Geometric Optics
Activity A: Signing in

(1) Before starting this experiment you must sign in. All students working with this piece of apparatus MUST enter their names in the boxes on this page.

![Sign-in sheet with boxes for first and last names for student #1, student #2, and student #3.

(2) IMPORTANT: If you want to clear data from a graph (for example, to redo a measurement) DO NOT use the command under the "EXPERIMENT" menu... "DELETE ALL DATA RUNS". If you do you will lose all your data and you, and your partners will have to redo the ENTIRE experiment. Instead use the command "DELETE LAST DATA RUN" under the "EXPERIMENT" menu or, more safely, type "all-".
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An urgent request!

Today you will be using optical equipment, including lenses and mirrors. Please, only handle these objects by their edges.

Never touch the faces of the lenses and mirrors directly!

You will leave fingerprints, and future measurements will suffer.
Activity B: Convex and Concave Lenses

In this activity we will explore the difference between convex and concave lenses and observe their focal lengths.

When parallel light rays pass through a thin lens, they emerge either converging or diverging. The point where the converging rays (or their extensions) cross is the focal point of the lens. The focal length of the lens is the distance from the center of the lens to the focal point. If the rays diverge, the focal length is negative.

Apparatus Setup

1. Place the light source in ray-box mode on a white sheet of paper. Plug in the power cable, turn the wheel to select five parallel rays.
2. Shine the rays straight into the convex lens (Note: Place the flat edge of the lens on the white paper so that it stands stably.) Are the outgoing rays converging, diverging or parallel?
3. Shine the rays straight into the concave lens. Are the outgoing rays converging, diverging or parallel?
Activity C: Color Addition

In this activity we will discover the results of mixing red, green, and blue light in different combinations.

Addition of Colored Light

(1) Turn the wheel on the light source to select the red, green, and blue color bars. The colored rays should now be projected along the white paper.

(2) Place the convex lens near the ray box so it focuses the rays and causes them to cross. At the location where the three rays appear to come together, take another sheet of white paper and place it in the beam’s path. What color appears on the paper at this crossing point?

(3) Now block the green ray with a pencil. What color results from adding red and blue light?

(4) Now block the red ray with a pencil. What color results from adding green and blue light?

(5) Now block the blue ray with a pencil. What color results from adding red and green light?
Activity D: Snell’s Law

The purpose of this experiment is to determine the index of refraction of acrylic. For rays entering the lens, you will measure the angles of incidence and refraction and use Snell’s Law to calculate the index of refraction.

For light crossing the boundary between two transparent materials, Snell’s Law states

\[ n_1 \sin(\theta_1) = n_2 \sin(\theta_2) \]

where \( \theta_1 \) is the angle of incidence, \( \theta_2 \) is the angle of refraction, and \( n_1 \) and \( n_2 \) are the respective indices of refraction of the materials.

The Index of Refraction

1. Place the light source in ray-box mode. Turn the wheel to select a single ray.
2. Place the ray table close to the ray-box and place the D-shaped lens over the lens outline on the optics table. Notice that you can change the angles of incidence by rotating the upper half of the optics table while the non-skid feet keep the base firmly in place.
3. Position the light source such that the ray crosses the center of the optics table; rotate the optics table to place one of the “*” marks on the incident ray, such that the ray is directly incident on the flat surface of the lens.
4. Rotate the optics table to have a non-zero angle of incidence. Measure the angle of incidence and the angle of refraction on the ray table. Record the angles in the first row of the table on the right.
5. Repeat steps (3)-(4) with a different angle of incidence. Repeat these steps again with a third angle of incidence. The first two columns of the table should now be filled.
6. For each row of the table on the right, use Snell’s Law to calculate the index of refraction, assuming the index of refraction of air is 1.0.
Total Internal Reflection

In this experiment, we will determine the critical angle at which total internal reflection occurs in the D-shaped lens and confirm your result using Snell's Law. We will study a ray as it passes out of the D-shaped lens, from acrylic to air ($n_{air} = 1$).

If the incident angle ($\theta_1$) is greater than the critical angle ($\theta_c$), there is no refracted ray and total internal reflection occurs. If $\theta_1 = \theta_c$, the angle of the refracted ray ($\theta_2$) is 90°, as in the figure below.

In this case, Snell's Law states:

$$n \sin (\theta_c) = 1 \sin (90°)$$

Solving for the sine of critical angle gives:

$$n = \frac{1}{\sin (\theta_c)}$$

(1) Position the light source such that the ray crosses the center of the optics table; rotate the optics table to place one of the 0° marks on the incident ray, such that the ray is incident to the cylinder surface of the lens.

(2) Rotate the optics table until the refracted ray just disappears. Now the incident angle is the critical angle of acrylic. Measure the critical angle and record the angle in the table on the right.

(3) Repeat steps (1)-(2), but this time, rotate the table in the opposite direction.

(4) Calculate the index of refraction of acrylic for each angle, and record the average of the two values. Compare the average to your previous measurement, and calculate the percent difference between the two methods.
Activity E: Focal Length and Magnification for the Convex Lens

In this activity we will determine the focal length of a thin lens and to measure the magnification for a certain combination of object and image distances.

For a thin lens:

\[ \frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \]

where \( f \) is focal length, \( d_o \) is the distance between the object and the lens, and \( d_i \) is the distance between the image and the lens. By measuring \( d_o \) and \( d_i \), the focal length can be determined.

Magnification, \( M \), is the ratio of image size to object size. If the image is inverted, \( M \) is negative.

**Focal Length for the Convex Lens**

1. Place the light source, the **200mm convex lens** and the screen on the optics bench with the lens in the middle and 30cm distance between the light source and the lens.

2. Starting with the screen close to the lens, slide the screen away from the lens to a position where a clear image of the crossed-arrow object is formed on the screen. Measure the image distance \( d_i \) and record the value of \( \frac{1}{d_i} \) in the appropriate row in the Table’s right-hand column.

3. Repeat steps (1) and (2) with light source-to-lens distances (object distances) of 35cm, 40cm, 45cm, 50cm, 55cm, 60cm, 65cm, and 70cm. For each light source-to-lens distance, find the screen position where clear image is formed.

4. Click “Fit”, select “Linear Fit”, record the y-intercept. 

5. Calculate the focal length for the convex lens from the y-intercept. Show your work.

6. Compare the experimental value to the true value (\( f = 20 \text{cm} \)) by calculating the percent difference.
Magnification for the Convex Lens

Magnification, $M$, is given by:

$$ M = \frac{\text{Image Distance}}{\text{Object Distance}} $$

Magnification is also the ratio of the image size to the object size. If the image is inverted, $M$ is negative.

$$ |M| = \frac{\text{Image Size}}{\text{Object Size}} $$

In this experiment, we will compare the absolute values of $M$ found using the two methods.

1. Place the light source, the convex lens and the screen on the optics bench with the lens in the middle and 30 cm distance between the light source and the lens.
2. Starting with the screen close to the lens, slide the screen away from the lens to a position where a clear image of the crossed-arrow object is formed on the screen. Is the image formed by the lens upright or inverted, real or virtual?
3. Measure the image distance and the object distance.
   - **Object Distance (cm):** 
   - **Image Distance (cm):** 
4. Using the Vernier calipers, measure the object size and the image size for this position of the lens.
   - **Object Size (cm):** 
   - **Image Size (cm):** 
5. Calculate the magnification, $M$, using the image distance and the object distance.
6. Calculate the magnification, $M$, using the image size and the object size.
7. Calculate the percent difference between the absolute values of $M$ found using the two methods.

Activity F: Focal Length and Magnification of a Concave Mirror

In this activity we will determine the focal length of a concave mirror and to measure the magnification for a certain combination of object and image distances.

For a spherically curved mirror:

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

where $f$ is focal length, $d_o$ is the distance between the object and the mirror, and $d_i$ is the distance between the image and the mirror. By measuring $d_o$ and $d_i$, the focal length can be determined.

Magnification, $M$, is the ratio of image size to object size. If the image is inverted, $M$ is negative.

**Focal Length for the Concave Mirror**

In this part, we will determine the focal length of the mirror by measuring several pairs of object and image distances and plotting $1/d_o$ versus $1/d_i$.

1. Place the light source and the mirror on the optics bench 50 cm apart with the light source's crossed-arrow object toward the mirror and the concave side of the mirror toward the light source. Place the half-screen between them.
Magnification for the Concave Mirror

1. With the mirror at 25cm from the light source and a clear image formed on the half-screen, measure the object distance and the image distance.

   Object Distance (cm): ___________  Image Distance (cm): ___________

2. Using the Vernier calipers, measure the object size and the image size. If less than half of the pattern is visible on the screen, have your partner slightly twist the mirror to bring more of the image into view.

   Measure the object size between the corresponding points directly on the light source.

   Object Size (cm): ___________  Image Size (cm): ___________

3. Calculate the magnification, M, using the image distance and the object distance.

   \[ M = \frac{\text{Image Distance}}{\text{Object Distance}} \]

4. Calculate the magnification, M, using the image size and the object size.

   \[ |M| = \frac{\text{Image Size}}{\text{Object Size}} \]

5. Calculate the percent difference between the absolute values of M found using the two methods.

   ___________ %
Activity G: Virtual Images

In this activity we will study virtual images formed by a diverging lens.

A virtual image cannot be viewed on a screen. It forms where the backwards extensions of diverging rays cross. We can see a virtual image by looking at it through a lens. Like all images, a virtual image formed by a lens can serve as the object of another lens.

**Virtual Image Formed by a Diverging Lens**

In this part, we will set up a diverging lens to form a virtual image. We will then use another lens to form a real image of the virtual image. In this way we can identify the location of the virtual image.

1. Place the -150mm lens on the optics bench at the 30cm mark.
2. Place the light source at the 10cm mark with the crossed-arrow object toward the lens.
3. Record the object distance \( d_o \) (the distance between the light source and the lens).
4. Look through the lens toward the light source. Describe the image. Is it upright or inverted? Does it appear to be larger or smaller than the object?
5. Which do you think is closer to the lens: the image or the object?
6. Place the +200mm lens on the bench anywhere between the 50cm and 80cm marks. Record the position here ________.
7. Place the viewing screen behind the positive lens. Slide the screen to a position where a clear image is formed on it. Record the position here ________.
8. Remove the negative lens from the bench. What happens to the image on the screen?
(9) Slide the light source to a new position so that a clear image is formed on the screen. (Do not move the positive lens or the screen.) Record the position of the light source here.

![Diagram of light source, lens, and screen with arrows indicating movement]

(10) The current position of the light source is identical to the previous position of the virtual image. What, then, was the virtual image distance \( d_v \) (the distance between the negative lens and the virtual image)? Remember that it is negative.

(11) Calculate the focal length of the diverging lens using the object distance from step (3) and the virtual image distance from step (10). Show your work:

(12) Compare the experimental value to the true value \((f = -150\text{mm})\) by calculating the percent difference.