

LABORATORY I: GEOMETRIC OPTICS

In this lab, you will solve several problems related to the formation of optical images. Most of us have a great deal of experience with the formation of optical images: they can be formed by flat or curved mirrors, water surfaces, movie projectors, telescopes, and many other devices. We can see because the cornea and a flexible lens in each eyeball form images on our retinas (sometimes with the aid of "corrective lenses," in the form of contacts or eyeglasses). Solving the problems in this laboratory should help you explain many of your daily experiences with images with the concept of light rays that travel from sources or illuminated objects in straight lines.

OBJECTIVES:

After successfully completing this laboratory, you should be able to:

- Describe features of real optical systems in terms of ray diagrams.
- Use the concepts of real and virtual images, as well as real and virtual objects, to explain features of optical systems.
- Explain the eye's function in human perception of images.

PREPARATION:

Before coming to lab, read Sections 1-4 of Chapter 25 and Sections 1-4 of Chapter 26 in Serway & Jewett. Keep the objectives of the laboratory in mind as you read the text. It is likely that you will do these laboratory problems before your lecturer addresses this material; the purpose of this laboratory is to introduce you to the material.

Before coming to lab you should be able to:

- Create graphs of measured quantities, and determine mathematical relationships between the quantities based on the graphs.
- Draw a ray diagram to locate the image formed by an object and a convex lens.
- Use the geometrical properties of similar triangles to find unknown quantities.

PROBLEM #1: IMAGES WITHOUT LENSES OR MIRRORS

Your group is developing an imaging device for use in diagnosing ulcers. Because it will be used inside the human stomach, the device must be small and durable. To meet these criteria, you would like to develop a camera that does not use a lens. While developing an initial presentation about lens-less image formation for your clients, you investigate a model of a lens-less camera: a light source (representing the object to be imaged), a mask with a small hole, and a screen. What are the properties of an image projected on a screen by a small hole?

EQUIPMENT

For this problem, you will be provided with a flashlight, a long filament bulb and stand, masks with various holes and a holder for the masks, an optics bench, and an empty lens holder for attaching a sheet of white paper to serve as a screen.

PREDICTION

Write an equation that relates the size of the image produced on the screen to the size of the light source, the distance between the light source and the mask, and the distance between the mask and the screen.

WARM-UP

Read Serway & Jewett: sections 25.1, 25.2.

1. Suppose you held a point-like light source close to a mask with a small circular hole in it, as shown below. Draw a diagram, showing the light rays that would make it from the light source to the screen. Beside the diagram, sketch a picture of what you expect to see on the screen.



2. What would happen if the light were moved down? On your original diagram, add the light rays that would make it from the light source in its new position to the screen. How would the position of the light spot on the screen change?
3. Draw a new ray diagram for a similar situation with a new light source, in the shape of a vertical arrow that emits light from all parts. Sketch a picture of what you would expect to see on the screen.
4. How would the size of the image on the screen change if you move the screen away from the mask? What if you move the screen closer to the mask? Use your ray diagram to write a

relationship among the length of the arrow, the distance from the arrow to the mask, the length of the arrow's image on the screen, and the distance from the mask to the screen.

The ratio of the size of the arrow and the size of the arrow's image is the magnification of the system. (Note that the length of an inverted image is customarily negative, so that an optical system that results in an inverted image has a magnification < 0 .)

5. What would you expect to see on the screen if the top half of the arrow were covered? What would you expect to see on the screen if the hole in the mask were made smaller? What would you expect to see on the screen if the mask were removed altogether, leaving just the arrow-shaped light source and the screen? Draw a sketch to support each of your predictions.

EXPLORATION

Remove the cover from the maglite, so that it acts as a point-like light source. Describe what you see on the screen without the mask. Does this match your prediction from the warm-up questions?

Place the mask with the smallest hole between the maglite and the screen. Describe what you see on the screen in this case. What happens when you move the maglite up? Down? Left? Right? Toward the mask? Away from the mask? Does this match your predictions from the warm-up questions?

Place the mask with the smallest hole between the bulb with a long straight filament and the screen. Describe what you see on the screen in this case. What happens to what you see on the screen when you cover the top part of the light bulb? When you cover the bottom part of the light bulb? Do your observations match your predictions from the warm-up questions?

Describe what you see on the screen when you slowly tip the light bulb to the left or the right. What happens when you move the light bulb toward the mask or away from the mask. What happens when you move the screen toward the mask or away from the mask?

How does the size or shape of the mask's hole affect what you see on the screen?

MEASUREMENT

Make measurements sufficient to quantitatively examine the relationship of the size of the image to the distance between the light source and the mask, and the distance between the mask and the screen. Be sure to measure the length of the bulb's filament.

ANALYSIS

Did your warm-up question responses match the observations you made in the explorations? If not, how can you change the sketches from the warm-up questions to account for your observations? When an image of the long filament of the light bulb appeared on the screen, did it appear erect or inverted? How could you tell?

Compare your predicted values for the size of the image with those you measured. Also compare your predicted values for the magnification with those you measured. Were your predictions

accurate? If not, can you adjust your prediction (if so, support with new diagrams) or otherwise account for any discrepancy?

<p style="text-align: center;">CONCLUSION</p>
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In designing a camera with no lens, what factors might be important in your choice of pinhole size, and why would they be important? What factors might be important to the distance between the camera's pinhole and its imaging surface, and why?

PROBLEM #2: IMAGE FORMATION WITH A PARTIALLY COVERED LENS

Your group, consulting for a drug company that hopes to develop new antibiotics, needs to make a video recording of a bacteria specimen under special conditions. These conditions involve light levels too intense for your recording equipment. One of your colleagues suggests partially blocking the microscope lens with a shutter to reduce the light levels for the recording equipment. Others argue that this would block part of the image, so that some parts of the sample would not be recorded.

You decide to test your co-worker's idea with a simplified optical system. You arrange a light source, a lens, and a screen on an optical bench, so that a focused image of the light source appears on the screen.

EQUIPMENT

For this problem, you will be provided with an optical bench, a convex lens mounted in a lens holder, an empty lens holder for attaching a sheet of white paper to serve as an imaging screen, a long filament bulb and stand, and a ruler.

PREDICTION

Describe how covering part of a convex lens will change the shape and the brightness of the image produced.

WARM-UP

Read Serway & Jewett: 25.1, 25.2, 25.4, 26.3, 26.4.

1. Draw a fairly large sketch, showing a convex lens and a source of light that has a defined top and bottom.
2. Sketch the paths of two light rays from the top of the light source to the lens, and continue the sketch for each ray on the other side of the lens. (For the rays you choose, simple rules should tell you the path they take after passing through the lens, if confused, refer to Chapter 26 of Serway.) Do you expect an image to form in this situation? If so, indicate the position of the image in your sketch. Where should you position the screen in order to see the image?
3. Repeat steps 1 and 2, placing the light source at one of the lens's focal points. Do you expect an image to form in this situation?
4. Repeat steps 1 and 2, placing the light source closer to the lens than its focal point. Do you expect an image to form in this situation?
5. What will happen to the image if the top half of the lens is covered? Indicate on your diagram which rays could pass through the lens in this situation, and which would be blocked.

6. Side-by-side, sketch the light source, the image you expect to see when the lens IS NOT covered, and the image you expect to see when the top half of the lens IS covered. Qualitatively compare the sizes, shapes, orientations, and brightness of the source and the two images.

EXPLORATION

Experiment to find a way to estimate the focal length of your converging lens. (Hint: Parallel light, as from a distant object, is focused very close to the focal point of a converging lens.)

Position the light source, the convex lens, and a screen on the optics bench so that a focused image appears on the screen. Does the image still exist if the screen is removed? How could you check?

Can you project an image on the screen when the distance from the light source to the lens is longer than the focal length? When the light source is closer to the lens than its focal length? What happens when the light source is *at* the lens's focal length?

Project a clear image of the light source on the screen. Sketch the shapes of the light source and its image. Is this sketch similar to the one you drew for the warm-up questions? If not, describe the differences.

Cover part of the lens. How does the image change? What changes if you cover different parts of the lens – top, bottom, right, left, middle? What changes if you cover more than half of the lens?

Draw sketches in your lab notebook of what you see on the screen. Indicate which part of the lens was covered for each sketch, as well as the alignment of the image relative to the source. Point out differences among the images formed when different parts of the lens are covered.

Gradually move the cover from the lens to the light source, in such a way that it always blocks about half of the light traveling toward the lens. Describe carefully how the image on the screen changes during this process.

ANALYSIS

Did your prediction and warm-up question responses match your observations? If not, how can you change the sketches from the warm-up questions to account for your observations? Can you use the fact that light travels in straight lines, and sketches similar to your (amended) sketches from the warm-up questions, to explain how the image changed as you moved the cover from the lens to the light source?

CONCLUSION

Do your results rule out use of the method proposed by your colleague for reducing light intensity? How is an image formed by a lens? Which rays “participate” in forming the image for a point on an object?

Do your results suggest any advantages that lenses with large diameters have over small lenses? Do your results suggest any advantages of using lenses instead of pinholes to form images, or advantages of using pinholes instead of lenses?

PROBLEM #3: IMAGE POSITION I

Your group is working to develop and study new proteins. To analyze the composition of a protein mixture you have produced, the protein solution is placed in an electric field. Proteins with different total charges will drift at different speeds in the solution, and can be separated for further analysis.

Your group needs to focus an optical apparatus at known positions within the protein solution in order to record an image of a small part of the volume. For every point in an image, you must be able to specify the location of the corresponding point in the protein solution. To accomplish this, you must know two relationships: (a) the relationship between an object's distance from the lens and the distance of its image from the lens, along the principal axis; and (b) the relationship between the distance of a point on the object from the principal axis and the distance of the corresponding point of the image from the principal axis. For simplicity, you decide to model your optical apparatus with a single convex lens. Your group will investigate relationships between the positions of points on an object and points in its image in two parts. In the present problem, you will investigate relationship (a). In the next problem, you will investigate relationship (b).

EQUIPMENT

For this problem, you will be provided with an optical bench, a set of convex lenses in lens holders, a light bulb with vertical filament and stand, an empty lens holder for attaching a sheet of white paper to serve as a screen, and rulers.

PREDICTION

Write out an expression that relates the distance of the image from the lens to the distance of the object from the lens and the focal length of the lens. Use this expression to predict features of the graphs of *the distance of the object from the lens vs. the distance of the image from the lens* and *(1/the distance of the object from the lens) vs. (1/the distance of the image from the lens)*.

WARM-UP

Read Serway & Jewett: 25.1, 25.2, 25.4, 26.3, 26.4.

It is useful to have an organized problem-solving strategy such as the one outlined in the following questions.

1. Draw a fairly large sketch, showing a convex lens and a source of light (a vertical arrow). Label the lens's focal points, and position the source so that an image will be created, which could be projected on a screen.
2. Determine the position of the image, by sketching the paths of two light rays from the top of the light source. Indicate the position of the image in your sketch. Where should you position the screen in order to see the image?
3. Repeat the steps above with a lens of the same focal length, but with the light source farther away from the lens. Has the image moved closer to or farther from the lens?

4. From your ray diagrams and geometrical knowledge of similar triangles, write an equation that relates the distance between the lens and the image, the distance between the lens and the object, and the lens's focal length.
5. Solve the equation in step 4 for $(1/\text{the distance of the object from the lens})$. What do you predict as a shape for a graph of $(1/\text{the distance of the object from the lens})$ vs. $(1/\text{the distance of the image from the lens})$ for a lens of fixed focal length? What are the values of the intercepts where the graph crosses each axis? Draw a sketch of the graph shape you expect and indicate the expected values of the intercepts.
6. Solve the equation in step 4 for $\text{distance of the object from the lens}$. What do you predict as a shape for a graph of $\text{the distance of the object from the lens}$ vs. $\text{the distance of the image from the lens}$ for a lens of fixed focal length? Sketch the shape of the graph you expect. Does the graph cross the each axis? If so, what are the values of the intercepts?

EXPLORATION

Estimate the focal length of each convex lens. To do so, take advantage of a convenient source of light that is much more distant than the focal length of each lens. (Where should light from a very distant object be focused?)

Position the light source, the convex lens, and a screen on the optics bench. Align the light source with the principal axis of the lens. Adjust their positions so that a focused image appears on the screen.

Move the source slightly toward and away from the lens, each time adjusting the screen's position to show a crisp image. Does the direction in which you have to move the screen match your responses to the warm-up questions?

Try focusing an image of the vertical filament light bulb on the screen. Can you adjust the position of the screen, lens, or bulb to project an image of the front part of the bulb on the screen? The filament? Other parts of the bulb?

MEASUREMENT

Record the positions of the image, lens and light source for several distances between the lens and the light source. In order to explore features of $\text{the distance of the object from the lens}$ vs. $\text{the distance of the image from the lens}$ and $(1/\text{the distance of the object from the lens})$ vs. $(1/\text{the distance of the image from the lens})$ graphs, record several measurements and plan your experiment so the data points are not "clumped together" on the graphs. Plot the points on each graph *as you go*. Take measurements for at least two different convex lenses.

ANALYSIS

In the warm-up questions you predicted the shape of two different graphs. Choose one of these graphs to use for your measurements and determine the focal length of each lens. Compare the focal length found on your graphs with the focal length calculated from your prediction equation.

CONCLUSION

How does the image position change as an object is moved along the optical axis? If you know the focal length of a lens and the position of the image, could you use your graphs *and* the relationship you predicted among *the distance of the object from the lens, the distance of the image from the lens, and the focal length* to determine the position of the object producing that image? Which would be more useful, and why?

Are your results consistent with your predictions? Did your graphs have the shape you expected? Were the estimated and calculated values for the focal length of each lens in agreement? Explain any discrepancies between your predictions and your measurements.

PROBLEM #4: IMAGE POSITION II (MAGNIFICATION)

Your group is working to develop and study new proteins. To analyze the composition of a protein mixture you have produced, the protein solution is placed in an electric field. Proteins with different total charges will drift at different speeds in the solution, and can be separated for further analysis.

Your group needs to focus an optical apparatus at known positions within the protein solution in order to record an image of a small part of the volume. For every point in an image, you must be able to specify the location of the corresponding point in the protein solution. To accomplish this, you must know two relationships: (a) the relationship between an object's distance from the lens and the distance of its image from the lens, along the principal axis; and (b) the relationship between a point of the object a distance from the principal axis and the distance of its corresponding point of the image from the principal axis. For simplicity, you decide to model your optical apparatus with a single convex lens. Your group will investigate relationships between the positions of points on an object and points in its image in two parts. In the previous problem, you investigated relationship (a). In this problem, you will investigate relationship (b).

EQUIPMENT

For this problem, you will be provided with an optical bench, a set of convex lenses in holders, a Pasco light source with a measurement grating, an empty lens holder for attaching a sheet of white paper to serve as a screen, a long-filament bulb and stand, and rulers.

PREDICTION

Write an expression relating the size of an object to the size of its image, in terms of the distance from the object to the lens and the distance from the lens to the image. Explain how this can be used to relate the position of a point on an object to the position of a corresponding point on the image.

WARM-UP

Read Serway & Jewett: 25.1, 25.2, 25.4, 26.1, 26.3, 26.4.

1. Draw a fairly large sketch, showing a convex lens and a source of light (such as a vertical arrow). Label the lens's focal points, and position the source so that an image will be created, which could be projected on a screen.
2. Determine the position of the image, by sketching the paths of two light rays from the top of the light source. Indicate the position of the image in your sketch. Where should you position the screen in order to see the image?

3. To your initial diagram, add a second object at the same position, but approximately twice as long. Determine the position and size of the image, as you did for the first object. How do the position and size compare to those of the original object?
4. From your diagrams and geometrical knowledge of similar triangles, write an equation that relates the height of the object to the height of the image, in terms of the *distance of the object from the lens* and *the distance of the image from the lens*.
5. Write an equation for the magnification in terms of *distance of the object from the lens* and *the distance of the image from the lens*. (Magnification is the ratio of image height over object height. The magnification is traditionally negative if the image is inverted.)
6. What shape would you predict for a graph of *magnification vs. distance of object from lens/distance of image from lens*? What is the significance of the slope of this graph? Where do you expect the graph to intercept the horizontal and vertical axes? How could you use such a graph to determine the distance from a point in an object to the principal axis of the optical system, if you knew the distance from the principal axis to the corresponding point in its image?

EXPLORATION

Position the light source with the transparent grid, the convex lens, and a screen on the optics bench. Align the light source with the principal axis of the lens. Adjust their positions so that a focused image of the grid appears on the screen.

Cover part of the light source. If half of the light source is covered, what fraction of the image disappears?

Shift the light source in a direction *perpendicular* to the principal axis. How does the position of the image change? How does the image change as it moves further from the principal axis? If you double the distance of a point on the object from the principal axis, what happens to the distance of the corresponding point on the image from the principal axis?

MEASUREMENT

Measure the spacing of the lines on the light source.

Arrange the light source so that a clear image of the lines is projected on the screen. Measure *the distance from the object to the lens* and *the distance from the image to the lens*. Make any other measurements necessary to determine the magnification for this arrangement. Repeat with the same lens for at least two more variations in the distance of the object from the lens.

Repeat the above series of measurements with a second convex lens.

ANALYSIS

Did the magnification for each series of measurements agree with your predicted relationship between *magnification*, *the distance of the object from the lens*, and *the distance of the image from the lens*?

CONCLUSION

Is the magnification of an optical system solely a property of the lens in the system, or are other factors important as well?

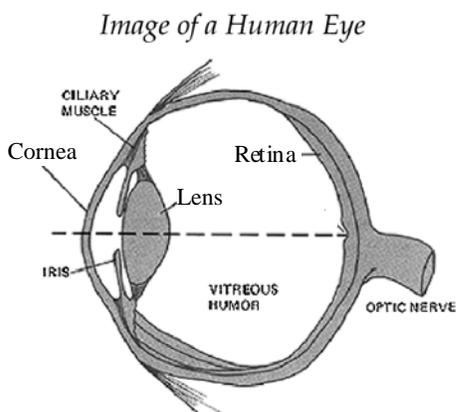
Are your results consistent with your predictions? If not, explain the sources of any discrepancies. How does the position of a point on an image change as the corresponding point on the object is moved perpendicular to the principal axis?

If you know the distances *of the object and the image from the lens*, and the position of a point on an image, can you determine the corresponding position on the object?

If an optical system has a magnification, and the image of an object moves upward a distance X perpendicular to the principal axis, how far did the object move, and in what direction?

PROBLEM #5: THE EYE -- COMPENSATING FOR AN ARTIFICIAL LENS

A diagram of a human eye is shown below. In an eye with normal vision, the *cornea* and the *lens* can project a focused image of objects at a wide range of distances (not shown in the diagram) on the *retina*. To achieve such flexibility, the *ciliary muscle* in the eye can slightly change the shape of the *lens* to adjust its focal length.



Your friend's grandmother has just had cataract surgery. During the surgery, the flexible *lens* in one of her eyes was removed, and was replaced with a plastic lens whose focal length cannot be adjusted. As a result, she can only see clear images of objects when they are held at one particular distance from her eyes. Your friend's grandmother has asked you to recommend a set of corrective lenses -- one that will help her see at close range. She already has a good set of corrective lenses for seeing far away. Before making specific recommendations for a corrective lens, you and your group decide to work with a simplified model of her eye.

Your eye model will use a single convex lens to approximate the behavior of the inflexible lens and cornea, and a screen to take the place of the retina. You will use additional lenses to model the effects of corrective lenses. You will be given one concave lens that allows your model to focus on a distant object.

EQUIPMENT

For this problem, you will be provided with convex lenses and a single concave lens in lens-holders, an empty lens holder for attaching a sheet of white paper to serve as a screen, a long-filament light bulb and stand, masking tape, an optical bench, and a ruler.

PREDICTION

Formulate an expression that gives the focal length of a corrective lens, to be used in conjunction with a fixed lens. You may assume that both lenses are on the same plane. The corrective lens should allow an object at a specified distance from the lenses to produce an image at a specified distance from the lenses. You may assume that the corrective lens is "weaker" than the other lens, i.e. $|f_0| < |f_c|$.

WARM-UP

Read Serway & Jewett: 25.1, 25.2, 25.4, 26.3, 26.4.

1. Sketch a model representing a surgically repaired eye, use an arrow as the object. Sketch a ray diagram to indicate the optimal position of the retina for "seeing" an object at this distance.
2. Sketch ray diagrams to show what happens to the image position if the object moves *closer* to the "eye," or *farther away* than in the first diagram. If a corrective lens were added in each situation, would it have to be convex or concave to project a clear image on the "retina"?
3. Calculations in this problem will be simpler if you can assume that the distance between the "eye" lens and the corrective lens is small relative to other distances, so that bending due to *both lenses occurs in a single plane*. Sketch a diagram of the eye model (without the "retina") with a corrective lens just in front of the "eye" lens. Indicate the focal points of both lenses.
4. To determine the position of an image produced by the system of two lenses, first draw a ray diagram to show the position of the image (real or virtual) that would be produced by *just the corrective lens*.
5. Then, treat the *image* (real or virtual) that would be produced by the corrective lens alone as the *object* (virtual or real) to be imaged by the "eye" lens. (The object is treated as virtual if it is on the same side of the "eye" lens as the final image will be, or real if it is on the opposite side.) Add rays to show the position of the final image, produced by the "eye" lens.
6. Label each important distance in your sketch. Use the diagram and the results of your work on earlier problems to write down equations relating these distances. (Watch the sign conventions!) Write an equation for the focal length of the corrective lens, in terms of the focal length of the "eye" lens, the distance from the lenses to the object, and the distance from the lenses to the image.
7. What does it mean if your equation predicts a corrective lens with a negative focal length? A positive focal length? An infinite focal length? Is each result possible? Could each of the three cases describe an actual lens?

EXPLORATION

Consider the constraints on an eye with an inflexible lens. Can the focal length of the lens change? Can the distance between the lens and the retina change? With these constraints in mind, construct a model on the optics bench. Experiment to determine the size your model should be. Using the simple eye model without any corrective lens you should be able to demonstrate that an object is out of focus at a large distance, clearly focused at a moderate distance, and out of focus at a short distance. See if you can focus a far away image with the concave corrective lens. Can you focus an image outside the window?

Investigate the effect of increasing distance between the corrective lens and the eye lens. Why is it important for this distance to be minimized? With the equipment available, how can the distance be minimized?

MEASUREMENT

Determine the focal lengths of the convex lenses you will use in this experiment as precisely as possible, using new measurements and/or your results from previous problems.

With the corrective concave lens, determine the size of your model eye (distance from lens to retina) by focusing a far away object. When you have successfully produced a clear image, record the positions and focal lengths of each lens, as well as the positions of the light source and screen.

Repeat with the convex lenses, focusing on close up objects.

ANALYSIS

Compare your measured results for the long distance with the predicted focal length f_c of the required corrective lens given by your prediction. For the short distance, calculate the focal length of the required corrective lens from your measurements, by using the relationship you predicted among *the distance of the object from the lens, the distance of the image from the lens, the eye focal length and the focal length of a corrective lens.*

CONCLUSION

How do your results compare to your predictions? If you made assumptions in the warm-up questions, how well were they met by your physical model of the eye? What effect would the observed deviations from those assumptions have on the comparison between your predictions and the measurements you made? Can you account for differences between your measurements and your predictions?

People with *myopia* are nearsighted, so that they can clearly see objects close to their eyes, while objects far away appear blurry. Use your results to answer the following questions about myopia. Should corrective lenses for nearsighted people be concave or convex? Myopia results from slightly misshapen eyeballs: are the eyes of myopic people too short (placing the retina too close to the lens) or too long (placing the retina too far from the lens)? Support your reasoning with a sketch.

People with *hyperopia* are farsighted, so that they can clearly see objects far away; however, objects that are close appear blurry. Use your results to determine whether corrective lenses for farsighted people should be concave or convex, and whether those people have eyeballs that are too short or too long. Support your reasoning with a sketch.

PROBLEM #6: MICROSCOPE

While studying bacteria cultures for a medical research laboratory, you are exhausted at the end of each day, which invariably includes hours bent over a microscope. One of your co-workers proposes a solution: projecting magnified images onto a screen, where observations could be made more easily. Your boss claims that this is impossible but is unable to explain why. You and your colleagues decide to investigate the optics in a model microscope, in order to determine whether the suggestion might work.

You decide to model your microscopes with a "simple" compound microscope: the "objective lens" -- a strong (short focal length) convex lens placed near the object to be imaged -- and an "eyepiece lens" -- a weaker (longer focal length) convex lens placed near the eye. If the lenses and object are arranged properly, you should see an inverted and enlarged image of the object when you look through the eyepiece lens. Is it possible to project an image from a microscope onto a screen?

EQUIPMENT

For this problem, you will be provided with an optical bench, a set of convex lenses in lens holders, a Pasco light source with grating lines, a light bulb with vertical filament and a stand, an empty lens holder for attaching a sheet of white paper to serve as a screen, and rulers.

PREDICTION

Given an objective lens and an eyepiece lens with known focal lengths, determine appropriate positions for the two lenses and for an object to be imaged by a model microscope. Determine the position of the image produced, and predict whether or not that image could be projected on a screen.

WARM-UP

Read Serway & Jewett: 25.1, 25.2, 25.4, 26.3, 26.4.

1. Draw a sketch to represent the compound microscope and an object, which meets the following specifications. The two lenses should share the same optical axis. The distance from the object to the objective lens should be between the focal length and 2 times the focal length of the objective lens. The position and focal length of the "eyepiece" lens will be determined in step 3 below.
2. Draw a ray diagram to show the position and size of the image that produced by the objective lens.
3. In a compound microscope, the *image* produced by the objective lens is the *object* for the eyepiece lens. The eyepiece lens will be placed so that the *image* from the objective lens is between the two lenses, and is at a focal point of the eyepiece lens. Add an eyepiece lens to create this arrangement in your sketch.

4. Add rays to show how light will travel after passing through the eyepiece lens. Do the rays converge or diverge? Does the eyepiece lens form a real or virtual image? If so, what is its location?
5. Does the microscope form an image that could be projected on a screen? If so, where should the screen be placed? If not, should it be possible to adjust the microscope so that it could project an image on a screen?

EXPLORATION

Arrange an approximate model of a compound microscope before taking careful measurements. First, estimate the focal lengths of each lens you will use to model the microscope.

Position the light source and a convex lens with short focal length (the “objective”) on the bench. Verify that the principal axis of the lens is parallel to the bench and passes through the center of the source. Find the position of the image formed by the objective lens.

Place another convex lens (the “eyepiece”) in position so that the image formed by the objective lens is approximately at a focal point of the eyepiece lens.

Look through the eyepiece lens. Can you see an image of the light source? Is it inverted or erect? Does it appear to be enlarged? Can you estimate how much the image is enlarged? Can an image be projected onto a screen? What do you observe if you move the eyepiece lens along the principal axis, or if you adjust the position of the light source or objective lens? How can you tell when you have achieved the conditions described in the warm-up questions for a compound microscope?

Try focusing the microscope on the vertical filament light bulb. (The filament is very bright, so you may wish to focus on some other part of the bulb.) Can you focus on different parts of the bulb?

MEASUREMENT

Carefully determine the focal length of each lens you will use in the model microscope.

Place the light source and the objective lens at a convenient distance apart. Following the methods you developed in the exploration, adjust the position of the eyepiece lens until you have achieved the conditions necessary for a compound microscope. Measure and record the relevant positions and focal lengths.

Will the microscope project an image on a screen, or can it be adjusted to do so? If so, measure image positions, magnification, lens positions and light source positions, and describe the image produced.

Repeat the process for a new distance between the light source and objective lens.

Repeat, if possible with the same two distances between light source and objective lens, for a second eyepiece lens.

ANALYSIS

For each distance between the lamp and objective lens, compare the observed separation of the two lenses with the expected value, from the warm-up questions. Can you account for any discrepancies?

Qualitatively, how did the second eyepiece lens change the magnification of the microscope? Why did you (or why didn't you) expect this change?

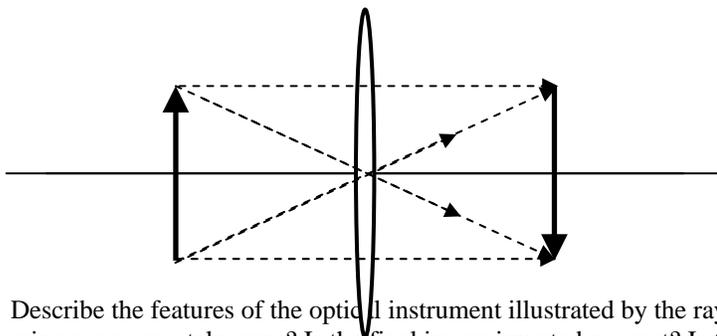
CONCLUSION

How does the position of the eyepiece depend on the distance between the object and the objective lens, and on the focal lengths of the lenses?

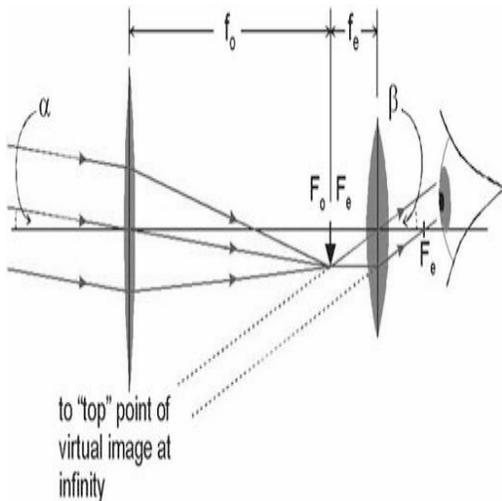
Is it possible to use a microscope to project an image on a screen for observation, without extra optical equipment? Do you support your boss's claim that it is not possible? If it is possible, explain why or why not you think it could be useful.

☑ CHECK YOUR UNDERSTANDING

1. Use a ray diagram to determine the size and position of the image when a 5 cm tall object is located 18 cm from a converging lens with focal length 9 cm.
2. What would happen if the same object were located 9 cm from a converging lens with focal length 18 cm?
3. What would happen if the same object were located 18 cm from a converging lens with focal length 18 cm?
4. What would happen if the same object were located 18 cm from a diverging lens with focal length -18 cm?
5. In any of the situations above, what would happen if the middle 2/3 of the lens were blocked?
6. In which of the situations above could an image be projected on a screen? In which of the situations above could an image be seen without a screen?
7. Describe the problems with the ray diagram below:



8. Describe the features of the optical instrument illustrated by the ray diagram below. Is this a diagram for a microscope or a telescope? Is the final image inverted or erect? Is the final image magnified?



CHECK YOUR UNDERSTANDING

PHYSICS 1202 LABORATORY REPORT

Laboratory I

Name and ID#: _____

Date performed: _____ Day/Time section meets: _____

Lab Partners' Names: _____

Problem # and Title: _____

Lab Instructor's Initials: _____

Grading Checklist	Points
LABORATORY JOURNAL:	
PREDICTIONS (individual predictions and warm-up completed in journal before each lab session)	
LAB PROCEDURE (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
PROBLEM REPORT:*	
ORGANIZATION (clear and readable; logical progression from problem statement through conclusions; pictures provided where necessary; correct grammar and spelling; section headings provided; physics stated correctly)	
DATA AND DATA TABLES (clear and readable; units and assigned uncertainties clearly stated)	
RESULTS (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
CONCLUSIONS (comparison to prediction & theory discussed with physics stated correctly ; possible sources of uncertainties identified; attention called to experimental problems)	
TOTAL (incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
BONUS POINTS FOR TEAMWORK (as specified by course policy)	

* An "R" in the points column means to rewrite that section only and return it to your lab instructor within two days of the return of the report to you.

