Name: ________________________________ Book: ___ Period: ___ Due Date: _________
Lab Partners: ____
Mirror Labels: ________A and ________B

CONCAVE AND CONVEX MIRRORS

Purpose: Your goals are to learn several methods of estimating the focal length of a spherical mirror; to develop your skills in using the mirror equations; to analyze the properties of several mirrors; to observe the real images projected by concave spherical mirrors; to see how the image position responds to changes in the object position. You will complete three written assignments that expect you to think about what you see and explain it.

Theory: Spherical mirrors may be concave or convex. Concave mirrors have the focal point in front of the mirror, and convex mirrors have the focal point behind the mirror. **F** is the symbol for the focal point. The focal length or focal distance is f. The object distance, d_o, and the image distance, d_i, can be used to estimate the focal length, f, and the radius, **R**. ***Equation I*** is known as the **Thin Lens Equation**, or the **Mirror Equation**. In this equation, the symbols d_o and d_i represent the distances from the mirror to the ***o***bject and to the ***i***mage, respectively

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$ ***Equation I***

For Mirrors:

In this lab d_i and d_o are measured values. R and f are calculated using the measured values of d_i and d_o.

By convention, the focal length, f, is **positive** for concave mirrors but **negative** for convex mirrors.

By convention the object distance, d_o, is **always positive**.

By convention, the image distance, d_i, is **positive** for real images but **negative** for virtual images.

By convention, the object height, h_o, is **always positive**.

By convention, the height of the image, h_i, is **positive** for upright images but **negative** for inverted images.

For geometric reasons, the radius of curvature, **R**, the distance from the mirror to the center, **C**, is twice the focal length, i.e. (*This relationship between* **R** *and* f *is known as the* **Mirror-Makers' Equation**.)

$$R \approx 2f$$ ***Equation II***

The magnification can be estimated from the **Magnification Equation**:

$$M = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$ ***Equation III***

The magnification is
positive for upright (virtual) images
negative for inverted (real) images.

(Important Reminders: The object distance, d_o, and the object height, h_o, are always positive.

For real images, the image distance, d_i, is always positive, and the image height, h_i, is always negative.

For virtual images, the image distance, d_i, is always negative, and the image height, h_i, is always positive.**)**

Equation I can be rearranged several different ways. In this lab you will conduct a graphical investigation of one such rearrangement of the **Thin Lens Equation**. Re-write ***Equation I*** according to the following steps. Later, you will create graphs based on the final rearranged form of ***Equation I***. You will also consider how well this graphical method works compared with other methods.

In the blank space to the right, write the form of the equation resulting from the instructions in that step.

a) Re-write ***Equation I*** from right to left so the $1/f$ term is alone on the left. ______________________________

b) Multiply all numerators of the equation by d_i. ______________________________

c) Let $d_i / d_i = 1$, enclose the right side in parentheses. ______________________________

d) Multiply both sides of the equation by f. ______________________________

e) A graph of d_i vs. $1+(d_i / d_o)$ should plot as a straight line through the origin (y=Ax) with a slope of f, if you have done all the steps correctly. Make sure your equation has the correct form before you continue. For the real images projected by the concave mirrors in this lab, d_i and d_o are both positive. Therefore, all your data points will be in the first quadrant. You must show the origin on the printed version of all graphs created in this lab.

CONCAVE MIRRORS

Part One: Point focus estimates of the focal length and radius for two concave mirrors.

Procedure. A Quick and Simple (*and modestly accurate*) Method of Estimating the Focal Length:

1. Use a very distant light source as the object. (*We will use a light bulb in the back of the lab; approx 15 m away*.)
2. Place the mirror at the zero-end of a ruler; aim the mirror and ruler directly at the light bulb.
3. Use a small screen to locate the point-focus image. The distance from the mirror to this image provides you with your first estimate of f for each of the mirrors.
4. Then, estimate the radius of curvature, **R**, of each mirror using the **Mirror-Maker's Equation**?

Mirror#A (Mirror __A) d_i = _________ cm; d_o = _________ cm; f = ________ cm; $R = 2f$ = _________ cm

Mirror#B (Mirror __B) d_i = _________ cm; d_o = _________ cm; f = ________ cm; $R = 2f$ = _________ cm

Part Two: Procedure. **Identifying Projected Images formed by Concave Mirror#A**

1. Use a small candle (*object*), a small card (*screen*), a meter stick and Mirror#A. Use the card to locate the focused image (*of the flame*). Begin with the section labeled **at C** to locate the center. Measure the image distance for object distances greater than **R** before attempting the last section Midway Between **C** & **F**.
2. Record the image distance and orientation (Virtual or Real? / Upright or Inverted?). Calculate the magnification.
3. Move the candle to the object distances in the table. Use the Thin Lens Equation to calculate f. Then find **M**.

Mirror#A (Mirror Label = _____A)

Use your measured image, d_i, and object, d_o, distances and the Thin Lens Equation to solve for the focal length in each row of the table below. Measurements and calculations must be made carefully.

d_o (Object Distance)	d_i (Image Distance)	*Circle one from each pair* (Real or Virtual) (Upright or Inverted)	Magnification $M = -d_i / d_o$	f (focal length)
at C. Move the candle to your best estimate of the radius. Adjust the candle and screen positions until a well-focused screen image is at the same position as the candle. The condition that $d_i = d_o = R$ is now satisfied. After locating **C** by this trial and error method, calculate the focal length using the result that, at **C**, $f = R/2$. **R** = (distance to **C**) = __________ cm				
________ cm	_________cm	(Real or Virtual) (Upright or Inverted)	_______	_________cm
Pick a precise location for the object distance on the centimeter mark nearest to the Radius + the specified distance.				
_______ ˜ R+60 cm	_________cm	(Real or Virtual) (Upright or Inverted)	_______	_________cm
_______ ˜ R+40 cm	_________cm	(Real or Virtual) (Upright or Inverted)	_______	_________cm
_______ ˜ R+25 cm	_________cm	(Real or Virtual) (Upright or Inverted)	_______	_________cm
_______ ˜ R+20 cm	_________cm	(Real or Virtual) (Upright or Inverted)	_______	_________cm
_______ ˜ R+15 cm	_________cm	(Real or Virtual) (Upright or Inverted)	_______	_________cm
_______ ˜ R+10 cm	_________cm	(Real or Virtual) (Upright or Inverted)	_______	_________cm
_______ ˜ R+ 5 cm	_________cm	(Real or Virtual) (Upright or Inverted)	_______	_________cm
Midway between C & F. Move the candle until it is near the midway point between **C** and **F.** Adjust the candle and find the well-focused screen position until the image distance is exactly twice the candle distance. The condition that $d_i = 2\,d_o$ is now satisfied. Calculate the magnification and focal length.				
________ cm	_________cm	(Real or Virtual) (Upright or Inverted)	_______	_________cm

Average of all 9 values of f = _________cm

Create Graph I: Use the data from Mirror#A, including **at C** and **Midway between C&F**. Create a Graph of d_i vs.$1+(d_i/d_o)$. (*On the graph plot* d_i *on the vertical axis and* $[1+(d_i/d_o)]$ *on the horizontal axis.*) Scale both axes from zero to show the origin. Fit the data to a **straight line through the origin (y = Ax)**.

The slope = f = ____________ cm

Part Three: Procedure. Identifying Projected Images formed by Concave Mirror#B

1. Use a small candle (*object*), a small card (*image finder*), a meter stick and Mirror#B. Use the card to locate the focused image (*of the flame*). Begin with the section labeled **at C** to locate the center. Measure the image distance for object distances greater than **R** before attempting the last section Midway Between **C** & **F**.
2. Record the image distance and orientation (Virtual or Real? / Upright or Inverted?). Calculate the magnification.
3. Move the candle to the object distances in the table. Use the Thin Lens Equation to calculate f. Then find **M**.

Mirror#B (Mirror Label = _____B)

d_o (Object Distance)	d_i (Image Distance)	*Circle one from each pair* (Real or Virtual) (Upright or Inverted)	Magnification $M = -d_i / d_o$	f (focal length)
at C. Move the candle to your best estimate of the radius. Adjust the candle and screen positions until a well-focused screen image is at the same position as the candle. The condition that $d_i = d_o = R$ is now satisfied. After locating **C** by trial and error, find the magnification and focal length using the fact that, at **C**, f = **R/2.** **R** = (distance to **C**) = __________ cm				
________ cm	_________cm	(Real or Virtual) (Upright or Inverted)	_______	_________cm
Pick a precise location for the object distance on the centimeter mark nearest to the Radius + the specified distance.				
_______ ˜ R+60 cm	_________cm	(Real or Virtual) (Upright or Inverted)	_______	_________cm
_______ ˜ R+40 cm	_________cm	(Real or Virtual) (Upright or Inverted)	_______	_________cm
_______ ˜ R+25 cm	_________cm	(Real or Virtual) (Upright or Inverted)	_______	_________cm
_______ ˜ R+20 cm	_________cm	(Real or Virtual) (Upright or Inverted)	_______	_________cm
_______ ˜ R+15 cm	_________cm	(Real or Virtual) (Upright or Inverted)	_______	_________cm
_______ ˜ R+10 cm	_________cm	(Real or Virtual) (Upright or Inverted)	_______	_________cm
_______ ˜ R+ 5 cm	_________cm	(Real or Virtual) (Upright or Inverted)	_______	_________cm
Midway between C & F. Move the candle until it is near the midway point between **C** and **F.** Adjust the candle and find the well-focused screen position until the image distance is exactly twice the candle distance. The condition that $d_i = 2\ d_o$ is now satisfied**.** Calculate the magnification and focal length.				
________ cm	_________cm	(Real or Virtual) (Upright or Inverted)	_______	_________cm

Average of all 9 values of f = _________cm

Create Graph II: Use the data from Mirror#B, including **at C** and **Midway between C&F**. Create a Graph of d_i vs.1+(d_i / d_o). (*On the graph plot* d_i *on the vertical axis and* [*1+* (d_i / d_o)] *on the horizontal axis.*) Scale both axes from zero to show the origin. Fit the data to a **straight line through the origin (y = Ax)**.

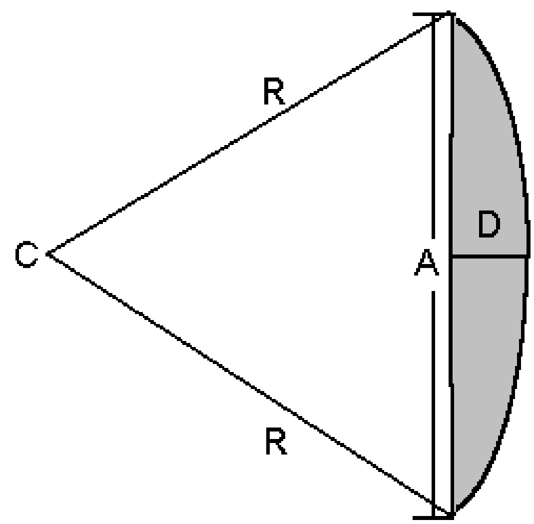
The slope = f = ____________ cm

Part Four: Large Convex Mirror

Procedure.

It is impossible to find the radius of curvature of a convex mirror optically. Convex mirrors generate only virtual images that cannot be cast on a screen. It is necessary to measure the shape of the mirror itself rather than the distance to the images it creates. To estimate the radius of a section from a sphere, measure the chord length (A), and the depth of curvature of the mirror (D). The radius of curvature, **R**, equals the distance from any point on the mirror to the center, **C**. As long as A and D are measured in the same units, **R** can be estimated in those same units using the **Spherometer Equation**:

$$\mathbf{R} = (A^2 + 4D^2) / 8D \qquad \{\text{Note: } (cm^2+cm^2)/cm = cm\}$$



A = +___________ cm; D = −___________ cm; **R** = −___________ cm; Convex Mirror f = −___________ cm.

Part Five: Large Concave Mirror (Possibly the same radius as the large convex mirror.)

Procedure.

Because convex mirrors only produce virtual images, we cannot project the images they produce onto screens, as we did for the concave mirrors in Part One. There are some tricks we can use to get around that limitation. One old trick is to silver both sides of the mirror. Provided the glass has a uniform thickness, the concave side can be used to measure the focal length (*and radius of curvature*) of both sides of the glass.

We don't have such a double-sided mirror, however, we do have two large mirrors with nearly identical radii of curvature. While the concave might not be identical to the convex mirror, inspection suggests that it should be close enough to give us at least a rough estimate of the convex mirror's true focal length.

First, use the point-focus procedure from Part One to estimate the focal length of the large concave mirror.

Concave Mirror f = +__________ cm

Then, for comparison, repeat the measurements from Part Four on this concave mirror. We do this to see if the optically measured focal distance and geometrically estimated focal distance agree. You should start asking questions like: Do both methods agree? Which method works best? (See the Analysis section AIII for more ideas.)

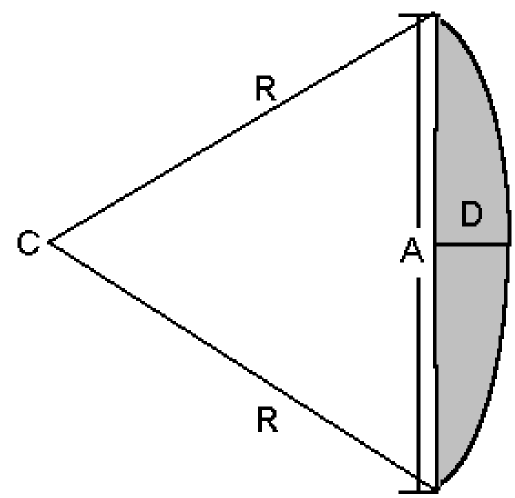
A = +___________ cm; D = +___________ cm; **R** = +___________ cm; f = +___________ cm.

Analysis:

AI. Complete the table below. Each column (a through h) is a separate problem for a different mirror. Use the mirror equations to solve for the blank spaces. Be sure to fill-in plus & minus signs wherever an underline, _, indicates a sign is missing. Show the signs (both + and –) for all your results, too. Possible mirror types include concave, convex and flat mirrors. (***Note to instructor: The given values in this table change every year.***)

	a	**b**	c	d	**e**	f	g	**h**
Type	Concave						Convex	
f (cm)	_40		+40			_40		
R (cm)					–50		_60	
d_i (cm)					–12.5		_6	
d_o (cm)	+30	+20	+60	+80				+25
M		+1		–0.5		+0.10		_0.20
Real Image?		no		yes				
Upright Image?								no

AII. Derive the **Spherometer Equation** used to estimate the radius of curvature, **R**, of the large spherical mirrors in Parts Four and Five. (*Start with a famous geometry theorem and complete your derivation in about five simple steps.*)



AIII. Compare the calculated radii of the large concave and convex mirrors examined in Parts Four and Five.

a. Do the optically measured and geometrically estimated radii of the concave mirror agree? ***YES / NO.***
(How close should they be to be considered as agreeing with each other? Considering the differences in the methods, what is the best we could hope for?)

b. Do the geometrically estimated radii of these two mirrors agree? ***YES / NO.***
(Are they from the same sphere?)

c. Does the **Spherometer Equation** correctly estimate the radius of the spherical convex mirror? ***YES / NO.***

d. Which method, optical vs geometric gives the most accurate estimate of the radius?

Optical : Geometric Why?

The following written assignments will each receive a separate grade. These grades will be recorded as quiz grades. Do not skip any of these assignments. Any skipped assignments will count as zero. These are personal writing assignments and you may not copy or borrow from anyone else's work on these assignments. Plagiarized writing assignments will result in zeros both parties. Do not let anyone use or borrow you written assignments.

Written Assignment #1. You have tested five methods of finding f:

In Part I you i) Estimated f using the point focus method;
In Parts II and III you ii) Estimated f as the average of many fs;
iii) Calculated f when both object and image were at **C**;
iv) Calculated f when the object was midway between **C** & **F**;
v) Obtained an estimate of f from the slope of the line in Graph I or Graph II.

On a separate sheet discuss the relative merits of these five methods of obtaining f for a single mirror and offer your opinion of which one or ones yield the most accurate estimate of f and why.

Written Assignment #2. On a separate sheet, explain the methods and reasoning you used in analyzing each of the mirrors **b, e,** and **h** in Section AI.

Describe what you did in detail.
Describe the order in which you found the missing items
Describe your method for calculating each missing item in these three columns.

Write in whole sentences. Include equations and calculations for each step where appropriate. This might take one page per mirror.

Written Assignment #3. ***Explain your answers to questions AIII a, b, c, and d.*** *Write your explanations on a separate sheet of paper*.