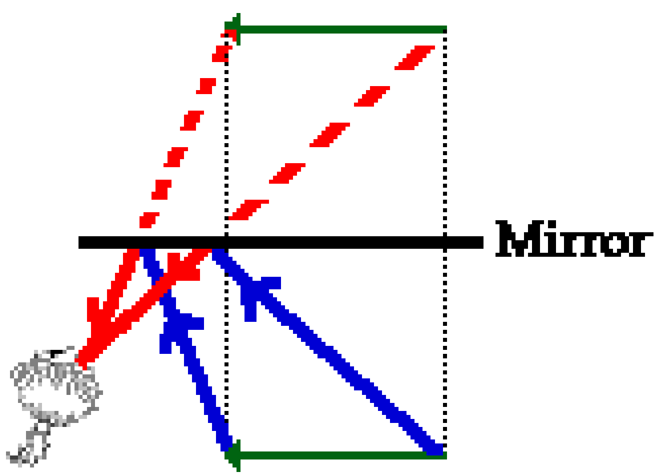
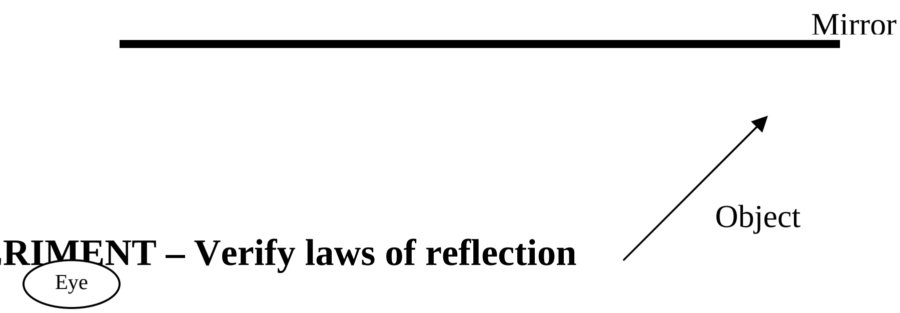


Figure 6: Ray diagram for plane mirror

Draw the ray diagram for the case shown below.



EXPERIMENT – Verify laws of reflection

For this part of your lab, you will need

1. A plane mirror (from the optics kit used last week)
2. A sheet of white paper
3. A drawing board
4. A protractor
5. Ruler
6. Four pins
7. Pencil

You are going to place a pin as an object and are going to obtain the position of the pin by observing it from different angles.

Procedure

1. Tape a clean sheet of paper on the drawing board.
2. Place the plane mirror in the middle of the paper such that the mirror's surface is perpendicular to the paper.
3. Mark the mirror's surface using ruler and pencil.
4. Select a pin as your object. Place the pin about 5 cm in front of the mirror's surface. Mark its position as O_1. Draw an incident ray from the pin to the mirror such that the incident ray makes a 30° angle of incidence with the normal. All angles are to be measured with respect to the normal.
5. Pick a second pin and place it on the incident ray between the object pin and mirror. Mark its position as O_2.
6. You will now observe the reflections of the base of the two pins (O_1 and O_2) on the mirror and place two more pins on the drawing board such that the bases of all the four pins (two pins and two images) are aligned in a straight line. Mark the positions of the base of the two pins as I_1 and I_2.

7. Draw the reflected ray from the mirror that passes through I_1 and I_2. Make sure that the reflected ray intersects the incident ray only at the mirror surface. Repeat the above procedure if the rays don't intersect exactly.
8. Measure the angle of reflection. The angle of reflection should be the same as the angle of incidence.
9. **Pull out all pins except O_1**. With O_1 fixed, repeat steps 4 - 8 for 45° angle of incidence.
10. Extend both reflected rays (with 30° and 45° incidence angles) beyond the surface of the mirror till they intersect.
11. Verify whether the object distance is the same as the image distance and whether they lie in the same line perpendicular to the mirror surface.
12. Mark all angles and distances neatly on the paper and attach it to the end of your worksheet.

PART III: CONCAVE MIRRORS

We have so far covered image formation by plane mirrors. We will now deal with image formation by curved mirrors. We will pick **spherical mirrors** for our study. Spherical mirrors can be thought of as a portion of a sphere which was sliced away and then silvered on one of the sides to form a reflecting surface. **Concave mirrors** were silvered on the inside of the sphere and **convex mirrors** were silvered on the outside of the sphere.

Anatomy of a curved mirror

If a concave mirror is thought of as being a slice of a sphere, then there would be a line passing through the center of the sphere and attaching to the mirror in the exact center of the mirror. This line is known as the **principal axis**. The point in the center of sphere from which the mirror was sliced is known as the **center of curvature** and is denoted by the letter **C** in the diagram below. The point on the mirror's surface where the principal axis meets the mirror is known as the **vertex** and is denoted by the letter **A** in fig. 7. The vertex is the geometric center of the mirror. Midway between the vertex and the center of curvature is a point known as the **focal point**; the focal point is denoted by the letter **F** in fig. 7. The distance from the vertex to the center of curvature is known as the **radius of curvature** (abbreviated by "R"). The radius of curvature is the radius of the sphere from which the mirror was cut. Finally, the distance from the mirror to the focal point is known as the **focal length** (abbreviated by "**f**"). Since the focal point is the midpoint of the line segment adjoining the vertex and the center of curvature, the focal length would be one-half the radius of curvature.

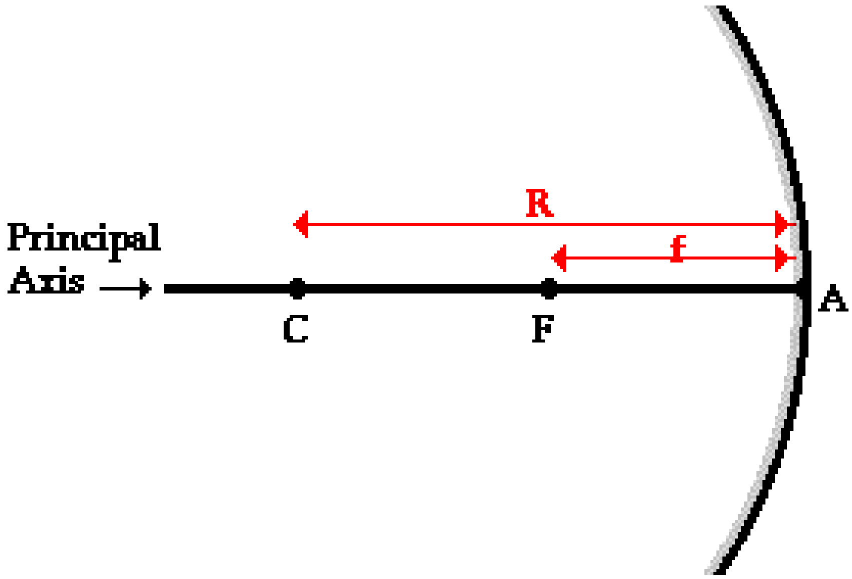


Figure 7: Anatomy of a concave mirror

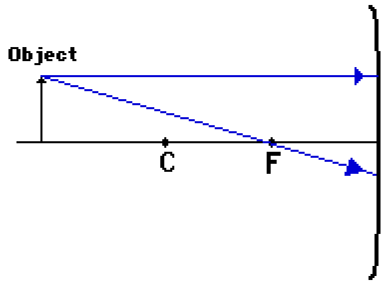
The focal point is the point in space at which light incident towards the mirror and traveling parallel to the principal axis will meet after reflection. We will now try and understand how images are formed in concave mirrors. Concave mirrors are capable of producing both real and virtual images. Depending on the object location, the image could be enlarged or reduced in size or even the same size as the object; the image could be inverted or upright; and the image will be located in a specific region along the principal axis. We will use ray diagrams to understand these relationships between object and image.

Rules of Concave mirror reflection

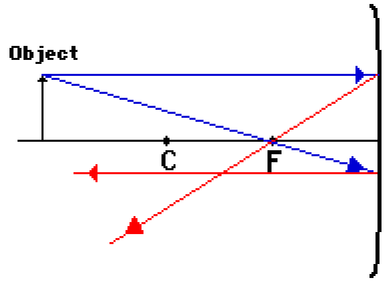
1. A concave mirror behaves exactly like a plane mirror at the point of reflection. A tangent drawn to the surface of the mirror at the point of reflection can be considered for simplicity of understanding.
2. Concave mirrors are capable of producing **real images** (as well as virtual images). When a real image is formed, it still appears to an observer as though light is diverging from the real image location. Only in the case of a real image, light is actually passing through the image location.
3. Any incident ray traveling parallel to the principal axis on the way to the mirror will pass through the focal point upon reflection.
4. Any incident ray passing through the focal point on the way to the mirror will travel parallel to the principal axis upon reflection.

Based on the rules above, we will now see how to draw ray diagrams.

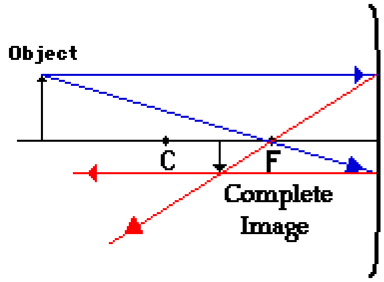
1. Pick a point on the top of the object and draw two incident rays traveling towards the mirror. Using a straight line, accurately draw one ray so that it passes exactly through the focal point on the way to the mirror. Draw the second ray such that it travels exactly parallel to the principal axis. Place arrowheads upon the rays to indicate their direction of travel.



2. Once these incident rays strike the mirror, reflect them according to the last two rules of reflection for concave mirrors. The ray that passes through the focal point on the way to the mirror will reflect and travel parallel to the principal axis. Use a straight line to accurately draw its path. The ray which traveled parallel to the principal axis on the way to the mirror will reflect and travel through the focal point. Place arrowheads upon the rays to indicate their direction of travel. Extend the rays past their point of intersection.



3. Mark the image of the top of the object. The image point of the top of the object is the point where the two reflected rays intersect.



4. Repeat the same procedure for the bottom of the image.

The mirror equation

There are several special cases for image formation in concave mirrors. These would be dealt with while performing experiments.

The equation described below gives the relation between focal length of mirror (f), distance of image from mirror (d_i) and distance of object from mirror (d_o).

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

The Magnification equation relates the ratio of the image distance and object distance to the ratio of the image height (h_i) and object height (h_o). The magnification equation is stated as follows:

$$M = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

These two equations can be combined to yield information about the image distance and image height if the object distance, object height, and focal length are known.

Experiments

You are provided with a meter stick, a concave mirror, a mirror mount, a screen and a light source. Please use the equipment with care. Before you begin your experiments, please make sure that the mirror mount, light source and screen are aligned to be in the same height. Please ask your TA for help if needed.

Finding the focal length of the concave mirror

Mount the given concave mirror on the mirror mount. Place the mirror such that you can see the reflection of a distant object (door of the classroom would be ideal).

1. Use a white sheet of paper as screen for this part of the experiment. Capture the reflected image of the distant object on the screen. Move the paper towards / away from the mirror along the line of sight till the image is sharp.
2. Measure the distance from the mirror to the screen. This is the focal length of the mirror you have.
3. The radius of curvature of the mirror = 2 * focal length.

FOCAL LENGTH OF MIRROR = ______________ cm.

RADIUS OF CURVATURE = ______________ cm.

Use the same mirror for the following parts of the experiment.

There are several cases for image formation. We will explore each case now. You will now use the screen. Draw neat ray diagrams for each of the cases. It would be ideal if you draw scaled versions of what you measure.

CASE 1: Object is beyond C

1. The focal length of the mirror was estimated in the first experiment of the section. Place the mirror in a fixed position at one end of the table.
2. Place the light source at some convenient distance d_o from the mirror such that $\mathbf{d_o > C}$.
3. Now slide the screen along the line of sight till you have the image clearly in focus. Measure the image distance d_i.
4. Measure the height of the cross on the light source as h_o. Measure the height of the cross in the image as h_i.
5. Calculate the focal length using the mirror equation.
6. Calculate the magnification using the magnification equation.
7. Draw the ray diagram for this case.

d_i = ____________ cm. **d_o = ____________ cm.**

f = ____________ cm.

h_i = ____________ cm. **h_o = ____________ cm.**

M = ____________ cm.

Is the image real / virtual? Magnified / diminished? Erect / inverted?
Draw Ray Diagram below

CASE 2: Object is at C

1. The focal length of the mirror was estimated in the first experiment of the section. Place the mirror in a fixed position at one end of the table.
2. Place the light source at some convenient distance d_o from the mirror such that $\mathbf{d_o} = \mathbf{C}$.
3. Now slide the screen along the line of sight till you have the image clearly in focus. Measure the image distance d_i.
4. Measure the height of the cross on the light source as h_o. Measure the height of the cross in the image as h_i.
5. Calculate the focal length using the mirror equation.
6. Calculate the magnification using the magnification equation.
7. Draw the ray diagram for this case.

d_i = ____________ cm. **d_o = ____________ cm.**

f = ____________ cm.

h_i = ____________ cm. **h_o = ____________ cm.**

M = ____________ cm.

Is the image real / virtual? Magnified / diminished? Erect / inverted?

Draw Ray Diagram below

CASE 3: Object is between F and C

8. The focal length of the mirror was estimated in the first experiment of the section. Place the mirror in a fixed position at one end of the table.
9. Place the light source at some convenient distance d_o from the mirror such that **F < d_o < C**.
10. Now slide the screen along the line of sight till you have the image clearly in focus. Measure the image distance d_i.
11. Measure the height of the cross on the light source as h_o. Measure the height of the cross in the image as h_i.
12. Calculate the focal length using the mirror equation.
13. Calculate the magnification using the magnification equation.
14. Draw the ray diagram for this case.

d_i = ____________ cm. **d_o = ____________ cm.**

f = ____________ cm.

h_i = ____________ cm. **h_o = ____________ cm.**

M = ____________ cm.

Is the image real / virtual? Magnified / diminished? Erect / inverted?

Draw Ray Diagram below

CASE 4: Object is at F

15. The focal length of the mirror was estimated in the first experiment of the section. Place the mirror in a fixed position at one end of the table.
16. Place the light source at some convenient distance d_o from the mirror such that **F = d_o**.

17. Now slide the screen along the line of sight till you have the image clearly in focus. Measure the image distance d_i.
18. Measure the height of the cross on the light source as h_o. Measure the height of the cross in the image as h_i.
19. Calculate the focal length using the mirror equation.
20. Calculate the magnification using the magnification equation.
21. Draw the ray diagram for this case.

d_i = ____________ cm. **d_o = ____________ cm.**

f = ____________ cm.

h_i = ____________ cm. **h_o = ____________ cm.**

M = ____________ cm.

Is the image real / virtual? Magnified / diminished? Erect / inverted?

Draw Ray Diagram below

CASE 5: Object is between the mirror and F

22. The focal length of the mirror was estimated in the first experiment of the section. Place the mirror in a fixed position at one end of the table.
23. Place the light source at some convenient distance d_o from the mirror such that **F > d_o**.
24. Now slide the screen along the line of sight till you have the image clearly in focus. Measure the image distance d_i.

25. Measure the height of the cross on the light source as h_o. Measure the height of the cross in the image as h_i.
26. Calculate the focal length using the mirror equation.
27. Calculate the magnification using the magnification equation.
28. Draw the ray diagram for this case.

d_i = ____________ cm. **d_o = ____________ cm.**

f = ____________ cm.

h_i = ____________ cm. **h_o = ____________ cm.**

M = ____________ cm.

Is the image real / virtual? Magnified / diminished? Erect / inverted?

Draw Ray Diagram below

References

Figures from http://www.glenbrook.k12.il.us/gbssci/phys/Class/BBoard.html