Lab 11: Lenses and Optics DUE: 04 Dec 2024

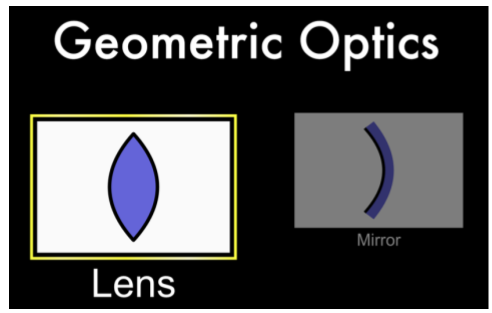
Introduction

Do you need glasses? I sure do. I am very, very nearsighted. What does that mean? Nearsightedness means that you cannot see distant objects clearly. How distant? Well, in my case, anything further away than about 10 inches is blurry!

Why are some people nearsighted, and how does a pair of glasses fix it? For that matter, what about farsightedness?

No seals were harmed in the taking of this photograph, and it's not Photoshop. The extreme refraction you see here is the result of (on bottom) light bending at the water-glass boundary, and then again at the glass-air boundary. But the seal's head is seen only through the glass: air-glass bends the light, but then the glass-air transition bends it back. The different amounts of bending make the part below and the part above the water seem like two separate objects!

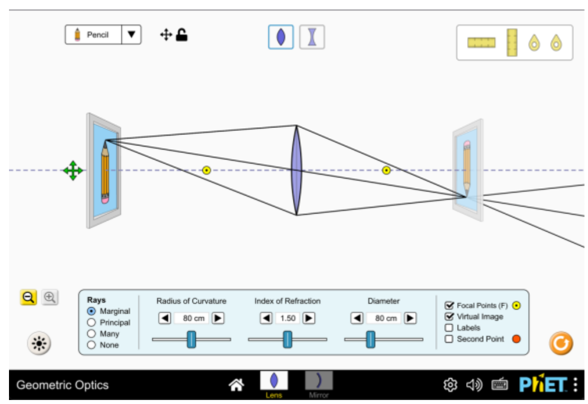
Objectives



- Introduce the concept of geometric optics
- Examine image formation for converging and diverging lenses
- Distinguish between real and virtual images
- Discover the conditions for the formation of virtual images as opposed to real images
- Determine how to use corrective lenses to compensate for vision defects

Equipment

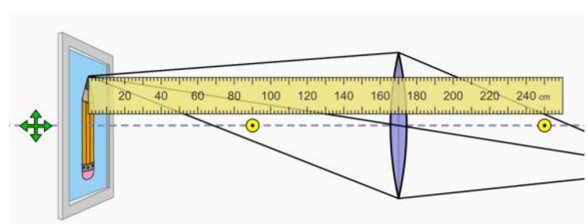
- Internet-capable device with the ability to run a browser
- Paper, pencil, calculator
- Scientific Calculator



Procedure

1. Read this handout completely before you try to dive in. It will save you time and frustration later. If you are able to print it, you will not have to tab between windows—you can look at this and the refraction simulator at the same time.
2. Do you have paper and pencil handy? Don't forget your calculator.
3. In a browser window, navigate to the PhET Geometric Optics Sim. Don't try to start doing the lab yet! Just verify that the interactive opens properly. Unfortunately, this particular sim does not have a downloadable App for your phone.
4. There are two simulations; click on LENS. The figure above on the right shows what the interface looks like on the web page. By default, you have a converging lens forming an image of a pencil.
5. Notice at the top, you can change objects. I'm going to use the plain arrow, since it will be the easiest thing to measure. You can switch between converging and diverging lenses, and you have rulers to measure distances and heights.
6. The toolbox at the bottom allows you to control the parameters of the lens, and how you view the rays.

Converging Lenses



Notice that the toolbox lets you control the radius of curvature of the lens. How is the radius of curvature related to the focal length of the lens? Let's establish that by using the default simulation and the lens equation. Drag the ruler over to the object and measure the distance from the object to the center of the lens. You should get $d_o = 170\text{cm}$, like the figure on the right.

1. Reposition the ruler to measure the image distance d_i from the center of the lens to the image. The image distance is closest to

A) $d_i = 140\text{cm}$
B) $d_i = 145\text{cm}$
C) $d_i = 150\text{cm}$
D) $d_i = 155\text{cm}$
E) $d_i = 160\text{cm}$
F) $d_i = 165\text{cm}$
G) $d_i = 170\text{cm}$
H) $d_i = 175\text{cm}$

2. Use the lens equation and your values for d_o and d_i to calculate the focal length of the lens:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

The calculated focal length is

A) $f = 86.23\text{cm}$
B) $f = 85.00\text{cm}$
C) $f = 83.73\text{cm}$
D) $f = 82.42\text{cm}$
E) $f = 81.08\text{cm}$
F) $f = 79.69\text{cm}$
G) $f = 78.25\text{cm}$
H) $f = 76.77\text{cm}$

3. How is your calculated focal length f related to the radius of curvature?

A) With only one observation, there's just no way to tell.
B) They're the same, to within our ability to measure the distances given the available tools.
C) They're unrelated, which is a nuisance, since we need the focal length far more than we need the radius of curvature!

Go ahead reposition that ruler one more time (do I need to tell you where?) if you're not sure about Question 03! Now adjust the radius of curvature to 50cm (you might also swap the arrow in place of the pencil to make measuring easier) and position the ruler so that you can easily place the object at a distance $d_o = 100\text{cm}$ from the center of the lens. Pay attention to the ruler! You will notice that the scale of the ruler changes depending on how far you are zoomed in or out. The ruler is always in centimeters, but it's not always scaled to 1 tick = 1 cm, so measure carefully.

4. The image formed by the converging lens is

A) an upright virtual image.
B) an inverted virtual image.
C) an upright real image.
D) an inverted real image.

5. What is the magnification of this image?

$$M = -\frac{d_i}{d_o} = \frac{h_i}{h_o}$$

A) $M = -1$
B) $M = +1$
C) $M = -100$
D) $M = +100$

6. Where do you need to position the object so that the image formed will be inverted and magnified ($M > 1$)? (Test this by changing the object distance!)

A) Any object located at $d_o < f$ will form a real, magnified image.
B) Any object located at any distance $d_o > f$ will form a real, magnified image.
C) An object must be placed in the region $f < d_o < 2f$ to form a magnified real image.
D) Anywhere; that converging lens can only form inverted images that are larger than the actual object!

Increase the radius of curvature to 58cm. Use the arrow as an object and adjust the height to $h_o = 50\text{cm}$. Once you have adjusted the height, click the lock next to the object selector at the top to prevent the object height from changing. Now adjust the object distance d_o until you have formed a virtual image with a magnification $M = +4$.

7. If the magnification $M = +4$, what must the image height be?

A) $h_i = 12.5\text{cm}$
B) $h_i = 50\text{cm}$
C) $h_i = 58\text{cm}$
D) $h_i = 200\text{cm}$

8. What is the object distance d_o?

A) $d_o = -175\text{cm}$
B) $d_o = -117\text{cm}$
C) $d_o = -58\text{cm}$
D) $d_o = -44\text{cm}$
E) $d_o = +44\text{cm}$
F) $d_o = +58\text{cm}$
G) $d_o = +117\text{cm}$
H) $d_o = +175\text{cm}$

9. What is the image distance d_i?

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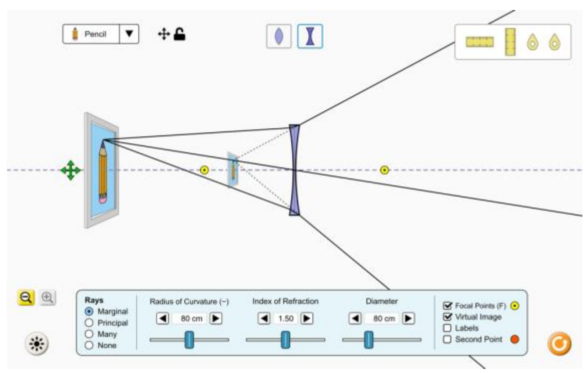
Diverging Lenses



Click the orange RESET button on the lower right to return to the default sim. Now choose the diverging lens instead of the converging lens. Don't change anything else (yet!).

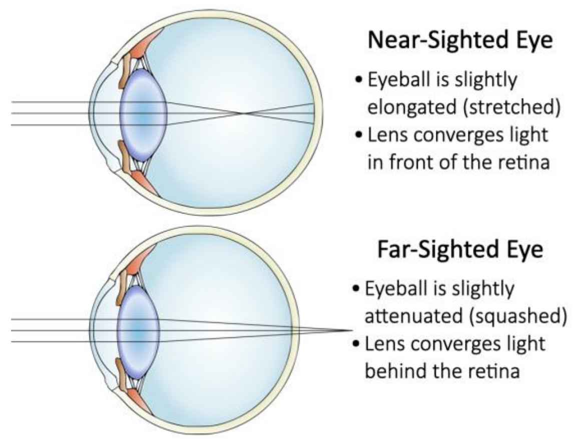
10. What changed when you replaced the converging with the diverging lens?

A) The radius of curvature changed. It's negative for a diverging lens.
B) The object distance changed; the object is now farther from the center of the lens.
C) The image changed; the diverging lens produces a virtual image.
D) The image changed, but it went from being virtual (converging lens) to real (diverging lens)!
E) All of the above!
F) Some of the above; only A and C are correct.
G) Some of the above, but it's B and D that are correct.

Use the pencil, arrow, or whatever object you prefer and make some qualitative observations of the images formed by a diverging lens. Change the object height, slide the object closer to or further from the lens, change the focal length of the lens.

11. Where should you place an object to create a virtual image?
    A) Only objects located at $d_o < f$ will form a virtual images.
    B) Only objects located at a distance $d_o > f$ will form a virtual images.
    C) An object must be placed in the region $f < d_o < 2f$ to form a virtual image.
    D) Anywhere; that diverging lens can only form inverted images that are smaller than the actual object!
12. Refer back to the very first image in the Introduction of this handout. A pair of eyeglasses sits in front of a computer screen. When you look through the lenses in the photo, what type of image are you seeing?
    A) A real image with $M < 1$.
    B) A virtual image with $M < 1$.
    C) A real image with $M > 1$.
    D) A virtual image with $M > 1$.
13. What type of lenses are in these glasses?
    A) A convex, converging lens
    B) A concave, diverging lens.

Vision Correction

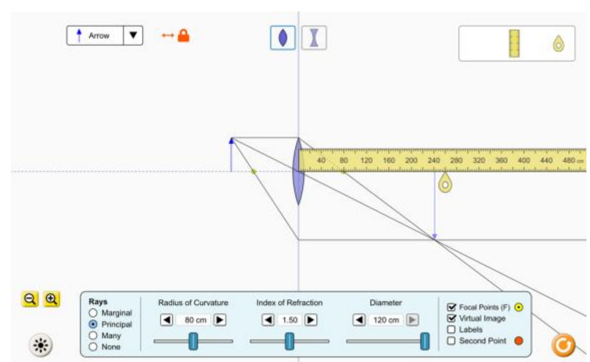


I already asked once: do you wear glasses? Or contact lenses? Chances are, if you need corrective lenses, your eyes are nearsighted. Distant objects are blurry, and without your glasses, you need to bring objects closer to focus on them. Why?

As shown on the right, the shape of your eyeball might not be a perfect sphere; if it's a little too long (top figure), light focuses in front of the retina, and what hits your retina is blurry. Bringing the object closer helps push that focal plane back onto your retina.

Far-sightedness is a less common vision defect. If your eyeball is a bit too short (squashed), the lens focuses the light behind the retina, and moving an object further from your eye helps pull that focus forward onto your retina. Either way, you're going to need a pair of glasses!

Let's simulate a nearsighted eye, then see if we can figure out what kind of corrective lens we'll need for our glasses. Set up the sim with the arrow as the object at a distance $d_o = 120\text{cm}$ (object height doesn't matter here). Adjust the radius of curvature to 80cm. Now grab one of the teardrop-shaped markers from the toolbox and place it at 260cm from the center of the lens, as shown on the right. The converging lens represents the lens in your eye, and the marker represents the position of your retina (not to scale! Your retina is only about 2.5cm from your actual lens!).



Thus, your ray diagram represents a near-sighted eye. The location of the image is in front of the retina.

14. Adjust the radius of curvature to try to move the image to the location of the marker. What focal length lens gets you closest to the marker?
    A) $f = 74\text{cm}$
    B) $f = 76\text{cm}$
    C) $f = 78\text{cm}$
    D) $f = 80\text{cm}$
    E) $f = 82\text{cm}$
    F) $f = 84\text{cm}$
15. In order to focus the image on the retina (the location of the marker), do you need the light to bend more or less (compared to the original configuration with $f = 80\text{cm}$)?
    A) To reach the retina, the lens should bend the light less.
    B) To reach the retina, the lens should bend the light more.

Unfortunately, the sim doesn't allow us to place a second lens in front of the original lens. And your glasses don't change the focal length of the actual lens inside your eye! Now what? Return to the original configuration, with $f = 80\text{cm}$ and $d_o = 120\text{cm}$.

16. Can you get the image aligned with the marker just by moving the object? Try it.
    A) No, moving the object is pointless; it doesn't affect the location of the image at all!
    B) Yes! If you slide the object to a new location further from the lens, to about $d_o = 130\text{cm}$, the image aligns with the marker.
    C) Yes, but you need to pull the object closer to the lens. Moving the object just slightly, to $d_o = 118\text{cm}$ actually aligns the image!
    D) Yes! If you place the object at exactly the focal point of the lens ($d_o = 80\text{cm}$), the image perfectly lines up with the marker.

The whole point of the eyeglasses is so that you *don't* have to keep pulling objects right up to your face in order to see them!

17. So what type of lenses go into a pair of glasses to correct near-sightedness? (Hint: If you're still not sure, check this out!)
    A) A diverging lens.
    B) A converging lens.

Are you not just near-sighted, but *really* near-sighted? The stronger your corrective lenses, the thicker the lens gets. What if you could make the lens thinner, but still correct the vision? With the object at $d_o = 120\text{cm}$ and the radius of curvature 80cm, test what happens if you change the index of refraction of the lens. Don't change anything else!

18. What happens when you increase the index of refraction of the lens?
    A) The lens gets thicker, but nothing else changes.
    B) Increasing the index of refraction increases the focal length of the lens.
    C) Increasing the index of refraction decreases the focal length of the lens!
    D) Changing the index of refraction doesn't change anything; the lens gets darker, but everything else stays the same.

Now set the index of refraction to $n = 1.70$. Your object should still be at $d_o = 120\text{cm}$ and the marker should still be 260cm from the lens. Adjust the radius of curvature until the image aligns with the marker.

19. What happens to the lens? What does that mean for your glasses?
    A) The higher index combined with a longer radius of curvature gives you a thinner lens that gets the same results!
    B) Using a higher index means you must decrease the radius of curvature to get the same results. A thicker lens is not really a benefit, is it?
    C) Changing the index of refraction doesn't do anything, as we already established. Why are we even doing this?