Chapter 36: Mirrors and Lenses

We have seen that light can be reflected and refracted in predictable ways, according to the Law of Reflection and Snell's Law. Knowedge of this can, and does, lead us to design devices to manipulate the bahvior of light for different reasons. The most basic, and primary reason is to change the apparent size or focus of an object. Before we look at how we can do this, we will need to discuss and become familiar with the idea of an "image".

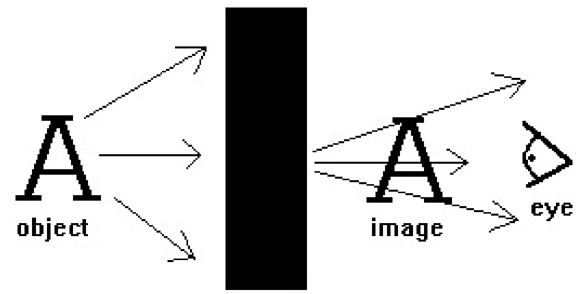
Images

The term image is one that many people are familiar with in everyday usage. It usually means "an apparent replica of an object that does not exist in the usual sense of the word". In other words, we say something is the image of something else as long as it appears identical, even if it is an illusion. In physics, image means much the same thing, but I find that often beginning (and many advanced) students are using the term without completely understanding it.

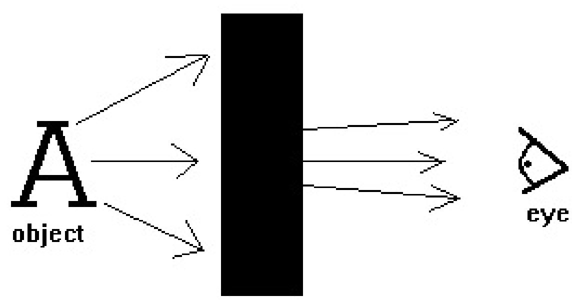
We see objects by having the reflected light leave their surface and reach our eye. Our brain interprets this pattern of light using subtle clues (tiny shadows mean textured, for example). However, it is possible to construct a situation where the light that is reaching our eyes appears to be coming from a different place than it actually is. For example, imagine that you are looking at a pencil. You believe you know where it is because your brain is interpreting the light that reaches your eyes. But now imagine that the light reaching your eyes isn't really coming from the pencil at all. Imagine that there was some machine there that could accurately reproduce the light from a pencil at any location. When you reached for the pencil it is not there. We would have called that an image of a pencil. Thus images are not real things, they are "misinterpretations" of an object by your brain. But don't blame your brain (bad brain, bad brain!), since the situation is constructed for exactly that reason.

The purpose of lenses and mirrors is to create images of objects. One of the most important questions to ask about an image is: Where is it? Since images do not "exist" as things, the question at first seems unrealistic. However, what is really being asked is, "Where does the image appear to be?" or "Where is the light originating from in this case?" The answer to this would be called the image distance.

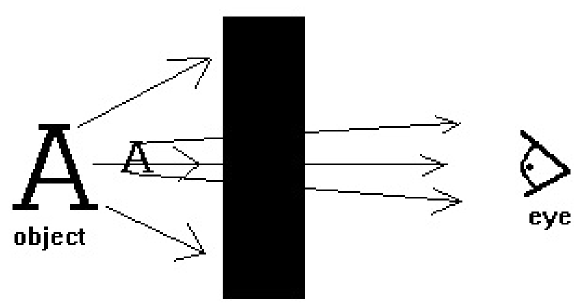
There are two kinds of images that can be formed: virtual and real images. Let us give definitions, and then discuss further what is meant. A <u>Real Image</u> is an image where all the light forming the image is actually coming from the image. A <u>Virtual Image</u> is one formed by light that is not actually coming from the image, but only appears to be originating at the image. Let us use our imagination to construct and example. Suppose we had a machine that allowed light from an object to enter one side, and could form an image out of the other side. In other words, it would take in light from an object and redirect it so that it appears to originate from somewhere else. Such a situation is shown below.



Notice how in this case, the device causes the light to be leaving the image exactly as it leaves the object. Now ask your self, does the light forming the object ever pass through the point at which the object is located? Yes, and thus it is a real image. But now imagine that the device was changed and the three representative light rays left the device like this:



So we ask ourselves, where do these light rays appear to be coming from? Although there are many possible answers, one of the more interesting ones is:



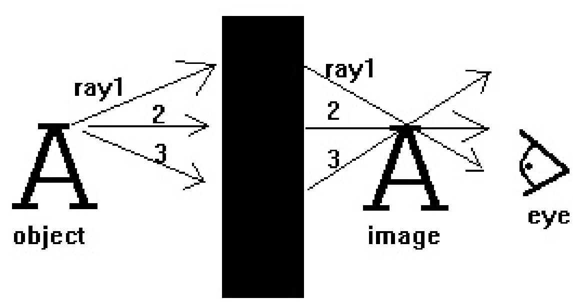
Your brain could interpret these rays as coming from a smaller object somewhere behind the device. Do the rays that reach your eyes come from that spot? Do they every pass through that spot? Is there anything really at that spot? The answers to all three questions are the same: NO. What is important to see is that your brain interprets an image as being there based on the rays that reach your eyes and their apparent origin. The image above is called a virtual image, since the light never passes through the image itself, it simply appears to come from that spot.

An interesting fact arises at this point: real images can be projected onto a screen, virtual images cannot. In other words, if a blank sheet of paper is held up at the spot where the A is formed in the top diagram, an A will appear on the paper (like on a movie screen). However, if a blank paper is placed at the position of a virutal image (like the second diagram), nothing will show up on the screen.

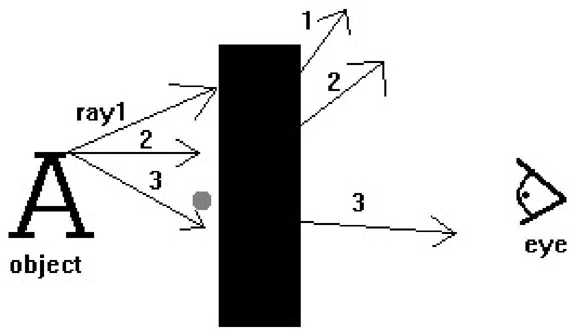
A good way to think about what an image is is to think about it as if nothing else were there and it was all you were seeing. In other words, imagine that you didn't know that the box or the original A were there, all you would see would be image of the A and you would think there really was an A in that location. This brings us to a point that will be very important later as we investigae mirrors and lenses: <u>Only the light rays that reach your eyes after the device can determine the image. Light rays from the object into the device are not part of the image at all.</u>

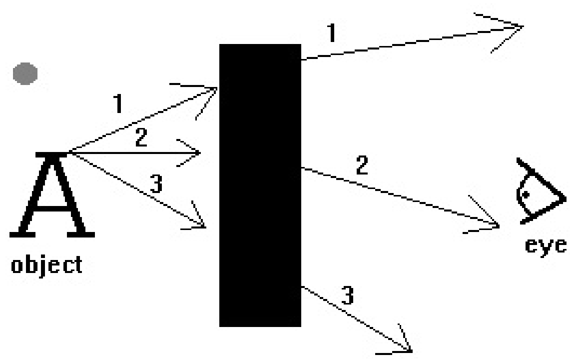
<u>Locating Images and Focusing</u>

You may have noticed that in the last example it was stated that we couldn't tell exactly where the second A was coming from. That is because (for a specific reason) we were not locating images properly in those examples. We now need to discuss what it means for an image to be in focus and how to locate its position. First, consdier the A and the box device of previous examples. Think about one point at the top of the A. When light leaves that point, it goes out in all directions. When all of those beams hit the box, they may all come out with differnt paths. However, if the image is focused, all the light that leaves one point on the object will be brought back to that same point. The diagram below illustrates this.



All the rays are not traveling the same direction as they originally were, but <u>they all meet back together after starting from the same spot</u>. This image is called in focus. If an image is not in focus, then all the rays from one spot are not brought back together. Think about a picture that is not in focus. It is blurry because some of the light from say, the persons nose did not get back to where the rest of the "nose light" is meeting. Instead, it might have ended up in the mouth position. As we said, a screen can be placed at the spot where a real image is formed and we could see the image on the screen. However, if a screen were placed between the image and the box, the light would not have met back up yet and we would see an image that was out of focus. For a virtual image, the situation is a little more complicated. In this case, the light rays do not meet again, but they appear to have met somewhere they never traveled to. Two examples are shown. In both cases, the grey dot represents the spot where they seem to have met.



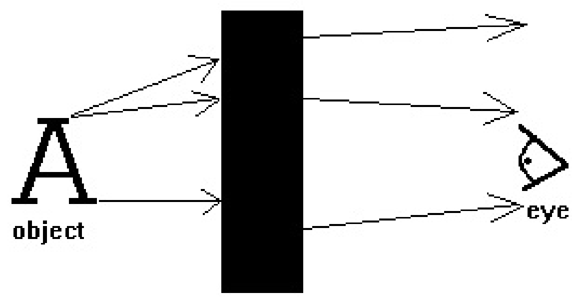


In both situations, if an image was formed, the top of the A would be at the grey dot.

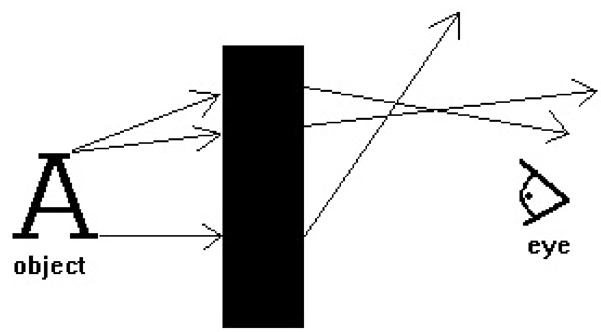
If the image is formed and in focus, this situation is true not only for one point on the object, but for every point. Thus <u>if an image is formed, light that spreads out from every point on the object will meet back at the image position exactly as if left the object.</u>

The next question is then how to locate an image after the light from an object has passed through an optical device. If we think about it, we can see from our previous discussion that following rays (after they emerge from the device) until they meet will give us the postion of one point of the image. A little further thought will show us that two rays are sufficient to locate the point. However, that is not enough. While this will tell us where that one point is located (say the top point of the A), there are many ways that could be the case. The object could be smaller or larger than the original, or even upside down. We need one more ray from some other point on the object to finish the task. Imagine tracing one ray from the bottom of the object. We could say for sure that the bottom of the image lies along that ray after it leave the device. Since we know exactly where the top of the object is, we could now draw the image.

EX HJU.) Draw the image formed in the following case:



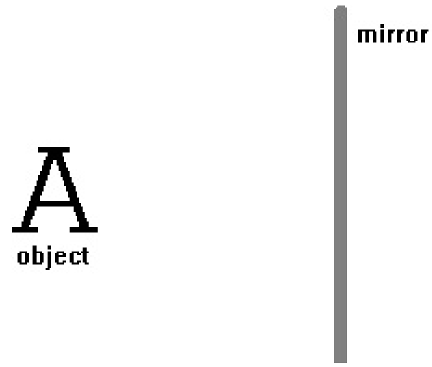
Example HJV.) Draw in the image of the object formed in the following case.



<u>Plane Mirrors</u>

Now that we know about images and image location, we can move on to optical systems consisting of lenses and mirrors. We will begin by discovering some things about the simplest mirror, the plane mirror. There is only one difference between a mirror and our box like device used in the examples. Instead of the light passing through the device, it is reflected off. Thus the "eye" of the observer is located on the same side of the mirror as the object.

EX EBM.) Loacte the image of the object below in the plane mirror. Do so by tracing out the paths of light rays and using the law of reflection.



An astute student should be able to prove the following three facts that we can see from this problem.

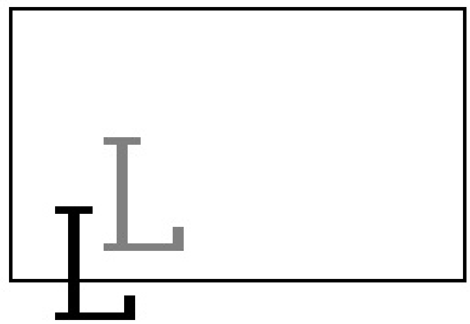
1.) The image distance (measured from the mirror to the image) is always the same as the object distance (from the mirror to the object).
2.) The image is the same size as the object.
3.) The image is virtual.

These are true for all plane mirrors. You always look the same size and the same distance away when you view yourself in a flat mirror. Two other facts are not as obvious. The next example illustrates the first.

EX ADE.) Find the minimum length of mirror needed to fully view yourself from head to foot. Do this by tracing rays from the top of your head and the bottom of your feet to your eyes.

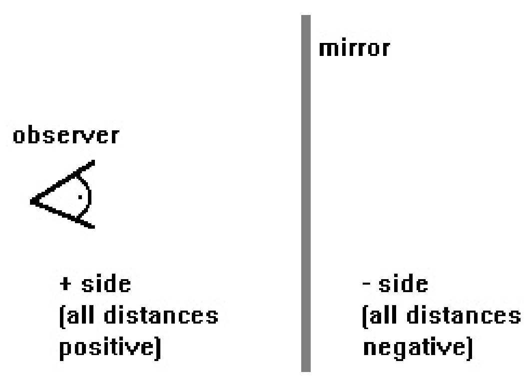
This is a simple, yet often unbelieved conclusion. You only need a mirror that is half of your height to see yourself completely. It does not matter how far away you stand. Often students say, "But if I had a small mirror, say one foot high, and I stood a block away, I could see all of myself". Obvioulsy they are not the astute student. The percent of yourself that you can see in a mirror depends on the height of the mirror compared to your height and is in no way affected by how far away you stand. Try it, most people are suprised. This also explains why you see a lot of "full length mirrors" sold in the stores that are only three feet high.

The second conclusion is hard to explain, but it is the truth and it takes alot of thinking to understand. Mirrors do not reverse left to right. They reverse front to back. Consider the letter L, viewed in the mirror below. One thing is not obvious from the diagram, the front (the face that is away from you) of the original L is colored grey and the back (towards you) is black.



Notice that the bottom part of the original L is towards the right. In the mirror, the bottom part is still to the right. Certainally mirrors cannot reverse left to right. But the front has now become the back and the back has now become the front. Mirrors reverse front to back while preserving left and rightedness (is this a word?). One effect of this is that you never see yourself in a mirror the same way people see you (since it would be impssible to turn you front to back and still preserve your sidedness). The only way to see the proper side of your face on the proper side is to view yourself in a corner reflector. Since there are two mirrors, you look exactly as people see you.

Before we leave plane mirrors, we need to make mention of two more concepts that we will be using in the rest of this chapter. The first is a sign convention. When dealing with mirrors, we will call the "real" side of the mirror positive and the "virtual" side negative, as shown below.



With this convention we can see that the <u>object distance</u> (from the mirror to the object, and abbreviated with an o) and the <u>image distance</u> (measured from mirror to image and abbreviated with an i) are equal but opposite.

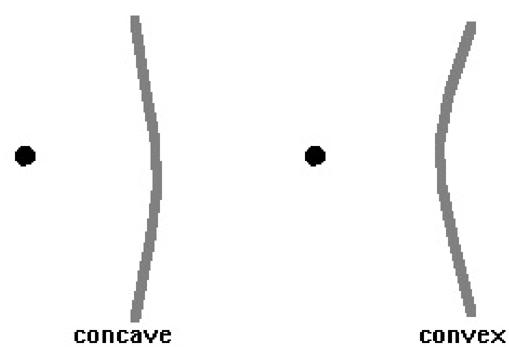
$o = -i$ (for a plane mirror)

We now introduce a new concept called <u>magnification</u> which indicates how large (or small) an image is in comparison to the obejct creating it. We have already said that the image and object of created by a plane mirror are the same size, thus we would expect a magnification of 1. We have a general formula for all cases that will yield the magnification.

$m = -i/o$ (for all cases).

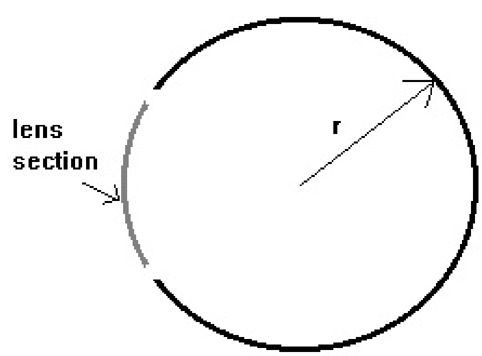
Concave and Convex Mirrors

At this point we can begin to apply our ideas to more complicated situations. The first to examine is the case of concave and convex mirrors (sometimes called converging and diverging mirrors, respectively). These mirrors are shaped like so:



In each case the position of the observer is noted with a black dot. Often students are told to remember the difference between the two by remembering that the concave one is "caved-in" on the observers side.

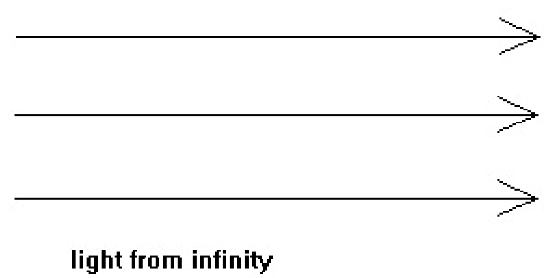
In this chapter, we will only treat mirrors that are spherical. What this means is that every concave or convex lens is considered to be a small part of a sphere.



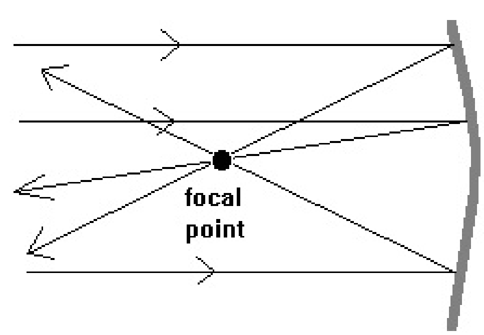
In reality, concave and convex mirrors are generally not spherically formed, but formed as part of a parabola, because parabolas have better optical properties than spheres. However, a small section of a sphere is very close in shape to a small section at the bottom of a parabola. In many ways, the optics that we are investigating is an approximation using spherical properties instead of parabolic.

Since mirrors are considered parts of spheres, they will have a radius of curvature associated with them (r). Notice that for a concave mirror the radius is positive and for a convex mirror, the radius is negative.

Concave and convex mirrors also have what is called a focal point, which is defined as the point where light from infinity comes together (or appears to come together). Although we have already used the term focus to mean an image that is sharp or crisp, this is a related topic. The focus of a mirror (or lens) is an extremely important property. What happens at the focus is a convergence of light coming from a great distance. When light comes from a great distance, we consider its rays to be parallel to the axis of the mirror and we call it light coming from infinity.



When such light hits a concave mirror, it all bounce back and meets at the same spot. That spot is called the focus and the distance from the mirror to the focus is called the focal length or focal distance.

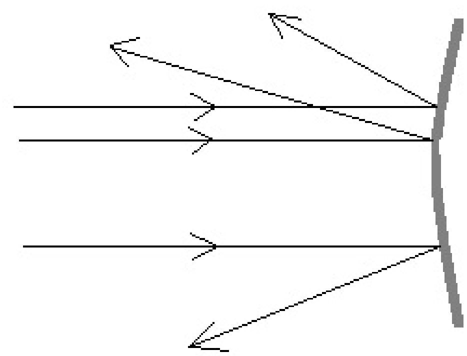


This phenomena can be proved with the aid of the law of reflection and the formula that describes a spherical surface, but we will not do so in this section (an astute student might want to try it). It should also be said that although only a few rays are shown above, all the light from infinity is reflected back to the focus.

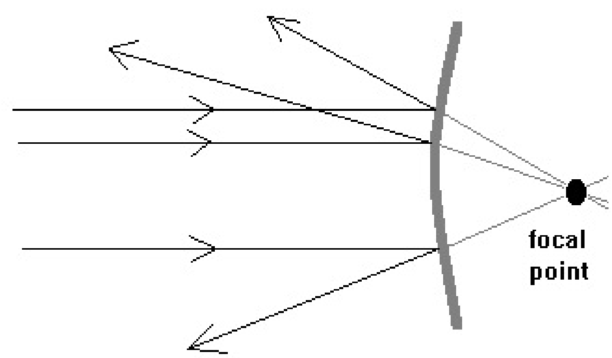
You can witness this phenomena by taking a convex mirror and reflecting the light from the sun onto a piece of paper. It is possible to get the paper to catch fire in this manner (just don't do it on the grass on a dry day!) It is rumored (and part of legend that is probably not true), that the Lighthouse of Alexandria, one of the seven wonders of the ancient world had a mirror to focus the light of the sun on enemy ships and set them on fire as they approached. It is also legend (and also probably not true) that Archimedes instructed the soldiers of his town to use their shields as mirrors and set fire to approaching Roman ships.

The phenomena illustrated above is what is called <u>convergence</u> of light and sometimes a concave mirror is called a <u>converging</u> mirror, since it brings the light together at one point.

If we try to apply the same priciple to a convex lens, we see a problem.



Here, the light never seems to converge after it leaves the surface fo the mirror (remember: we are concerned only with the rays leaving the surface). In this case, we can see that a convex mirror has a virtual focus, located behind the surface.



After reflection, the light appears to have come from that one point behind the mirror.

- Therefore, a concave mirror has a real focus and a positive focal length while a convex mirror has a virtual focus and a negative focal length.

The concave mirror is sometimes called a diverging mirror, since light that comes into it is spread out after reflection.

Geometry will tell us something that both mirrors have in common. It can be proved (but we won't), that the focus of a spherical mirror is always located at (1/2) of the radius. Thus:

$f = r/2$ (only for spherical mirrors).

Solving Mirror Problems

After our in depth discussion, we can now easily do sample problems with mirrors. We only need one more piece of information: the main formula. Its derivation is rather intense, so we present it here without proof. For all mirrors, the following relation holds:

$$1/i + 1/o = 1/f$$

A few warnings here: remember to watch your signs and remember that this is a "one over" formula, this does not mean $i + o = f$!

The answer to all problems in this chaper where you are asked to find the image of an object will consist of four parts. You need to include all four parts in your answer. They are:

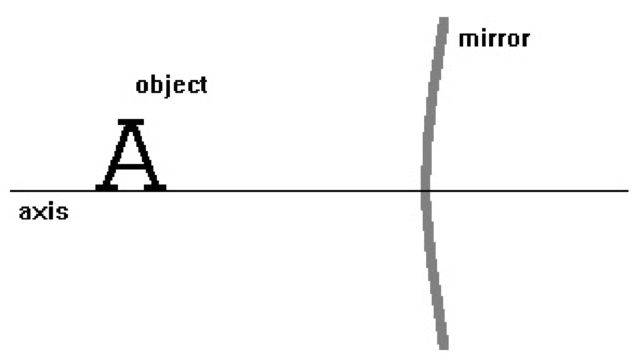
- The image distance.
- The magnification of the image ($m = -i/o$)
- Whether the image is real or virtual.
- Whether the image is erect (upright) or inverted.

The last answer has not yet been discussed, but suffice it to say that some images are upside down and some are right side up. If the magnification is negative, the image is upside down, if it is positive, the image is erect.

EX BRO.) Find the image of an object located at a.) 5 cm, b.) 15 cm, and c.) 25 cm from a concave mirror of radius 30 cm. Draw a sketch of each situation.

EX YGG.) Find the image of an object located at a.) 10 cm, and b.) 30 cm from a convex mirror of focal length 15 cm. Draw a sketch for each situation.

These mirror problems can also be solved graphically, using scale drawings (these must be done with care, involving a ruler and some patience). In these cases we always assume (to simplify things) that the bottom of the object is on the axis of the mirror (the axis is the line that passes through the middle section of the mirror.



We have already discussed the steps needed to locate an image. We need to find two rays from the top of an object and one ray from the bottom (or some other point). It turns out that there are four special rays that are very easy to trace in these situations. Let us see if you can discover them by doing sample problems.

EX GBV.) Trace out the path of a light ray that leaves the top of an object and strikes the mirror exactly at the axis. (Do this for both convex and concave mirrors.)

EX WLO.) Trace out the path of a light ray that leaves the top of an object and passes through the center of curvature of the mirror. (Do this for both convex and concave mirrors. On the concave mirror, do this twice, once for an object outside the radius and once for an object inside the radius.)

EX AFR.) Trace out the path of a light ray that leaves the top of an object and travels to the mirror parallel to the axis. (Do this for both convex and concave mirrors.)

EX UHX.) Trace out the path of a light ray that leaves the top of an object and passes through the focus of the mirror. (Do this for both convex and concave mirrors. For concave mirrors, do this twice, once for an object inside the focal lenght and once for an object outside the focal length.)

Special Rays for Ray Tracing

To summarize:

- A ray that strikes the axis is reflected down at the same angle that it was incident.
- A ray that passes through (or is headed for, or appears to come from) the radius is reflected back on itself.
- A ray that travels parallel to the axis is reflected back through (or away from) the focus.
- A ray that passes throught the focus (or is headed for the focus, or appears to come from the focus) is reflected back parallel to the axis.

The way we solve these problems is simply to draw a scale diagram of the situation, draw in some object (most books use an arrow) at the proper location with its base on the axis, draw any two (or more) or the specail rays and then draw in the object (why only two? where is the bottom of the object located?). For the final answer, your measure the image distance, either find magnification by measuring height of image and object or using -i/o, determining if it is real or virutal by examining the diagram and finding if it is erect or inverted by examinging the diagram.

For practice, let us repeat the previous examples, now solving them graphically.

EX BRO.) Find the image of an object located at a.) 5 cm, b.) 15 cm, and c.) 25 cm from a concave mirror of radius 30 cm. Draw a sketch of each situation.

EX YGG.) Find the image of an object located at a.) 10 cm, and b.) 30 cm from a convex mirror of focal length 15 cm. Draw a sketch for each situation.

Conclusions Regarding Mirrors

In order to make some conclusions regarding images formed by mirrors, I would like to challenge the student to finish the following statements as best as they can. Be careful, remember: always means in all situations.

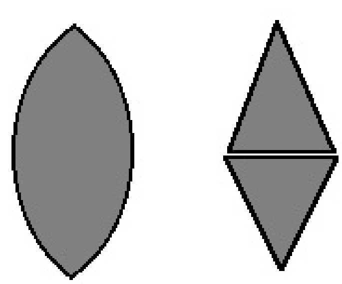
- Images formed by a convex mirror are always...
- Images formed by an object inside the focal length of a concave mirror are always...
- All virtual images are...
- All inverted images are...
- All real images are...

At this point the student might be wondering what purpose these different mirrors serve. First let us consider a concave mirror, which magnifies objects. Two main purposes come to mind: the first is telescopes and the second is vanity or "make-up" mirrors. The next type of mirror, a convex, diminishes objects. The benefit to this is that a greater field of view (the amount of landscape viewable in a mirror) is afforded by such a mirror. Most passenger side mirrors are fomed like this, so that the driver can see more area than if a flat mirror was used (why the warning so often printed on these mirrors?). Likewise you sometimes see these mirrors installed at the corner of alleys or streets so that a driver can tell if another car is approaching.

Thin, Spherical Lenses

With our knowledge of how to analyze the behavior of light when it reflects off of a mirror, we can turn to lenses. We will find that lenses and mirrors have many of the same properties, but naturally they have some differences also.

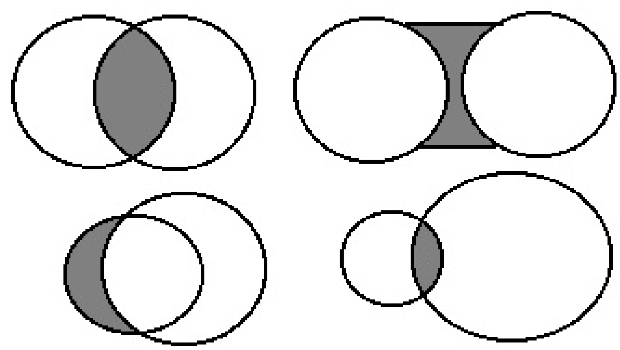
Firstly, lenses redirect light by using the principle of refraction instead of reflection. Lenses can actually be thought of as modified prisms used in combinations. For example, the lens below refracts light in much the same was as two prisms would.



The main difference being that the lens more gradually sloping sides.

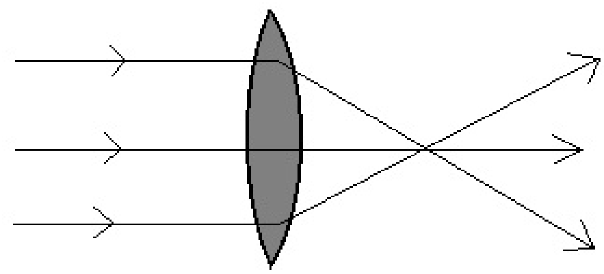
In our discussion of lenses, we will restrict ourselves to thin, sperical lenses. All of our equations (as in the past) will be approximations that only hold true if we consider our lenses to be "thin". Technically, this means that the thickest part of the lens must be small in comparison to the other measurements considered (o, i, f). Thick lenses present more difficulty and should not be dealt with by approximations.

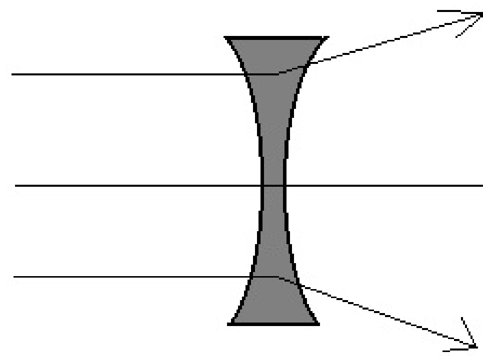
We are also going to limit ourselves to spherical lenses. Once again, most high quality lenses are parabolic, not spherical, but in many cases the difference is small. Spherical lenses are those that are created with surfaces that are sections of a sphere. Below are a number of examples of how to use two different spheres to create lenses. The lenses are in grey.



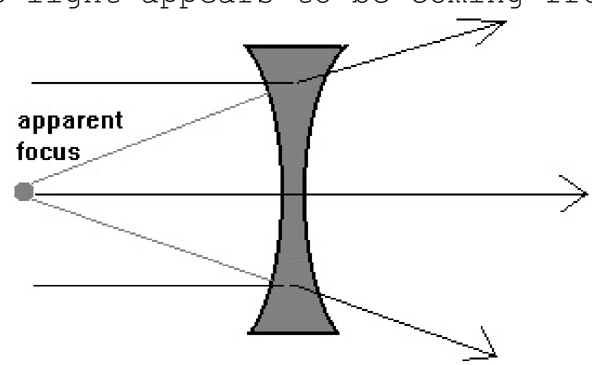
As can be seen from the last two examples, the two spheres that make up the lenses need not be of the same radii. This poses a small problem, since when we dealt with mirrors, we only used one radius. We will see that the only thing we need to use the radius for in the case of lenses is to calculate the focal distance.

The top two lenses in the diagram are the most popular lenses to solve problems with. Often they are called a convex and concave lens, respectively. However, the student can see (in the third example) that some lense have both concave and convex sides. Because of this, it is impractical to describe lenses as concave or convex. Instead, we usually describe a lens according to what it does with the incoming light. Lenses are usually termed either converging or diverging lenses. The situations are shown below.



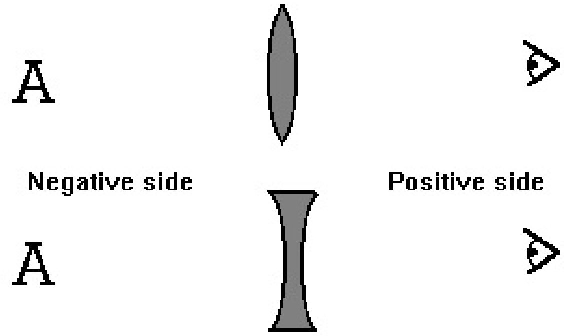


These diagrams should lead us to think about the focal length of a lens. The top lens (the converging lens) makes it obvious that a focal length exists where the light from infinity comes together. The diverging lens, however, is not so obvious. If we recall how we discussed mirrors, we can see that in the case of the diverging lens, we have a focus where the light appears to be coming from:



Indeed, the focal point of a converging lens is located on the same side of the lens as the object. When we dealt with mirrors, diverging focal lengths were negative and converging lengths positive. The same is true for lenses.

- <u>With the exception of the object distance, all measurements on the same side of the lens as the object are negative and all measurements on the other side (the observers side) are positive.</u>



The student should keep this in mind, it will be important for solving problems. The exception (as stated) is that the object distance will always be positive.

Before we can calculate the focal length of a lens, there is one more difference between lenses and mirrors that must be discussed. Lenses work by refraction (as previously stated) and refraction depends not only on the index of the material the light is entering, but also the material that light is exiting from. In other words, light bends differently going from air to glass than it does going from water to glass. The focal length of a lens must therefore be a function of the both the index of refraction of the lens and of the material by which it is surrounded.

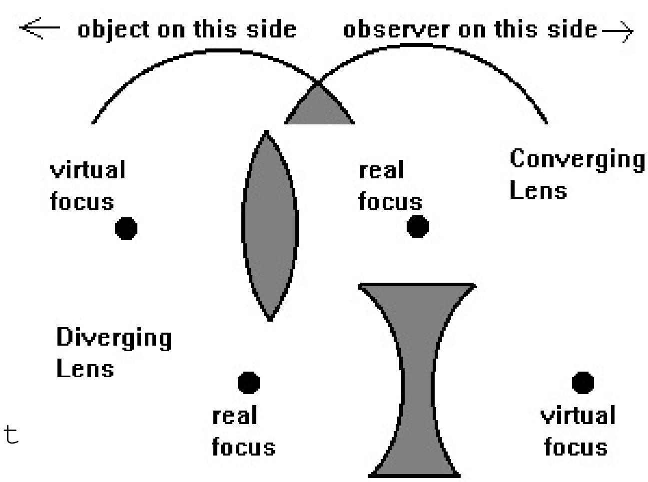
Something called "the Lensmaker's Formula" is used to calculate the focal length of a lens.

$$1/f = (n-1)(1/r_1 - 1/r_2)$$

where

$$n = n_{lens}/n_{medium}$$

To use this formula, we need to distinguish between r_1 and r_2. These refer to the radii of curvature of the sphere that made up each face of the lens. The first surface that the light hits is considered to be the surface to which r_1 applies and r_2 is then the surface from which the light exits.



Notice, however, that

if you get them mixed up, the only thing that changes is the sign of the focal length. This leads us to an interesting and important conclusion: lenses have TWO focal points, one on each side of the lens. Each one has the same focal length, and each has a purpose. In reality, lenses are only considered to have one focal point, I will call the second point the "virtual focus".

At this point I want to remind the student that although we have always been drawing double convex lenses for converging and double concave lenes for diverging, combinations of convex and concave lenses can produce a lens that falls into either of those categories.

Solving Lens Problems

It turns out that our old formula,

$$1/i + 1/o = 1/f$$

works for thin spherical lenses, just as it did for mirrors. This, along with the lensmaker's formula, should be all you need to begin to do problems.

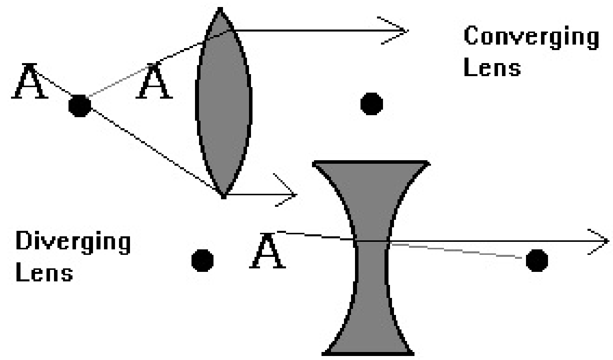
EX QGN.) For a double convex lens with r_1 = 35 cm and r_2 = 43 cm, made out of material with n = 1.56, find the image of an object 60 cm in front of the lens. Do so for the lens being submerged in air and again in water. Draw a sketch illustrating each case.

EX QGO.) For a double concave lens with r_1 = 35 cm and r_2 = 43 cm, made out of material with n = 1.56, find the image of an object 60 cm in front of the lens. Draw a sketch illustrating the situation.

What remains here is for us to investigate ray drawing for lenses. This is handled the same way as it was for mirrors, but we must once again figure outwhere each ray goes. In this case there are only three special rays, and only one of them (perhaps two, for the astute student) is simple enough to leave to the students to determine.

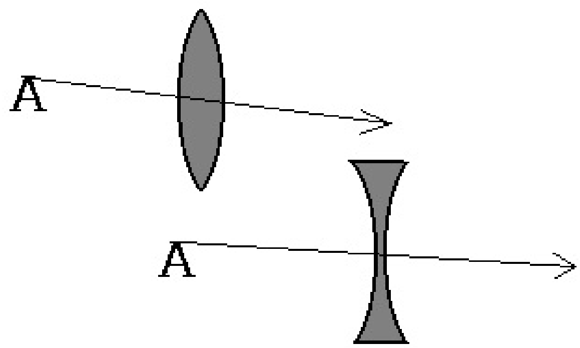
EX IJD.) Draw where a ray that leaves an object parallel to the axis ends up after passing through a.) a converging lens and b.) a diverging lens.

The reverse situation is a little more difficult to figure out. If a ray passes through (or attempts to pass through, or appears to come from) the virtual focus, it will be be refracted parallel to the axis. The three case of this are illustrated below.



The grey lines indicate parts of the rays that are not really there, but must be shown to indicate the pattern.

The last ray takes into account our approximation of "thin lenses". If a ray strikes the lens at the axis in the center of the lens, we can assume that both sides of the lens in that area are nearly flat. Because of this, the light ray leaves the lens undflected.



To summarize:

- A ray that passes through (or attempts to pass through, or appears to come from) the virtual focus, goes off parallel to the axis.
- A ray that comes in parallel to the axis, leaves through the real focus (or appears to leave from the real focus).
- A ray that strikes the lens at the axis will leave undeviated.

Now we will attempt to use these to solve some image problems. Do each problem with ray tracing diagrams and then verify mathematically.

EX PKJ.) Locate the image of an object that is 45 cm in front of a double convex lens with a focal length of 25 cm.

EX ECV.) Locate the image of an object 45 cm in front of a diverging lens with f = 25 cm.

EX RUY.) Locate the image of an object that is 10 cm in front of a converging lens with f = 25 cm.

The Human Eye

Like microscopes and telescopes, the human eye is an incredible optical instrument. It consists of a compound lens system (made up of the cornea, the aqueaous humor and the lens), the retna (where the light is interpreted by rods and cones and a signal is sent to the brain) and the ciliary muscles (which control the lens. Light from objects enters the eye and is refracted as it passes from the air into the cornea and then refracted more as it passes through the aqueous humor and through the lens. Most of the refraction occurs at the air-cornea interfaces, and only about 25% of the refraction occurs because of the lens.

To form a sharp image on the retna, the ciliary muscles must adjust the lens to change its focal length. Consider that the eye has a fixed image distance (lens to retna) and the image determines its distance. The only thing left to change would be the actual focal length of the lens if a clear image is to be formed. When the ciliary muscle is relaxed completely, the eye is set to focus objects at its “far point”, the greatest distance away someone can see clearly (for most people this is infinity). When the ciliary muscles are tensed up, the eye is focused at its near point, the closest that someone can view something (this is usually around for 25 cm for people in their 20s and increases with age sometimes up to 5 or 6 meters).

If someone is nearsighted, that means that they can see things clearly when they are near, but not when they are far away. This occurs when the relaxed ciliary muscles do not allow the image to be clearly focused on the retna. Instead, an image from infinity is formed in front of the retna. This is corrected by diverging lenses, that spread the light apart and make a virtual image that is closer to the eye. The eye can correctly focus on the virtual image. For the correction to work properly, the virtual image must be created at the far point of the person, since this is where they can see clearly with the ciliary muscle relaxed.

Farsightedness occurs when the image formed by the tensed ciliary muscles is behind the retna. This means that people with farsightedness can see far things clearly and cannot focus on things near their eyes. This is corrected by using a converging lens to create a virtual image of a near object at a point behind its actual location. To do this properly, the image should be formed at the near point of the eye.

Optical Systems

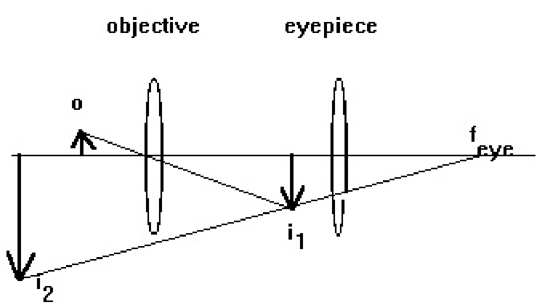
Optical systems are systems that consist of two or more lenses used together. In such a situation, the lens closest to the object is called the objective and the lens near the eye is called the eyepiece. Calculating the location of the final image for an optical system is simply a matter of using the image formed by the objective for the object of the eyepiece. For example:

EX KIJDE.) Graphically and mathemataically locate the image of an object that is 65 cm from an eyepiece of f=20 cm that is separated from an eyepiece of f=-20 cm by a distance of 25 cm.

Three such examples of optical systems to briefly discuss are magnifying glasses, compound microscopes, and telescopes. Consider trying the see a small object clearly. It would make sense to move the object as close to the eye as possible in order to see it as "large" as possible. However, the nearest a person can get is at their "near point". If a converging lens is placed near the eye, the object can be brought closer, since the eye will actually focus on the virtual image produced by the lens instead of the object. The net result is that the object will look larger. Such a device is called a microscope.

It is possible to improve on this set up, by using another lens to premagnify the object before the magnifying glass can see it. In other words, to magnify the object and produce a larger image which is then magnified by the eyepiece. Such a device is called a compound microscope. In a microscope, the objective lens creates a virtual, magnified image that is located just inside the focal length of the eyepiece. The eyepiece then acts as a magnifiying glass, producing another virtual, inverted image that the eye percieves.

For a telescope, the situation is somewhat similar, but in this case, the object is at infinity. This cases the image created by the objective lens to be at its focal point. In a telescope, the distance between the two lenses equals the sum of thier focal points. Thus if the image is formed at the focal point of the objective, then the image is also at the focus of the eyepiece, producing a magnified image that can be viewed with a “relaxed” eye.



Assignment #376

1.) Determine the location of the image of an object located 10 cm from a concave mirror with a focal length of 4 cm. (L21)

2.) If the object distance of a particular lens is 30 cm and the image distance is 45 cm, what is the focal length of the lens ? (L9)

3.) Suppose you wished to correct a persons eyesight by using a lens of focal length 4.3 cm. What radii of curvature should be used ? (assume both the radii on the lens will be equal and that the glass will have an index of refraction of n = 1.67) (L4)

For the problems below you are to find the image distance, state whether the image is real or virtual, determine the magnification, and state whether the image is inverted or erect. You should determine your answer in two fashions, numerically (using the formulas) and graphically (by drawing scale diagrams). (L3)

4.) Find the image of an object that is 5 cm from a concave mirror with a radius of curvature of 6 cm. (L3a)

5.) Find the image of an object that is 5 cm from a convex mirror with a focal length of 6 cm.(L3b)

6.) Find the image of an object that is 20 cm from a double convex lens that has a radius of curvature of 34 cm on both sides and is made of glass with an index of refraction of n = 1.67. (L3c)

7.) Find the image of an object that is 50 cm from a double concave lens that has a radius of curvature of 30 cm on both sides and is made of glass with an index of refraction of n = 1.67. (L3d)

8.) Consider a double convex lens with r_1 = 30 cm and r_2 = 40 cm (these are distances only, no signs included) constructed of glass with an index of refraction of 1.67. (a.) What is the focal length in air ? (b.) What is the focal length in water (n = 1.33) ? Graphically locate the image of an object that is 50 cm in front of the lens (c.) when it is in air and (d.) when it is in water. (L10)

Lab# 16 - Thin Lenses

In this lab you will find the focal length of a thin lenses by measuring the image distances for a number of different object distances.

Procedure:

Converging Lens

1.) Set up the optical bench as instructed.

2.) Postition the candle 40 cm from the lens and record this as your object distance.

3.) Move the screen back and forth until a clear image of the candle flame is formed on the screen. The image distance is the distance from the lens to the image (watch your signs).

4.) Repeat this procedure for object distances of 50, 60, 70, and 80 cm.

5.) Make a graph of 1/i versus 1/o. Be careful when graphing this - watch your scale.

6.) Determine the slope of your graph and compare it to the accepted value, then determine the focal length from your answer.

7.) A quick way to determine the focal length of a lens is to find the image for an object that is very far away. Hold the lens as shown in figure 2 and move the paper until a clear image of the light bulb is formed on the paper. The focal length of the lens is then the distance from the lens to the paper.

8.) Using the length found in step 7 as your accepted, determine the percent error of the focal length obtained from your graph.

9.) Repeat the entire procedure using a second lens.

Diverging Lens

1.) You will now try to repeat the above procedure using a diverging lens. Remember, however, that you cannot form an image from a diverging lens on a screen. You can form the image of the image by using a converging lens of know focal length. Attempt to do so and find the focal length of the diverging lens by graphing (as was done with the converging lens).

Activity #654 - Telescope and Microscope

In this activity, you are given two lenses and asked to construct a microscope and an astonomical (refracting) telescope. To do so, you must first accurately know the focal lengths of each lens.

Procedure:

Telescope

1.) Determine the focal length of each lens by finding the image of an object at infinity (the distance from the lens to the image should be the focal length).

2.) As explained in the chapter, the first lens must form an imgae at the focal point of the second lens. Position the lenses so that the total distance between them is equal to the sum of the thier focal lengths.

3.) View some object far away through your telescope. Comment on the success of the telescope and the quality of the image formed.

Microscope

1.) As explained in the chapter, the first lens must form an image inside the focal length of the second lens (eyepiece). Arrange the two lenses so that this is the case (you will need to set an image distance).

2.) View an object and comment on the success and quality of the image.