Image Formation

Apparatus: calipers, desk lamps, optics benches, Basic Optics viewing screens, Basic Optics Light Source, Basic Optics Light Source Power Supplies, concave/convex mounted mirror (± 100 mm), half-screen accessory, mounted lenses (focal lengths $+100$ mm, $+200$ mm, & -150 mm), colored pencils

WARNING: Keep the optics clean! Avoid fingerprints on optic surfaces. Handle all optics by the edges.

TIME SAVING TIP: Talk to your group members in advance and decide who will be student 1, 2, 3, or 4. Once this is known, you should be able to do all theoretical calculations and ray diagrams at home *before* lab. If you do all the theory in advance, it should be super fast to finish up the lab.

Goal: Compare theoretical predictions (both from ray diagrams and equations) to experimental observations for image formation in systems with mirrors and/or lenses.

Each student should do all work and submit a document.

Use plain white paper or properly use engineering paper (gridlines on the *back* side) for derivations.
Include the standard header on page 1 of your work (author name, partners names, early/late lab, date).
Start each experiment on a new page. Do work on one side of page only (grading a ray diagram is difficult enough without bleed through).
Practice each ray diagram on scratch paper BEFORE attempting to write up your final submission.
Please refrain from wasting lab printer paper as best you can.
Be neat. Use a ruler. Ensure a line parallel to the optic axis is actually quite close to parallel.
Draw *meticulously* in your final submission.

When labeling ray diagrams, clearly indicate all of the following:

- Vertical scale (e.g., `1.0 cm on paper = 2.0 cm in real life` or something similar)
- Horizontal scale (label major tick marks on optic axis and make a comment about the units somewhere)
  - Horizontal & vertical scale can be different to ensure the diagram fits on the paper
- Focal points
- Object & Image
- Center of curvature (for mirror ray diagram only)
- Label the optic elements in each diagram as `Mirror` or `Lens` as appropriate.
- For Experiments 1 & 2:
  - Include all three primary rays
  - Label the primary rays (e.g., `Ray 1` for input parallel to axis & output through focal point)
  - Use Blue for Ray 1, Red for Ray 2, and choose any other high contrast color you want for Ray 3.
- For Experiment 3:
  - It is ok to use 2 primary rays instead of all 3 primary rays to reduce clutter.
  - Include subscripts 1 & 2 on lenses, focal points, objects, and images.
  - Use a single color to draw `Lens 1` and all associated rays.
  - Use a different color to draw `Lens 2` and all associated rays.

The object we will be using is the larger white circle of diameter with 4.00 cm diameter shown at right. Note: when you get to lab it is important to measure the diameter carefully with calipers to determine if the 4.00 cm height corresponds to the *inner* diameter, the *outer* diameter, or the *middle* of the larger white ring.

Experiment 1: Image created by a mirror

1) Use the equations

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \qquad \& \qquad M = -\frac{d_i}{d_o} = \frac{h_i}{h_o}$$

to derive algebraic expressions for $d_i, h_i, \& M$ assuming $d_o, h_o, \& f$ are given. Simplify your final results. As an example, for this experiment you should find:

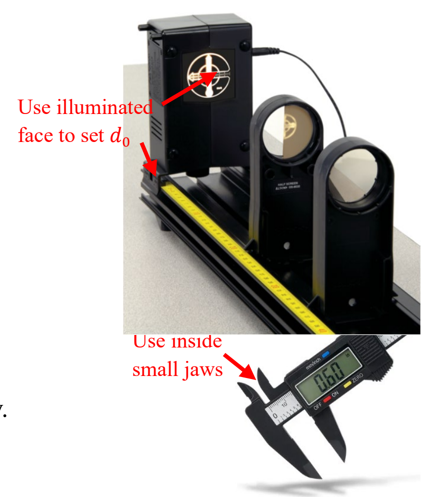
$$d_i = \frac{d_o f}{d_o - f}$$

Your derivations should be on white paper or engineering paper (not lined paper).
Remember to include the standard header on page 1!

2) Draw a ray diagram to scale to determine $d_i, h_i, \& M$ for a given $d_o, h_o, \& f$.
Assume we are using a *concave* mirror with focal point 10.0 cm from the mirror.
THINK: should the focal length should be $+10.0$ cm or -10.0 cm? You are expected to know this on a test.
Notice you must draw to scale in the *vertical* direction as well as along the optic axis. Note: you may use different horizontal and vertical scales.
Each student in the lab group must use a different value of d_o as indicated by the chart below.

Student 1	Student 2	Student 3	Student 4
$d_0 = 24$ cm	$d_0 = 28$ cm	$d_0 = 32$ cm	$d_0 = 36$ cm

3) Use the optics bench and optics to experimentally determine $d_i, h_i, \& M$ for a given $d_o, h_o, \& f$.
Use the concave mirror to produce an image on the half screen as shown in the figure at right.
Each student must use a different d_o as listed above.
WATCH OUT! Object location is at the illuminated face of the source.
Ensure you set object distance accordingly!
A small error in d_o creates a massive error in M.



To experimentally determine parameters:
Slide the half screen back and forth until the image is in sharpest focus.
Once you think it is in focus, deliberately slide it a tiny bit back and forth very slowly.
Use this to verify you really did get the sharpest focus possible.
Once you are confident you have a sharp focus, measure d_i using the optics bench.
Measure h_i using calipers using the inside small jaws.

WATCH OUT! Check the zero on your calipers before each measurement!
Think: it is up to you to determine if h_i should be positive or negative.

Compute magnification experimentally using $M = \frac{h_i}{h_o}$.

Experiment 1 Ray Diagram & Summary Table

Horizontal Scale: **Vertical Scale:**

d_o (cm)	h_o (cm)	f (cm)

	Experiment	From $\frac{1}{f}$ math	% Difference $\frac{1}{f}$ math vs Exp.	From Ray Diagram	% Difference Ray Diag. vs Exp.
d_i (cm)					
h_i (cm)					
M					

Experiment 2: Image created by a lens

In this experiment you will predict both object and image distance given for a desired magnification and known focal length.

1) Derive algebraic expressions for h_i, d_i & d_o in terms of given quantities $h_o, M,$ & f.

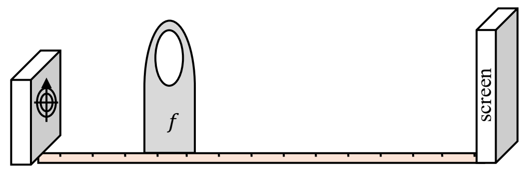
2) Use the biconvex lens with focal points 20 cm from the lens. Think: is focal length $+20.0$ cm or -20.0 cm? You are expected to know this on a test.
Each student must use a different M as listed below.

Student 1	Student 2	Student 3	Student 4
$M = -1.250$	$M = -0.800$	$M = -0.625$	$M = -1.818$

Compute the expected values of $d_o, d_i,$ & h_i using your algebraic formulas.

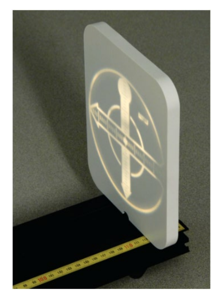
3) Draw the ray diagram *before doing the experiment*. Use the values of d_0 & f from step 2 to get the ray diagram started. Determine $d_i,$ & h_i from the ray diagram.

4) Set up the optics bench similar to the figure shown at right.
Place the object at the zero position on the optics bench.
Adjust the lens position to match d_0 determined in step 2.



WATCH OUT! Object location is at the illuminated face of the light source.
Ensure you set object distance accordingly!
A small error in d_o creates a massive error in M.

Adjust the screen until you have a crisp image.
It should look something like the image shown at right.



Experiment 2 Ray Diagram & Summary Table

Horizontal Scale:

Vertical Scale:

f (cm)	M	d_o (cm) From $\frac{1}{f}$ math Assume this is a given for the experiment	h_o (cm) From source

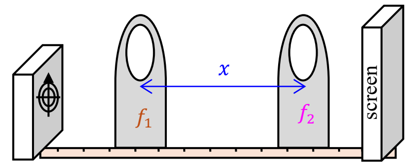
	Experiment	From $\frac{1}{f}$ math	% Difference $\frac{1}{f}$ math vs Exp.
d_i (cm)			
h_i (cm)			

Experiment 3: image from a two-lens system

1) Write down algebraic expressions for d_{i1}, & M_1 assuming d_{o1} & f_1 are given.
This should look identical to experiment 1.

2) Write down algebraic expressions for d_{i2} & M_2 assuming d_{o2} & f_2 are given.
This should look identical to experiment 1.

3) Image formation theory tells us the image formed by lens 1 becomes the object for lens 2. In lecture we have shown this implies $d_{o2} = x - d_{i1}$.
Use this equation with steps 1 & 2 of this page to determine d_{i2} & M_2 in terms of given parameters $d_{o1}, f_1, x,$ & f_2. Your final results should look like



$$d_{i2} = \frac{x(d_{o1} - f_?) - d_{o1} f_?}{d_{o1} f_? - f_?(d_{o1} - f_?)} \qquad M_2 = \frac{-f_?(d_{o1} - f_?)}{x(d_{o1} - f_?) - d_{o1} f_?}$$

Note: when you do the derivation you must determine correct subscripts (1 or 2) for the focal distances shown in the above equation.

4) Using the parameters stated below, determine numerical predications for $d_{i1}, M_1, d_{i2}, M_2, M_{total},$ & h_{i2}.
In other words, use your formulas to fill in the chart at the bottom of the next page.

	Student 1	Student 2	Student 3	Student 4
d_{o1} (cm)	14.0	15.0	16.0	17.0
f_1 (cm)	+10.0	+10.0	+10.0	+10.0
x (cm)	28.0	24.0	20.0	18.0
f_2 (cm)	-15.0	-15.0	-15.0	-15.0
HINT 1	$d_{o2} \approx -7$ cm	$d_{o2} \approx -6$ cm	$d_{o2} \approx -7$ cm	$d_{o2} \approx -6$ cm
HINT 2	Final image is ≈ 55 cm from source	Final image is ≈ 50 cm from source	Final image is ≈ 50 cm from source	Final image is ≈ 50 cm from source
HINT 3	$M_{total} \approx -5$ Draw *short* object 1	$M_{total} \approx -3$ Draw *short* object 1	$M_{total} \approx -3$ Draw *short* object 1	$M_{total} \approx -2.5$ Draw *short* object 1

5) Draw a ray diagram for the two-lens system.
Use one color for lens 1 and all rays associated with it.
Use a different color for lens 2 and all rays associated with it.
WATCH OUT! Getting d_{i2} from the ray diagram is tricky with a virtual object for lens 2 ($d_{o2} < 0$)!
The last page of this document has examples of ray diagrams with virtual objects.
Side note: I often draw the focal point associated with Ray 1 as a solid circle and the focal point associated with Ray 2 as an open circle. This helps me keep track of which lens has positive versus negative focal length.

6) Do the experiment on the optics bench.
Record your experimental values.
Determine the % differences from your ray diagrams & $\frac{1}{f}$ math predictions.

Experiment 3 Ray Diagram & Summary Table

Horizontal Scale: **Vertical Scale:**

d_o (cm)	h_o (cm)	f_1 (cm)	x (cm)	f_2 (cm)

	Experiment	From $\frac{1}{f}$ math	% Difference $\frac{1}{f}$ math vs Exp.	From Ray Diagram	% Difference Ray Diag. vs Exp.
d_{i1} (cm)	NA		NA		NA
M_1	NA		NA		NA
d_{i2} (cm)					
M_2	NA		NA		NA
$M_{total} = M_1 M_2$					
h_{i2} (cm) $h_{i2} = M_{total} h_{o1}$					

Ray Diagram Examples Using Virtual Objects