THIN LENSES

IDEA TO REMEMBER!

Light waves can bend!

OBJECTIVE:

Understand how light interacts with thin lenses using the "thin lens" equation.

MATERIALS:

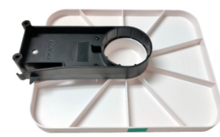
Optics track

Light source

+100 Lens

-150 Lens

Ruler



Viewing screen

CONCEPT:

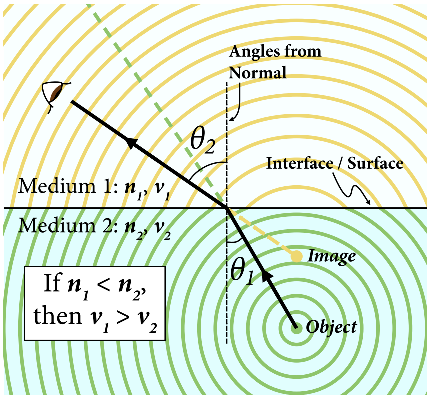
What does spearfishing, the aurora borealis, eyeglasses, and gravitational microlensing, Figure (1a), have in common? They all involve the "bending"—or change in speed—of light, known as **refraction**. This occurs when light reaches the interface or surface of a new medium, as shown in Figure (1b). To help us interpret this bending effect, we use light rays, which are the straight line vectors of a light wave, propagating outward from a single point. Thus the law of refraction was derived by and named after a Dutch mathematician, Willebrord Snell (1591–1626):

$$n_1 sin\theta_1 = n_2 sin\theta_2 \quad (1)$$

However, others, such as the Persian physicist Ibn Sahl, accurately described the law of refraction as far back as *AD 984!* **Snell's Law** assigns an *index* of refraction (n_1 and n_2) to each medium, which is derived from the ratio of the speed of light in vacuum to the speed through the medium. The **angle of incidence** θ_1 and the **angle of refraction** θ_2 are with respect to the normal to the interface/surface.

THINK: Imagine you are spearfishing in a shallow river or creek. How would you aim at a fish's image? How does the image change as you get closer? At what distance does the "critical angle" hide a fish from sight? (Use your eye height and a fish depth of 3ft.)

(a) gravitational microlensing of a galaxy



(b)

Figure 1

Taking Snell's Law further, we want to find a mathematical relationship between the **object distance d_o**, the **image distance d_i**, and the parameters of the lens. Using small-angle approximation we can assume from Snell's Law that $\sin\theta \approx \theta$, and then we can derive that $\theta_1 = \alpha + \phi$ and $\theta_2 = \phi - \beta$ from the setup shown in Figure (2), which leads to the following general equation:

$$\frac{n_1}{d_o} + \frac{n_2}{d_i} = \frac{n_2 - n_1}{R} \qquad (2)$$

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Using this general equation, we can use the set up as shown in Figure (3) to create two equations from Equation (2), one solving for the image at Q and one for Q', inserting the various distances and radii. Then using the thin-lens approximation ($t \ll d_i'$ or $t \ll R_1$ and R_2) we can derive the *thin-lens equation*:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \qquad (3)$$

Where f is the focal length of the lens, describing how strongly the lens converges or diverges light.

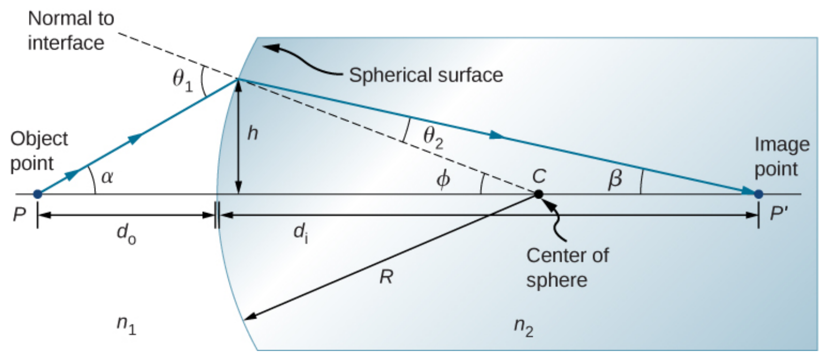

Figure 2 (OpenStax)

THINK: Give it a try! Play—aka experiment—with Equation (3) to understand the relationship between the focal length and the distances.

Table (1) is helpful to understand the positive and negative signs with the distances and focal length from a lens.

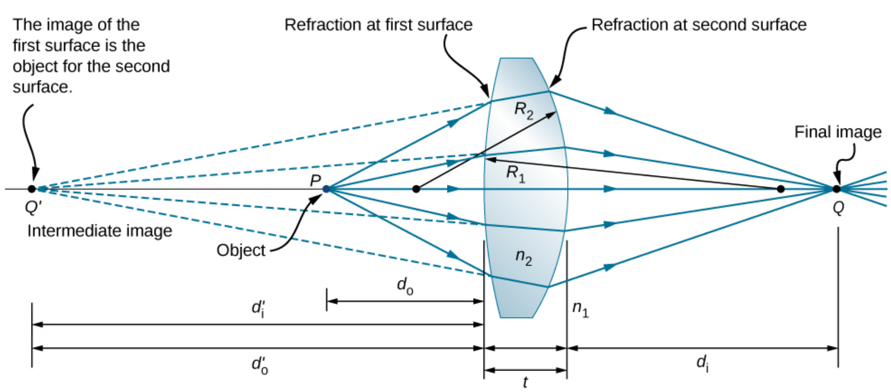

Figure 3 (OpenStax)

Let's assume that we have an object that is significantly far away. In this case, we would say that the object distance is infinitely large ($d_o = \infty$). Plugging this into our equation, we find that the first term approaches 0. That means we drop that term and are left with:

$$\frac{1}{d_i} = \frac{1}{f} \qquad (4)$$

We can relate the object and image distances and heights to produce an expression for **magnification**:

$$m \equiv \frac{h_i}{h_o} = -\frac{d_i}{d_o} \qquad (5)$$

Table 1

d_o	+	object (real) on the incoming ray side	–	object (virtual) on the outgoing ray side
d_i	+	image (real) on the outgoing ray side	–	image (virtual) on the incoming ray side
f	+	if converging lens	–	if diverging lens

> **FUN FACT!** An image, in terms of optics, is defined as a collection of light rays coming from different focal points on an object's surface.

Where h_i is the image height and h_o is the object height. A negative sign indicates an inverted orientation: positive represents **upright**; we can see in Figure (4a) that the image is inverted and thus h_i would be negative.

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>
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In this lab we will focus on two types of lenses: **convex** (converging) and **concave** (diverging) lenses. The names come from how they bend light, either focusing it or spreading it out. Figure (4a) shows a ray diagram for a converging lens and (4b) for a diverging lens. The rules for these rays are as follows (taken from OpenStax):

1. A ray entering a converging lens parallel to the optical axis passes through the focal point on the *opposite* side of the lens (ray 1 in part (a)). A ray entering a diverging lens parallel to the optical axis exits along the line that passes through the focal point on the *same* side of the lens (ray 1 in part (b)).

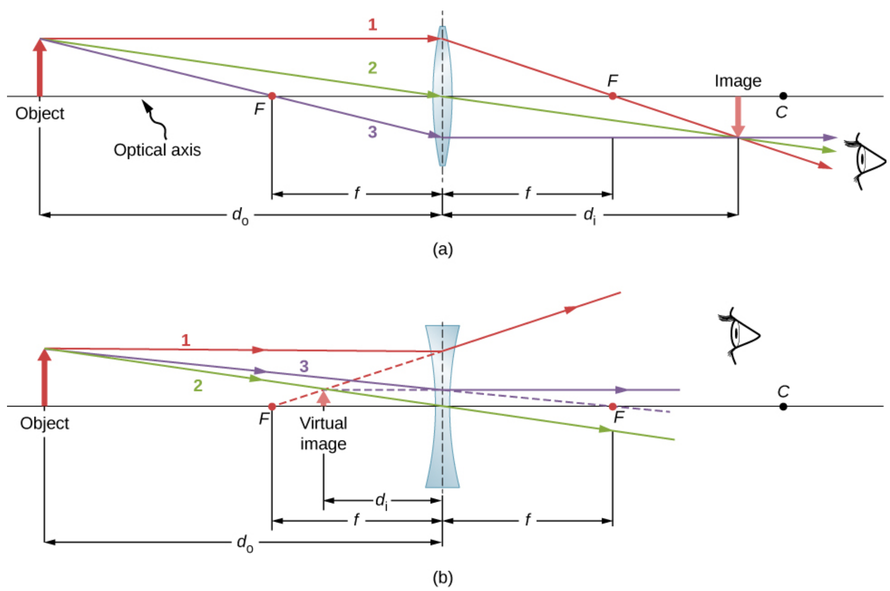

Figure 4 (OpenStax)

2. A ray passing through the center of either a converging or a diverging lens is *not deviated* (ray 2 in parts (a) and (b)).
3. For a converging lens, a ray that passes through the focal point first will *exit the lens parallel* to the optical axis (ray 3 in part (a)). For a diverging lens, a ray that approaches the lens along the line that passes through the focal point on the opposite side *exits the lens parallel* to the axis (ray 3 in part (b)).

Real World Applications

- These concepts of thin lenses are vital for the creation of **telescopes, cameras, lasers, and phones** to either capture light rays or to focus them for direct use.
- Our eyes act as lenses. When we have issues with our eyes, we use **contact lenses and glasses**, which are designed using these concepts, to help us focus light into our eyes to improve our sight.

1) How camera lenses work!
2) How glasses lenses are made!

PRECAUTIONS:

Not much for worry! Have fun and learn!

PROCEDURE:

Part 1

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

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

3. ☐ Switch off the lights and open the window shade slightly (about 30cm).

4. ☐ Assemble the setup as shown in Figure (5a) and (5b).

    4.1. Snap the converging lens (+100) into the optical bench track.

    4.2. Snap the viewing screen into the track on the side of the lens away from the window. Move it back and forth until the image becomes clear (at the focal point/length).

5. ☐ Measure the distance between the screen and lens using the optical bench scale. Record it in Question 1 on the worksheet and answer Question 2.

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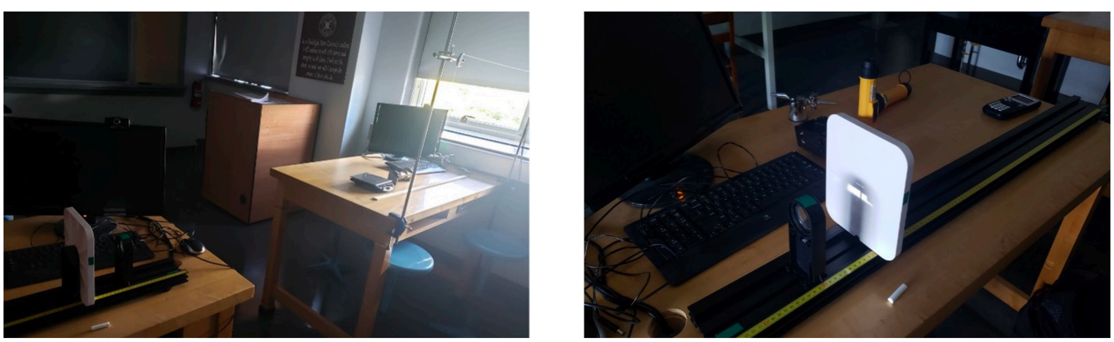
CONCEPT & PROCEDURE VIDEOS:



(a) (b)

Figure 5

Part 2

1. ☐ The TA may switch on the lights.

2. ☐ Assemble the setup as shown in Figure (6a).

    2.1. Plug in the light source to power and snap it into the optical track at one end (0cm or 100cm) using the front of the foot as a guide. (This will replace your window as the source.)

2.2. Ensure the lens is located between the viewing screen and light source, which should be some random distance further away than the lens' focal length found in step 4 (5–15cm further should be sufficient).

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3. ☐ Measure the distance between the lens and the light source and record in Table 1 on the worksheet.

4. ☐ Move the screen back and forth until the image on the screen is clear. Measure the distance between the lens and the screen and record in Table 1 on the worksheet.

5. ☐ Calculate and record the focal length for Table 1 on the worksheet.

6. ☐ Measure the height of the object and image and record in Table 1 on the worksheet. Use Table 1 in the *Concept* section to get the correct signs.

7. ☐ Calculate the ratio of the heights and distances for the object and image (magnification) and record in Table 1 on the worksheet.

8. ☐ Move the lens back and forth until the image becomes clear again in a different position (other than where it was), as shown in Figure (6b). Record the object and image distances from the lens as Trial 2 in Table 1 on the worksheet and repeat steps 9–11.

9. ☐ Answer Questions 3–4 on the worksheet.

(a) (b)

Figure 6

Part 3

1. ☐ Assemble the setup using Part 2, step 2.2—Figure (6a). Record the object and image distances of the converging lens and recompute its focal length in Table 2 on the worksheet.

2. ☐ Move the screen away from the converging lens and snap the diverging lens (–150) into the track.

3. ☐ Move the diverging lens until the image on the screen is clear, as shown in Figure (7).

4. ☐ Answer Question 5 on the worksheet.

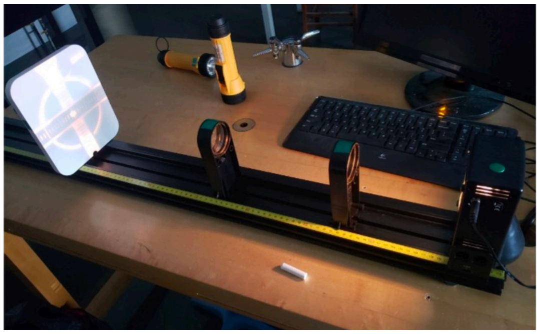

Figure 7

IDEA TO REMEMBER!

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5. ☐ Measure and record the object and image distances for the diverging lens in Table 2 on the worksheet. Use Table 1 in the *Concept* section to get the correct signs.

6. ☐ Calculate the focal length of the diverging lens for Table 2 on the worksheet.

7. ☐ Follow the **Let's THINK!** instructions below.

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
2022.09	Chase Boone, Brooks Olree, Ahmad Sohani	2022 Summer Improvement: Created new format.

Name: ______________________________ *PH1123* Section #:__________

Name: ______________________________ TA Name:____________________

THIN LENSES
WORKSHEET [70 points]

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Memory exercise [each 2 extra credit points]:

M1) Sound is a pressure wave created from ____________________
Hint: oscillations.

M2) Waves are categorized as ____________ or ____________
Hint: "across" and "parallel".

M3) Plotted across time, oscillations create a ____________ curve
Hint: angular frequency and motion around a circle can convert to this.

Part 1

1) Distance between lens and screen (focal length): ____________ cm [5 points]

2) a) Draw a ray diagram of the setup below, b) Label the light source and viewing screen in your ray diagram as the object or the image, c) Is the object real or virtual? Is the image real or virtual? [10 points]

Part 2

Table 1: Converging Lens [8 points, 0.5 per cell]

Trial	Object distance d_o (cm)	Image distance d_i (cm)	Focal length f (cm)	Object height h_o (cm)	Image height h_i (cm)	Magnification $m = h_i/h_o$	Magnification $m = -d_i/d_o$
1							
2							

Show your focal length calculations here [4 points]:

3) Are the calculated focal lengths in **Table 1** similar to the measured focal length in **Part 1**? What could be the reason for (potential) errors? [5 points]

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4) How do the magnification ratios compare in **Table 1**? What could be the reason for (potential) errors? [3 points]

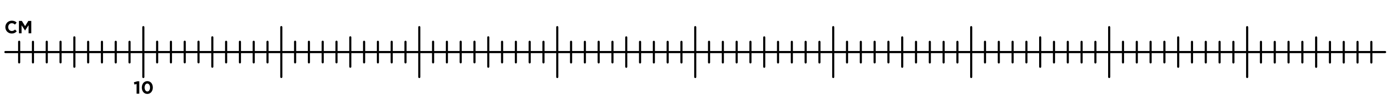
Part 3

Table 2: Multi-Lens [6 points, 0.5 per cell]

Object 1 distance d_{o1} (cm)	Image 1 distance d_{i1} (cm)	Focal 1 length f_1 (cm)	Object 2 distance d_{o2} (cm)	Image 2 distance d_{i2} (cm)	Focal 2 length f_2 (cm)

Show your focal length calculations here [4 points]:

5) a) Draw a ray diagram to scale below, b) Is the diverging lens' object a real or virtual image? [15 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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