OPTICAL INSTRUMENTS

OBJECTIVE:

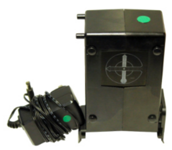
Construct a basic microscope and basic telescope using the principles of optics.

IDEA TO REMEMBER!

The image of one lens becomes the object of the next!

MATERIALS:


Optics bench


Light source


Viewing screen


4x PASCO lenses


Ruler

CONCEPT:

Let's take the next step to apply the thin lens concepts to the real world. The effect of one lens can be significant—thankfully that's all we need to correct our vision!—but scientific and engineering applications often require multiple lenses. First, we will explore how thin lenses work together in a system and when virtual images are useful. Then we will engineer a simple microscope and telescope.

THINK: To start, recall the thin lens and magnification equations and drawing ray diagrams from the Thin Lens lab. What pattern/graph should we expect from the inverse distance relationships? What phenomenon occurs at the "focal length"?

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \qquad (1)$$

$$m \equiv \frac{h_i}{h_o} = -\frac{d_i}{d_o} \qquad (2)$$

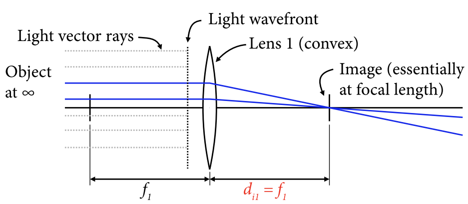
When playing with thin lenses, we find that light bends in a predictable way—called **refraction**. Notice, firstly, that the image distance is inversely proportional to object distance: as the object <u>moves closer</u> to the focal length from outside the focal length, the image <u>moves away</u> from the focal length on the opposite side. However, the relationship switches at the origin, the focal point: when the object <u>moves away</u> from the focal length from *within* the focal length, the (virtual) image <u>moves closer</u> to the focal length. You can visualize this by plotting image distance d_i vs object distance d_o according to the Thin Lens equation—$F(x) = 1/x$.

There are a few more basic things to notice. An object (representing the center point of a light wave) at an "infinite" distance away produces a light wavefront that is essentially flat, making the incoming rays parallel.

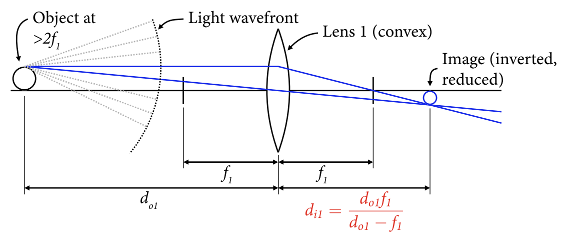
Thus, the lens refracts the light on the opposite side to make a **real** image. For this situation, the distance from the lens to this point is called the **focal length**. Technically, the image is always "inverted" and "reduced" when the object is between infinity and twice the focal length. If the object is *at* twice the distance of the focal length then an inverted, 1:1 scale image will be produced. However, the image will be enlarged when the object sits between 1–2x the focal length. By contrast, if the object sits exactly at the focal point then the light refracts into parallel lines. Study Table (1) and the diagrams in Figure (1) to visualize these concepts.

IDEA TO REMEMBER!

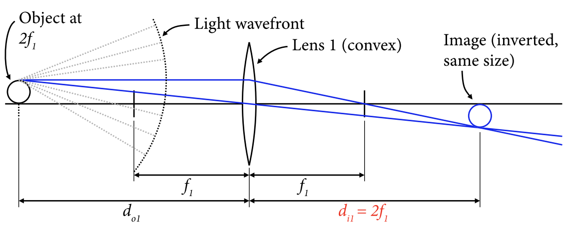
The image of one lens becomes the object of the next!



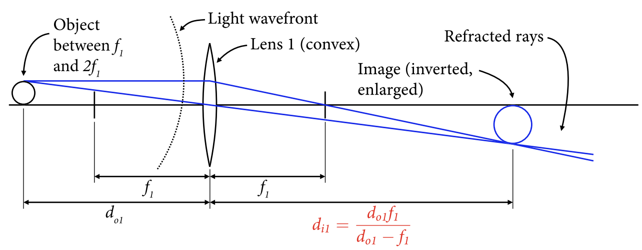
(a) Object at ∞; image at *f* (inverted extremely reduced)



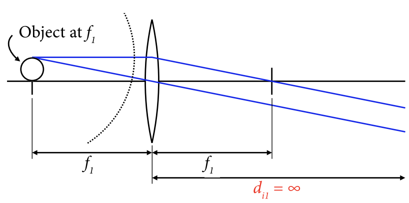
(b) Object at >2*f*; image inverted and reduced



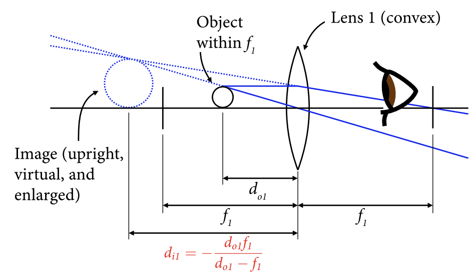
(c) Object at 2*f*; image inverted and same size



(d) Object between *f* and 2*f*; image inverted and enlarged



(e) Object at *f*; image does not converge—useful for telescopes



(f) Object within *f*; image upright, virtual, and enlarged

Figure 1

Table 1: Image observations for converging (convex) lenses

Object distance	Image distance	Upright or Inverted?	Magnified or Reduced?	Real or Virtual?
$d_o = \infty$	di = f		>> Reduced	
$d_o > 2f$	*		Reduced	
$d_o = 2f$	di = $2f$	Inverted	Same size	Real
$2f > d_o > f$	*		Magnified	
$d_o = f$	di = ∞		N/a	
$d_o < f$	**	Upright	>> Magnified	Virtual

$$* \quad d_i = \frac{1}{\frac{1}{f} - \frac{1}{d_o}}$$

$$** \quad d_i = -\frac{1}{\frac{1}{f} - \frac{1}{d_o}}$$

There is yet another phenomenon, which is one of the main "focuses" of this lab (pun intended). If the object sits *inside* the focal length of the lens then the light refracts out, scattering the light on the other side. But, some of the light is reflected back on the same vector at the surface of the lens and an enlarged **virtual image** is created on the same side as the object, as seen in Figure (1f). <u>This phenomenon is useful for **eyepieces** in microscopes and telescopes</u>, in which a virtual image is necessary for viewing at any distance. A similar thing happens for a diverging (concave) lens: the refracted light creates an upright, reduced, virtual image at the intersection of the rays. Refer back to the Thin Lens lab manual for more details.

> **IDEA TO REMEMBER!**
>
> The image of one lens becomes the object of the next!

All of these concepts hold true for compound systems using multiple lens. But, there is only one more concept to know: <u>**the image of one lens becomes the object of the next lens**</u>, and so on. Figure (2) combines the concepts as seen in the Figure (1) diagrams to show how all of these concepts work together in a multi-lens system. This also displays how the microscope will be constructed.

A microscope requires <u>a small focal length lens</u> objective lens—close to the object. Then other lens can be added a certain distances to create the desired magnification. For microscopes, the total magnification is calculated as the product of all magnifications for all lenses, however the eyepiece has a distinct magnification m_e:

$$M = m_1 m_2 ... \quad (3)$$

$$m_e = \frac{25cm}{f_e} \quad (4)$$

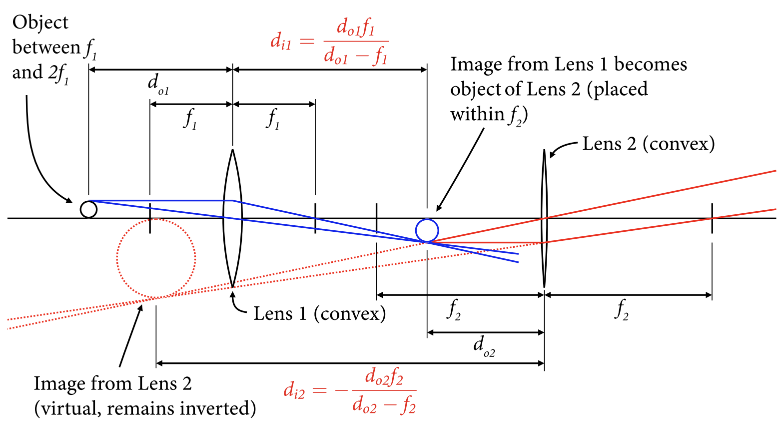


Figure 2

A telescope uses the opposite orientation: <u>a large focal length lens</u> is needed for the objective lens. Since the object of a telescope so far away and the <u>distance between the lenses is the sum of the focal lengths</u> ($d = f_1 + f_2$), the object distance renders the previous magnification Equation (3) unusable. Therefore, an approximation is used to determine the magnification of a telescope:

$$M_T \approx -\frac{f_o}{f_e} \quad (5)$$

Real World Applications

1) Hubble Space Telescope YT channel!

2) Smarter Every Day — James Webb Space Telescope (JWST)

3) Explanation of Optics and how the JWST works

4) Transmission Electron Microscope (TEM) vs STEM

PRECAUTIONS:

Not much for worry! Have fun and learn!

PROCEDURE:

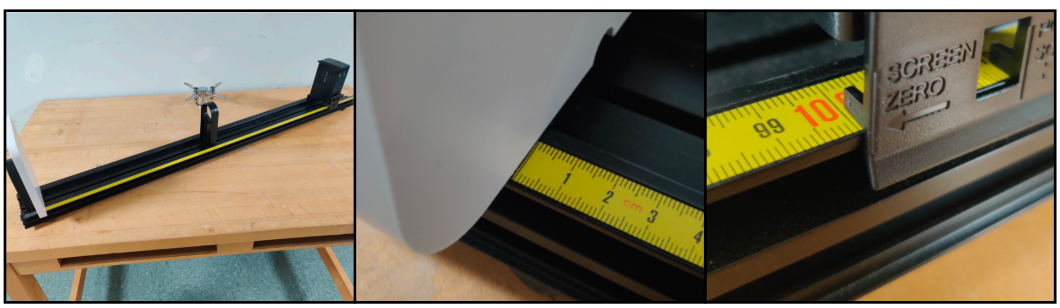
1. ☐ Fill out the top information on the worksheet and complete the memory exercise—Questions M1–M3.

2. ☐ REQUIRED: Read the *Concept* section.

3. ☐ Assemble the setup as shown in Figure (3).

   3.1. Place the Light source and Viewing screen on opposite ends of the Optics bench with the +100mm convex Lens in the middle.

   3.2. Use the appropriate points on the components to identify their position on the Optics bench, as shown in Figure (3b) and (3c).



(a) (b) (c)

Figure 3

IDEA TO REMEMBER!

The image of one lens becomes the object of the next!

CONCEPT & PROCEDURE VIDEOS:

Microscope

1. ☐ Move the +100 mm Lens and Viewing screen to recreate Figure (1b) and (1e)—a) outside the focal length ($d_o > 2f$) and b) inside the focal length ($d_o < f$). Then answer Question 1 on the worksheet.

2. ☐ Now recreate Figure (1d) by moving the +100 mm Lens to an appropriate distance from the object ($2f > d_o > f$) and use the Viewing screen to find the location of the image. (This +100 mm lens will be the “objective lens” nearest to the object in your microscope setup).

3. ☐ Record the location of the Viewing screen where the image is clearest in Table (2) on the worksheet.

4. ☐ Remove the Viewing screen and add the +250 mm “eyepiece” Lens behind the objective Lens. Answer Question 2 on the worksheet.

5. ☐ Keeping your eye 25 cm away from the eyepiece, view the Light source through both Lenses.

6. ☐ Move the eyepiece Lens back until you see a clear image.

7. ☐ Record the location of the eyepiece Lens in Table (2) on the worksheet.

8. ☐ Answer Questions 3 and 4 to complete Table (2) on the worksheet.

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Kepler Telescope

9. ☐ Remove the Light source from end of Optics bench.

10. ☐ Separate your Lenses (+250 mm and +100 mm) a distance that is the sum of their focal lengths ($f1+ f2$).

11. ☐ Try to sight a distant object out of the lab room window (if too dark, stand at the back of the room and use an object on the opposite side, like the clock). Answer Question 5 on the worksheet.

12. ☐ Answer Question 6 on the worksheet and record the theoretical magnification in Table (3) on the worksheet.

13. ☐ To validate your calculation, while holding the Optics bench and eyepiece at the same distance measure the perceived, unmagnified width of a stationary object with a ruler (at the same distance to your eye as the eyepiece Lens). Then use the ruler across the eyepiece to measure the perceived, magnified width. See Figure (4). Record these measurements in Table (3) on the worksheet.

14. ☐ Complete Table (3) and answer Question 7 on the worksheet.

(a) (b) (c)

Figure 4

Galileo Telescope

15. ☐ Replace the +100 mm Lens with the -150 mm Lens.

16. ☐ Move the eyepiece closer to the objective lens until you get a clear image as you repeat steps 11–14 with the corresponding Questions and Table (4) on the worksheet.

17. ☐ Follow the **Let's THINK!** instructions on the next page.

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Let's THINK!

- **Ask questions**: What are you learning here?... Why is this Physics concept important and how can it be used?... What do you not understand?... (For more information on this Physics topic, scan the QR codes in the *Real World Applications* and at the start of the *Procedure* section.)
- **Discuss** the concept and demonstration with your partner to help each other understand better. Discussion makes learning active instead of passive!
- For **FULL PARTICIPATION [15 points]** you must call on the TA when you have finished your group discussion to answer some comprehensive questions. If you do not fully understand and the TA asks you to discuss more, you must call on them one more time to be dismissed with full marks.
- **CONCLUSION [10 points]**: In the Conclusion section at the end of the worksheet, write 3 or more sentences summarizing this concept, how this lab helped you understand the concept better, and the real world implications you see. Do you still have questions? If so, write those as well.

Updated Date	Personnel	Notes
2023.04	Chase Boone, Bryan Semon, Bob Swanson	2023 Spring Improvement: Created new format.

Name: ______________________________ *PH1123* Section #: __________

Name: ______________________________ TA Name: ____________________

OPTICAL INSTRUMENTS
WORKSHEET [70 points]

IDEA TO REMEMBER!

The image of one lens becomes the object of the next!

M1) Substances capture and release limited amounts of ______________.

M2) The brain is the only organ more complex than the ______________.

M3) ____________________ is when two or more waves pass through one another.

Microscope

1) Describe the images you see on the View screen. Note whether it is clear, unclear; upright or inverted; reduced, enlarged, or the same size; real or virtual. [4 points]

a)

b)

Table 2 [4 points; 1 point per cell]

Position of clear image from first Lens (mm)	Position of second Lens (mm)	Position of second image (mm)	Theoretical magnification

2) What does the image of the objective Lens become for the next Lens? [2 points]

3) Calculate the position (convert distance) of the second image in your microscope. Show your work below. [6 points]

4) Calculate the theoretical magnification of your microscope. Show your work below. [5 points]

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Kepler Telescope

5) What happens to the image if the +250 mm Lens is the objective? When the +100 mm Lens is objective? Why does this happen in terms of the light rays (explain why the magnification approximation is true)? [7 points]

6) Calculate the theoretical magnification of the Kepler Telescope. Show your work below. [4 points]

Table 3 [4 points; 1 point per cell]

Theoretical magnification	Measurement in eyepiece	Position of second image	Calculated magnification
	(mm)	(mm)	

7) What is the percent error between the theoretical and calculated? What might cause this error in the equipment and methodology? How could you improve it? [5 points]

Galileo Telescope

8) What happens to the image if the +250 mm Lens is the objective? When the -150 mm Lens is objective? Why does this happen in terms of the light rays (explain why the magnification approximation is true)? [6 points]

IDEA TO REMEMBER!

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9) Calculate the theoretical magnification of the Galileo Telescope. Show your work below. [4 points]

Table 4 [4 points; 1 point per cell]

Theoretical magnification	Measurement in eyepiece (mm)	Position of second image (mm)	Calculated magnification

10) What is the percent error between the theoretical and calculated? What might cause this error in the equipment and methodology? How could you improve it? [5 points]

Conclusion

Write 3 or more sentences summarizing this concept, how this lab helped you understand the concept better, and the real world implications you see. Do you still have questions? If so, write those here as well. [10 points]

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