# THIN LENSES: THE MICROSCOPE

**OBJECTIVE:** To see how thin lenses are used in a microscope by designing, building, and using a simple microscope.

**THEORY:** The microscope works with two positive lenses to magnify something that is small but close. The final image is in fact bigger than the object, and the final image is located at the 'easy viewing' distance of ≈ 25 cm from the eye (and hence from the eyepiece lens).

[The telescope also works with two positive lenses to magnify something, but in this case the object is far away and the telescope actually only magnifies the angle that the image makes with the eye. Another way of saying this is that it makes the object seem closer than it actually is.]

In a microscope, the lens close to the object (called the *objective*), is used as a projector: it projects a real image that is bigger than the object; the object distance is small in comparison with the image distance, with both distances being positive. [You did this with a positive lens in the Thin Lenses: Basics experiment.] The second lens (called the *eyepiece*) is used as a magnifying lens. It takes as its object the image of the objective lens. However, instead of projecting a real image on the other side of the lens, the eyepiece lens creates a virtual image on the same side of the lens as its object. Most microscopes are designed so that this virtual image is seen at the easy viewing distance of 25 cm from the eyepiece. Hence, we need $s'_e$ to be -25 cm. [The eye then uses this virtual image as its object and acts as a camera to record an image on the retina of the eye.]

**PROCEDURE:**

1. Determine the focal lengths of the four lenses on your table: the nominal values of these four lenses are 50 mm, the white 100 mm, the black 100 mm, and the 200 mm. Do this for each lens by setting the lens about 2 times the nominal focal length of the lens from the object, and then adjust the screen so that the image is in focus. **Measure and record** the object distance, s, and the image distance, s'. ***Recall that the object distance is the distance from the object to the lens, and the image distance is the distance from the lens to the image (on the screen).*** Now use the thin lens equation, **$1/f = 1/s + 1/s'$**, to **calculate** the focal length. Do this for all four lenses, and **record** these focal lengths. **In all the following steps, use the values for f that you determined in this step, not the nominal values.**

2. The object for our microscope will be the tick marks on the object arrow that we used in our previous experiment with lenses. The small tick marks are 1 mm apart. **Place** the object at one end of the rail. We'll determine where to place the objective lens in the next step.

3. In our microscope, we want to have a magnifying power of 2 for the objective lens:

$$M_o = -s'_o / s_o = -2 \qquad (1)$$

We will use an objective lens with a focal length, $f_o$, of approximately +10 cm. Use the value for the focal length you obtained from Procedure #1. Recall that

$$1/f_o = 1/s_o + 1/s'_o \qquad (2)$$

From these two equations, knowing both M and $f_o$, **calculate** the necessary values for $s_o$ and $s'_o$ to give a magnification of -2. You have two equations for two unknowns, s and s'.

4. Using the $s_o$ value found in Step 3, **place** the objective lens a distance $s_o$ from the object.

5. Move the screen so that you can focus an image. **Measure and record** the image distance, $s_o$'.

6. Measure the image height, h', of the arrow, and knowing the object height = 3.0 cm of the arrow, **calculate** the magnification (**$M \equiv h'/h$**) and see if it is close to the desired 2X.

7. We now will use the other lens of approximately +10 cm focal length for the eyepiece. In this case we know $f_e$ for this lens from Procedure #1, and we want $s'_e$ = -25 cm. Thus, **calculate** the necessary $s_e$ using the thin lens equation ($1/f_e = 1/s_e + 1/s'_e$ ). Then **calculate** the magnification of the eyepiece ($M_e = -s'_e/s_e$ ).

8. Having recorded the screen position (location of the image) for the objective lens in step 5, remove the screen from the track, and **place** the eyepiece a distance $s_e$ (calculated in previous step) from the location of the image of the objective lens; the eyepiece should now be a distance $s'_o + s_e$ from the objective lens.

9. Look through the eyepiece so that you also look through the objective lens. If the light is too bright, you may turn off the light for the object. You should see the tick marks magnified by a total power of $M_{tot} = M_o \times M_e$ . You may have to adjust the focus by moving the eyepiece slightly (due to the lenses not having the exact focal lengths you determined because of experimental uncertainties). Verify that these two lenses do indeed act as a microscope, and then **calculate** the theoretical total magnification of this microscope. Note that as you adjust the distance your eye is from the eyepiece, you also adjust how much of the objective lens you can successfully look through. There should be a best eye to eyepiece distance to get the largest field of view.

10. To show that the objective lens does indeed create a real image and that this real image is roughly $M_o$ bigger than the object, **place** a ruler between the eyepiece and objective lens at a position approximately $s_e$ from the eyepiece (this should be the location where your 1$^{st}$ lens, the objective lens, first focused its image). You should see that both the ruler and the tick marks are in focus. Now compare the spacing of the tick marks with the spacing of the millimeter markings of the ruler. What does the tick mark spacing seem to be as measured by the ruler? Is the spacing in fact $M_o$ bigger than it really is on the object? (2 x 1 mm = 2 mm)?

11. Measuring the size of a virtual image is hard because the light does not really come from that place. Thus we will not try to verify the exact value of $M_e$. We can, however, **observe** that the eyepiece does indeed magnify the tick marks just as it magnifies the millimeter markings of the ruler.

12. **Note** whether the image of the object is inverted. Now note whether the eyepiece inverts the image of the ruler. From this, what do you conclude about whether the objective lens inverts the image? Is this consistent with how a projector lens works?

13. Keep both lenses you used above. **Repeat** Steps 2-10 but adjust the objective lens so that the microscope objective lens gives a magnification of -5 instead of -2.

14. Keep the objective lens as it is from step 13, but replace the eyepiece lens with the 50 mm nominal lens. **Repeat** Steps 7-10 but with the 50 mm lens as the eyepiece instead of the 100 mm lens. Keep the objective lens the same with the same 5X magnification.

**REPORT:**

1. Draw a diagram of the first microscope setup. On the diagram indicate the object, the objective lens, the eyepiece lens, and the eye. Also indicate the following distances: $s_o$, $s'_o$, $s_e$, and $s'_e$.

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For all three microscopes:

2. Show your calculations for $s_o$, $s'_o$ and $s_e$.

3. Show your calculations for $M_o$, $M_e$, and $M_{tot}$.

4. Record your observations and discuss the questions in Steps 10 and 12.

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5. When you look into some microscopes, you can see a set of cross-hairs or a ruled scale to measure sizes of features on your specimen (such a scale is called a *reticule*). Where are the actual cross-hairs or reticule placed in a microscope? (Contemplate Step 10.)

6. Comment on the differences in the fields of view and the difficulties of focusing using the microscope with the higher magnification.