

Experiment 14: Virtual Images

Required Equipment from Basic Optics System

Light Source
Bench
-150 mm lens
+200 mm lens
Viewing screen
Concave/convex Mirror
Half-screen

Other Equipment

Tape

Purpose

In this experiment, you will study virtual images formed by a diverging lens and a convex mirror.

Theory

A virtual image cannot be viewed on a screen. It forms where the backwards extensions of diverging rays cross. You can see a virtual image by looking at it through a lens or mirror. Like all images, a virtual image formed by a lens or mirror can serve as the object of another lens or mirror.

Notation

d_{i1} = image distance for lens #1

d_{o2} = object distance for lens #2

Part I: Virtual Image Formed by a Diverging Lens

In this part, you will set up a diverging lens to form a virtual image. You will then use another lens to form a real image of the virtual image. In this way you can identify the location of the virtual image.

Procedure

1. Place the -150 mm lens on the bench at the 30 cm mark. ** Use photo to estimate an error on d_i & d_o*
2. Place the light source at the 10 cm mark with the crossed-arrow object toward the lens.
3. Record the object distance d_{o1} (the distance between the light source and the lens) in Table 14.1.

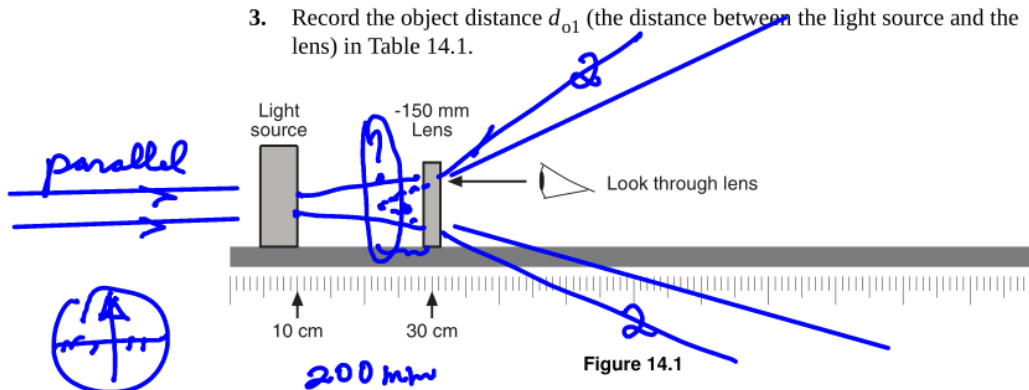


Figure 14.1

4. Look through the lens toward the light source (see Figure 14.1). Describe the image. Is it upright or inverted? Does it appear to be larger or smaller than the object?

Placing a screen where your eye is will confirm no real image is generated.

5. Which do you think is closer to the lens: the image or the object? Why do you think so?

6. Place the +200 mm lens on the bench anywhere between the 50 cm and 80 cm marks. Record the position here. _____

7. Place the viewing screen behind the positive lens (see Figure 14.2). Slide the screen to a position where a clear image is formed on it. Record the position here. _____

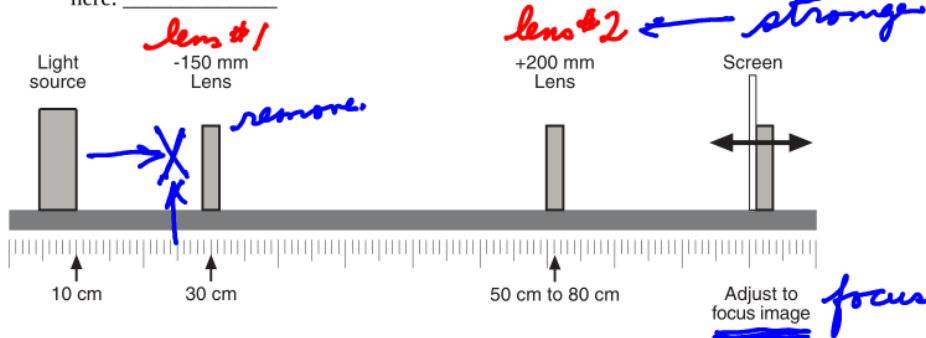


Figure 14.2

The real image that you see on the screen is formed by the positive lens with the virtual image (formed by the negative lens) acting as the object. In the following steps, you will discover the location of the virtual image by replacing it with the light source.

- * 8. Remove the negative lens from the bench. What happens to the image on the screen? _____

9. Slide the light source to a new position so that a clear image is formed on the screen. (Do not move the positive lens or the screen.) Write the bench position of the light source here. _____

Demonstration + photos.

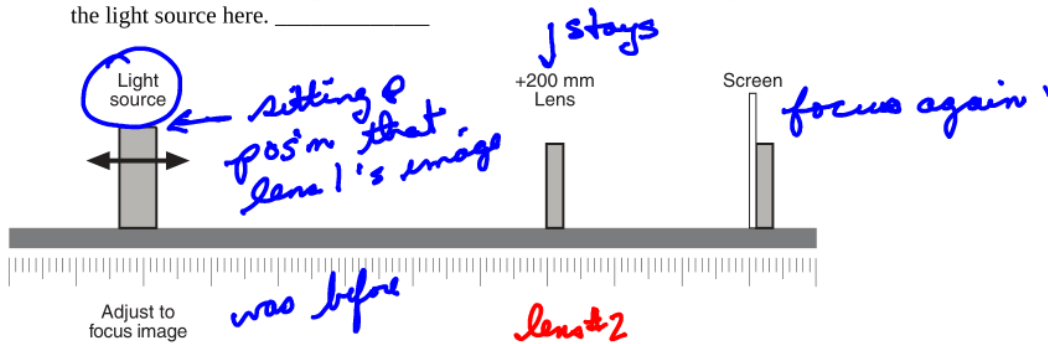


Figure 14.3

Error: Combine using adding/subtracting multiply/dividing rules.

Analysis

The current position of the light source is identical to the previous position of the virtual image.

1. Calculate the virtual image distance d_{i1} (the distance between the negative lens and the virtual image). Remember that it is a negative. Record it in Table 14.1.
2. Calculate the magnification and record it in Table 14.1.

(eq. 14.1)

$$M_1 = -\left(\frac{d_{i1}}{d_{o1}}\right)$$

$d_i \equiv s'$
 $d_o \equiv s$

Table 14.1: Negative Lens

d_{o1}	
d_{i1}	
M_1	

All values pertain to lens #1, not the image on the screen due to the converging lens #2

Questions

1. How do you know that the current position of the light source is identical to the position of the virtual image when the negative lens was on the bench?
2. In step 5 of the procedure, you predicted the position of the virtual image relative to the light source. Was your prediction correct?
3. Is M_1 positive or negative? How does this relate to the appearance of the image?
4. Draw a scale diagram showing the light source in its original position, both lenses, the screen, and both images. Label every part.
5. Draw another diagram at the same scale showing the light source in its final position, the positive lens, the screen, and the image.

Part II: Virtual Image Formed by a Convex Mirror

In this part, you will find the location of a virtual image formed by convex mirror.

Procedure

We can use the grid

1. ~~Stick a piece of tape~~ to the viewing screen and draw a vertical line on it as shown in Figure 14.4.
2. Place the half-screen on the bench near one end. Turn the screen so its edge is vertical (see Figure 14.5).
3. Place the concave/convex mirror on the bench, about 20 cm from the half-screen, with the convex side facing the half-screen.



Figure 14.4

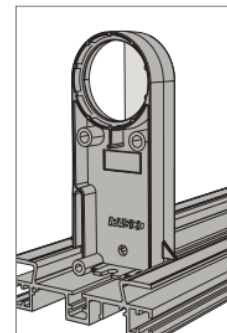


Figure 14.5

4. Look through the half-screen into the mirror. Describe the image of the half-screen. Is it upright or inverted? Does it appear to be larger or smaller than the object?

5. Guess where the image is. Place the viewing screen on the bench at this location (see Figure 14.6).

In the following steps, you will adjust the position of the viewing screen so that it is in the same place as the virtual image.

6. Look over the top of the half-screen (Figure 14.7a) so that you can see the virtual image of the half-screen and the line drawn on the viewing screen at the same time (Figure 14.7b).

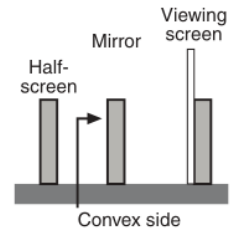


Figure 14.6

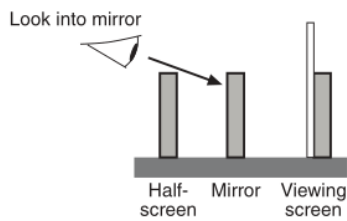


Figure 14.7a

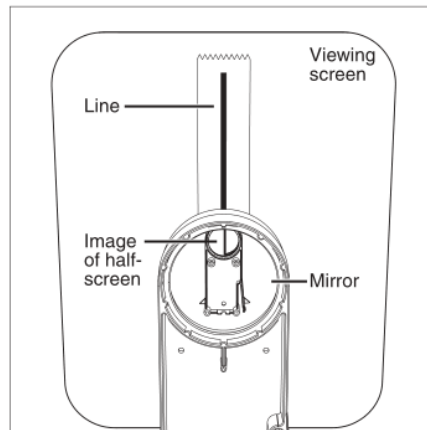


Figure 14.7b

7. Move your head left and right by a few centimeters. If the line on the viewing screen and the image of the half-screen are not at the same distance from your eye, they will appear to move relative to each other. This effect is known as parallax.
8. Adjust the position of the screen and check for parallax again. Repeat this step until there is no parallax between the line and the image. When you move your head, they should appear to be “stuck” together.

Analysis

The viewing screen is now in the same location as the virtual image.

1. Record the object distance d_o in Table 14.2.
2. Calculate the image distance d_i (the distance between the mirror and the virtual image). Remember that it is a negative. Record it in Table 14.2.

The mirror to screen difference.

3. Use d_o and d_i to calculate the magnification and record it in Table 14.1.

$$M = - d_i / d_o$$

d_i is negative

Table 14.2: Convex Mirror

d_o	
d_i	
M	



Questions

1. Is the magnitude of d_i less than or greater than d_o ? If you replace the convex mirror with a plane mirror, what would be the relationship between d_i and d_o ?
2. Is M positive or negative? How does this relate to the appearance of the image?
3. Draw a scale diagram showing the half-screen, mirror, viewing screen, and virtual image. Label every part.

Experiment 15: Telescope

Required Equipment from Basic Optics System

- Bench
- 2 Convex Lenses (+100 mm and +200 mm)
- Screen
- Paper grid pattern (see page 57), or a 14 × 16 grid of 1 cm squares
- +250 mm and -150 mm lenses (optional, for further study)

The diagram below has a very near object compared to normal telescope-use. This is to allow a table-top experiment.

Purpose

In this experiment, you will construct a telescope and determine its magnification.

Note that the lenses are manipulated to put the image formed by lens #2 @ the same location of the object for lens #1!

Theory

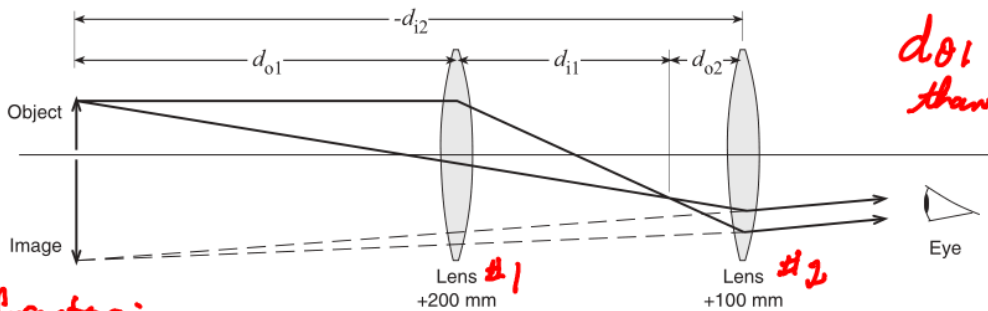


Figure 15.1

d_o1 must be larger than f_1. Why?

d_i2 is a negative value in this case.

What sign is d_i1?

Keplerian refractor: two converging lenses.

Galilean refractor: had a negative eyepiece lens.

An astronomical telescope consists of two convex lenses. The astronomical telescope in this experiment will form an image in the same place as the object (see Figure 15.1).

The lenses are thin compared to the other distances involved, which allows the Thin Lens Formula to be used:

(eq. 15.1)
$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

where f is focal length, d_o is the distance between the object and the lens, and d_i is the distance between the image and the lens.

The magnification, M , of a two-lens system is equal to the product of the magnifications of the individual lenses:

(eq. 15.2)
$$M = M_1 M_2 = \left(\frac{-d_{i1}}{d_{o1}}\right) \left(\frac{-d_{i2}}{d_{o2}}\right)$$

These negatives indicate an inverted image.

Set Up

1. Tape the paper grid pattern to the screen to serve as the object.
2. The +200 mm lens is the objective lens (the one closer to the object). The +100 mm lens is the eyepiece lens (the one closer to the eye). Place the lenses near one

end of the optics bench and place the screen on the other end (see Figure 15.2). Their exact positions do not matter yet.

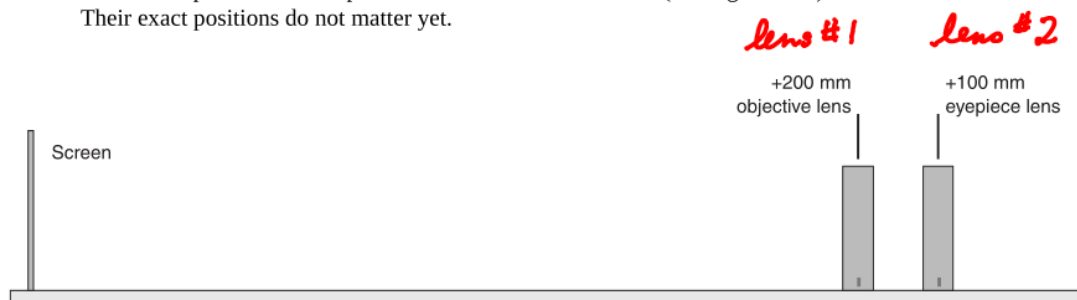


Figure 15.2

Procedure

1. Put your eye close to the eyepiece lens and look through both lenses at the grid pattern on the screen. Move the objective lens to bring the image into focus.

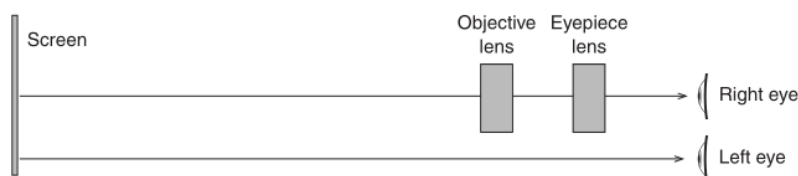


Figure 15.3

2. In this step, you will adjust your telescope to make the image occur in the same place as the object. To do this, you will look at both image and object at the same time and judge their relative positions by moving your head side to side. If the image and object are not in the same place, then they will appear to move relative to each other. This effect is known as parallax.

Open both eyes. Look with one eye through the lenses at the image and with the other eye past the lenses at the object (see Figure 15.3). The lines of the image (solid lines shown in Figure 15.4) will be superimposed on the lines of the object (shown as dotted lines in Figure 15.4). Move your head left and right or up and down by about a centimeter. As you move your head, the lines of the image may move relative to the lines of the object due to the parallax. Adjust the eyepiece lens to eliminate parallax. Do not move the objective lens. When there is no parallax, the lines in the center of the lens appear to be stuck to the object lines.

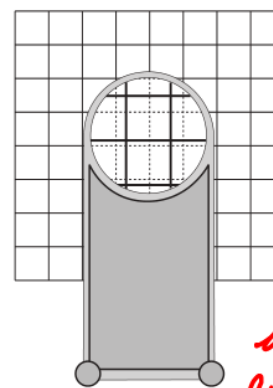


Figure 15.4

difficult to execute our eyes like to pick one or the other grid pattern.

Note: You will probably have to adjust the eyepiece lens by no more than a few centimeters.

3. Record the positions of the lenses and screen in Table 15.1.
4. Estimate the magnification of your telescope by counting the number of object squares that lie along one side of one image square. To do this, you must view the image through the telescope with one eye while looking directly at the object with the other eye. Remember that magnification is negative for an inverted image. Record the observed magnification in Table 15.1.

Analysis

To calculate the magnification, complete the following steps and record the results in Table 15.1:

1. Measure d_{o1} , the distance from the object (paper pattern on screen) to the objective lens.
2. Determine d_{i2} , the distance from the eyepiece lens to the image. Since the image is in the plane of the object, this is equal to the distance between the eyepiece lens and the object (screen). Remember that the image distance for a virtual image is negative.
3. Calculate d_{i1} using d_{o1} and the focal length of the objective lens in the Thin Lens Formula (Equation 15.1).
4. Calculate d_{o2} by subtracting d_{i1} from the distance between the lenses.
5. Calculate the magnification using Equation 15.2.
6. Calculate the percent difference between the calculated magnification and the observed value.

Table 15.1: Results

Position of Objective Lens	
Position of Eyepiece Lens	
Position of Screen	
Observed magnification	
d_{o1}	
d_{i2}	
d_{i1}	
d_{o2}	
Calculated Magnification	
Percent Difference	

Questions

1. Is the image inverted or upright?
2. Is the image that you see through the telescope real or virtual?

Further Study

Image Formed by the Objective Lens ✓

Where is the image formed by the objective lens? Is it real or virtual? Use a desk lamp to brightly illuminate the paper grid (or replace the screen with the light source's crossed-arrow object). Hold a sheet of paper vertically where you think the image is.

yes Do you see the image? Is it inverted or upright? ~~Remove the sheet of paper and hold a pencil in the same place. Look through eyepiece lens; you will see two images, one of the pencil and one of the grid pattern. Are both images inverted? Use parallax to determine the location of the pencil image.~~

~~Object at Infinity~~

~~Remove the screen and look through the lenses at a distant object. Adjust the distance between the lenses to focus the telescope with your eye relaxed. Estimate the observed magnification. Now calculate the magnification by taking the ratio of the focal lengths of the lenses. Compare the calculated magnification to the observed magnification.~~

~~How is the distance between the lenses related to their focal lengths?~~

~~Galilean Telescope~~

~~Make a new telescope using the -150 mm lens as the eyepiece and the +250 mm lens as the objective lens. Look through it at a distant object. Adjust the distance between the lenses to focus the telescope with your eye relaxed. How is the distance between the lenses related to their focal lengths?~~

~~How does the image viewed through this telescope differ from that of the previous telescope? Is the magnification positive or negative?~~

Experiment 16: Microscope

Errors on positions are large and difficult to quantify.

Required Equipment from Basic Optics System

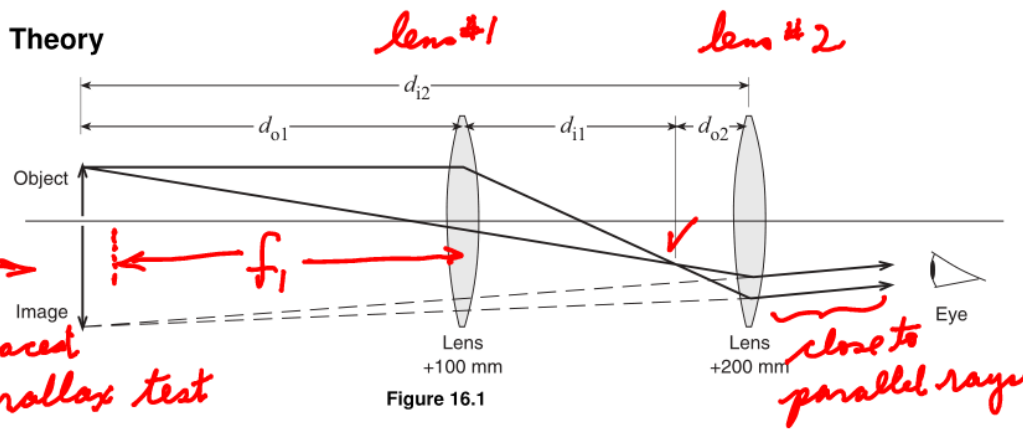
- Bench
- 2 Convex Lenses (+100 mm and +200 mm)
- Screen
- Paper grid pattern (see page 57), or a 14 × 16 grid of 1 cm squares

Hears text: "The object is just outside the objective's f distance."

Purpose

In this experiment, you will construct a microscope and determine its magnification.

Theory



A microscope magnifies an object that is close to the objective lens. The microscope in this experiment will form an image in the same place as the object (see Figure 16.1).

The lenses are thin compared to the other distances involved, which allows the Thin Lens Formula to be used:

(eq. 16.1)
$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

where f is focal length, d_o is the distance between the object and the lens, and d_i is the distance between the image and the lens.

The magnification, M , of a two-lens system is equal to the product of the magnifications of the individual lenses:

(eq. 16.2)
$$M = M_1 M_2 = \left(\frac{-d_{i1}}{d_{o1}} \right) \left(\frac{-d_{i2}}{d_{o2}} \right)$$

Set Up

1. Tape the paper grid pattern to the screen to serve as the object.
2. The +100 mm lens is the objective lens (the one closer to the object). The +200 mm lens is the eyepiece lens (the one closer to the eye). Place the lenses near the

middle of the optics bench and place the screen near the end of the bench (see Figure 16.2).

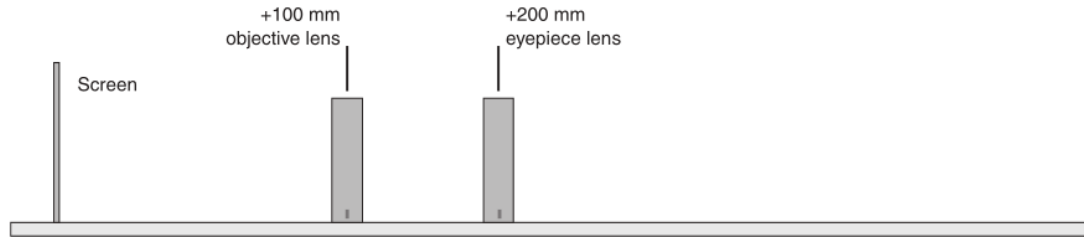


Figure 16.2

Procedure

1. Put your eye close to the eyepiece lens and look through both lenses at the grid pattern on the screen. Move the objective lens to bring the image into focus.

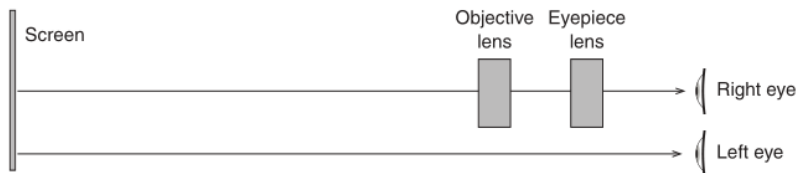


Figure 16.3

2. In this step, you will adjust your microscope to make the image occur in the same place as the object. To do this, you will look at both image and object at the same time and judge their relative positions by moving your head side to side. If the image and object are not in the same place, then they will appear to move relative to each other. This effect is known as parallax.

Open both eyes. Look with one eye through the lenses at the image and with the other eye past the lenses at the object (see Figure 16.3). The lines of the image (solid lines shown in Figure 16.4) will be superimposed on the lines of the object (shown as dotted lines in Figure 16.4). Move your head left and right or up and down by about a centimeter. As you move your head, the lines of the image may move relative to the lines of the object due to the parallax. Adjust the eyepiece lens to eliminate parallax. Do not move the objective lens. When there is no parallax, the lines in the center of the lens appear to be stuck to the object lines.

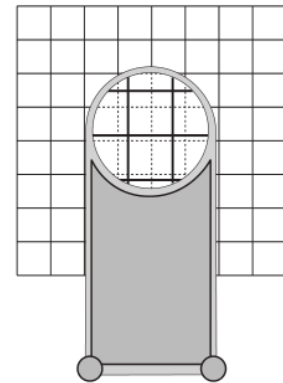


Figure 16.4

Note: Even when there is no parallax, the lines may appear to move near the edges of the lens because of lens aberrations. Concentrate on the part of the image seen through the centers of the lenses. Be sure that the eye looking at the object (the left eye in Figure 16.3) is looking directly at the object and not through the objective lens.

3. Record the positions of the lenses and the object in Table 16.1.
4. Estimate the magnification of your microscope by counting the number of object squares that lie along one side of one image square. To do this, you must view the image through the microscope with one eye while looking directly at the object with the other eye. Remember that magnification is negative for an inverted image. Record the observed magnification in Table 16.1.

Barrell distortion. Rays going through different parts of the lens are refracted differently.

Analysis

To calculate the magnification complete the following steps and record the answers in Table 16.1:

1. Measure d_{o1} , the distance from the object (paper pattern on screen) to the objective lens.
2. Determine d_{i2} , the distance from the eyepiece lens to the image. Since the image is in the plane of the object, this is equal to the distance between the eyepiece lens and the object (screen). Remember that the image distance for a virtual image is negative.
3. Calculate d_{i1} using d_{o1} and the focal length of the objective lens in the Thin Lens Formula (Equation 16.1).
4. Calculate d_{o2} by subtracting d_{i1} from the distance between the lenses.
5. Calculate the magnification using Equation 16.2.
6. Calculate the percent difference between the calculated magnification and the observed value.

Table 16.1: Results

Position of Objective Lens	
Position of Eyepiece Lens	
Position of Screen	
Observed magnification	
d_{o1}	
d_{i2}	
d_{i1}	
d_{o2}	
Calculated Magnification	
Percent Difference	

Questions

1. Is the image inverted or upright?
2. Is the image that you see through the microscope real or virtual?

Further Study

Image Formed by the Objective Lens

Where is the image formed by the objective lens? Is it real or virtual? Use a desk lamp to brightly illuminate the paper grid (or replace the screen with the light source's crossed-arrow object). Hold a sheet of paper vertically where you think the image is. Do you see the image? Is it inverted or upright? ~~Remove the sheet of paper and hold a pencil in the same place. Look through eyepiece lens; you will see two images, one of the pencil and one of the grid pattern. Are both images inverted? Use parallax to determine the location of the pencil image.~~

Increasing Magnification

While looking through your microscope, move the objective lens a few centimeters closer to the object. Which way do you have to move the eyepiece lens to keep the image in focus? How close can you move the objective lens and still see a clear image? (Make a pencil mark on the paper grid so you have something very small to focus on.) What is the theoretical limit to how close you can move the objective lens?

I only demo'd the fact that M magnification changes/increases.