Curved Mirrors and Images

INTRODUCTION

While we all feel familiar with the images we see in plane mirrors, our experiences with their curved counterparts might be limited to cosmetic mirrors or the side view mirrors on automobiles. In this experiment, you will explore the characteristics of the real and virtual images formed by curved mirrors. Then you will develop a mathematical relationship describing the relationship between the positions of the object and the real image formed by concave mirrors.

OBJECTIVES

In this experiment, you will

- Use curved mirrors to produce real and virtual images.
- Explore how the position of the object affects the appearance, orientation, and size of real images produced by concave mirrors.
- Explore how mirror characteristics and the position of the object affect the appearance, orientation, and size of virtual images produced by concave and convex mirrors.
- Determine the relationship between object distance, image distance, focal length, and magnification in real images produced by concave mirrors.

MATERIALS

Logger *Pro* or LabQuest App	Vernier Mirror Set
Vernier Dynamics System track	small plane mirror
Vernier Optics Expansion Kit	

PRE-LAB INVESTIGATION

1. Place the convex mirror at one end of the track. Position your eye at the other end of the track and examine the image of yourself. In what way does the image of yourself differ from that which you would see if you were looking into a plane mirror? How does the image change when you move the mirror closer to you?

2. Replace the convex mirror with the concave one and move it to the end of the track. As you did before, position your eye at the other end of the track and examine the image of yourself. In what ways does the image of yourself differ from that which you observed with the convex mirror? What happens to the image when you move your head slightly from side to side?

3. Gradually move the concave mirror closer to you. How does this affect the image you observe? What happens to the image when the mirror is approximately 20 cm from your eye?

In your class discussion, you will learn how the use of ray diagrams can help you to determine how and where light from a particular point on an object converges to form an image. You can get a conceptual understanding of the process of image-formation by a curved mirror using the simulation available at the Davidson University web site.[1]

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[1] webphysics.davidson.edu/course_material/py230L/optics/lenses.htm

PROCEDURE

Part 1 Concave mirror and real images

1. Set up the light source and concave mirror to project a clear image on the half screen.

   a. Attach the light source assembly from the Optics Expansion Kit to the Vernier track. Position it so that the pointer in the base is at the 10 cm mark and the light source faces the other end of the track.

   b. Place the concave mirror near the other end of the track so that it faces the light source. Attach the half screen to the track between the light source and the mirror.

   c. Turn the light source wheel until the number "4" is visible in the opening. This will be your "object" for this investigation.

   d. Adjust the position of the screen until the image of the "4" on the screen is in focus (see Figure 1). You may need to adjust the angle of the mirror in its holder so that the image projected by the mirror shows on the screen. One approach to obtain the sharpest image, once you think you have it, is to move the screen in either direction until the image begins to blur, then move it back until it again appears sharp.
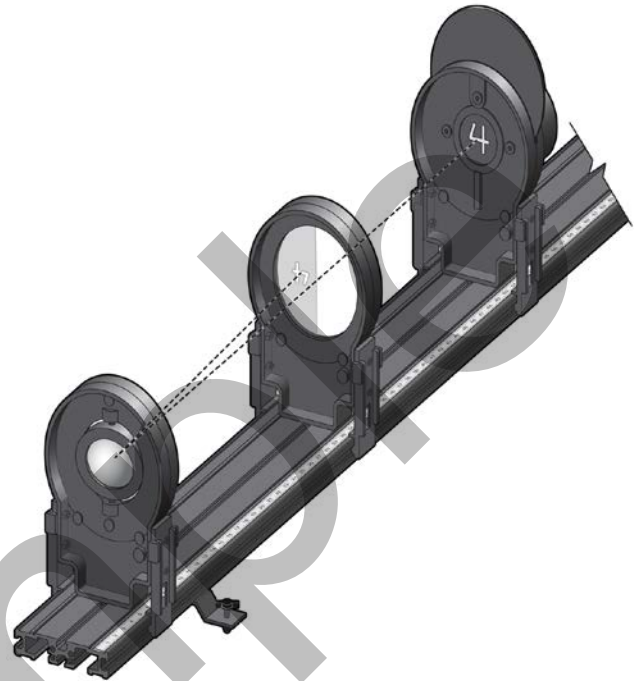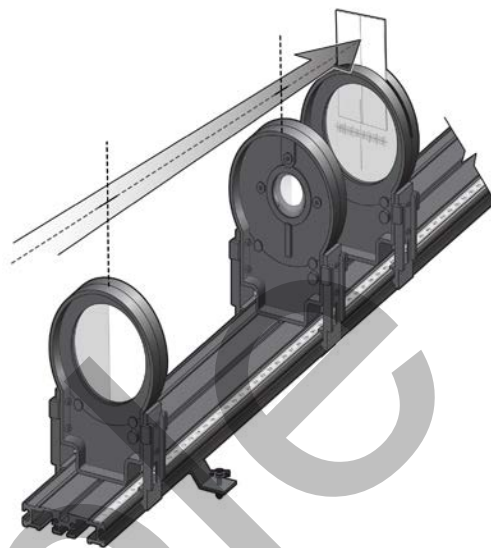
Figure 1

2. Describe the size, shape, and orientation of the image.

3. Now, move the mirror to the 100 cm mark, then move the screen toward the mirror until you can see a sharp image of the "4" on the half screen. Record the distance between the light source and the mirror as "object distance" and the distance between the mirror and the screen as "image distance" in your lab notebook.

4. Obtain object distance and image distance data for four more points, moving the mirror 10 cm closer each time. Note what happens to the size of the image as the object distance decreases.

5. Move the mirror to the 50 cm mark, leaving the light source at 10 cm. Note that you cannot obtain a sharp image on the screen. If you remove the screen and rotate the mirror slightly, you can observe a sharp image of the "4" on the light source assembly itself. Compare the size of the image to that of the object.

6. It is possible to obtain another data point for which the mirror is even closer to the light source. To do so, move the light source to the middle of the track and the mirror 30 cm away. Hold the screen off to the side *behind* the light source and rotate the mirror until you can observe the projected image on the screen. Make your best estimate of the image distance.

Part 2 Convex mirror and virtual images

Locating a virtual image is more difficult because it cannot be projected onto a screen, like a real image. The technique described below involves the use of parallax to determine the position of the virtual image.

1. Draw a vertical line on a 3″ × 5″ index card; place this card in the slot on the full viewing screen. This screen is your image position marker. Place the half screen (which serves as the object), convex mirror, and full screen on the track as shown in Figure 2.

2. Move the convex mirror to a position 40 to 50 cm from the half screen. Record this as the object distance. Stand at the end of the track near the half screen so that you can view both the virtual image of the half screen and the index card attached to the full screen.

3. Place the index card and screen serving as the position marker just behind the convex mirror. Position your head directly behind and above the half screen. As you look over the top of the half screen toward the mirror, you can view the half screen in the mirror. Move your head so that the line on marker and the edge of the half screen are aligned.

4. Move your head to the right of the half screen. Note that the edge of the screen in the image appears to the right of the line on the marker. When you move your head to the left of the half screen you should note that the edge in the image shifts to the left of the marker line. (See Figure 3.) This difference in relative positions is called parallax.

5. Move the marker 5 cm farther from the mirror. When you repeat Step 4, the parallax is reduced. Gradually move the marker farther from the mirror and check the alignment of the edge of the half screen and the line on the marker until there is no parallax. Record this distance as the distance of the virtual image. If you go beyond the no-parallax point, the image and the object will move in opposite directions.

Figure 2
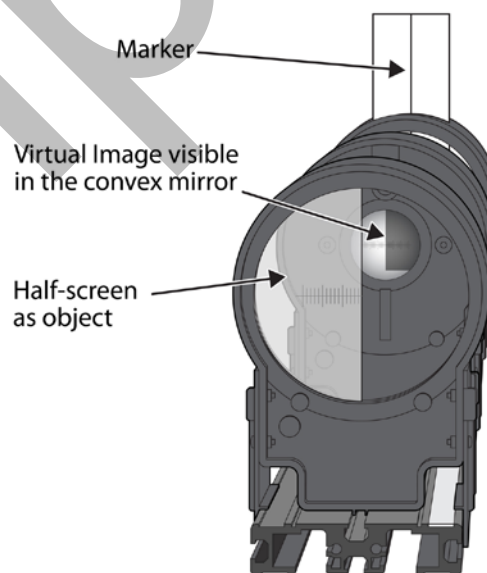
Figure 3

EVALUATION OF DATA

1. Choose New from the File menu in the data-collection program. In the table, manually enter your data for your measurement with the concave mirror. Enter **d-o** (for object distance) and **d-i** (for image distance) as the Names of the columns.

2. Examine your graph of image distance *vs.* object distance. What relationship appears to exist between these variables? Rather than performing a curve fit to the data, take steps to modify one of the variables so as to produce a linear graph.

   Using Logger *Pro*

   Choose New Calculated Column from the Data menu. After entering a name and units for the column, click the equation field, enter the expression to modify the variable you choose from the drop-down menu, then click Done. Change the variable on the axis you have chosen to modify to see the resulting graph.

   Using LabQuest App

   Choose New Calculated Column from the Table menu. After choosing a name and units for the column, select *A/X* as the Equation Type. Enter the column you wish to modify, then select OK. Tap the Graph tab and change the variable on the axis you have chosen to modify to see the resulting graph.

   You may find it necessary to modify the variables on *both* axes to linearize the graph. When you have done so, write the equation of the best-fit line.

3. Examine the value and the units of the slope. Discuss with your instructor what the ideal value of the slope might be.

4. Examine the value and units of the vertical intercept. In view of the modifications you made to the object distance and image distance in order to produce a linear graph, draw a conclusion about the physical significance of the intercept.

5. Write a general equation of your best-fit line in terms of d_i, d_o and f; rearrange the equation so that d_i and d_o are on the same side. Compare your results to the spherical mirror equation in your text or a web-based resource.

6. The magnification, m, of an image is the ratio of the image height, i, to the object height, o. Using similar triangles, one can show that it is also equal to the ratio of the image distance to the object distance.

$$m = \frac{i}{o} = -\frac{d_i}{d_o}$$

   Note: the negative sign is included as part of the convention to indicate that the real image is inverted.

   Find a configuration of the mirror and the screen that produces an image of the "4" used as the object that measures 10 mm across. Measure d_i and d_o and compare the agreement between the two ratios. Repeat this process for an image that is half as large. The "4" on the light source is 20 mm across.

7. In the sign convention used for spherical mirrors, both the focal length of a convex mirror and the image distance for a virtual image have negative values. The focal length of the convex mirror in the mirror set is –20 cm. Use the spherical mirror equation to calculate the expected distance for the virtual image. How does this compare to the value you obtained from your observations?

EXTENSIONS

1. Suppose you had used a 15 cm concave mirror in your experiment. Predict the slope and intercept of the graph of $1/d_i$ *vs.* $1/d_o$.

2. In what ways are the virtual images one can see with both convex and concave mirrors the same? How are they different?

3. Determine the virtual image distance for at least five more positions of the half screen serving as the object as you did in Part 2. Create a new Data Set in your Logger *Pro* or LabQuest App file and enter the values for the object and image distances. Insert a new graph and choose $1/d_i$ as the vertical axis label and $1/d_o$ as the horizontal axis label. Apply a linear fit as before and determine the agreement between your data and the spherical mirror equation.

Curved Mirrors and Images

In this lab, students first examine real and virtual images formed by concave and convex mirrors. Then they collect the data used to derive the spherical mirror equation, which has the same form as the thin lens equation. If you choose to have your students perform this experiment, you may wish to skip Experiment 16, because in it, students accomplish similar goals with lenses.

This lab is written with the assumption that the instructor will engage the students in discussions at critical junctures. These discussions can take place with the entire class or with individual lab groups. The icon at left indicates where these discussions should occur.

The Microsoft Word files for the student pages can be found on the CD that accompanies this book. See *Appendix A* for more information.

OBJECTIVES

In this experiment, the student objectives include

- Use curved mirrors to produce real and virtual images.
- Explore how the position of the object affects the appearance, orientation, and size of real images produced by concave mirrors.
- Explore how mirror characteristics and the position of the object affect the appearance, orientation, and size of virtual images produced by concave and convex mirrors.
- Determine the relationship between object distance, image distance, focal length, and magnification in real images produced by concave mirrors.

During this experiment, you will help the students

- Recognize that a real image is the result of the convergence of rays emitted from a point on an object. If a screen is placed at the plane of the real image, then many observers can see it.
- Recognize that a virtual image perceived by a viewer forms behind the mirror at the location from which the diverging rays reflected by the mirror appear to have originated.
- Recognize that the slope of the graph of $1/d_i$ *vs.* $1/d_o$ is ideally equal to -1 and that the intercept is the reciprocal of the focal length.

REQUIRED SKILLS

In order for students to succeed in this experiment, they must know how to

- Create calculated columns in the software so as to linearize a graph. Calculated columns are addressed in Activity 3 in *Advanced Physics with Vernier–Mechanics*. This activity can be found on the CD that accompanies this book.
- Perform linear fits to graphs. Linear fits and linearzing data are addressed in Activity 1 in *Advanced Physics with Vernier–Mechanics*. This activity can be found on the CD that accompanies this book.

EQUIPMENT TIPS

For this experiment, we recommend using the Optics Expansion Kit and the Mirror Set with the Vernier Dynamics System track. It is certainly possible for students to observe the formation of real images with mirrors and to collect the data that will enable them to derive the spherical mirror equation with other apparatus. There are several advantages to using the equipment in the Optics Expansion Kit and Mirror Set. The holders for the light source, mirrors, and screen snap onto the dynamics track so that these optical elements remain well aligned when they are moved; also, the fiducial marks in their bases enable one to readily locate their positions. The concave mirror can be rotated on its axis, allowing the projected image to be viewed when the mirror is close to the light source. The object distances specified in the procedure are predicated on the use of the 20 cm concave mirror in the kit. If you use another focal length you should make adjustments so as to ensure that students obtain data for object distances corresponding to *c* and between *c* and *f*.

PRE-LAB DISCUSSION

The Pre-Lab Investigation allows students to observe characteristics of the virtual and real images from curved mirrors. Students may, at first, think that the image from the convex mirror is no different from that observed in a plane mirror. If they do, have them place a small plane mirror on the track just below the convex mirror so they can simultaneously view their images in both mirrors. While both are upright, the image in the curved mirror is smaller and easier to center than that viewed in the plane mirror. The image in the curved mirror gets slightly larger as the mirror is moved closer to the observer. With the plane mirror, the situation is more complicated. The image may appear larger when the plane mirror is closer, but it fills the same fraction of the mirror regardless of the distance.

When the concave mirror is placed at the end of the track, students observe an inverted image of themselves. It is important for students to recognize that the image is not merely inverted, it is *real*; i.e., light rays emanating from each point on the object are reflected by the mirror and converge at a point in front of the mirror. If a screen were placed at this location, the image could seen by observers not directly in line with the center of the mirror.

This investigation sets the stage for the use of ray diagrams to determine the location and size of the image for both concave and convex mirrors. The java applet at the Davidson University web site[1] gives students the opportunity to explore how moving the position of the object relative to the mirror affects the image location and size. While not as elegant as the one that shows ray diagrams for images formed by lenses at the PhET web site, it is certainly helpful.
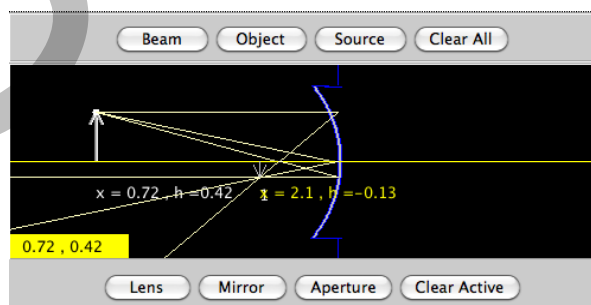

Figure 1 Java applet

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[1] webphysics.davidson.edu/course_material/py230L/optics/lenses.htm

LAB PERFORMANCE NOTES

The LED in the Light Source Assembly is bright enough that students should be able to determine when the image is in sharp focus if the ambient lighting is not too bright. However, it is helpful to dim the lights when the students investigate the magnification – the final step in the Evaluation of Data.

In Step 5, when the object is at $c = 2f$, the image may be observed on the front of the light source assembly if the screen is removed. To view the image when the object distance is between c and f (in Step 6), the mirror must be rotated slightly and the screen held close to the track and behind the light source.

For most, it is difficult at first to locate the virtual image formed by the convex mirror. Familiarize yourself with the procedure outlined in Part 2 so that you can assist students who find the no-parallax technique difficult to master.

SAMPLE RESULTS AND POST-LAB DISCUSSION

Steps 1 and 2

The plot of image distance *vs.* object distance appears to be a hyperbola but one that does not have the asymptotes at the coordinate axes (see Figure 2).
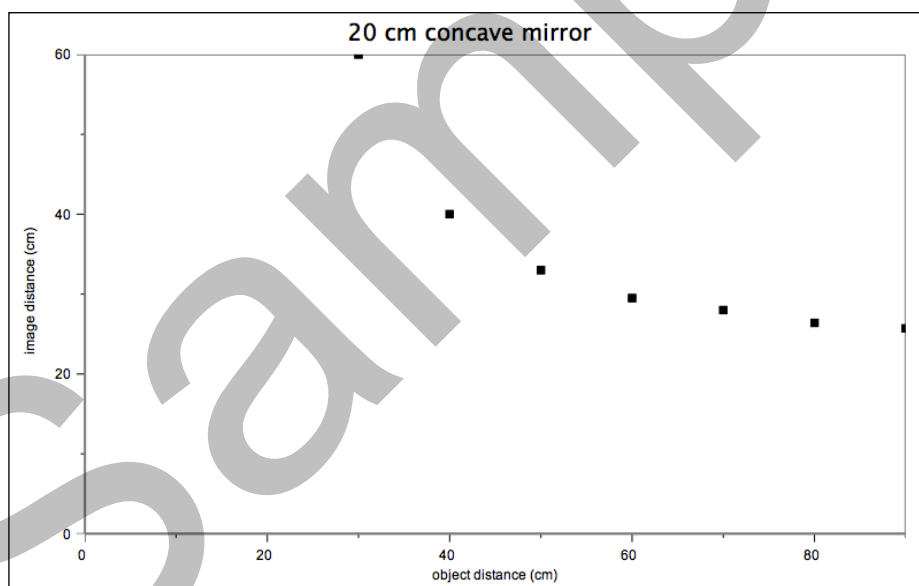

Figure 2

Students are likely to conclude that the image distance, d_i, is inversely proportional to the object distance, d_o. However, they will find that the standard technique of plotting d_i vs. $1/d_o$ does not produce a linear graph (see Figure 3).
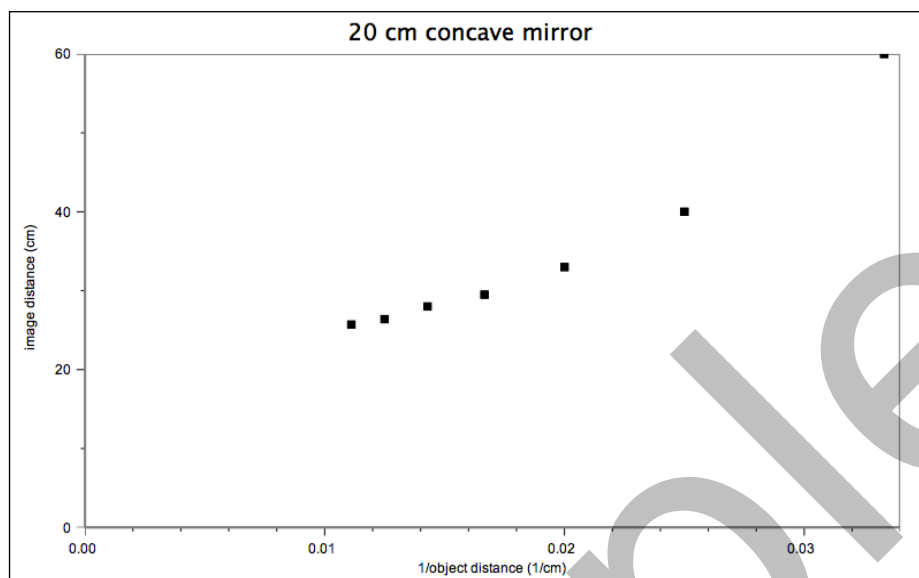

Figure 3

Inversion of the image distance is also required in order to obtain a linear graph (see Figure 4).
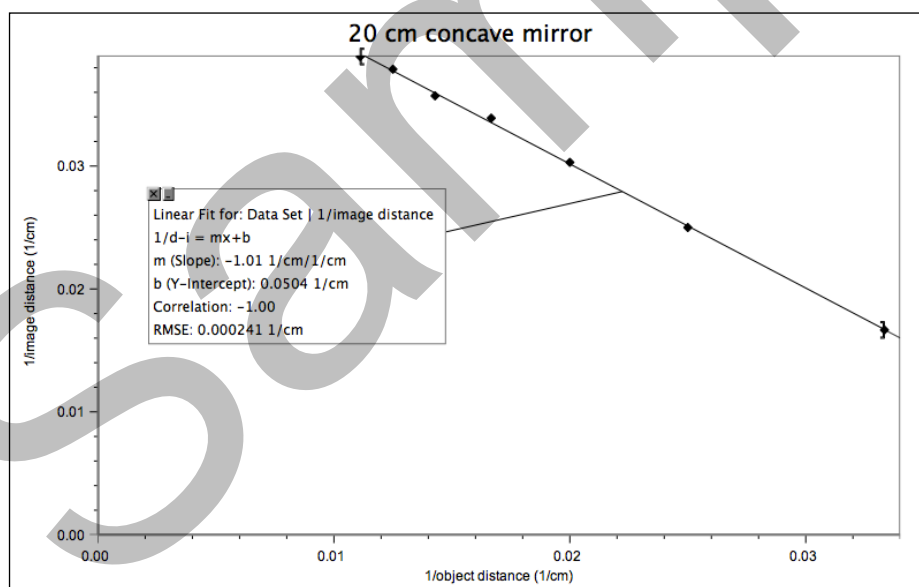

Figure 4 Linearized graph

For the graph shown above, the equation is $1/d_i = (-1.01)1/d_o + 0.0504 \ 1/\text{cm}$.

Steps 3 and 4

The units of the slope, 1/cm/1/cm, cancel completely. The value, in this case, –1.01, is very nearly –1. Students may need to be reminded that their experimental results are unlikely to be ideal. The vertical intercept has units of 1/cm. Given that the variables on the axes of the original graph were replaced by their reciprocals, it is not unreasonable for students to conclude that the reciprocal of the intercept is physically significant. In fact, the vertical intercept is $1/f$.

Step 5

Once students have reached the conclusion that the ideal value of the slope is –1, they should be able to express the general equation describing the relationship between the object and image distances as

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

When this equation is rearranged to get the two distance terms together, one obtains the spherical mirror equation, better known as the thin lens equation.

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

Step 6

Students could use the known values of 10 mm for the image size and 20 mm for the size of the object to find that d_o must be twice as great as d_i. By substituting $2d_i$ for d_o in the thin lens equation and solving for d_i, they could find that the image distance must be 30 cm and the object distance 60 cm. But it is much more fun for the students to obtain values of d_o and d_i empirically, then check their experimental value for m against the theoretical value of 0.50.

For an image of the "4" to measure 5.0 mm across, the magnification must be 0.25. The required image and object distances with this mirror are 25 cm and 100 cm respectively.

Step 7

For the –20 cm convex mirror, an object distance of 40 cm should produce an image distance of –13.3 cm.

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

$$\frac{1}{d_i} = -\frac{1}{20\ \text{cm}} - \frac{1}{40\ \text{cm}}$$

$$\frac{1}{d_i} = -\frac{3}{40\ \text{cm}}$$

$$d_i = -13.3\ \text{cm}$$

Student answers will vary depending on their ability to ascertain the no-parallax point, but they should be able to place the marker within 0.5 cm of this distance.

EXTENSIONS

1. The ideal slope of the graph of $1/d_i$ *vs.* $1/d_o$ is –1. Based on the experimental results, students should expect an experimental value within 3% of this figure. The intercept should be the reciprocal of the focal length. In this case, a value of 0.17 1/cm could be expected.

2. The virtual images from convex and concave mirrors are both upright and appear to form behind the mirror. The virtual image from a convex mirror is always reduced in size, whereas the one from a concave mirror is enlarged.

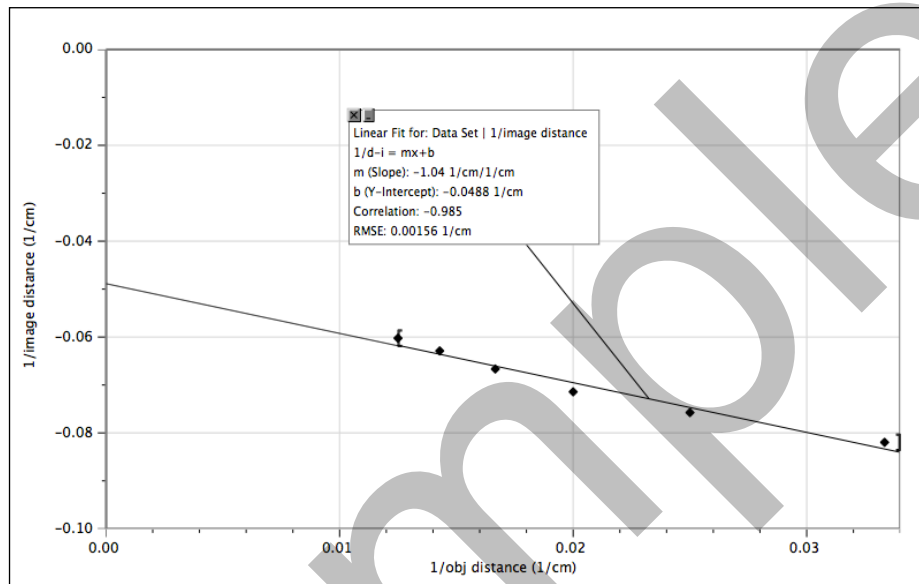3. A plot of $1/d_i$ *vs.* $1/d_o$ for the convex mirror is shown in Figure 5.

Figure 5

Student results may vary depending on their ability to judge the no-parallax point to locate the virtual image. The slope of the graph is nearly –1 and the reciprocal of the intercept is within 3% of the focal length.