Experiment 18: Mirrors and Lenses

OBJECTIVE

The branch of physics that describes the behavior and properties of light and its interactions with matter is known as **optics**. In particular, **geometrical optics** predicts the path of light after it goes through a lens or hits a mirror. In this experiment, the topic of study will be concave (converging) and convex (diverging) mirrors as well as converging (biconvex) and diverging (biconcave) lenses and the different ways they bend light from an object. The objectives of this experiment are as follows:

1. To study the imaging properties of mirrors and lenses.
2. To measure the image distances and heights produced by various mirrors and lenses.
3. To calculate focal lengths and magnifications of mirrors and lenses in various cases

THEORY

Spherical mirrors (as well as lenses) are shaped out of spherical solids with desired optical properties, and various radii of curvature (R). Spherical mirror has a single curvature radius R that is considered as positive for the concave mirror and as negative for the convex mirror. Lenses have two different curvature radii at both sides.

The **principal axis** is a horizontal line drawn perpendicular to the mirror or lens through its center (see Fig. 1). Light rays going close to the principal axis are called **paraxial** rays. Paraxial light rays going from infinity (or from a distant object) parallel to the principal axis converge in the focal point F upon reflection from the concave mirror or upon crossing a converging lens. For a convex mirror or diverging lens, rays upon reflection or crossing diverge, and their continuations are crossing in the focal point. For spherical mirrors, the focal distance f is half of the curvature radius, $f = R/2$. For lenses, focal distance depends on the curvature radius and the refraction index of the glass and is given by the lensmaker's formula (see the book).

If the object is placed further from the concave spherical mirror than the focal length, $d_o > f$, the image is real and upside-down (see Fig. 1). In this case the image distance is defined as positive, $d_i > 0$. This is the basic case. If the object is closer to the mirror than the focal distance, $d_o < f$, the image is upright and virtual, behind the mirror. In this case, $d_i < 0$.

For converging lenses, the basic case is that of $d_o > f$, in this case the image is on the other side of the lens, $d_i > 0$, real and upside-down. For $d_o < f$, the image is upright and virtual, on the same side of the lens, $d_i < 0$.

For convex spherical mirrors and diverging lenses, $f < 0$ and the image is always virtual, $d_i < 0$.

Both for spherical mirrors and for lenses, the mirror-lens equations

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

holds. The ratio of the heights of the image and object is magnification defined as

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

The height of the upside-down image is considered as negative. Thus in the basic case (real images) one has $m < 0$. For virtual images one has $m > 0$.

APPARATUS

This is a virtual experiment performed with the help of four SWF applets that can be downloaded:

- Concave mirror:

http://www.siegelsoft.com/hoeling/ReflectionMirrors/concave_mirror.swf

- Convex mirror:

http://www.siegelsoft.com/hoeling/ReflectionMirrors/convex_mirror.swf

- Converging lens:

http://www.siegelsoft.com/hoeling/RefractionLenses_4/principle_ray_diagram.swf

- Diverging lens:

http://www.siegelsoft.com/hoeling/RefractionLenses_4/principle_ray_diagram_concave.swf

and run on a Windows or Mac computers with the help of a standalone SWF player that can be downloaded from the internet. Also, on Windows computers, SWF files can be played online with Microsoft Internet Explorer 11. Since SWF is a rudimentary format, it is not supported by more up-to-date browsers and computers issue warnings at downloading that should be ignored. SWF files are compatible with Blackboard and they will be uploaded there by instructors.

PROCEDURE

Run the applets and move the object by its top with the mouse to the right and to the left, changing d_o and d_i, as well as the type of the image (real, virtual), as shown in the Figures below. Measure the distances, as well as the object and image heights, by a plastic ruler on the screen. Alternatively, you can use Screen ruler from https://sourceforge.net/projects/screenruler/ that works at least on Windows.

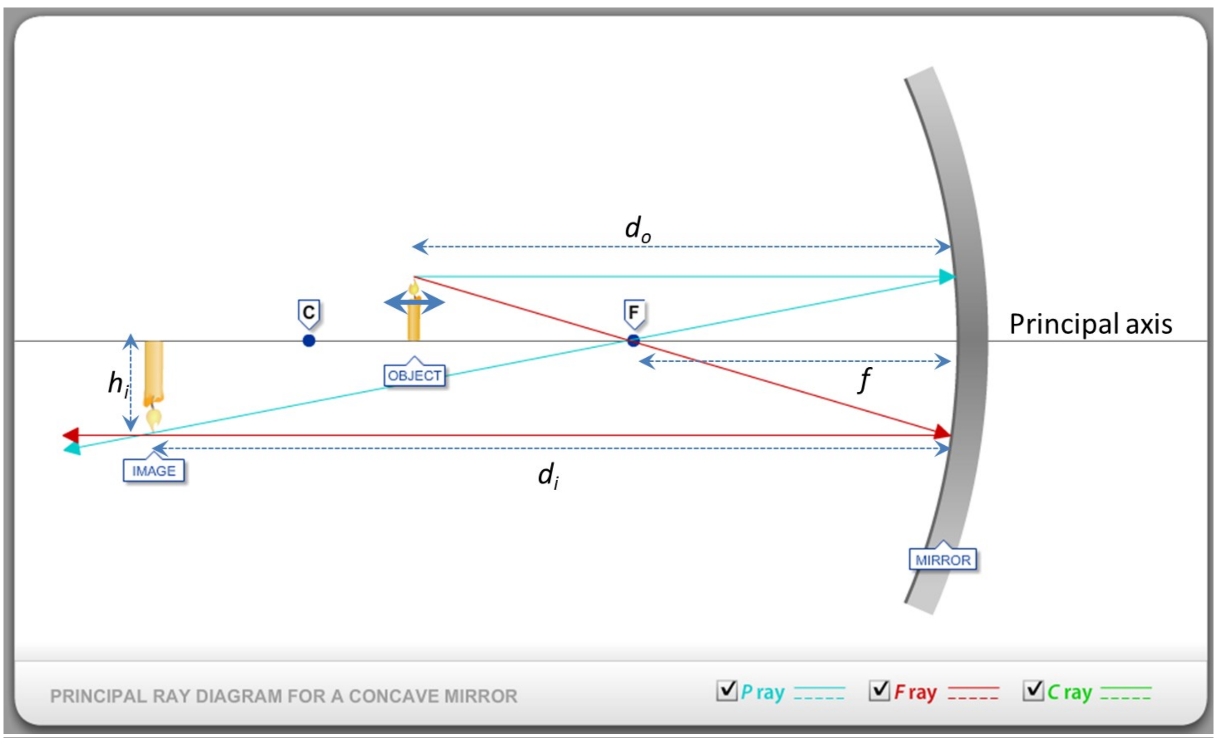

Figure 1: Applet "Concave mirror". Real image.

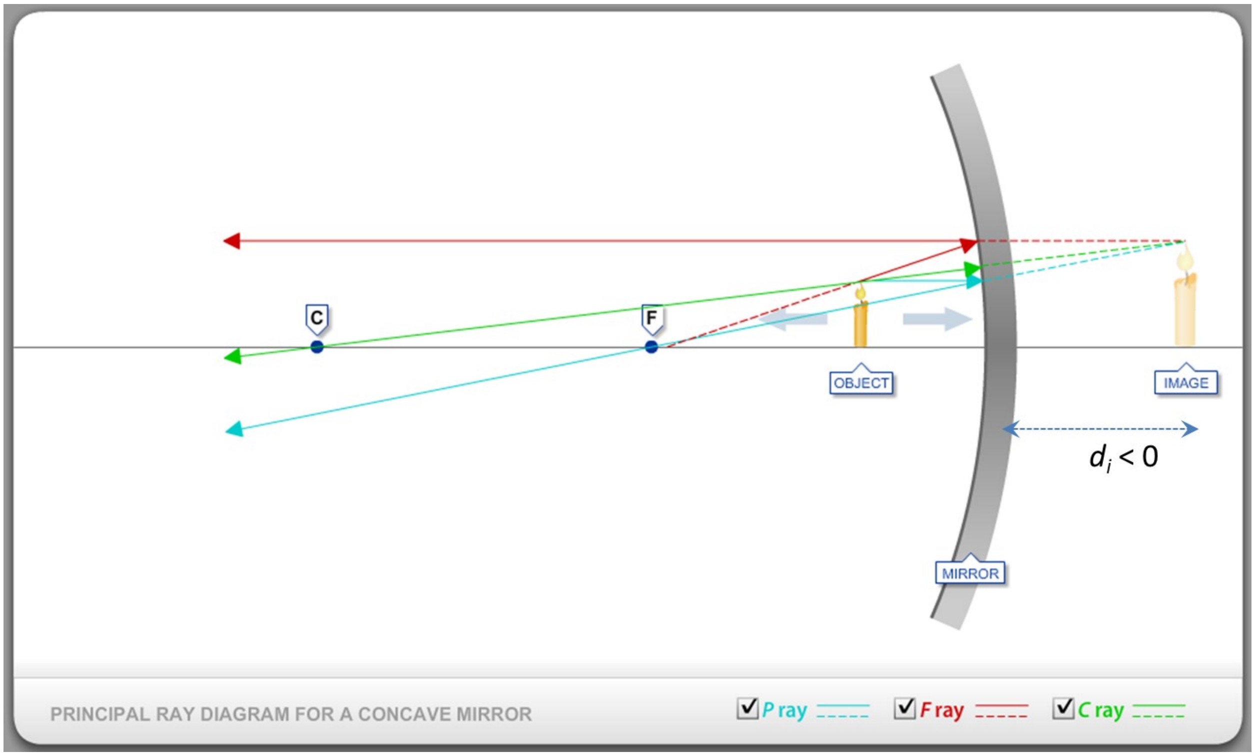

Figure 2: Applet "Concave mirror". Virtual image.

Perform experiments using four applets for the systems listed below, using indicated recommended settings

PART A: CONCAVE MIRROR

i. $1.5f < d_o < 2f$

ii. $2f < d_o$

iii. $d_o < ½ f$

PART B: CONVEX MIRROR

i. $d_o = ½ |f|$

ii. $d_o = |f|$

PART C: CONVERGING LENS

i. $d_o = f$

ii. $f < d_o < 2f$

iii. $f > d_o$

PART D: DIVERGING LENS

i. $d_o > |f|$

ii. $d_o < |f|$

In each case, calculate the focal distance using the formula

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

that follows from the mirror-lens equation above and calculate the magnification using the definition for the magnification above.

DATA

PART A	d_o (cm)	d_i (cm)	h_o (cm)	h_i (cm)	f (cm)	$m=h_i/h_o$	$-d_i/d_o$	$\bar{f}$ (cm)	% Err
i									
ii									
iii									
PART B	d_o (cm)	d_i (cm)	h_o (cm)	h_i (cm)	f (cm)	$m=h_i/h_o$		$\bar{f}$ (cm)	
i									
ii									
PART C	d_o (cm)	d_i (cm)	h_o (cm)	h_i (cm)	f (cm)	$m=h_i/h_o$		$\bar{f}$ (cm)	
i									
ii									
iii									
PART D	d_o (cm)	d_i (cm)	h_o (cm)	h_i (cm)	f (cm)	$m=h_i/h_o$		$\bar{f}$ (cm)	
i									
ii									

ANALYSIS

1) Complete the data table by calculating the focal lengths, ***f* (cm)**, as well as $m=h_i/h_o$ and $-d_i/d_o$. For the latter two quantities, you should obtain approximately the same value, according to the formula above. You must show your work for Parts A & C and magnification, ***m*,** from your experimental data.
2) Calculate the experimental average (mean), $\bar{f}$ **(cm)** for each part of the experiment and then calculate the respective **errors** for each case as a % deviation from the average value.
3) For each of the Parts A-D, state what position(s) of the object leads to the formation of a virtual image (i.e. located behind the mirror or the same side of the lens as the object, which is also the left side of the mirror/lens for all of the simulations we are using).
4) Are the images magnified or diminished for all of the virtual cases stated in your answer to the previous question?
5) Observe what happens when you move the object further and further away from the converging lens and the concave mirror. Where does the image move towards?
6) State what kind of lens or mirror is used, with the respective positions (relative to the focal point) of the object and the image, for each of the following cases:
   a) A dentist's mirror
   b) Rearview mirror of a car
   c) A document magnifier
   d) A lens to project film onto a screen
   e) A focused solar beam for burning ants (or just scorching paper)