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 \( \approx 25 \) 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. 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. Leave the lamp off.

2. In our microscope, we want to have a magnifying power of 2 for the objective lens:
   \[ M_o = -s'_o / s_o = -2 \]  (1)
   We will use an objective lens with a focal length of approximately +10 cm. Recall that
   \[ 1/f_o = 1/s_o + 1/s'_o \]  (2)
   From these two equations, calculate the necessary \( s_o \) and \( s'_o \) values.

3. Using the \( s_o \) value found in Step 2, position the objective lens a distance \( s_o \) from the object.

4. We now will use another lens of approximately +10 cm focal length for the eyepiece. In this case we know \( f_e = +10 \) cm, 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 \( (M_e = -s'_e/s_e) \).

5. Now position the eyepiece a distance \( s'_o + s_e \) from the objective lens.

6. Look through the eyepiece so that you also look through the objective lens. 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 exactly 10 cm focal length). 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.

7. 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 $s_o$ from the eyepiece. 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)?

8. To measure 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.

9. 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?

10. REPEAT Steps 2-10 but adjust the lenses so that the microscope objective gives a magnification of -5 instead of -2.

11. REPEAT Steps 4-10 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 $s'_e$.

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. Show your calculation to verify $M_o$ from Step 7.

5. Record your observations and discuss the questions in Step 9.

6. 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 7!)

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