Image Formation by Plane and Spherical Mirrors

Purpose
To become familiar with the nature of the images formed by plane and spherical mirrors.
To learn to distinguish between real and virtual images.
To discover the relationships among object position, image position, focal length, magnification, and the radius of curvature of plane, converging, and diverging mirrors.
To become familiar with sign conventions and why they’re used.

Equipment
Virtual Optical Bench        PENCIL

Explore the Apparatus/Theory
Open the Virtual Optical Bench Lab on the website.

Figure 1
The virtual Optical Bench apparatus simulates the formation of images by plane mirrors and by converging and diverging mirrors and lenses. We’ll focus on mirrors in this lab.

Were it not for the development of eyes there wouldn’t be a lot to say about the interaction of light with reflective and refractive media except that it sometimes reflects and sometimes refracts, and sometimes does both. But because of the wondrous way that our eyes can take the light leaving an object and reconstruct a replica of that object on our retinas which can then inform the brain of the original object, we have developed the powerful study of optics.

Everyone is very familiar with the plane mirror and has had at least some experience with curved mirrors and lenses in a number of settings. From our extensive experience with our daily primping we feel very confident with the use of plane mirrors. But when we first try to use a car’s rear-view mirrors we find that we a have a lot more to learn.
When you start up the optical bench lab it should look like Figure 1, except the plane mirror will be in use instead of the convex lens. There’s a dashed line in Figure 1 that separates two parts of the apparatus. Below the line is the Ray Optics Tool where light rays are used to show the geometry behind the formation of images. Above the dashed line is the Optical Bench and its object and image tools. The Ray Optics Tool serves another important function. It controls the Optical Bench. Let’s try it with the concave (converging) mirror.

Move your pointer over each of the five lenses and mirrors. The info box will identify each one and tell you how to switch choices. Click and drag the concave mirror until your pointer is over the plane mirror (below on the ray optics tool) and release. The plane mirror should be replaced by the concave mirror. If not, try again. Remember, your pointer needs to be over the device being replaced.

To the right of the mirror there are two vertical arrows. The one pointing upwards with the small grey drag handle on the bottom is the Object. It emits light in all directions, but we display only two of these rays. Drag the object arrow from side to side. You’ll see that the rays are continually redrawn, and the other arrow, the Image, can move, resize and flip vertically.

There’s also action on the optical bench. Notice how the little box with the cow on the front moves in sync with the object arrow on the ray tool. That’s the optical bench’s Object. It’s a slide illuminated from behind. Thus it emits light rays in all forward directions. Leave the object somewhere near the back end of the optical bench.

We’ve seen that the image on the ray tool moves, flips, and changes size. To let us see the image on the optical bench we allow it to illuminate a screen. To form an image on the screen, the translucent screen must be moved to where the image is located. The Screen Position Tool is used to move the screen. It’s a vertical gray line with a small semicircular handle at one end. Drag it from side to side and notice how the screen moves on the optical bench. Also notice, that when it’s to the right of the mirror a smudge of light appears on the screen. As you move the object, the smudge looks more or less like an inverted cow, depending on the location of the object. Leave the screen somewhere between the mirror and the object.

Drag the object to the point labeled 2F on the right end of the ray tool. Drag the Screen Position Tool to the same 2F point. Ta da! A nicely focused, upside down cow appears on the frosted glass. An enlarged version also appears in the upper right in the Image Close-up screen next to the Object Close-up screen. Each screen has a grid that can be moved around to make size measurements. Also, try zooming in on the cow image on the bench. You can right click (Mac: CTRL click) as many as six times to zoom way in. “Show all” will take you back to 100%.

One last thing for now. You can trade in your cow for a Taj Mahal, a fast red car, or the moon, depending on your mood. The text of this lab generally refers to the cow as the object.

I. Plane Mirrors; Virtual and Real Images

We’re going to look at the behaviors of our three mirrors to learn the nature of the images they form as well as the geometry behind the image formation. Then we’ll look at the algebraic descriptions of this geometry. We’ll start with the plane mirror.

Drag the plane mirror in place on the ray optics tool. It should look something like Figure 2.

The law of reflection states that when a ray of light reflects from a mirror the angle of incidence equals the angle of reflection. The lower, teal-colored rays illustrate this. A ray leaves the top of the object arrow, strikes the mirror at its midpoint and then reflects down to the right. The principle axis (dashed line) conveniently helps us see that the angles are indeed equal.
There are two other ray pairs that illustrate the same fact. The orange rays at the top clearly show the same effect. But the purple rays in the middle are less obvious. A ray leaves the top of the object and hits the mirror normally, that is, at a right angle to the mirror. Thus it reflects straight back on itself. The angles of incidence and reflection are both zero in this case.

Be sure to remember that there are many more rays from the object which hit the mirror. We just need two for our work.

Behind the mirror (on the left) we see the image. Its height, $h_i$, is clearly equal to that of the object, $h_o$, and with the draggable ruler you can verify that the image is as far behind the mirror as the object is in front. This becomes even more obvious when you move the object toward and away from the mirror.

1. As you drag the object toward the mirror, try to picture the equivalent activity of walking toward a bathroom or dressing room mirror. If you walked toward the mirror at 2 m/s, at what speed is your image moving toward the mirror? __________

2. At what speed is your image moving toward you? Remember, you’re moving too __________

We clearly see our image move toward and away from our body when we move toward and away from a plane mirror. But there’s really nothing there. An image is not something that has any solid reality in the physical world like the object it mimics. If this is so how can it have a location?

To understand the location of images, we first need to understand how we locate actual objects. In Figure 3 we’ve added a pair of eyes. These belong to a person (whose head is seen from above) who is located between the object and the mirror. That is, you’re looking down on the top of this person’s head. Note that the eyes are pointed toward the top of the object so that a different ray from the object enters each eye. When this happens we mentally connect the two sources of light as a part of the image formation process. In addition, based on the amount the eyes have to turn relative to straight ahead, we compute the distance to the object and adjust the focus of the eye’s lenses to properly focus the light. Amazing. You probably remember learning to do that by examining your feet when you were lying on your back as a baby.

Try it. Look at something far away. Now, focus on something close by. You can feel your muscles straining to turn your eyes away from their relaxed parallel alignment. (A good vacation spot always provides an ample supply of interesting things to look at with relaxed eyes. An ocean, for example!) Again, this is the process of locating an object, that is, assigning it a location.

In Figure 4 the person has turned around and is now facing the mirror. Now light is allowed to reflect from the mirror before entering the eyes. (Magically passing through the person’s head.) Note that a different pair of rays, from the many available, is used this time. In Figure 4 the reflected rays entering the eyes look no different than the direct rays used in Figure 3. They’re all just rays of light. The mind does the same triangulation. But this time it notices that the eyes don’t have to point inward so much and concludes that the more parallel rays are coming from a source farther away and thus behind the mirror. All the information that’s needed for the mind to conjure up an impression of the existence of the object is available.

We say that the person is now looking at (locating) an image of the object. When the rays entering the eye are in any way redirected from their straight line path away from the object, we say that the observer is looking at an image. In this particular case, if you extrapolate back to the apparent source of the light, the image, you find that the rays never passed through that location (behind the mirror). We call this a virtual image. Virtual means “in effect, but not in reality.” Plane mirrors always form virtual images – the image will always be behind the mirror where the light never goes. And since there’s no light present at the image, you can’t form a virtual image on a screen.
Let’s take a closer look at these two types of images. Replace the plane mirror with the converging (concave) mirror. Move the object to the 2F point. Move the screen position controller to the 2F position which is where the image arrow is located. You'll see the **real image** on both of the images screens. The light is actually hitting the screen and point by point creating the full image. (We just follow rays from one point, but they all work the same.)

Now switch back to the plane mirror. The image arrow is now behind the mirror as we saw in Figure 4. Drag the screen position tool to the new image position. The geometry (two lower rays) starts out the same, but there’s no image on the screen because no light actually gets there. Instead it reflects back, continuing on the same trajectories except bent (reflected) backwards. If you stand to the right of the mirror, your eyes can capture the reflected light as in Figure 4 and create an image (of an image) on your retina.

Does this mean that you **have to** have a screen to see a real image? No. Switch back to the converging mirror. How could a person produce a similar image on their retina using light reflected from the mirror? Notice the teal and purple lines that have passed through the tip of the image. They’re just like the reflected rays in the plane mirror – they’re traveling away from the image. You just have to get them to enter your eyes! The figure at the right shows where your eyes need to be in order to form images on their retinas. So eyes down to the right of the image will “locate” the image at the position predicted by the geometry.

**Real vs. Virtual Images**

For **real images**, the light passes through the image and then diverges. We can put a screen at the location of the image and see it displayed there. Or we can allow the light diverging from the image to pass into our eyes which can then form an image (of an image) on our retinas.

For **virtual images** the light only appears to diverge from the image. The light doesn’t actually pass through the image. And as a result a virtual image can never be displayed on a screen.

**The Nature of an Image**

Categorizing an image as real or virtual is a part of the process of determining the **nature of an image**. The nature of an image is determined based on three criteria.

1. Is the image **real** or **virtual**?
2. Is the image **reduced in size**, the **same size**, or **enlarged in size** relative to the object.
3. Is the image **upright** or **inverted** relative to the object?

In the Data section of the lab, Table 1 has copy of a figure similar to Figure 4 and a place for you to record the nature of the image formed by a plane mirror. Circle one choice from each category.

**Ray diagrams vs. real optical instruments**

You may have noticed in our apparatus and our figures that the light is shown to reflect off the back of the glass. The glass on an ordinary plane mirror is only there to protect the reflective surface behind it. It actually diminishes the quality of the images formed by the mirror. To produce a clear image, which is what we are interested in, front surface mirrors would always be used. The figures in this apparatus show the rays reflecting from the back surface in order to make the figures easier to draw. Also for ease of drawing we allow rays to reach the mirror at a wide range of angles.

In actual use, only very nearly parallel incoming rays would be in focus. If you look into a reflective sphere like a Christmas tree ornament everything is distorted except the image of your eye because only the rays coming nearly straight back at your eye will be well-focused. And with a camera the clearest images are created in bright light or with relatively long exposure time. This is because a very small aperture (opening) can be used while still getting adequate light to produce an image. The small aperture only allows light rays nearly parallel to the axis to reach the lens or mirror.
II. Concave (Converging) Mirrors

The second mirror choice (which you’ve already seen) is a concave mirror. Drag it onto the ray optics tool and then drag the object until the screen looks similar to Figure 6.

![Figure 6](image_url)

Both the object and the image are on the right side of the mirror. Drag the screen position tool all the way to the left. Now start dragging it slowly to the right and watch the screen on the optical bench. Drag it just “through” the mirror and stop.

Notice what happened on the **Image Close-up Screen** at the top right of the lab screen. There’s something fuzzy there. That’s a very poor image of a cow. The problem is that it’s not focused because the screen isn’t where the image is located. Drag it a little more and you’ll see the image begin to clear up both on the close-up screen and on the optical bench. Now go ahead and get it as well-focused as possible. Use the close-up screen to make these determinations. Also, in case you missed it, drag the plane mirror back on to the stage and watch the object and image screen on the optical bench. Now drag the concave mirror back. Poof! We had to make some adjustments to let the light get to the mirror.

1. What is the nature of this particular image? Circle your choices. (Hint: real, increased, inverted) 
   a) real  
   b) virtual? 
   a) reduced in size  
   b) the same size  
   c) increased in size  
   (relative to the object) 
   a) upright  
   b) inverted  
   (relative to the object) 

You’ll always want to notice the nature of images along with some other observations. It’s important. Here’s an example of why it matters.

2. Dentists use mirrors to see what they’re doing when they’re working on your teeth. Would you want your dentist to use a mirror system like this one when working on your teeth? Why or why not?

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**Focal Length, f, Object Distance, d_o, and Image Distance, d_i**

The nature of the images formed by a concave mirror is not as neat and tidy as what we found with plane mirrors. The nature of the image and its location depend on the particular curvature of the mirror and the location of the object relative to the mirror. As shown in Figure 7a, the **object distance, d_o, is the distance from the reflective surface of the mirror out to the object, O.** Similarly, the **image, I, is located a distance d_i, from the reflective surface of the mirror.**

Just as with plane mirrors we draw the rays as if they reflected off the back surface of the mirror.

![Fig. 7a](image_url) ![Fig. 7b](image_url)
The property of the mirror that determines the nature of the image is its **focal length**, which is determined by the curvature of the mirror. The **focal point**, or **focus**, \( F \), from the Latin word for hearth, is the point where rays of light traveling parallel to the principle axis of the mirror come together after reflecting from the mirror. See Figure 7b. (With diverging mirrors the definition is somewhat different as we’ll see.)

**The focal length, \( f \), is the distance along the principle axis from the focus to the center of the mirror.** We can find this experimentally with our ray optics tool. Using the object position tool (above the ray tracing area), adjust the object position to 120 mm. Notice that the **incident rays**, the two rays leaving the tip of the object arrow, are maybe 20° apart. The **reflected rays**, the two rays reflecting off the mirror, cross below the axis near the right end of the axis. Click the up arrow on the position tool until the object is at 280 mm. As you do this, notice how the angle between the incident rays becomes increasingly smaller and that the reflected rays now cross increasingly closer to the mirror and to the axis. Now start clicking the up arrow on the object position tool for a while and watch the two pairs of rays. Stop at about 1 m.

3. What did you observe about the trend in the angle between the two incident rays?

Now, right-click on the screen to the right of the mirror and select “zoom in.” You should still see most of the ray optics tool along with the object position tool above it. If not, click and drag anywhere in the screen until you can see both. Now run the object distance up to 3 m.

4. The incident rays continue to get closer to parallel. What’s happening to the reflected rays? Where does their crossing point appear to be heading? Click the object position tool a few times and watch what’s happening.

What you’ve observed is the behavior of a concave spherical mirror. **Rays parallel to the principle axis of a concave spherical mirror reflect and pass through the focal point** as in Figure 7b. While you’re zoomed in, grab the ruler and measure the **focal length**, \( f \), of your mirror. Measure from the back of the mirror where it’s attached to the bluish mounting surface, out to the **focal point**, \( F \). **Record this focal length in data Table 2.** You can now right-click and select “show all” or “100%” to return to a normal-size screen.

Incidentally, the reverse behavior is also true. If you place a light source, say a small bulb, at the focal point, the rays will reflect off the mirror parallel to the axis. This is the principle of a flashlight, searchlight, etc.

The focal length is not an arbitrary distance. A spherical mirror is actually a small section of sphere. Thus it has a certain **radius of curvature**, \( R \). **The focal point is half way between the mirror and its center**, \( C \). That is

\[
f = \frac{R}{2}
\]

For convenience we label the center point 2F.
Images Formed by a Concave Mirror
With our plane mirror we found that the image and object are always equidistant from the mirror and that the image is always upright, virtual, and the same size as the object. We’d also like to be able to determine all the same information about images formed by concave and convex mirrors. We’ll develop methods for determining this geometrically with drawings and algebraically with equations based on the geometry. With concave mirrors, there are a number of different outcomes all depending on the relative values of the focal length and the object distance. Although there are several outcomes, actually five, there is a logical pattern. We specify these as Cases I – V.

Yes, you do need to know these cases and be able to draw them!

Case I: Object distance, \( d_o > 2f \) \( (d_o > R) \)
For case I, the object is at any distance greater than two times the focal length from the mirror.

With the Object Position tool, move the object back into view. Drag the object to about half-way between the 2F point and the right end of the axis. You’ll see that the image is formed between the F and 2F points. Remember, when you adjust the object position always drag the screen position controller until you get a sharp image on the screens That is, if there is an image. Here’s how the geometry works for this case.

If we can find the image of one point on our object, all other points can be similarly found. We’ll start with the tip of the object arrow. All rays leaving the tip of the object, after hitting the mirror, will pass through the matching point on the image. There is no limit to the number of rays that you could draw from the tip of the arrow to its image. And any two will do since all reflected rays converge at the same point.

Our apparatus draws what’s called the parallel ray in magenta. This ray is easy to draw since it leaves the object traveling parallel to the axis and then reflects back through the focal point and continues.

A second, cyan ray strikes the center of the mirror and reflects back at an equal angle below the axis. It’s not reliable in hand drawings since an “equal angle” is not easy to draw. So we won’t use it in our hand drawn figures. Instead we’ll choose from two others. You’re now going to begin recording more observations in the tables that start a few pages back in this document.

In Table 3 there is an area labeled “1. Ray Diagram, with eyes.” It contains a mirror and principle axis with the F and 2F points labeled. You need to add to this figure the object, image, and two rays to locate the image. You have three rays to choose from as described and illustrated in Figure 9. Use Ray 1 and either Ray 2 or Ray 3. So your diagram will look just like Figure 9, but with one fewer rays.

Ray 1. The parallel ray goes from the tip of the object, parallel to the principle axis, and then reflects back through the focal point.

Ray 2. The focal ray goes from the tip of the object, through the focal point, and then back parallel to the principle axis.

Ray 3. The chief ray goes through the center of curvature, C, (at 2F) and then reflects back through C.

Are you clear on what these drawings mean? We want to know where the image is as well as its nature. We said earlier that when rays of light from an object are redirected before they enter your eyes, the light will appear to come from a different location. The three rays in Figure 9, along with all the others not shown, diverge from the object and then converge at the image. But they then diverge apart just like from an object. If any two of these diverging, reflected rays enter your eyes you’ll be able locate the image. To emphasize this, you should also include a pair of eyes at the end of your two rays just as we did in Figure 4. Figure 9 also has a pair of eyes that look a bit like small arrows.
So here’s what to do. The numbers below correspond to numbers in Table 3.

1. If you haven’t already done it, draw your ray drawing in Table 3. It should be exactly like Figure 9 but with just two rays. **Be sure to include two eyes!**

2. How about the nature of the image? Circle the three appropriate choices in the space provided in Table 3.

3. Finally, we want a reminder of what the image looked like. There’s a picture of the object cow in Table 2. There’s also one on your computer screen. It will never change. Using your best cow-drawing skills, draw a scaled drawing of your image cow in Table 3. A stick figure would be fine. It just needs to suggest the orientation and size of the image relative to the object. Notice how it’s flipped horizontally and vertically.

4. In case I the object could be anywhere beyond a distance of 2f from the mirror. That’s a lot of territory. But it’s a specific range of territory – everywhere beyond $d_o = 2f$. The image also has a specific range of positions. **The image distance, $d_i$, is the distance from the image to the center of the mirror.** Drag the object back and forth, keeping outside the 2F point. How would you define the possible locations for the image? Write your answer in the space provided for #4 in Table 3.

5 – 8. We’ll come back to these a little later.

**Case II: Object distance, $d_o = 2f$ (do = R)**

In Case I the object and image both had a range of possible positions. In case II the object can be at exactly one point – the 2F point. Not surprisingly the image has one possible location.

You should be able to proceed from here. Complete items 1-4 in Table 4 to provide a qualitative description of this case.

**Case III: Object distance, $f < d_o < 2f$**

Now we return to a situation where the object has a range of positions. Move the object arrow somewhere between F and 2F. The image this time is enlarged so it won’t all fit on the image screen. Consider just part of the cow as the object so that you can see the entire image of that part on the screen.

Complete items 1-4 in Table 5 to provide a qualitative description of this case.

**Case IV: Object distance, $d_o = f$**

Now the going gets strange. As you move the object toward the focal point, notice what is happening to the reflected rays. Go ahead and move the object a little bit past F. You should be able to draw a conclusion about what is happening at F. As a result you’ll be more limited in what you can answer in the data table.

Complete items 1-4 in Table 6 to provide a qualitative description of this case.

**Case V: Object distance, $d_o < f$**

In this final case you should see some very significant changes in the nature of the image. You might want to return to the plane mirror figures if you have trouble interpreting your results.

Complete items 1-4 in Table 7 to provide a qualitative description of this case.
III. Convex (Diverging) Mirrors

A convex spherical mirror is essentially the reverse of the concave mirror. It has a radius of curvature and a focal length defined just like those of a concave mirror, but these two points are not on the side of the mirror where the light rays are found. Figure 10 shows its behavior.

All images formed by a convex mirror have the same nature. No matter where you position the object the image will be confined to one region.

Just as with concave mirrors, our apparatus determines the location of the image with a pair of rays, as shown in Figure 10. You’ll choose from two of three rays in your diagrams as described below.

The parallel ray acts in a manner similar to that of concave mirrors except that instead of reflecting toward the focal point, it reflects away from it as in Figure 11b. Measure the focal length of this mirror and record it in Table 8.

The focal ray and chief ray are also similar to those we found with concave mirrors. Again neither of them is displayed by the ray optics tool. See Figure 11a for an idea of how they work.

You also need to add a couple of eyes showing where an observer needs to be to use your two rays to view the image.

Ray 1. The parallel ray goes from the tip of the object, parallel to the principle axis, and then reflects back away from the focal point.

Ray 2. The focal ray goes from the tip of the object, toward the focal point, and then reflects ______

Ray 3. The chief ray goes toward the center of curvature, C, and then reflects ______

As before complete items 1-4 in Table 9 to provide a qualitative description of this case.

Learning about the various image cases has a practical purpose. We need different image types for different situations. Sometimes we need an enlarged image and sometimes we need it reduced. But we also care about the orientation of the image. An upside down image in some cases could cause big problems. In other cases it would not be a problem.

1. Explore these considerations by matching up the image cases on the left with the applications on the right. Each letter choice gets used exactly once.

Converging Mirrors

<table>
<thead>
<tr>
<th>Case I</th>
<th>Case II</th>
<th>Case III</th>
<th>Case IV</th>
<th>Case V</th>
<th>Diverging Mirror</th>
</tr>
</thead>
</table>

a) Telescope
b) Flashlight, headlights, searchlights
c) Dentist’s mirror
d) Shoplifting Surveillance Mirror
e) Photocopier in normal copy mode
f) Photocopier in enlarge mode
Equations and Sign Conventions for Spherical Mirrors

From our diagrams we can clearly see that the focal length and object distance geometrically determine the nature and location of any image. It should be very simple to produce equations to describe this geometry algebraically, and it is. There’s one problem however. For cases I-III you get one of equation, then a slightly different one for case V, and another slightly different one for the diverging mirror. If we look at lenses while we’re at it, we find a similar situation.

We could just memorize several equations, but the equations only differ by the signs of the different terms. Further examination reveals that the different signs are connected to the different natures of the images. So since we already need to know about the natures of the images it makes sense to use just a pair of equations and a set of sign conventions that adjust the signs of \( f \), \( d_o \), and \( d_i \) according to the situation. Here’s the system that we’ll use. Note: These sign conventions do not account for situations involving multiple devices such as a two lens telescope. In those cases the image of the first device becomes the object for the second device. We won’t consider that situation in this lab.

\[
\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \quad \text{Equation 1: Mirror or Thin Lens Equation}
\]

\[
M = -\frac{d_i}{d_o} = \frac{h_i}{h_o} \quad \text{Equation 2: Magnification Equation}
\]

Sign Conventions for Mirrors and Thin Lenses for use with Equations 1 & 2

Focal Length, \( f \)

+\( f \): Converging Device  
-\( f \): Diverging Device

Object Distance, \( d_o \)

+ \( d_o \): always  (unless it’s the image from another device, which we will not encounter in this lab)

Image Distance, \( d_i \)

+ \( d_i \): Image on the side of the device where light goes  
- \( d_i \): Image not on the side of the device where light goes

Magnification, \( M \), and image height, \( h_i \)

+\( M \), +\( h_i \): Virtual Image  
-\( M \), -\( h_i \): Real Image

The magnification, \( M \), is a measure of the degree of enlargement or reduction of the image relative to the object. It is a ratio of the images height, \( h_i \), to the object height, \( h_o \), and thus a dimensionless number.

Be careful not to rephrase these conventions. They are easily broken. For example,

“Image not on the side of the device where light goes”

can’t be translated into

“Image on the side of the device where light comes from”

because of differences in lenses and mirrors.
1. Let’s practice. 
Insert signs or N/A for each choice in the table.

<table>
<thead>
<tr>
<th>f</th>
<th>d_o</th>
<th>d_i</th>
<th>M</th>
<th>h_i</th>
</tr>
</thead>
<tbody>
<tr>
<td>Convex Mirror</td>
<td>Case I</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td>Case II</td>
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<td>Case V</td>
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<tr>
<td>Diverging Mirror</td>
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</tr>
</tbody>
</table>

The magnification can be tricky since its sign indicates one type of information while its value relative to 1.0 indicates another. This second consideration is due to the fact that it’s a ratio of \( h_i / h_o \).

2. What does the sign of the magnification indicate about whether an image is upright or inverted?

A positive sign indicates that the image is ____________________________________________
A negative sign indicates that the image is ____________________________________________

3. The absolute value of the magnification can be less than 1.0, equal to 1.0 or greater than 1.0. Ex. 0.5, 1.0, or 3.2.

What does each of these indicate about the image?

A magnification whose absolute value is less than 1.0 indicates that an image is ____________________________________________
A magnification whose absolute value is equal to 1.0 indicates that an image is ____________________________________________
A magnification whose absolute value is greater than 1.0 indicates that an image is ____________________________________________

4. A magnification of +3.2 means that the image is ___ times the size of the object and ____________.

5. A magnification of -.32 means that the image is ___ times the size of the object and ____________.

Determining Magnification and Image Location with the Mirror and Magnification Equations

We’ve qualitatively observed how the image position and magnification change with the object distance for a given focal length. We’ll now test our equations’ ability to predict these values for our five converging lens cases and single diverging lens case.

For each of these cases you’ll find a section in the corresponding table with items 5-8 as shown in the sample below. For all these measurements remember that zooming the screen will help you make accurate measurements.

**Item 5: Experimental data.** Select a representative object position for the case being examined and then measure and record \( d_o \) and \( d_i \), using the centimeter ruler. To measure \( h_o \) and \( h_i \) use the draggable grid on the close-up screens. Each grid square represents one centimeter. For very large images you’ll find that the image may go off scale by so much that you can’t measure the full image. In that case, just measure a part of the object and its corresponding image.

Also calculate \( h_i / h_o \) as your experimental value for the magnification. In the case of virtual images you won’t have an experimental value for \( h_i \) or \( M \). Just enter N/A for these values in the table.

**Item 6: Computed values.** Use equations 1 and 2 to compute values for \( d_i \) and \( M \) respectively. \( (M_{comp} = -d_i / d_o) \)

**Item 7: Percent differences.** Finally find percent differences between your experimental and computed values for \( d_i \) and \( M \). This won’t be possible in the case of virtual images. Again, just put N/A in these cases.

**8. Show the work that’s requested after the data tables.** Note that what’s requested varies.

(Don’t fill this in. It’s a sample.)
DATA
Most of your results in this lab are recorded in the tables that follow. The preceding pages explain what goes where. You’ll begin by filling in qualitative observations and then return to fill in the quantitative data.

**Part I – The Plane Mirror**

<table>
<thead>
<tr>
<th>Nature of image: (Circle one from each category)</th>
<th>Real</th>
<th>Virtual</th>
<th>No Image</th>
<th>Reduced</th>
<th>Same size</th>
<th>Enlarged</th>
<th>Upright</th>
<th>Inverted</th>
</tr>
</thead>
</table>

There are no numerical measurements or calculations to be made with the plane mirror.

\[ d_i = -d_o \]
\[ h_i = h_o \]
\[ M = +1 \]

**Part II – The Concave Mirror**

<table>
<thead>
<tr>
<th>Table 2 Concave Mirror</th>
<th>Object: Cow → You can measure just part of the cow as the object and use the same part for the image. Ex. Bottom of feet to top of back.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focal length, ( f ) from convergence of parallel rays</td>
<td>( ) cm</td>
</tr>
</tbody>
</table>
### Table 3 Concave Mirror - Case I: $d_o > 2f$ (R)

<table>
<thead>
<tr>
<th>1. Ray diagram, with eyes</th>
<th>2. Nature of Image (circle 3)</th>
<th>3. Stick Figure Image to Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Ray diagram" /></td>
<td>Real  Virtual  No Image</td>
<td>Reduced  Same size  Enlarged</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Upright  Inverted</td>
</tr>
</tbody>
</table>

4. Describe the position or range of positions available to the image in this case.

<table>
<thead>
<tr>
<th>5. Experimental</th>
<th>6. Computed</th>
<th>7. % difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d_o$ (cm)</td>
<td>$d_i$ (cm)</td>
<td>$h_o$ (cm)</td>
</tr>
<tr>
<td>$h_i$ (cm)</td>
<td>$M$ $h_i/h_o$</td>
<td>$M$ $d_i$ $d_o$</td>
</tr>
<tr>
<td>$M$ $d_i/d_o$</td>
<td>$d_i$</td>
<td>$M$</td>
</tr>
</tbody>
</table>

8. Show your calculations of $M_{\text{experimental}}$, $d_{i\text{computed}}$, $M_{\text{computed}}$, and both percent differences below.

Here’s my image cow. You’ve probably seen my work if you’ve visited Lascaux, France. Note that the cow is reversed both vertically and horizontally.
Table 4  Concave Mirror - Case II: \(d_o = 2f\) (R)

<table>
<thead>
<tr>
<th>1. Ray diagram, with eyes</th>
<th>2. Nature of Image (circle 3)</th>
<th>3. Stick Figure Image to Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Ray diagram" /></td>
<td>Real Virtual No Image</td>
<td>Reduced Same size Enlarged</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Upright Inverted</td>
</tr>
</tbody>
</table>

4. Describe the position or range of positions available to the image in this case.

<table>
<thead>
<tr>
<th>5. Experimental</th>
<th>6. Computed</th>
<th>7. % difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>(d_o) (cm)</td>
<td>(d_i) (cm)</td>
<td>(h_o) (cm)</td>
</tr>
<tr>
<td>(h_i) (cm)</td>
<td>(M)</td>
<td>(d_i) (cm)</td>
</tr>
<tr>
<td>(h_i/h_o)</td>
<td>(M)</td>
<td>(-d_i/d_o)</td>
</tr>
<tr>
<td>(d_i)</td>
<td>(M)</td>
<td></td>
</tr>
</tbody>
</table>

8. Show your calculations of \(M_{\text{experimental}}\), \(d_{i\text{\text{computed}}}\), \(M_{\text{computed}}\), and both percent differences below.
Table 5 Concave Mirror - Case III: $f < d_o < 2f$ (R)

<table>
<thead>
<tr>
<th>1. Ray diagram, with eyes</th>
<th>2. Nature of Image (circle 3)</th>
<th>3. Stick Figure Image to Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Ray diagram" /></td>
<td>Real</td>
<td>Virtual</td>
</tr>
<tr>
<td></td>
<td>Reduced</td>
<td>Same size</td>
</tr>
<tr>
<td></td>
<td>Upright</td>
<td>Inverted</td>
</tr>
</tbody>
</table>

4. Describe the position or range of positions available to the image in this case.

<table>
<thead>
<tr>
<th>5. Experimental</th>
<th>6. Computed</th>
<th>7. % difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d_o$ (cm)</td>
<td>$d_i$ (cm)</td>
<td></td>
</tr>
<tr>
<td>$h_o$ (cm)</td>
<td>$h_i$ (cm)</td>
<td></td>
</tr>
<tr>
<td>$M = h_i / h_o$</td>
<td>$M = -d_i / d_o$</td>
<td>$d_i$</td>
</tr>
</tbody>
</table>

8. Show your calculations of $M_{\text{experimental}}$, $d_i^{\text{computed}}$, $M^{\text{computed}}$, and both percent differences below.
### Table 6  Concave Mirror - Case IV: \(d_o = f\)

<table>
<thead>
<tr>
<th>1. Ray diagram, with eyes</th>
<th>2. Nature of Image (circle 3)</th>
<th>3. Stick Figure Image to Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Ray Diagram" /></td>
<td>Real  Virtual  No Image</td>
<td>Reduced  Same size  Enlarged</td>
</tr>
<tr>
<td></td>
<td>Upright  Inverted</td>
<td></td>
</tr>
</tbody>
</table>

4. Describe the position or range of positions available to the image in this case.

<table>
<thead>
<tr>
<th>5. Experimental</th>
<th>6. Computed</th>
<th>7. % difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>(d_o) (cm)</td>
<td>(d_i) (cm)</td>
<td>(h_o) (cm)</td>
</tr>
<tr>
<td>(h_i) (cm)</td>
<td>(M)</td>
<td>(d_i) (cm)</td>
</tr>
<tr>
<td>(h_i/h_o)</td>
<td>(M)</td>
<td>(-d_i/d_o)</td>
</tr>
<tr>
<td>(M)</td>
<td>(d_i)</td>
<td>(M)</td>
</tr>
</tbody>
</table>

8. You don’t need to show your calculations for this table.
Table 7  Concave Mirror - Case V: \(d_o < f\)

<table>
<thead>
<tr>
<th>1. Ray diagram, with eyes</th>
<th>2. Nature of Image (circle 3)</th>
<th>3. Stick Figure Image to Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Real</td>
<td>Virtual</td>
</tr>
<tr>
<td></td>
<td>Reduced</td>
<td>Same size</td>
</tr>
<tr>
<td></td>
<td>Upright</td>
<td>Inverted</td>
</tr>
</tbody>
</table>

4. Describe the position or range of positions available to the image in this case.

<table>
<thead>
<tr>
<th>5. Experimental</th>
<th>6. Computed</th>
<th>7. % difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>(d_o) (cm)</td>
<td>(d_i) (cm)</td>
<td>(h_o) (cm)</td>
</tr>
</tbody>
</table>

8. Show your calculations of \(d_i\) computed, \(M\) computed below.
**Part III – The Convex Mirror**

Table 8 Convex Mirror

<table>
<thead>
<tr>
<th>Focal length, f from divergence of parallel rays</th>
<th>cm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Object: Cow</strong></td>
<td></td>
</tr>
<tr>
<td>You can measure just part of the cow as the object and use the same part for the image. Ex. Bottom of feet to top of back.</td>
<td></td>
</tr>
</tbody>
</table>

Table 9 Convex Mirror – One case

<table>
<thead>
<tr>
<th>1. Ray diagram, with eyes</th>
<th>2. Nature of Image (circle 3)</th>
<th>3. Stick Figure Image to Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Real</td>
<td>Virtual</td>
</tr>
<tr>
<td></td>
<td>Reduced</td>
<td>Same size</td>
</tr>
<tr>
<td></td>
<td>Upright</td>
<td>Inverted</td>
</tr>
</tbody>
</table>

4. Describe the position or range of positions available to the image in this case.

<table>
<thead>
<tr>
<th>5. Experimental</th>
<th>6. Computed</th>
<th>7. % difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>d_o (cm)</td>
<td>d_i (cm)</td>
<td>h_o (cm)</td>
</tr>
</tbody>
</table>

8. Show your calculations of d_i computed, M_computed below.