Thin Lenses
Drawing Ray Diagrams

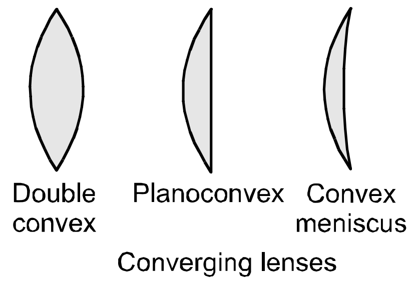


Fig. 1a

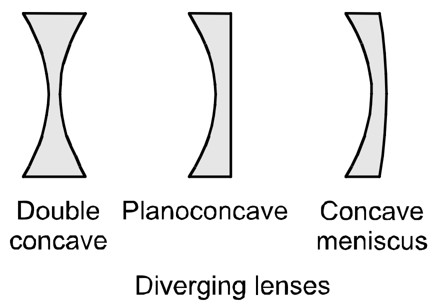


Fig. 1b

In this activity we explore how light refracts as it passes through a thin lens. Eyeglasses have been in use since the 13th century. In 1610 Galileo used two lenses to make a telescope. Soon thereafter lenses were used to make microscopes and cameras.

Lenses are typically made of either glass or plastic because these two materials show an index of refraction greater than one. Each lens has two faces. Each face is either flat or a part of a sphere. A lens is **convex** if it is thicker at the center than at the edges. These lenses refract light rays so that they meet or converge (Figure 1a). A lens is **concave** if it is thinner at the center than at the edges (Figure 1b). These lenses refract light rays so that they spread out or diverge.

Convex lenses can form real or virtual images. An image is **real** if it occurs on the *opposite side* of the lens from the object. An image is **virtual** if it occurs on the *same side* of the lens as the object. As light rays pass parallel to the principal axis and through the lens, they are refracted and converge at the **focal point, F** (Figure 2a). The position of the focal point depends on the index of refraction of the lens material and the shape of the lens. All refraction occurs on the **principal plane.** The principal plane is an imaginary plane that passes through the longitudinal or lengthwise center of the thin lens. The **focal length, *f*** is the distance from the principal plane and the focal point.

Concave lenses always form virtual images. The focal point of a convex lens is on the same side of the lens as the image. F is given a positive value for convex lenses and a negative sign for concave lenses.

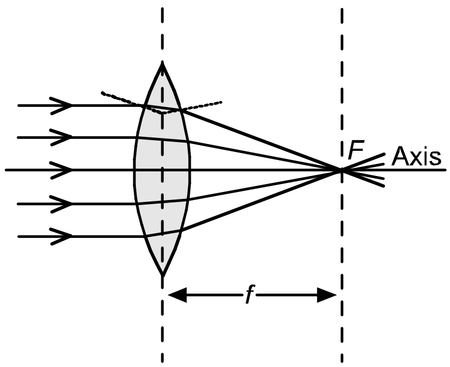


Fig. 2a

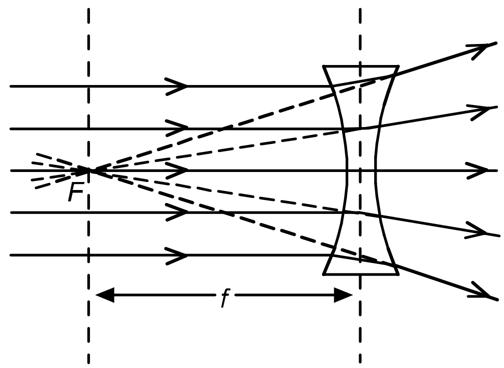


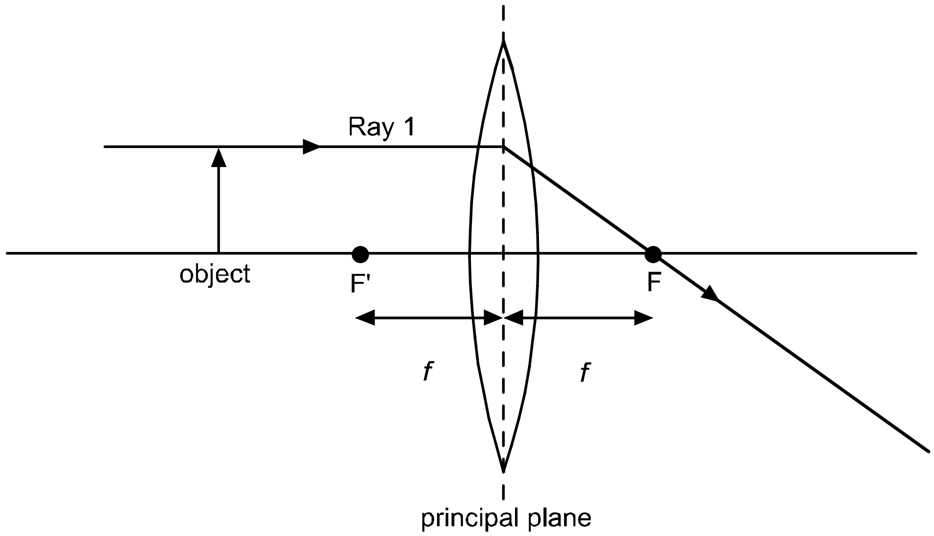
Fig. 2b

Some terms to know:

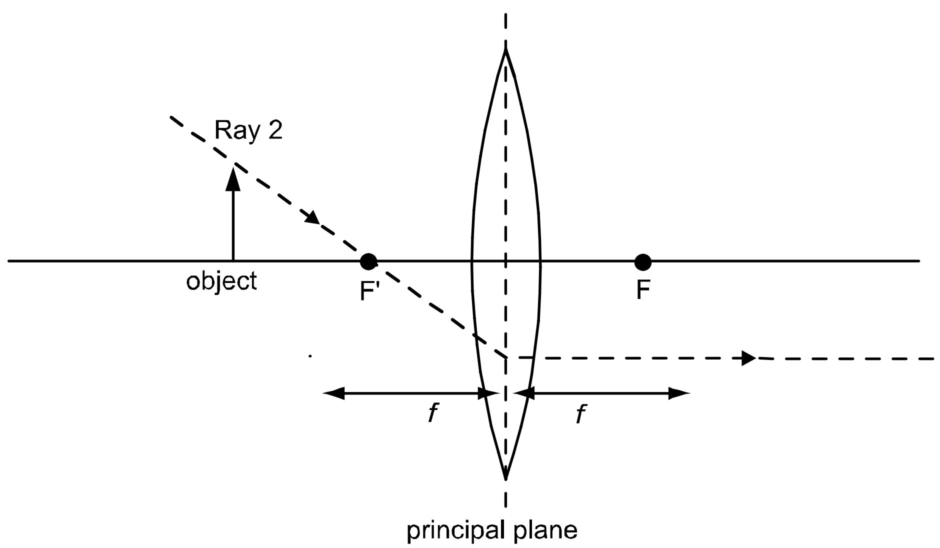
- **object** — the source of diverging light rays; the object is either luminous or illuminated
- **image** — the point where extended rays apparently intersect
- **virtual image —** rays diverge; cannot be projected onto a screen or captured on paper since rays DO NOT converge; rays **diverge**
- **real image —** light rays actually converge and pass through the image. Can be projected onto a screen or captured on paper
- **upright ↑ inverted ↓** — used to describe the position of the image
- **principal axis** — the straight line perpendicular to the surface of the lens and passes through the center of the lens
- **principal plane** — the plane passing through the longitudinal center of the lens
- **focal point, F —** where light rays converge on principal axis
- **focal length, *f* —** the distance along the principal axis that is between the principal plane and the focal point

DRAWING RAY DIAGRAMS TO LOCATE IMAGES FORMED BY COVEX LENSES:
Follow these three easy steps to locate the image. Use a straight edge to draw all rays.

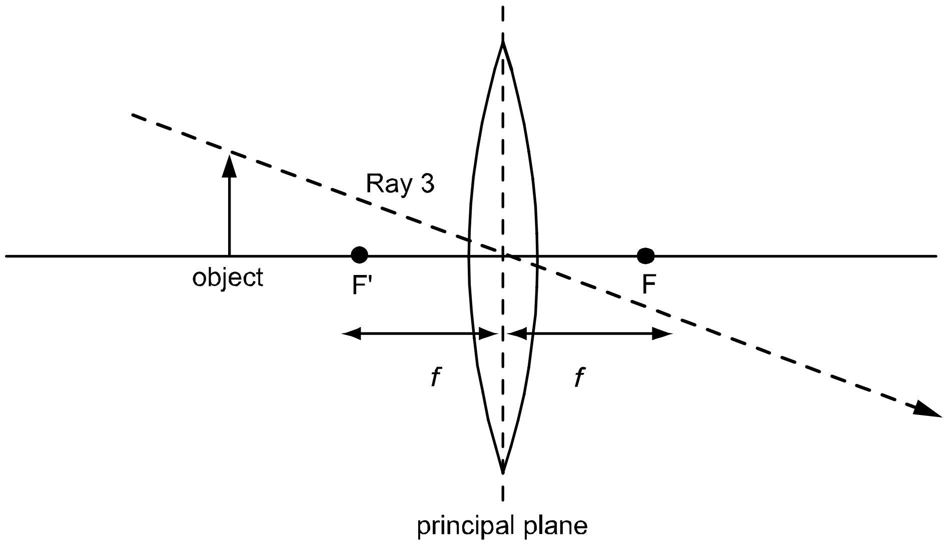
1. Draw Ray 1 from the top of the object, parallel to the principal axis, and into the lens stopping at the principal plane. Refract it through the focal point, F.



2. Draw Ray 2 from the top of the object, through F′ (a point equidistant from the principal plane as the focal point but, on the same side of the lens as the object) and into the lens. Refract it parallel to the principal axis.

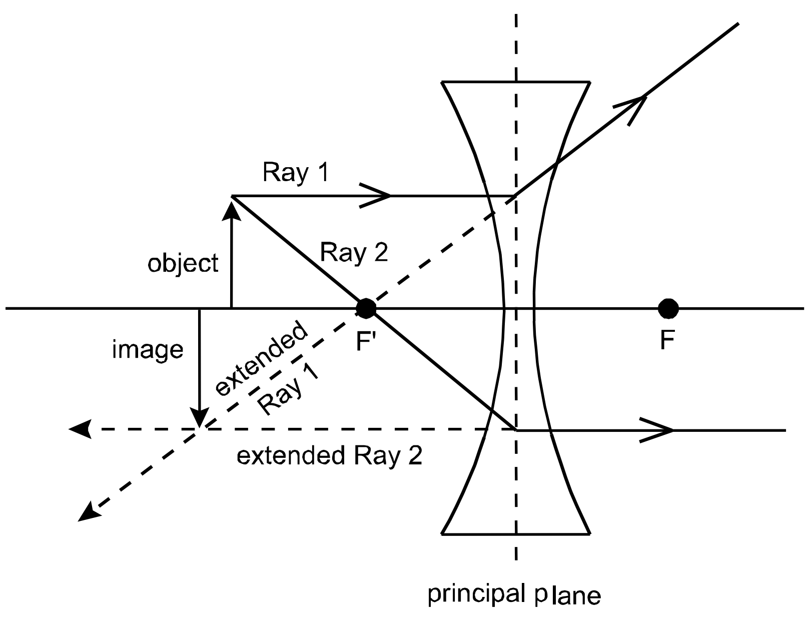


3. Draw Ray 3 from the top of the object through the exact center of the lens. This ray is not refracted.



It is best if you draw your principal axis, object and lens in black ink and then use a straight edge and different colored pencils or markers to draw each ray. When you draw all three rays on the same diagram you see that the three rays intersect. The image is located at that intersection. Draw the image using an arrow that originates on the principal axis and terminates at the intersection of your three rays. Pay attention to the scale of your drawings.

If the rays do not intersect, then you will have to extend them backwards. Use a dashed line to draw these extensions. The extended rays will intersect at the image location. If this intersection is on the same side of the lens as the object, a virtual image is formed.



We can see that the object is in front of the lens, yet the image is virtual, upright, and reduced in size.

We can determine the location of an image from the lens, d_i or the location of an object, d_o, as they are related to the focal length algebraically. Remember that the focal length is given a positive sign for convex lenses and a negative sign for concave lenses. When d_i is positive, the image is real. When d_i is negative, the image is virtual.

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

A similar relationship exists between the height of the image, h_i, and the height of the object, h_o. Use this relationship to solve for the height of an image,

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

We can also determine the magnification of the image using the heights of the image and object as they relate to the focal length.

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

SUMMARY

Convex lens (converging lens)

- A convex lens is **always** thicker in the center than at the edges.
- Light traveling through the lens goes slower through the thick center and faster through the thin ends causing the rays to focus or converge.
- The focal length of a convex lens is always positive.
- Real images are produced when the object is outside of the focus.
- No image is produced when the object is at the focus.
- Virtual images are produced when the object is within the focus.

Concave lens (diverging lens)

- A concave lens is **always** thinner in the middle than at the edges.
- Light traveling through a concave lens goes faster through the center and slower through the ends. This causes the rays to diverge or not to focus.
- The focal length of a concave lens is always negative.
- Only virtual images are produced by a concave lens.

Focal Length

- f is positive for converging lenses (convex)
- f is negative for diverging lenses (concave)

Object Distance

- d_o is positive if the object is on the same side of the lens from which the light is incident
- d_o is negative if the object is on the opposite side of the lens from which the light is incident

Image Distance

- d_i is positive if the image is on the opposite side of the lens from which the light is incident; d_i is positive for a real image
- d_i is negative if the image is on the same side of the lens from which the light is incident; d_i is negative for a virtual image

Object Height

- h_o is always positive

Image Height

- h_i is positive if the image is upright
- h_i is negative if the image is inverted

PURPOSE

In this exercise you will learn two methods for locating the image of an object placed in front of a lens. You will also be able to determine whether the image is real or virtual, upright or inverted, and enlarged or reduced.

MATERIALS

metric ruler
black ink pen
colored pencils or fine-tip markers
calculator

PROCEDURE

Use your own paper as your teacher guides you through the following examples. Then, complete the conclusion questions on your student answer page.

EXAMPLES

For each example, draw a ray diagram and describe the image. Your description should include the distance the image is in front of or behind the lens, whether it is real or virtual, reduced or enlarged and whether it is upright or inverted. Use your metric ruler to draw your diagrams to scale.

1. A 1-cm tall object stands 8.5 cm in front of a 4-cm focal distance converging (convex) lens.
2. A 1.5-cm tall object stands 4 cm in front of a 2-cm focal distance converging (convex) lens.
3. A 2-cm tall object stands 2 cm in front of a 5-cm focal distance converging (convex) lens.
4. A 2-cm tall object stands 5 cm in front of an 8-cm focal distance diverging (concave) lens.

Name ________________________________

Period ________________________________

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CONCLUSION QUESTIONS

For each of the following problems, use your own paper to draw an accurate ray diagram to locate the image formed by the given object. Use your metric ruler to keep you drawings to scale. Write a statement describing the image. Tell whether the image is real or virtual and give the image's location (distance in front of or behind the lens), orientation (upright or inverted) and magnification (reduced, enlarged or the same size). Confirm the accuracy of your drawings by solving for the unknowns algebraically.

1. A 2.0-cm tall object stands 10. cm in front of a 5.0-cm focal distance converging lens.

2. A 2.0-cm tall object stands 5.0 cm in front of a 5.0-cm focal distance converging lens.

3. A 2.0-cm tall object stands 5.0 cm in front of a 10.-cm focal distance converging lens.

4. A 1.5-cm tall object stands 15. cm in front of a 10.-cm focal distance diverging lens.

5. A 2.0-cm tall object stands 2.5 cm in front of a 5.0-cm focal distance diverging lens.