Section 12.3 Lens Technologies and the Human Eye

(Student textbook pages 502 to 511)

In this section, students will relate the theoretical ideas of light converging or diverging in lenses to the optical devices that exist today such as glasses, telescopes, and microscopes, and examine how these devices have changed the world.

Common Misconceptions

- Students may think that lenses focus only rays of light. They may not realize that other electromagnetic radiation can be focussed by other sorts of lenses. These lenses can be made of solid metal. For example, microwaves can be focussed with aluminum lenses.

Background Knowledge

Glasses are thought to have been a key factor in starting the Renaissance period because they extended the life span of a scholar. Before glasses existed, writing was only a useful manner of passing information down until people reach their 40s or so and their eyesight failed. After glasses were invented, scholars could continue to read for decades more, lengthening their academic careers.

The telescope had many applications in commerce and the military, but changed the world more through astronomy than either of these two applications. With it, Galileo (following on the work of Copernicus) and others were able to observe that there were motions in the heavens not predicted by naked eye astronomy. This was one of the key factors that upset the prevalent philosophical views of the world at that time—by challenging the ability of the Church to answer all questions, and throwing the centrality of human existence in the universe into doubt.

Microscopes enabled investigators to see new forms of life, and provided a window into both medicine and the germ theory of disease. Soon after they were in use, humans made more progress in medical science than had been made in the thousands of years prior to their invention. Microscopes gave investigators the tools to observe and make inferences about what they saw. It became possible to see that organisms were made up of smaller parts we now call cells, which were made up of even smaller components.

Literacy Support

Using the Text

- Throughout this section students will be exposed to text and diagrams that collectively demonstrate the path of light in optical instruments. Demonstrate the value of diagrams by asking students to explain in words what is happening to light in Figure 12.17. The point is that it is not difficult to do so. It just takes so much more effort to describe with words the details that are evident in the ray diagram.
- Refer to the margin notes to highlight the terms given to conditions requiring corrective lenses.

Before Reading

- Focus students on the Key Terms listed on page 502. Ask students wearing corrective lenses if they would like to share with the class why they need glasses. Focus students on the section that describes this condition and explains how corrective lenses help vision.

During Reading

- Remind students to use the strategy "Making Connections to Prior Knowledge" as outlined in the margin on page 505 of the student textbook.

Specific Expectations

- **E1.1** analyse a technological device or procedure related to human perception of light, and evaluate its effectiveness
- **E1.2** analyse a technological device that uses the properties of light, and explain how it has enhanced society
- **E2.1** use appropriate terminology related to light and optics, including, but not limited to: *angle of incidence, angle of reflection, angle of refraction, focal point, luminescence, magnification, mirage,* and *virtual image*
- **E3.5** describe the characteristics and positions of images formed by converging lenses, with the aid of ray diagrams
- **E3.6** identify ways in which the properties of mirrors and lenses (both converging and diverging) determine their use in optical instruments
- **E3.8** describe properties of light, and use them to explain naturally occurring optical phenomena

- Have students use a graphic organizer as outlined in the margin on page 510 of the student textbook. Make a cause-and-effect map to help clarify the process involved in a night-vision device. You may wish to have students use **BLM G-41 Cause-and-Effect Map** for this activity.

After Reading

- DI Students with a linguistic intelligence, or those who like history, might find it interesting to research and or write a story about the impact of either eyeglasses, the microscope, or telescopes on the world.
- Direct students to the Word Study feature on page 486 of the student textbook, to reactivate their understanding of base words. Have students use the strategy to make a table for words sharing the ending –*opia*.

Using the Images

- Figure 12.15 shows a representation of Galileo's telescope. Galileo's telescope still exists, although one of lenses was lost centuries ago. The exact specifications for this telescope are described on page TR-4-73 of this Teacher's Resource.
- Figures 12.16 and 12.17 show ray diagrams for telescopes. Students may wonder why a telescope, which appears to make things larger, has an image that appears so small. Remind them that the image has to appear inside of the telescope whereas the actual object can be huge but is at a great distance so it will appear small.
- Figure 12.18 shows the Newtonian or refractor telescope. Usually the mirror is replaced by a prism. As an extension, you could ask students to explain why. The answer is that light can pass through a prism, but not a mirror. Using a prism will allow more starlight to be gathered onto the lens. When it reflects up to the prism, total internal reflection means that the light from the curved mirror will all enter the eye of the observer.
- Figure 12.22 shows a giant squid. Students will find it interesting that the eye of a giant squid does not have a blind spot, because their optic nerves are placed behind their retinas. In humans and most vertebrates, the head of the optic nerve sits in front of the retina, causing a blind spot.
- Figure 12.23 accurately depicts light rays refracting at the cornea itself.
- As time goes on, the lens of the eye becomes less flexible. As is implied in Figure 12.24, this means that light rays can no longer focus exactly on the back of the retina and you do not get a clear image. Students will likely have seen this as many of their parents may have reached an age where it becomes difficult to read without glasses (e.g., in restaurants they hold menus further and further from their eyes, and otherwise move papers that they need to read further and further away).
- Figure 12.29 shows an image formed using night-vision glasses, which use both enhanced visible light and infrared radiation. The enhanced visible light aspect is good for some uses but can be disabled or dazzled with a fairly small amount of visible light, for example, a small fire. When seeing infrared radiation, you are actually seeing the world in the way a snake or a mosquito would see it. Tell students that Figure 12.29A is not blurry because it is a poor picture. The picture is blurry because infrared radiation has a sufficiently long wavelength that it does not pick up details as clearly as normal light can.

Assessment FOR Learning		
Tool	**Evidence of Student Understanding**	**Supporting Learners**
Learning Check questions, page 505	Students identify ways in which lenses and mirrors are used in different types of telescopes.	Answer question 2 as a class, using **BLM G-47 Venn Diagram.** Focus students on the light-gathering ability of optical instruments. Optical telescopes collect small amounts of light from a large area. Microscopes, on the other hand, gather large amounts of light from a small area.
Section 12.3 Review questions, page 511	Students can explain how the eye and various devices focus light using lenses.	Have small groups prepare concept maps summarizing the qualities of the various devices, including the number and type of lenses (and mirrors) they use. Students may find **BLM G-44 Main Idea Web** or **BLM G-45 Spider Map** helpful. Select alternative or remedial questions from **BLM 12-10 Section 12.3 Review (Alternative Format).**

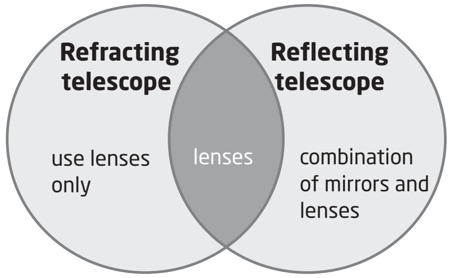
Instructional Strategies

- DI This section provides the intrapersonal learner with many opportunities to reflect on and internalize the ways in which the science they are learning about affects their own experience of the world.
- This section could be taught in a jigsaw format wherein small groups develop expertise in a single technology, then regroup to share expertise and learn from each other, or make presentations to the class as a whole. **BLM 12-9 Lens Technologies** will help students organize the information.
- Bring in an example of each technology and provide time for students to explore and try them. Consider showing a video of laser surgery or having an ophthalmologist speak to the class about the procedure and what problems it can correct.
- As student read pages 505, have them use a concept map to make connections to prior knowledge about microscopes. Refer students to Study Toolkit 4, in particular the section on Concept Maps on page 565 of the student textbook. They may also find **BLM G-42 Concept Map** helpful.
- After reading page 510, have students arrange the steps involved in night vision into a cause-and-effect map. Refer students to Study Toolkit 4, in particular the Cause-and-Effect Map section on page 566 of the student textbook. They may also find **BLM G-41 Cause-and-Effect Map** helpful.
- To give students the opportunity to test their own vision, have students carry out Inquiry Investigation 12–B I "Speye," on student textbook pages 514 to 515. See page TR-4-71 of this Teacher's Resource for notes on using this investigation.
- To engage interest, have students carry out Inquiry Investigation 12–C Making a Simple Telescope, on student textbook page 516. See page TR-4-73 of this Teacher's Resource for notes on implementing this investigation.
- Encourage students to sample other students' eyewear. The lens that provides corrective treatment for one student may cause vision blurriness for another student. Ask students to predict which type of lens will "improve" their vision.
- Eye glasses no longer used by students or members of their families can be collected and donated to developing countries. This could become a repeating class project to demonstrate the importance of corrective lenses for society.
- Challenge students to use a lens to boil water. You can set the conditions and the amount of water that must be used. You may wish to begin with a demonstration to show the value of concentrating the Sun's rays in a small area.
- To assess students' concept maps, use **BLM A-13 Concept Map Checklist.**

Learning Check Answers (Student textbook page 505)

1. Newton used a concave mirror as an objective instead of a lens to correct chromatic aberration.

2. Example:



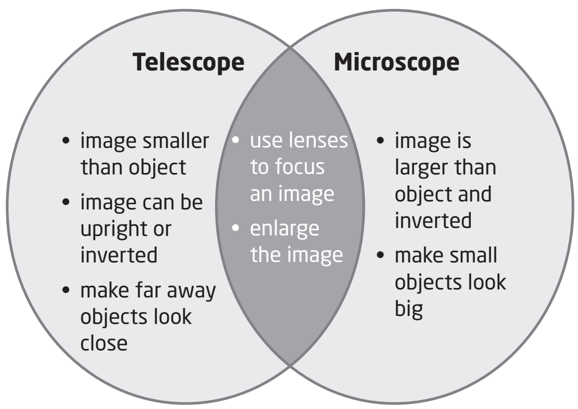
3. Most modern telescopes are reflecting because a large mirror is less expensive to make than a large lens, and both enable the telescope to collect more light.

4. Example: Telescopes are useful to see any object far away, such as between boats at sea, or from observation decks of very high buildings.

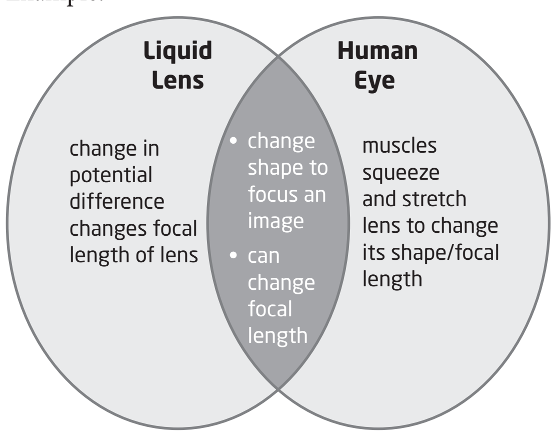
Section 12.3 Review Answers (Student textbook page 511)

Please also see **BLM 12-10 Section 12.3 Review (Alternative Format).**

1. Example:



2. Example:



3. Diagrams should show rays extending from the fly, crossing at the centre of the objective lens and reaching the ocular lens. The image will form between the two lenses, inside the microscope. The fly will appear enlarged and outside the microscope. See Figure 12.21 on student textbook page 505.

4. Example: Night-vision devices can be used by people in law enforcement to help them see illegal activities that occur at night and capture criminals; eyeglasses can be made to correct most people's vision so that they are able to see clearly, and read and write throughout their lifetime.
5. The lens can focus images of both distant objects and nearby objects on the retina by changing the shape of the lens.
6. The aperture controls the amount of light in the camera (iris changes the size of the pupil in the eye). Light-sensitive devices in a camera capture the image (retina in the eye). The ring that moves the camera lens in and out changes the focal length so the image focuses at the right point (muscles inside the eye adjust the shape of the lens).
7. A lens near the end of an image-intensifier tube focuses the light on a photocathode. At each point that light hits the photocathode, it emits an electron. Voltage generated by batteries attracts the electrons to the microchannel plate. As electrons pass through the channels, they collide with the walls, causing the walls to emit more electrons. A voltage then attracts the electrons to the phosphor plate. When electrons collide with the phosphor, the phosphor emits green light. Another lens focuses the green light onto the eye of the observer. See Figure 12.29B on student textbook page 510.
8. The cornea in eye A is more oval shaped than the cornea in B. So eye A likely has astigmatism. Astigmatism is blurred or distorted vision usually caused by an oval shaped cornea. Correctly shaped lenses can compensate for astigmatism.

Inquiry Investigation 12-A Image Characteristics of a Converging Lens (Student textbook pages 512 to 513)

Pedagogical Purpose

This activity satisfies the expectation that students experimentally determine the properties of a converging lens.

Planning		
Materials	Screen in a holder Converging lens in a holder Spreadsheet software (optional) **BLM 12-3 Image Characteristics of a Converging Lens** (optional)	Metric ruler Support stands Light source in a holder
Time	60 min	
Safety	If a candle is used as the light source, handle it with care. Keep flammable materials such as paper well away from the candle, and tie back loose hair and clothing.	

Background

This is an opportunity for students to experimentally verify the focal length of some converging lenses. They must accept that the given focal length is correct in order to set up the lenses at appropriate distances, because object distances and image distances are measured in multiples of the focal length. In this investigation, students assume to know focal length. They set up the object at a known distance and observe the image distance. From these measurements they calculate the actual focal length, which hopefully, is close to the one predicted.

Activity Notes and Troubleshooting

- If a candle is going to be used, caution students against using excessive hairspray, cologne, or other products that may be flammable.
- Have students prepare the observation table the day before, or hand out **BLM 12-3 Image Characteristics of a Converging Lens** which scaffolds this process.
- A sufficiently bright light source is required to enable focussing onto a screen. A candle, small light bulb, or phosphorescent glow stick can be used.
- The room does not have to be dark as students only need to be able to see the light focus on the screen.
- Unless you are pressed for time, emphasize step 4. You will likely be asking students for an error analysis or experimental error in this lab, as in most labs. It is important for students to realize that having experimental error is more a source of uncertainty than an excuse for not having done the lab correctly. If the two measurements disagree by more than about a centimetre, tell students they are to repeat and try to make the necessary alterations before they accept the result.
- Be prepared for confusion when students cannot quite focus the image when the lens is exactly at the focal length. If the light was from a distant source, the light rays would be parallel and converge to a single bright point that is one focal length away from the lens. However, here the light source is not a distant source. Drawing a ray diagram will help students understand what they are seeing: that the light does not actually focus to make an image at this distance.
- Use **BLM A-35 Measuring and Reporting Rubric** and **BLM A-18 Data Table Checklist** to assess students' data collection.

Additional Support

- DI This activity is well-suited for spatial and body-kinesthetic learners.
- DI Logical-mathematical learners may wish to begin with the calculations and verify their findings with the lens set-up.
- ELL English language learners can be grouped with students who have strong language skills. Assign each member a role they will be comfortable doing (e.g., positioning the lenses, recording distances in a table, performing calculations).
- Model the set up for students, especially if your apparatus differs from that shown in the student textbook.
- Allow students to use a programmable calculator or computer to calculate the inverse fractions.
- Allow student to use a spreadsheet for the calculations so they can focus on the physics rather than the mathematics of adding fractions. Cells should be set up as follows:

	A	B	C	D	E	F	G	H
1	Object distance d_o (focal lengths of lens)	Object distance d_o (cm)	$1/d_o$ (cm^{-1})	Image distance d_i (cm)	$1/d_i$ (cm^{-1})	$1/f = 1/d_i + 1/d_o$ (cm^{-1})	Focal length f (cm)	Image characteristics (erect/inverted, real/virtual, larger/smaller)
2	$2.5f$		=1/B2		=1/D2	=C2+E2	=1/F2	
3	$2.0f$		=1/B3		=1/D3	=C3+E3	=1/F3	
4	$1.5f$		=1/B4		=1/D4	=C4+E4	=1/F4	
5	f		=1/B5		=1/D5	=C5+E5	=1/F5	
6	$0.5f$		=1/B6		=1/D6	=C6+E6	=1/F6	

In the above chart, note columns A and B. Students may have difficulty understanding how the measurement of object distance can be expressed in terms of focal lengths because that is not a scale they are used to using. This is why a second column has been included to translate from focal lengths to distance. It will help students if you model one calculation. For example, if your lens has a focal length of 15 cm, the third row showing twice the focal length means you put the lens 30 cm away from the object.

Answers

1. a. When d_o is very large, $1/d_o$ is small.

b. When d_o is very large, the lens equation predicts that $1/f = 1/d_i$.

2. a. Example: When $d_o = 12.5$ cm and $d_i = 8.3$ cm, focal length (f) = 5 cm. When $d_o = 10$ cm and $d_i = 10$ cm, focal length (f) = 5 cm.

b. These values should be the same.

3. the position at $d_o = f$

4. the position at $d_o < f$

5. Example: There may be small discrepancies which result from the difficulty in accurately determining the location of the image distance from lens. This measurement is dependent on the quality and rigidity of the support stands, the quality of the lens used, and experimental error (e.g., students can be hasty in measuring this distance). Encourage students to use the maximum precision (and number of significant digits) of the ruler.

6. **a.** d_i increases
   b. The image gets larger.

7. **a.** The image is upright only when $d_o < f$.
   b. The image is inverted for all other values of d_o.

8. The lens must be held so that $d_o < f$, with the object and eye on opposite sides of the lens. The object position is $0.5f$.

9. The image will be dimmer, but otherwise unchanged. Each part of the lens brings rays of light to a focus, so any part of the lens will form an image.

10. Significant points include:
    1284, Italy—Salvino D'Armate invented first wearable eye glasses.
    1604, Germany—Johannes Kepler explained how lenses correct presbyopia and myopia.
    1727, UK—Edward Scarlett invented eyeglass arms that hook over ears.
    1784, USA—Benjamin Franklin invented bifocals.
    1825, UK—George Airy corrected astigmatism with lenses.

Inquiry Investigation 12-B I "Speye"

(Student textbook pages 514 and 515)

Pedagogical Purpose

This investigation provides students with the opportunity to examine the properties of binocular vision, as well as test the limits of their field of view. Some students may never have had an eye exam, and may not know they need one because they will have never seen through different lenses. The investigation also provides a link to the Science at Work feature, which deals with the donation, collection, and redistribution of eyeglasses to people in developing countries.

Planning		
Materials	Soft measuring tape	Piece of paper
Time	20 to 60 min	
Safety	Remind students not to let anything touch their eyes.	

Background

The blind spot exists because our optic nerve is actually in front of the retina where images are formed. Some creatures, such as a giant squid, have their optic nerves behind the retina and so do not have a blind spot. This is considered evidence of parallel evolution.

Anticipate that at least one student will discover some degree of vision difficulty he or she was not aware of. Students may wish to share their findings with a guardian, and follow up with an optician or family doctor. These investigations are not meant to be diagnostic nor serve as a measure of a student's abilities or worth.

Students may wonder why so many people need corrective eyewear. They may reason that if this many people with vision problems lived long ago in our hunter/gatherer past, most would not likely survive. They may conclude that natural selection should have eliminated such variations long ago. Explain that this is an area of ongoing medical research.

Activity Notes and Troubleshooting

- In part 3 of the investigation, students might need to be reminded to only have one eye open and to keep their eyes focused on the X. If they glance at the dot, it will reappear. They may also have to start with their eye only a few centimetres from the page and slowly pull back the paper.
- A favourite student activity after this investigation is to try on each other's glasses to see if they can improve their vision. Some may find success. You may wish to encourage this fun activity, by integrating it into the investigation and having students write a comment as to whether it is possible to see better using a pair of glasses.
- For further interest, have students read the Science at Work feature on pages 520 and 521. See page TR-4-5 of this Teacher's Resource for notes on using this feature.
- To extend, you may wish to have students read an eye exam chart or test their colour vision.
- To wrap up, make a general comparison between human vision with another animal's vision. For example, our blind spot shows our eyes are not particularly well-designed compared those of a giant squid.
- To assess students' process, use **BLM A-41 Conduct an Investigation Rubric** or use **BLM A-36 Process Skills Rubric Template** and work with students to develop assessment criteria.

Additional Support

- DI This investigation addresses spatial, bodily-kinesthetic, and intrapersonal intelligence.
- DI This is a good investigation for intrapersonal learners as they asses their own abilities and apply scientific concepts to their own experience of the world.
- This activity could be:
  - assigned as a homework
  - used to lead to a larger project on the human eye's structure or health
  - altered for a student-driven, independent investigation or a real-world investigation
  - the basis of independent assessment

Answers

1. Example: 25 cm
2. Example: 5 cm high and 4 cm wide. Using the scale factor given, 5 cm × 0.044 = 2.2 mm and 4 cm × 0.044 = 1.8 mm.
3. Light rays refract through the regions of different curvature and do not come to focus at the same point on the retina.
4. The lens is relatively thick. When an object is close, the focal length of the lens must decrease to keep the image focused on the retina. Shorter focal length lenses are thicker.
5. Bifocal lenses have distinctly different parts. The top part of each lens is usually shaped to improve distance vision and the bottom part of each lens is shaped to improve close-up vision. When reading, the wearer looks down at the words through the "close vision" section. When walking, the wearer looks up, through the main "distance vision" part of the lens.
6. **a.** corrective lenses (glasses or contacts) or laser surgery

   b. Example: Corrective lenses involve little risk beyond breaking a lens, while providing the full benefit of corrected vision. Laser surgery promises to completely correct vision without having to wear an appliance, but carries the usual risks of surgery as well as the possibility of chromatic aberration and halos.

Inquiry Investigation 12-C Make a Simple Telescope

(Student textbook page 516)

Pedagogical Purpose

This investigation allows students to construct a simple telescope, and then experiment with and experience the actual use of lenses. It fulfils the expectation that students will construct an optical instrument.

Planning		
Materials	Converging lens (large, with a long focal length) Converging lens (small, with a short focal length)	Diverging lens (small, with a short focal length) Long cardboard tubes (optional)
Time	60 to 90 min	
Safety	Do not point the lenses at the Sun.	

Background

The first telescope was not made by Galileo, but Galileo certainly became one of the more famous early users. His telescope consisted of two lenses, both curved on one side and flat (planar) on the other. His telescope is still in existence. The converging lens has a focal length of about 98 cm or just under one dioptre. The diverging lens in the eye piece was lost in the 1700s, but the focal length was believed to be about 98 cm as well.

Related note: one reason people used to think there were canals on Mars is that a small object, as Mars was seen in telescopes, will appear to have lines connecting different colour blotches. This was shown to be a psychological effect some time ago, a matter of the way the brain processes optical information.

Activity Notes and Troubleshooting

- Students wearing corrective lenses should remove them before engaging in this activity.
- The investigation can be sped up by having students do research in advance or by holding a contest to assemble a working telescope, and then have the first successful students share their knowledge.
- You may find it practical to have the students try and read something posted on one of the walls of the classroom from across the classroom. They could also assess success reading a variety of fonts and sizes.
- Extension—Since it is likely that your lenses are measured in dioptres, a good extension might be to allow students to take two lenses, some form of a tube in which they can insert them, and see if they can replicate Galileo's telescope and even some of his astronomical observations. After all, the planets of Jupiter and Venus are the brightest in the sky and are visible even from a major city.
- To assess students' process, use **BLM A-41 Conduct an Investigation Rubric** or use **BLM A-36 Process Skills Rubric Template** and work with students to develop assessment criteria.

Additional Support

- ELL Encourage students to describe the images in words as well as diagrams.
- DI This is an excellent activity for spatial learners.
- In addition to English, post text in other languages and of varying colours and fonts and challenge students to use their telescopes to read or state what they can and cannot see.

- Students should work in pairs to assist each other in trying different combinations of lenses.

Answers

1. The image formed by the Galilean telescope is upright. The Kepler telescope forms an inverted image.
2. The image becomes blurrier as the magnification increases.
3. The difference is whether the objective lens is a converging or diverging lens. Both use a common version lens at the far end of the telescope to initially focus the light.
4. Some students will see better with the Keplerian telescope, and some with a Galilean telescope.