Lesson Title	20. Physics of the Eye and Lens
Lesson Designer	Nicole Granucci
Standards	☐ CCSS ☑ NGSS ☐ ASCA ☐ Other PS4.B: Electromagnetic Radiation. Some materials allow light to pass through them, others allow only some light through and others block all the light and create a dark shadow on any surface beyond them, where the light cannot reach. Mirrors can be used to redirect a light beam. (Boundary: The idea that light travels from place to place is developed through experiences with light sources, mirrors, and shadows, but no attempt is made to discuss the speed of light.) PS4.B: Electromagnetic Radiation. An object can be seen when light reflected from its surface enters the eyes. Planning and Carrying Out Investigations. Planning and carrying out investigations to answer questions or test solutions to problems builds on prior experiences and progresses to simple investigations, based on fair tests, which provide data to support explanations or design solutions. Plan and conduct investigations collaboratively to produce evidence to answer a question. Cause and Effect. Simple tests can be designed to gather evidence to support or refute student ideas about causes.
Learning Objectives	Students will: 1. Create a diverging and converging lens on a simulation to observe the effects of light rays 2. Measure the refracted angle of water and an unknown material using an online simulation 3. Calculate the index of refraction of water and an unknown material using an online simulation 4. Verify the conditions of a converging lens 5. Verify the conditions of a diverging lens 6. Calculate an object distance using the thin lens equation 7. Calculate the magnification of an image using the magnification equation 8. Determine the detects of an eye using several optical visual tests

Timeline	Duration
Day 1 - Students will learn about the Human Eye, Refraction, types of lens and eye defects. Day 2 – Students work on Part 1 Refraction Lab Day 3 – Students work on Part 1 – Diverging/Converging Lens Day 4 – Students will work on Part 2 - The Eye Detect Activity	Activity 1 – 45 minutes Activity 2 – 45 minutes Activity 3 – 20 minutes

Teaching Strategies/Student Actions	Monitoring
Students can be given the notes sheet to read for information from, or the instructor can just use the notes as a basis for the necessary information. The laboratory activity contains detailed instructions for students to conduct independently.	• Teacher monitors student progress • Teacher facilitates discussion • Teacher questioning

Product Description	Student analysis of questions embedded in lab.
Evaluation	Student analysis of questions embedded in lab.

Resources and Materials	Additional Notes
Web resources: • Refraction by lens - https://www.physicsclassroom.com/class/refrn/Lesson-5/Refraction-by-Lenses • Converging Lens - https://www.physicsclassroom.com/class/refrn/Lesson-5/Converging-Lenses-Object-Image-Relations • Diverging Lens - https://www.physicsclassroom.com/class/refrn/Lesson-5/Diverging-Lenses-Object-Image-Relations • Human Eye Physics - https://www.physicsclassroom.com/class/refrn/Lesson-6/Image-Formation-and-Detection • Farsightedness - https://www.physicsclassroom.com/class/refrn/Lesson-6/Farsightedness-and-its-Correction • Nearsightedness - https://www.physicsclassroom.com/class/refrn/Lesson-6/Nearsightedness-and-its-Correction • Astigmatism - http://www.envisionoptical.com/astigmatism/	

Physics of the Eye and Lens

Human Eye

The human eye is an important feature of the human body as it collects information about our environment through the light it captures. The eye has three main functions that allow us to see. First, the eye takes in the light, then the light is carried through many nerves into the brain and lastly the brain puts the information together. Physics can explain how the light enters into the eye and can account for the detects in vision. This lab will take you through the basic properties of refraction of light, how lenses are modeled and how to correct the detects in eyesight.

The eye is comprised of the several parts as depicted in the figure below. The cornea is responsible for focusing the light. Every cornea has a constant index of refraction of 1.34, however, the shape and curvature of the cornea causes each person to have a unique finger print in their vision. If the cornea is too flat or too curved, it can lead to vision defects which will be discussed later in the introduction. The iris covers the pupil, the whole in the eye, and can contract or loosen to change the amount of light that enters the pupil. The lens acts a finer light focuser for the incoming light. The retina is a light sensitive region of the eyes that takes the light sensing nerves and translates them into electric signals for the brain. The Fovea is the most sensitive part of the eye because of the dense region of light sensors. The blind spot is the part of the eye where the optic nerve connects to the brain. There is no light sensors on that section of the eye, therefore if any light falls on that location, it will not be able to be interpreted into electrical signals.

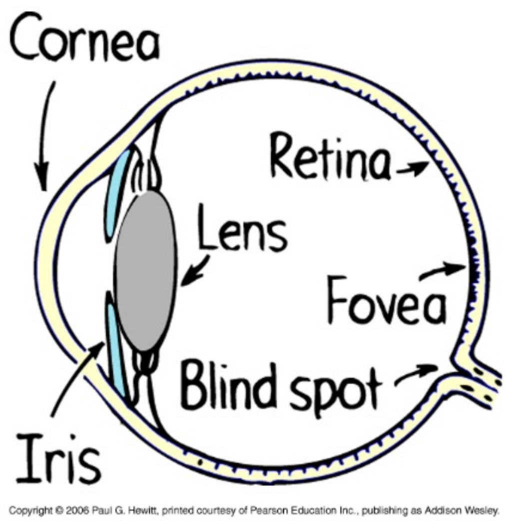


Figure 1 – Basic anatomy of the Eye

Refraction

Most of the physics happens at the cornea. As mentioned earlier, the cornea is a transparent covering that allows the light to enter the eye. Since the light is coming from the air and entering a different medium, the light is bent. This is referred to as refraction. Refraction is the bending of light due to the light entering a different medium. The thicker the medium, or higher index of refraction, the more the light bends. The index of refraction is a value that measures the quantity at which light slows down in a medium ranging from 1.00 (air) to about 2.42 (diamond). Light slows down when it enters a dense medium. The entering light wave is called the incident ray and the ray that gets bent after it enters the different medium is called the refracted ray. In reality, some of the light ray is reflected off the surface too as modeled in Figure 2. However, in this lab, we will ignore this effect.

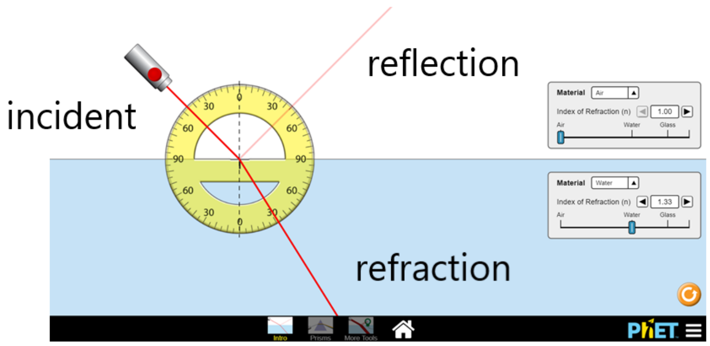


Figure 2 – Labeling the incident, refracted and reflected rays of light using the PHET – Refraction of light simulator

The measurement of the angle of refraction is taken from the normal to the surface. This is a dotted line that is 90 degrees to the surface. The incident and refracted angle is measured from the dotted line as seen in Figure 2. To measure the angle of refraction, Snells law is used

$$n_i sin\theta_i = n_r sin\theta_r$$

where n_i is the index of refraction for the incident medium, θ_i where n^r is the index of refraction for the refracted medium, θ_r. The cornea as a refractive index of 1.34 where the center of the lens has a refractive index of 1.41. The cornea for each person has a different shape and curvature despite having the same index of refraction.

Thin Lens – Converging and Diverging Lens

The main job of the cornea is to take the light and focus the light onto the fovea. If there are defects in the cornea, the light may not reach the fovea or the light does not focus properly. Therefore, a lens is needed. There are two general lens that help correct for these defects. A converging lens takes the light rays and converges them into one point called the focal point. A diverging lens takes the rays and spreads them out. Figure 3 depicts the two lens types. Lens have their own refractive index depending on what the lens is made from.

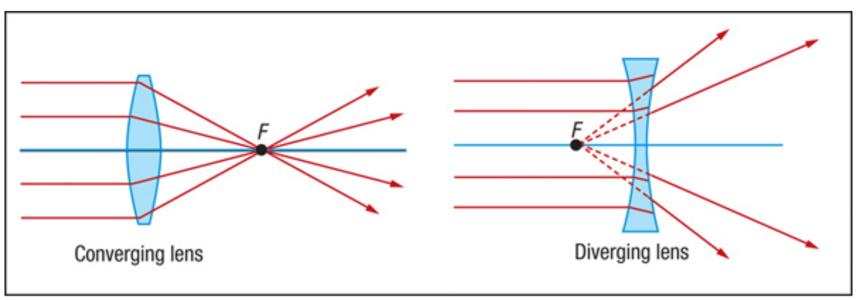


Figure 3 – Converging and Diverging Lens

The thin lens equation predicts the size, magnification and location of the image produced by a lens in relation to its focal point (The geometry of the lens).

$$\frac{1}{f} = \frac{1}{s_0} + \frac{1}{s_i}$$

where s_i is the image distance relative to the lens, s_o is the object distance relative to the lens, and f is the focal point location relative to the lens. The values as well as the signs give information about the system. Note: another version of the same equation is the following, using "d" instead of "s". It both cases "d" or "s" refer to position (distance) or location. It depends on the simulation or person teaching. It's the same relationship

$$\frac{1}{f} = \frac{1}{d_0} + \frac{1}{d_i} (1)$$

Data Table 1

	Positive (+)	Negative (-)
f	Converging lens	Diverging lens
d_o	In front of the lens	
d_i	Behind lens, Real	In front of lens, Virtual

You can also determine the change in size, or magnification of the object using the following equation:

$$M = \frac{h_i}{h_o} = -\frac{d_i}{d_o} \quad (2)$$

Where h_i is the image height, h_o is the object height and M is the magnification.

Data Table 2

	Positive (+)	**Negative (-)**
M	Upright	Inverted
	Less than 1	**Greater than 1**
M	Smaller	larger
	M = 1 Object same size as before	

In addition to the calculations, another way to determine the image characteristics given by the lens is to do a ray diagram. There are three rules for ray diagram.

Data Table 3

Ray 1 Rule	An incoming ray through the focal point will pass through the lens and pass through parallel
Ray 2 Rule	An incoming parallel ray will pass through the lens and bend through the focal point
Ray 3 Rule	A ray that passes straight through the center of the lens, will not refraction and continue in a straight line through the lens

In the simulation for this lab, the incoming rays are solid red lines. The outgoing rays are dotted lines. For ray 3, the incoming and dotted line overlap one another. You will confirm these attributes as well as calculate the image features using the simulation.

Eye Defects

The are several different types of eye defects that can be corrected using the right lens or combination of lenses. If the cornea is too flat or the eyeball is too short, then the light rays will not converge enough and focus the light beyond the eye. This will make a blurry image. This is called farsighted. It is a problem with focusing light that is up close. To correct for this problem, a converging lens is needed. This focuses the rays of light sooner to hit the back of the eye. This is also known as Myopia You are considered nearsighted if the rays of light converge before it hits the back of the eye. You are nearsighted because you can see objects up close but have trouble with objects that are far away. In order to correct for this, a diverging lens is needed. The diverging lens will spread the rays of light to push them to the back of the eye. This is also known as Hyperopia. Astigmatism is the result of the rays of light not focusing on the correct spot. It could either be two different focal points or the image is shifted because of the rays are not focusing in the right spot. This is caused by the eye having an irregular shape. Sometimes doctors refer to this as a "football" shaped eye, or that the cornea is not spherical. To correct for this eye defect, you need to use a lens that is curved in order to recurve the rays of light. Figure 4 depicts the three different eye defects and how to correct for it. The bottom row depicts what a normal eye would see given the corrected lens.

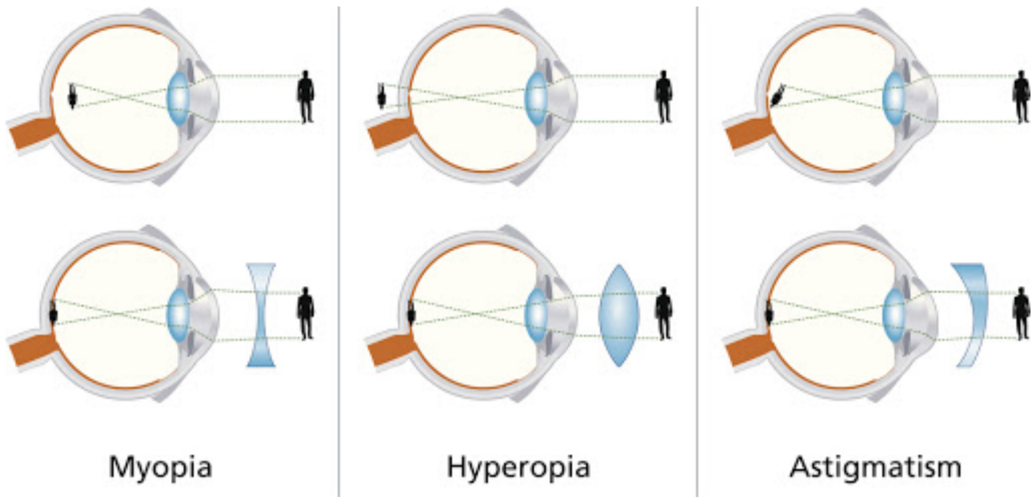


Figure 4 – Different types of eye defects and how to correct for them.

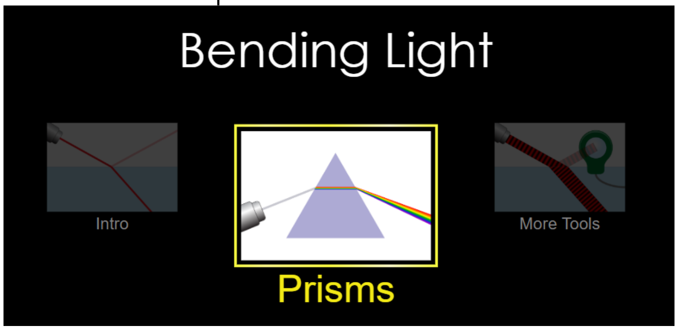
Another interesting coincidence of astigmatism is how it appears to the observer. Figure 5 shows how the world is view with the astigmatism. Notice how the image is blurry.

Figure 5 – Vision with and without Astigmatism

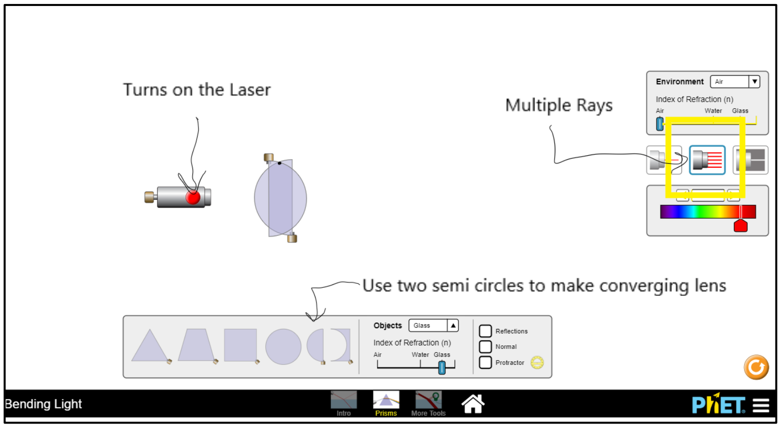
Investigation Procedure

Part 1 – Investigating Properties of Converging, Diverging Lens and Refraction

1. Go to the Simulation Website: https://phet.colorado.edu/sims/html/bending-light/latest/bending-light_en.html
2. Select the second option: PRISMS



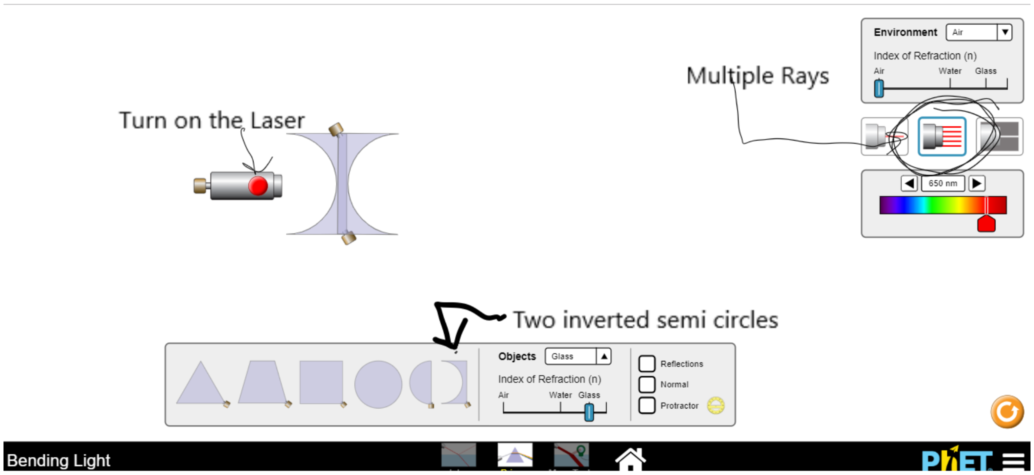
3. Make a converging lens by taking two semi circle prisms and putting them slightly over one another to make a curved surface on both sides. See figure below.
   a. Select the multiple ray option
   b. Turn on the laser



4. Screenshot what happens when you turn on the laser with multiple rays and pass it through the converging lens.

**Note: If you do not know how to screen shot, you may either take a photo with your phone and paste it here OR you can physically draw what you see, take a picture and insert it there. I'll accept any version to display the drawing. You may not look up an image from the internet and paste it there.*

5. Now, use the reset button to remove the two semicircles and use two inverted half circles to make a diverging lens.



**Note: If you do not know how to screen shot, you may either take a photo with your phone and paste it here OR you can physically draw what you see, take a picture and insert it there. I'll accept any version to display the drawing. You may not look up an image from the internet and paste it there.*

Summarize

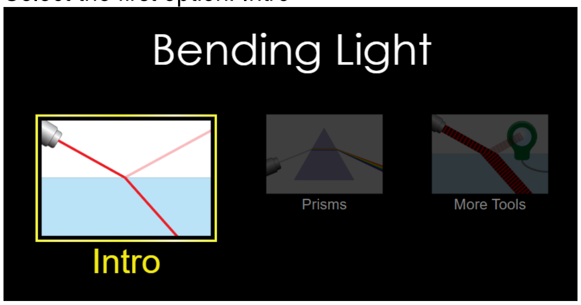
3. What does the converging lens do to all of the rays?

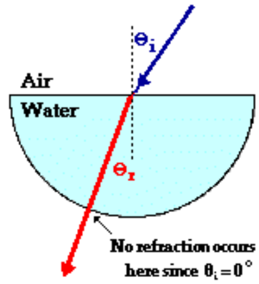
4. What does a diverging lens do to all of the rays?

5. If you are nearsighted, meaning that you have trouble seeing objects that are far away, your eye has trouble focusing the rays. In fact, the light focuses in the middle of the eye instead of the back of the eye as shown below. You can correct for this with glasses. What kind of lens would help this problem….converging lens or diverging lens? Explain.

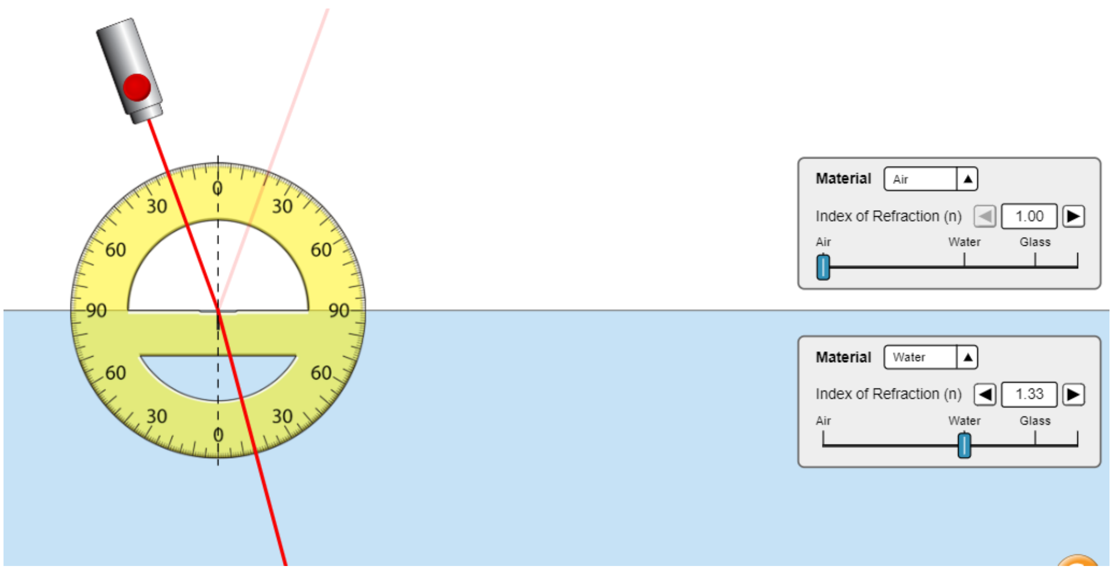
Part 2 – Determine the refraction index of the material

6. Refresh your web browser or go to the Simulation Website: https://phet.colorado.edu/sims/html/bending-light/latest/bending-light_en.html
7. Select the first option: Intro





8. Using the simulation,
   a. Select the ray option (top left)
   b. Select normal (bottom left)
   c. Select Protractor and set up so that the 90 is aligned with the horizontal and the 0 is lined up with the normal line (vertical dotted line)
   d. Turn on the laser
   e. Set material 2 as water, n=1.33
   f. Position laser for the incident ray of 20°



9. Line up the laser at the given incident angles in data table 1 so that the center of the beam passes through the center of the semi circle each time. The first angle of 20° is done for you as an example.
10. Measure the refracted ray from the normal line in material two. In this case the refracted angle is measured to be 15°. Record the value in the data table below. The first one is done for you as an example.
11. Repeat for each of the listed incident angles below in Data Table 1.
12. Calculate the index of refraction for each measured angle.

$$n_r = \frac{n_1 sin\theta_i}{sin\theta_r}$$

Where n_1 = refractive index of air = 1.00. θ_i where this is the incident angle and θ_r is the measured refracted angle.

Note: your calculator must be in deg mode, not radian mode. There are no units for index of refraction.

The first one is done for you as an example:

$$n_r = \frac{(1.00)\sin(20)}{\sin(15)} = \frac{0.342}{0.258} = 1.32$$

13. Data Table 2 – Measurements of the index of refraction of water
14. Determine the average of the index of refractions.
15. The refractive index of water is 1.33. According to your average, does your measurement match the simulation?
16. Repeat the entire experiment but change water to Mystery A.
17. Data Table 3 – Measurements of the refracted angle due to the Incident angle of Mystery A
18. Calculate the index of refraction for each measured angle.

$$n_r = \frac{n_1 sin\theta_i}{sin\theta_r}$$

19. Data Table 4 – Measurements of the index of refraction of Mystery A
20. Based on your average and using the data table below, determine the substance for Mystery A.

Indices of Refraction for Various Substances

Solids at 20°C	n
Cubic zirconia	2.20
Diamond	2.419
Fluorite	1.434
Fused quartz	1.458
Glass, crown	1.52
Glass, flint	1.66
Ice (at 0°C)	1.309
Polystyrene	1.49
Sodium chloride	1.544
Zircon	1.923

Liquids at 20°C	n
Benzene	1.501
Carbon disulfide	1.628
Carbon tetrachloride	1.461
Ethyl alcohol	1.361
Glycerine	1.473
Water	1.333

Gases at 0°C, 1 atm	n
Air	1.000 293
Carbon dioxide	1.000 450

*measured with light of vacuum wavelength = 589 nm

Part 3 – Converging Lens Rules

Go to the following simulation: https://www.geogebra.org/m/pfncxexz

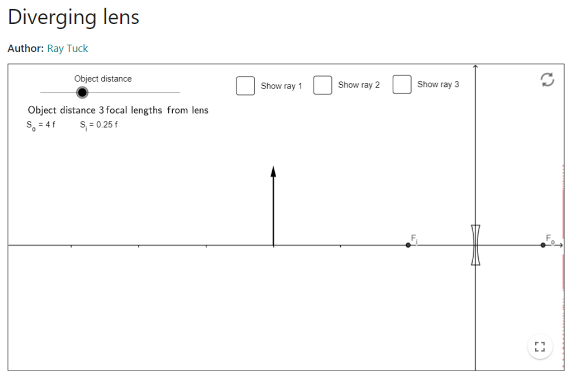
1. Set the:
    a. Object distance to 30
    b. Focal length 20
    c. Object height 15

    This models an object in front of the focal point of a converging lens
2. It should show two rays. Which of the Ray Rules in Data Table 3 in the introduction does the simulation use to draw an image?
3. Observe the image created – the green arrow.
    a. Record magnification.
        i. Is it greater than 1, less than 1 or equal to 1?
        ii. Is it upright or inverted?
        iii. Does the drawing match the characteristics in Data Table 1 & 2 in the Introduction?
    b. Record the image distance (under the ray check boxes).
        i. Is the image in front of the lens or behind the lens?
        ii. Is it real or virtual?
        iii. Does the drawing match the characteristics in Data Table 1 & 2 in the Introduction?
    c. Using the object distance as 30cm and the focal distance as 20 cm, calculate the object distance using the thin lens equation, equation 1, in the introduction. Does it match the simulation data?
    d. Calculate the Magnification using equation 2 in the introduction. Use the image height as -30cm and the object height as 15cm. Does it match the simulation data?
4. Set the
    a. Object distance to 15
    b. Focal length 30
    c. Object height 10

    This models an object behind the focal point of a converging lens
5. Why are their dotted lines for the green arrow and rays?
6. Observe the image created – the green arrow.
    a. Record magnification.
        i. Is it greater than 1, less than 1 or equal to 1?
        ii. Is it upright or inverted?
        iii. Does the drawing match the characteristics in Data Table 1 & 2 in the Introduction?
    b. Record the image distance (under the ray check boxes).
        i. Is the image in front of the lens or behind the lens?
        ii. Is it real or virtual?
        iii. Does the drawing match the characteristics in Data Table 1 & 2 in the Introduction?
    c. Using the object distance as 15cm and the focal distance as 30 cm, calculate the object distance using the thin lens equation, equation 1, in the introduction. Does it match the simulation data?
    d. Calculate the Magnification using equation 2 in the introduction. Use the image height as 20cm and the object height as 10cm. Does it match the simulation data?

Part 4 – Diverging Lens Rules

1. Open simulation: https://www.geogebra.org/m/W6Z67aN5



* Disclaimer – the simulation measures the object distance from the focal point after the lens. This is not typical of the lens equation given above. In our lab, we will ignore this as we are just looking at the characteristics and not the calculations.

Changes to the Image of 4f

2. Set the object distance to 4f.
3. Show ray 1.
4. Which Ray Rule from above does it satisfy?
5. Show ray 2.
6. Which Ray Rule from above does it satisfy?
7. Show ray 3.
8. Which Ray Rule from above does it satisfy?
9. Observe the image created – the red arrow.
   a. Record magnification.
      i. Is it positive or negative?
      ii. Is it greater than 1, less than 1 or equal to 1?
      iii. Is it upright or inverted?
      iv. Does the drawing match the characteristics in the table above?
   b. Record the image distance (under the ray check boxes).
      i. Is the image in front of the lens or behind the lens?
      ii. Is it real or virtual?
      iii. Does the drawing match the characteristics in the table above?
10. Uncheck all of the ray boxes and set the object distance to a 0.5f.
11. Changes to the Image of 0.5f
12. Set the object distance 0.5f (in front of the focal point).
13. Observe the image created – the red arrow.
   a. Record magnification.
      i. Is it positive or negative?
      ii. Is it greater than 1, less than 1 or equal to 1?
      iii. Is it upright or inverted?
      iv. Does the drawing match the characteristics in the table above?
   b. Record the image distance (under the ray check boxes).
      i. Is the image in front of the lens or behind the lens?
      ii. Is it real or virtual?
      iii. Does the drawing match the characteristics in the Data Table 2 in the introduction?

Part 5 – Eye Defects Activities

Blind Spot

1. Find your blind spot - A spot in the eye that does not contain tissue that can interpret information.
2. Close one eye and focus on the dot in the cross-hair.
3. Move forward/backward toward the computer screen until the "X" in your peripheral vision disappears.
4. When the "X" disappears from your vision, that is your blind spot.
5. Repeat with your other eye.

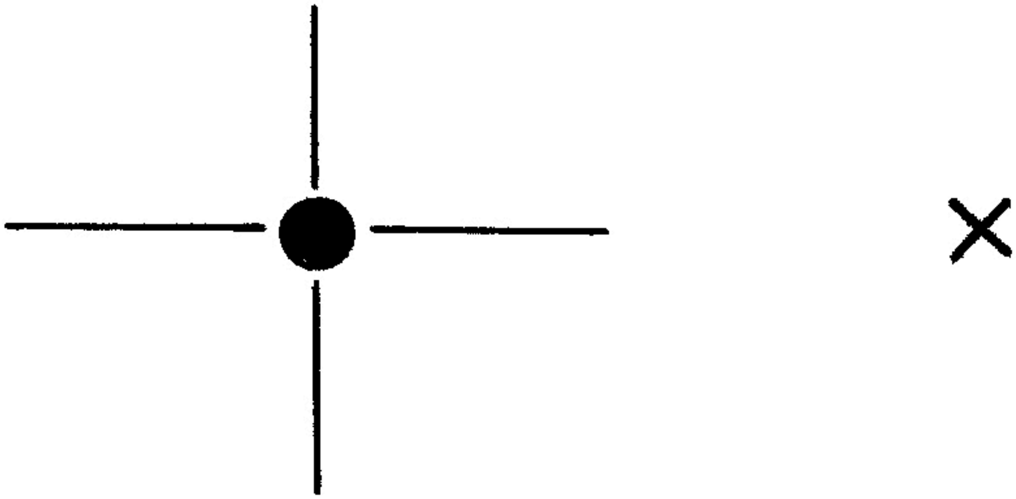


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Photo Credit: Hewitt Physics

Test for astigmatism

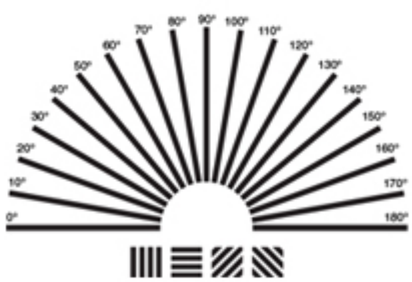


Photo Credit: http://www.envisionoptical.com/astigmatism/

1. Its best if you can take off your glasses/contacts. If you can not, just indicate that in the analysis questions.
2. Close one eye.
3. If some lines are more gray/blurry than others, than you might have an astigmatism.

Glasses Evaluation

Determine the type of detect a person has from the glasses

1. Find a pair of glasses – whether they are you own or a fellow student/teacher/etc.
    a. Take a pair of glasses and hold them over a object. It can be a book, lab sheet, pencil, it doesn't matter.
        i. Does the image appear smaller or larger
        ii. If it appears smaller – diverging lens = nearsightedness correction
        iii. If it appears larger – converging lens = farsightedness correction

Analysis Question for Eye Detects

1. How far away were you from your computer screen when your blind spot was detected?

2. Did both eyes have the same blind spot distance, or were they different?

3. Did either of the tests indicate astigmatism? Describe what you saw for each test. Do you have a known astigmatism? Did it show up in the test?

4. What did you determine with the eye glass evaluation?

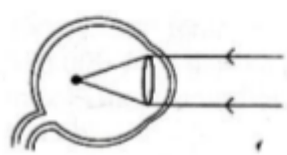
Lab Data Sheet

Part 1 – Investigating Properties of Converging, Diverging Lens and Refraction

1. Screen shot of ray tracing of a converging lens:

2. Screen shot of ray tracing a diverging lens:

3. What does the converging lens do to all of the rays?
4. What does a diverging lens do to all of the rays?
5. If you are nearsighted, meaning that you have trouble seeing objects that are far away, your eye has trouble focusing the rays. In fact, the light focuses in the middle of the eye instead of the back of the eye as shown below. You can correct for this with glasses. What kind of lens would help this problem….converging lens or diverging lens? Explain.



Part 2 – Determine the refraction index of the material

6. Data Table 1 – Measurements of the refracted angle due to the Incident angle of Water

Trials	Incident Angles	Refracted Angles	Calculated Index of Refraction
1.	20°	15°	1.32
2.	30°		
3.	40°		
4.	50°		
5.	60°		
6.		Average	

7. Data Table 2 – Measurements of the refracted angle Mystery A

Trials	Incident Angles	Refracted Angles	Calculated Index of Refraction
8.	20°		
9.	30°		
10.	40°		
11.	50°		
12.	60°		
13.		Average	

Analysis

1. The refractive index of water is 1.33. According to your average, does your measurement match the simulation?
2. Based on your average and using the data table below, determine the substance for Mystery A.

Part 3 - Converging Lens Rules

Which Rule is satisfied?

Object in front of the Converging Lens

	Observations
Magnification • Positive/Negative • Greater/less/equal to 1 • Upright/Inverted • Matching Characteristics in Table 1	
Image Distance	
Image • Infront/Behind • Real/Virtual • Matching Characteristics in Table 1	
Calculation of Image Distance	
Calculation of Magnification	

Object behind the Converging Lens

Why are their dotted lines for the green arrow and rays?	
	Observations
Magnification • Positive/Negative • Greater/less/equal to 1 • Upright/Inverted • Matching Characteristics in Table 1	
Image Distance	
Image • Infront/Behind • Real/Virtual • Matching Characteristics in Table 1	
Calculation of Image Distance	
Calculation of Magnification	

Part 4 – Diverging Lens Rules

	Which Rule is satisfied?
Ray 1	
Ray 2	
Ray 3	

Changes to the Image of 4f

	Observations
Magnification • Positive/Negative • Greater/less/equal to 1 • Upright/Inverted • Matching Characteristics in Table 1	
Image Distance	
Image • Infront/Behind • Real/Virtual • Matching Characteristics in Table 1	

Changes to the Image of 0.5f

	Observations
Magnification • Positive/Negative • Greater/less/equal to 1 • Upright/Inverted • Matching Characteristics in Table 1	
Image Distance	
Image • Infront/Behind • Real/Virtual • Matching Characteristics in Table 1	

Part 5 – Eye Defect Activity

Analysis Questions	
How far away were you from your computer screen when your blind spot was detected?	
Did both eyes have the same blind spot distance, or were they different?	
Did either of the tests indicate astigmatism? Describe what you saw for each test. Do you have a known astigmatism? Did it show up in the test?	
What did you determine with your eye glass evaluation?	