



Geometric Optics

Converging Lenses and Mirrors

Physics Lab IV

Objective

In this set of lab exercises, the basic properties geometric optics concerning converging lenses and mirrors will be explored. The goal of the experiment is to be able to analyze ray diagrams so as to determine fundamental properties of image formation. The results determined from the ray diagrams will be compared to the mathematical formulas governing image formation.

Equipment List

Optical bench, light source, concave mirror, convex lens, 1 full length viewing screen, 1 half screen, ruler.

Theoretical Background

General Theory

In the previous lab exercise, reflection and refraction from flat surfaces was explored. In this set of experiments, the reflection from a curved mirror and refraction through curved lenses will be explored.

There are two ways to describe the curved objects used in these experiments. The first is by the shape of the object. A lens or mirror that bulges outward from its center is referred to as a *convex* lens or mirror. A lens or mirror that curves inward is a *concave* lens or mirror. In addition to the shape, lenses and mirrors are classified by their response to light rays, that is incident light rays reflect off mirrors and refract through lenses. As will be seen, light rays incident on a concave mirror are reflected and converge to a point. For this reason, concave mirrors are also referred to as *converging* mirrors. Rays incident on a convex mirror diverge away from the mirror, and is therefore referred to as *diverging* mirror. Convex lenses converge the rays passing through them, and are therefore converging lenses. Concave lenses diverge the rays passing through them, and are therefore referred to as diverging lenses. Figure 1 summarizes these naming conventions.

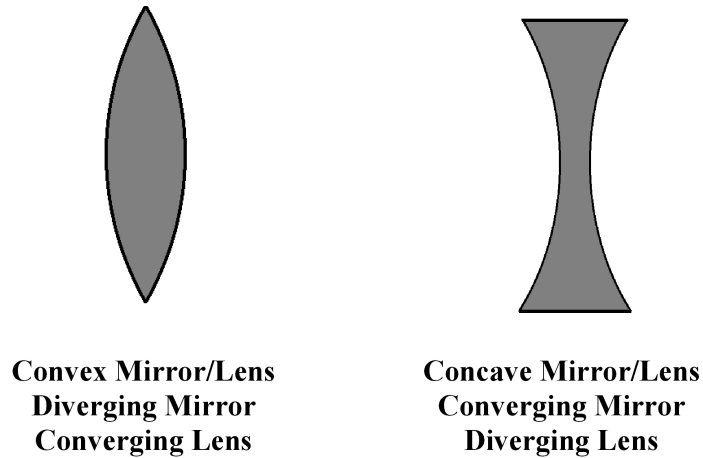


Figure 1: Types of lenses and mirrors

Consider reflection from a concave spherical mirror, as shown in Figure 2. This mirror is a portion of a sphere of radius R whose center is at C . R is the radius of curvature and is the distance C from the mirror.

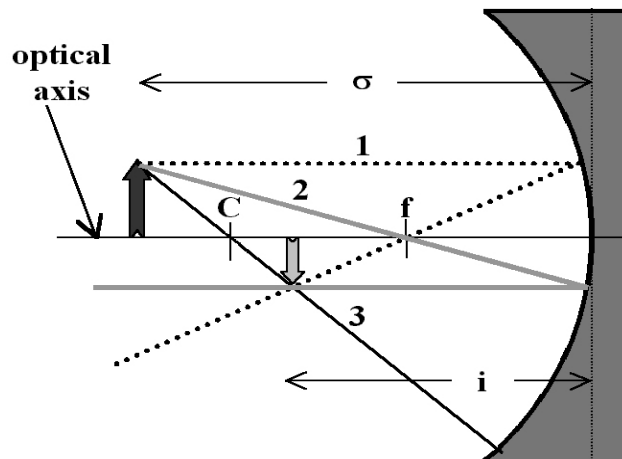


Figure 2: Image formation from a curved reflecting surface

In this case, the light rays converge after reflecting off of the mirror if the object is far enough away from the mirror. This convergence forms an *image*. The distance the object is from the mirror (σ), and the distance of the image from the mirror (i), are related to the focal length of the mirror (f) by the formula,

$$\frac{1}{f} = \frac{1}{\sigma} + \frac{1}{i}. \quad (1)$$

For objects far from the mirror, the incident rays are parallel and are reflected as illustrated in Figure 3. These reflected rays intersect at a point f (the focal point) and the distance from f to the mirror is the focal length. For a spherical mirror, the focal length is half of the radius of curvature, $f = R/2$.

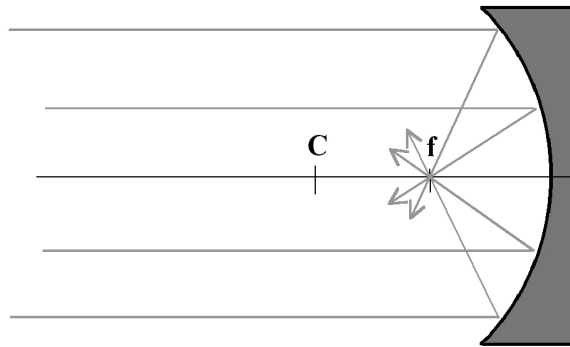


Figure 3: Focal Point of a curved mirror.

There are two types of images a mirror can produce: a *real image* or a *virtual image*. A real image is an image that can be observed on a screen or captured on photographic film. Real images are produced by the intersection of light rays. Figures 2 and 4 are examples of real images. Light rays producing virtual images seemingly diverge from the source and converge at the image however, the rays from the source and image never intersect. Virtual images are seen by the eye but can not be captured on a screen or on film since they seem to appear behind the lens or mirror. The image formed by a plane mirror is an example of a virtual image, since the image appears to form behind the mirror. However if a screen was placed behind the mirror no image would appear on the screen. As seen in Figures 2 and 4, in a single component optical system, real images are always inverted with respect to the orientation of the object. Virtual images are always upright (i.e. in the same direction) compared to the orientation of the object. For real images the images distance, i is positive whereas for virtual images the image distance is negative.

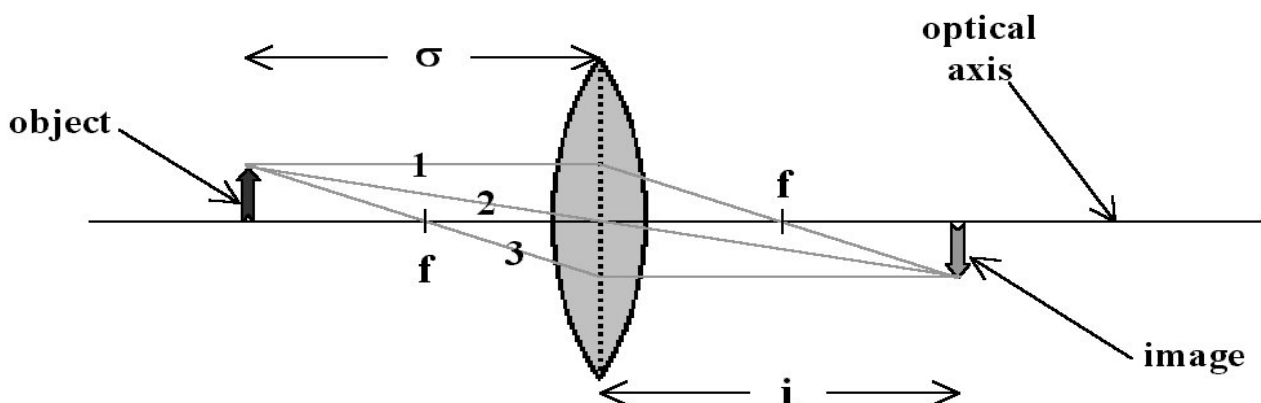


Figure 4: Image formation in a thin lens.

The size of the image, compared to the size of the object, could be increased, or decreased, by the interaction of light with the mirror. The change in the image size is called the *magnification* m , and is defined as the ratio of the image height, h_i to the object height, h_o ,

$$m = \frac{h_i}{h_o}. \quad (2)$$

These heights are the perpendicular distances of the image or the object from the optical axis. Using geometric relationships, the magnification can also be related to the image distance and the object distance,

$$m = \frac{h_i}{h_o} = \frac{-i}{o}. \quad (3)$$

The sign of m indicates the relative orientation of the object and its image. If $m > 0$, then they have the same orientation. If $m < 0$, then the image is inverted compared to the object. These same relationships exist for lenses. The main difference between curved mirrors and lenses is in where the image forms, and the fact that lenses have two foci as opposed to one for mirrors. For the curved mirror, a real image forms on the same side as the object, as shown in Figure 2. For lenses, a real image forms on the opposite side of the object, as shown in Figure 4. The focal length of lenses also does not have a simple relationship to the radius of curvature, as in the case for spherical mirrors, but instead depends upon the index of refraction of the lens as well as the radii of curvature of the lens. The equation that relates the focal length of the lens to the index of refraction and the radius of curvature is known as the lens makers equation.

Ray Diagrams

In addition to using the mathematical relationships to determine the properties of images, such as the image distance and magnification, simple diagrams, called *ray diagrams* can also be used to determine the image properties. Figures 2 and 4 are examples of ray diagrams for lenses and mirrors.

Concave Mirror Ray Diagrams

For mirrors, the following set of rays are typically used in ray diagrams.

Ray # 1 The first ray starts at the top of the object, parallel to the optical axis and is reflected through the focus of the mirror just as is shown in Figure 3. In Figure 2, the dotted line with the “1” above it is an example of this kind of ray.

Ray # 2 The second ray starts from the top of the object and passes through the focus of the mirror to the mirror surface. This ray then reflects off mirror parallel to the optical axis. In Figure 2, the gray line with the “2” above it is an example of this kind of ray.

Ray # 3 The final ray also starts from the top of the object and passes through the center of curvature of the mirror. Since this ray is travelling along the radius of the circular surface of the mirror, it is normal to the surface of the mirror and reflects back upon itself. In Figure 2, the black line with the “3” above it is an example of this kind of ray.

The intersection of any two of these three rays determines the location of the top of the image. The height of the image can then be determined by measuring the distance from the top of the image to the optical axis.

Convex Lens Ray Diagrams

For lenses, the following three rays are typically used in ray diagrams. Keep in mind that an infinite number of rays actually form the image.

Ray # 1 For a lens, the first ray starts from the top of the object and extends parallel to the optical axis to the center of the lens. This ray, for a converging (convex) lens, then extends through the focal point on the opposite side of the lens. In Figure 4, the ray marked “1” is an example of this type of ray.

Ray # 2 The second ray used starts from the top of the object and passes through the center of the lens straight through to the other side. In Figure 4, the ray marked “2” is an example of this type of ray.

Ray # 3 The final ray used in lens ray diagrams also starts at the top of the object and, for converging (convex) lenses, extends through the focus on the same side of the object through to the center of the lens. From the center of the lens, this ray then extend in a line parallel to the optical axis. In Figure 4, the ray marked “3” is an example of this type of ray.

As with mirrors, the intersection of the ray determine the location and height of the image produced by the lens.

In this series of experiments, these relationships will be tested for a curved mirror and a lens.

Procedure and Data Analysis

Concave Mirror

1. Align the light source on the optics bench so that it has a well defined position, such as the 1 cm mark on the optics bench. Consult with the lab instructor if you have difficulty aligning the light source.
2. Mount the concave mirror onto the optics bench. The mirror should be inserted so that the mirror label faces the light source.
3. Mount the half screen so that it is between the light source and the mirror.
4. Use a ruler to measure the height of the arrow on the light source. Record this as the height of the object h_o .
5. Using the Data Sheet marked “Mirror Ray Diagram # 1” and the rulers provided, draw a ray diagram to locate the image of an object 14 cm from the mirror. Use the height determined above as the height of the object on your ray diagram. Each person in your lab group should draw this ray diagram.

6. Use a ruler to measure the image distance and height from your ray diagram. Each person in your lab group should make this measurement separately and record their values on their data sheet. Compare your results with those of the other members of the group.
7. Your experimental group will now determine where the image forms experimentally. Set the mirror so that it is 14 cm from the light source. Record this distance as the object distance σ .
8. With the light source plugged in, adjust the position of the half screen until a sharply focused image appears. Determine the distance from the mirror to the screen, and record this distance as the image distance i . *The image distance is the distance from the mirror to the screen, not the distance from the light source to the screen.*
9. Using the focal length of the mirror, $f = +50$ mm, and the object distance, calculate the image distance from Equation 1.
10. Calculate the percent difference in the experimental value of the image distance from the image distance obtained from both the ray diagram and the calculation done above.
11. Each person in your lab group should now choose an object distance, from values of $\sigma = 17$ cm, $\sigma = 20$ cm, and $\sigma = 23$ cm, to construct a ray diagram. Using these distances and the height of the object measured previously, determine the image distance and image height.
12. For each of the object distance corresponding to a ray diagram, determine the image distance experimentally using the procedure outlined above. Record these image distances on your data sheets.
13. Use Equations 1 and 3 to calculate the image distance and the image height for each of the object distances.
14. Calculate the percent difference in the experiment value of the image distance from the image distances obtained from both the ray diagrams and the calculated values. Calculate the percent difference in the image height between the ray diagram and the theoretical value obtained from the equations.

Convex Lens

1. Remove the mirror and the half screen from the optical bench. Insert the lens marked “+100 mm” and the large white screen into the optical bench. Note that the focal length of the lens is not 100 mm (as printed on the lens), but is instead 110 mm.
2. Using the Data Sheet marked “Lens Ray Diagram # 1” and the procedure outlined in the Theoretical Background, find the image distance and the image height by constructing a ray diagram. Use an object distance of 16 cm and the object height measured previously. To construct the ray diagram, you will need to scale all of

- the distances by a factor of one-half. Using this scaling, the object distance you should draw is 8 cm from the lens drawn on the data sheet. The object height drawn on the page should also be divided in half. Each person in your lab group should construct a ray diagram.
3. Measure to scale the image distance and the image height on your ray diagram. Remember to re-scale the image distance and height by multiplying the measured distances by two. Record the re-scaled image distance and height on your data sheet. Compare your results with those of the other members of the group.
 4. Your lab group will now determine where the image forms experimentally. Set the lens so that it is 16 cm from the light source.
 5. Adjust the position of the white screen until a sharply focused image appears on the screen. Once the image is focused on the screen, tighten the bolt on the screen to hold it in place. Determine the distance from the lens to the screen and record this distance as the image distance i .
 6. Use a ruler to measure the height of the image on the screen. Record this measurement as the image height, h_i .
 7. Use the focal length of the lens, $f=11$ cm, the object distance, $\sigma = 16$ cm, the object height (measured previously), and Equations 1 and 3 to determine the image distance and the image height. Record these values on your data sheet.
 8. Calculate the percent difference in the experimental value of the image distance from the image distance obtained from both the ray diagram and the calculation done above.
 9. Each person in your lab group should now choose an object distance, from values of $\sigma = 22$ cm, $\sigma = 24$ cm, and $\sigma = 26$ cm, to construct a ray diagram. Using these distances and the height of the object measured previously, determine the image distance and height. Remember to scale the ray diagrams as was done previously.
 10. Loosen the bolt on the screen. For each of the object distances above, determine the image distances and image heights experimentally using the procedure outlined above. Record these image distances and image heights on your data sheets.
 11. Use Equations 1 and 3 to calculate the image distances and the image heights for each of the object distances.
 12. Calculate the percent difference in the experimental value of the image distances from the image distances obtained from both the ray diagrams and the calculated values. Calculate the percent difference in the experimental value of the image height from the image heights obtained from both the ray diagrams and the calculated values.
 13. Estimate the uncertainty in each of the experimental quantities, as indicated in the data table. Record the smallest measured value for each experimental quantity.

Use these values to calculate the percent uncertainty in each experimental quantity using

$$\% \text{ uncertainty} = 100 \times \frac{\text{measurement uncertainty}}{\text{smallest measured value}}. \quad (4)$$

14. Use the calculated values of the percent uncertainty in each measured quantity to determine the largest percent uncertainty in the experiment.

Selected Questions

1. Based upon the ray diagrams for the lens and mirror, how does the image distance and height vary as the object distance is increased?
2. What type of image did the lens and mirror produce in the experiment, a real image or a virtual image? Why?
3. Does Equation 1 hold for a plane mirror? If so, what would the focal length of the mirror be? What would the magnification of the plane mirror be?
4. A dog stands facing a convex lens with its tail in the air. If the nose and tail of the dog are each focused one at a time on a screen in turn, which will have a greater magnification? Explain why you think this is so. [Taken from **Physics**, by D. Giancoli 5th ed.]
(Hint: Look at your ray diagrams. How does the image height change as the object distance increases?)
5. Where must the film be placed relative to the focal point (near or far) if a camera lens is to make a sharp image of an object very far away? Explain why you think this is so.