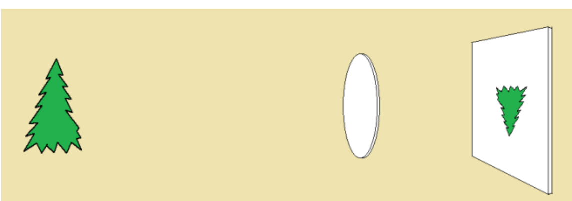
Lenses & Telescopes

Equipment	Number
Optical Bench	1
Converging Lenses	3
Diverging Lens	1
Concave/Convex Mirror	1
Light Source	1
Screen	1
Small Screen	1
Power Supply	1

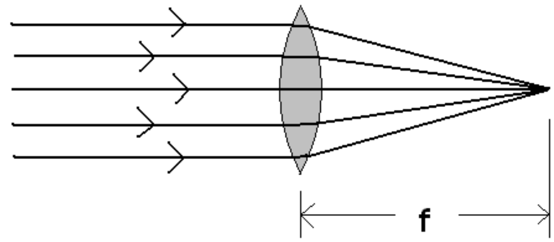
An image of an object can be formed simply by placing a glass lens between it and a screen, and adjusting the relative distances properly. Many telescopes work this way, as do cameras and the eyes of vertebrates.



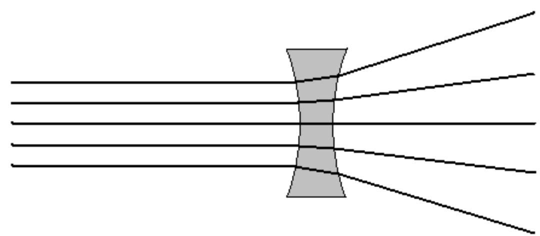
Let's call the distance between the object and the lens the **object distance** and symbolize it by d_o. The distance between the lens and the image will be called the **image distance**, and will be symbolized by d_i. The image will be in focus when the following relation is true.

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

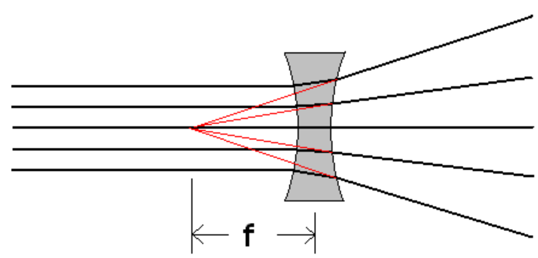
f is a property of the lens that's called its **focal length**. When parallel light rays pass through the lens, they are refracted and converge to a point at distance f from the lens's far side.



This type of lens is called a **converging lens**, and has (usually two) **convex surfaces**. Similarly, a lens with **concave surfaces** functions as a **diverging lens**.

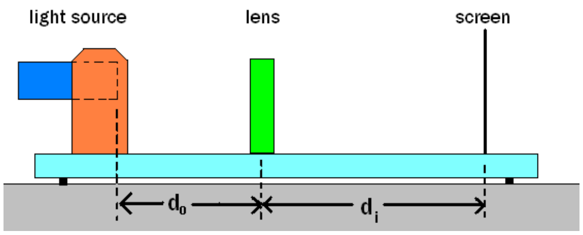


A focal length can be assigned to a diverging lens, but its value is negative, because the ray lines must be traced back to the focal point.



Measurement of Focal Length

We'll use the focal length equation to determine the focal length of several lenses.



The figure shows the basic setup of how this is done. The optical bench has a measuring scale with which d_o and d_i can be measured. The object in our experiments is the lighted figure on the light source. An image of this figure can be focused on the screen by adjusting the positions of one or more of the three items on the bench.

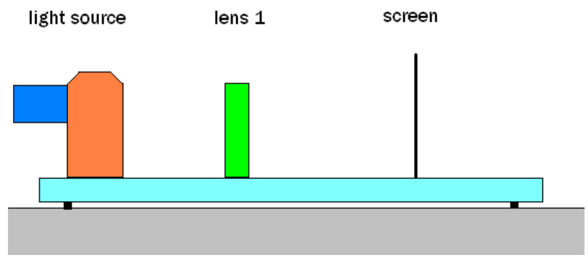
Procedure

1. Using the setup above, find d_o and d_i for each of the converging lenses. In each case, a clear image of the object must appear on the screen. If you can't get a clear image, try moving the lens and screen until you can get one.
2. For each lens, use the equation to calculate f.
3. Taking the listed focal lengths as the correct values, find the percent errors for your determinations.

Lens	d_o	d_i	f	% error
100 mm				
200 mm				
250 mm				

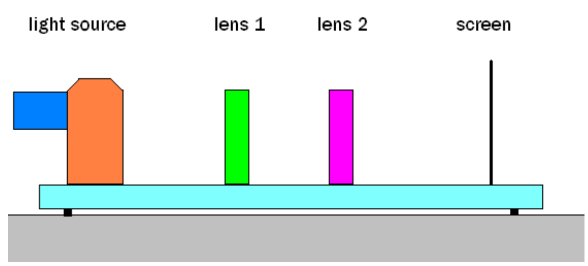
Finding the Focal Length of the Diverging Lens

The diverging lens, by itself, will not form an image because the rays do not focus. But it can be used together with converging lenses to make images. One application is the **Galilean Telescope**, which is the subject of the section after this one.

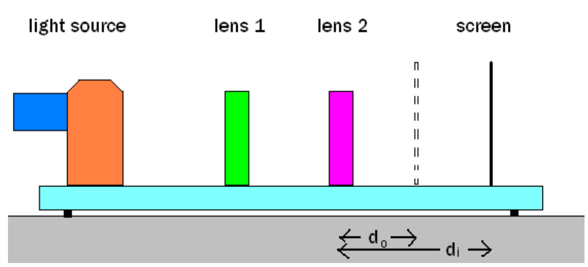


Procedure

1. Setup the light source, 100 mm lens, and screen, and focus the image (figure above). The 100 mm lens should be about 25 cm from the light source.
2. After adjusting the screen's position so that the image is clear, mark the position of the screen with a piece of tape.
3. Pull the screen away about 15 cm and put the diverging lens between the 100 mm lens and the tape.



4. Adjusting the position of the diverging lens until the image is once again clear.



5. Since the light has already gone through the 100 mm lens, an image has been formed at the former position of the screen. This serves as the *object* for the diverging lens, and so d_o is the distance from the diverging lens to the position of the tape. Note that this has a negative value since it's beyond the diverging lens.

$$d_o = \_\_\_\_\_\_\_\_\_$$

6. The image distance d_i for the diverging lens is then the distance from the lens to the present position of the screen.

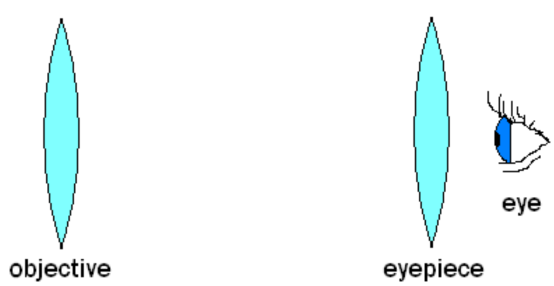
$$d_i = \_\_\_\_\_\_\_\_\_$$

7. Use the same focal length equation to calculate f. Remember that d_o is negative, which will cause f to also be negative. $f = \_\_\_\_\_\_\_\_\_$
8. Find the percent error between your value for f of the diverging lens and the value that is indicated on it.

$$\%\ err = \_\_\_\_\_\_\_\_\_$$

Building a Telescope With an Eyepiece

A camera or a telescope with a detector device needs only a single focusing element (lens or mirror) and a detector fixed in the plane where the image forms. But if the intent is to look through the telescope, an additional lens is called an **eyepiece** is required.



If the focal lengths of the two lenses are different from each other, then the object will appear different in size when viewed through the telescope. The telescope's **magnification** is the ratio of its apparent size viewed through the telescope to its apparent size viewed normally.

$$Mag = \frac{f_o}{f_e}$$

f_o is the focal length of the **objective** (the main focusing lens) and f_e is the focal length of the **eyepiece**. So, if for example the objective focal length is 500 mm and the eyepiece focal length is 100 mm, the magnification will be 5, meaning that the object will appear 5 times bigger.

Procedure

1. Remove all items from the bench.
2. Place the 250 mm lens at the 90 cm mark.
3. Place the 100 mm lens at the 55 cm mark. This is done because the distance between the lenses should be the sum of their focal lengths.
4. Pick up the bench and place it over your shoulder so that the eyepiece is near your eye and your line of sight goes through both lenses.
5. Look at a clearly resolvable object, like the wall clock. Try to view it with one eye through the telescope and the other eye normally (simultaneously).
6. Superimposing the two images, it should be possible to estimate the diameter ratio of the two. This provides an estimate of the magnification.

$$Est\ Mag = \_\_\_\_\_\_\_\_\_$$

7. Now calculate the theoretical magnification using the equation mentioned above.

$$Theo\ Mag = \_\_\_\_\_\_\_\_\_$$

Galilean Telescope

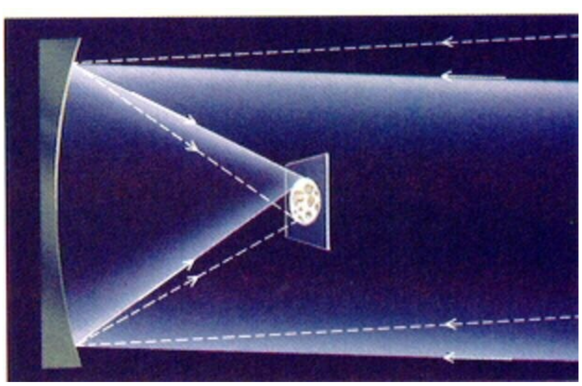
A diverging lens can be used as the eyepiece in a telescope, and this is the type of eyepiece that Galileo used when he made so many important astronomical discoveries.

1. Remove all items from the bench.
2. Place the $250\ mm$ lens at the $90\ cm$ mark and the diverging lens at the $80\ cm$ mark.
3. Pick up the bench and place it over your shoulder so that the eyepiece is near your eye and your line of sight goes through both lenses.
4. Use the same method that you did with the other telescope to estimate the magnification of this telescope.

   $Est\ Mag =$ ________
5. The view through this telescope has a certain advantage over the view through the telescope you made earlier. What is this advantage?

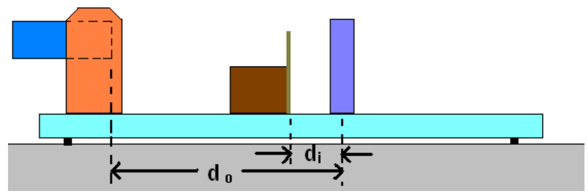
Focusing With a Concave Mirror

Most large astronomical telescopes don't use glass lenses to focus the light. They use concave mirrors, as in the figure below, and so they're known as **reflecting telescopes**.



You'll make an image using such a mirror.

1. Place the light source back on the bench, with the concave side of the mirror facing it.
2. Place the wooden block with its small screen between the light source and the mirror, as in the figure.



3. Focus the image on the screen by moving it with respect to the mirror.
4. Measure d_o, the distance from the object to the mirror, and d_i, the distance from the mirror to the image.

   $d_o =$ ________

   $d_i =$ ________
5. Use the focal length equation to calculate the focal length of the mirror.

   $f_m =$ ________