CHAPTER 12

Light and Vision

KEY IDEAS

- The human eye and a camera function in a similar way.
- There are several vision problems, some of which can be corrected by technology.
- The eye has special structures that enable us to see colours.
- White light is made up of six main colours, which can be combined in different ways to produce many colours.
- Telescopes have been designed to use different parts of the electromagnetic spectrum.

LEARNING TIP

As you read through this chapter, identify the main ideas. Active readers use clues in headings, illustrations, as well as the text to determine the main ideas.

Our eyes are very complex sense organs that allow us to view the world around us. They are the brain's main connection to the outside world. The brain relies on input from our eyes to interpret our surroundings. Although people who are blind or visually impaired function very well in society, most of us rely heavily on our sense of vision as we go about our everyday lives.

Most people do not have perfect vision—there are many defects and disorders that can negatively affect vision. An understanding of how our eyes work and how lenses affect the path of light has led to a number of vision correction technologies. How do corrective lenses solve our vision problems? What other technologies are available to solve our vision problems?

We see colours everywhere. For example, think about the colours of fall leaves—red, orange, yellow, green, maybe even purple. If you look at sunlight streaming through a window, however, it does not look like it has colour. How do our eyes allow us to see and to distinguish colour? Why do we not see everything in shades of grey, like a black-and-white movie? How does colour work? Is colour a property of light? Is it a property of matter? Is there another explanation?

The Human Eye and a Camera

12.1

The human eye is an amazing optical device that allows us to see objects near and far, in bright light and dim light. Although the details of how we see are complex, the human eye can be compared with an ordinary camera (**Figures 1** and **2**).

LEARNING TIP

Diagrams play an important role in reader comprehension. As you study **Figure 1**, look at the overall diagram and read the caption. Then look at each part of the diagram. Try to visualize (make a mental picture of) the human eye.

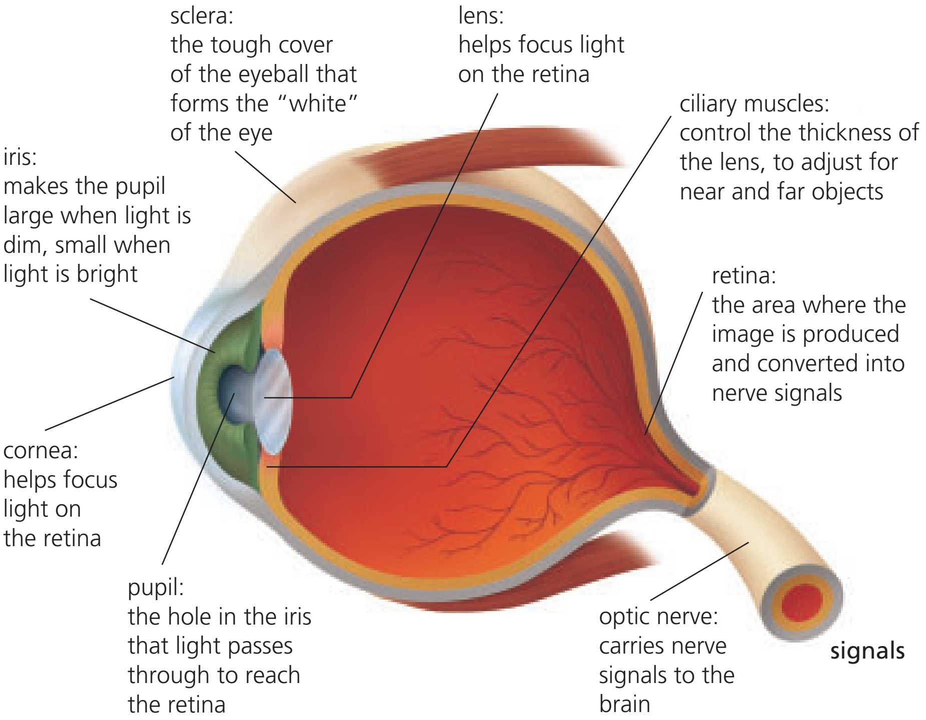


Figure 1
The human eye

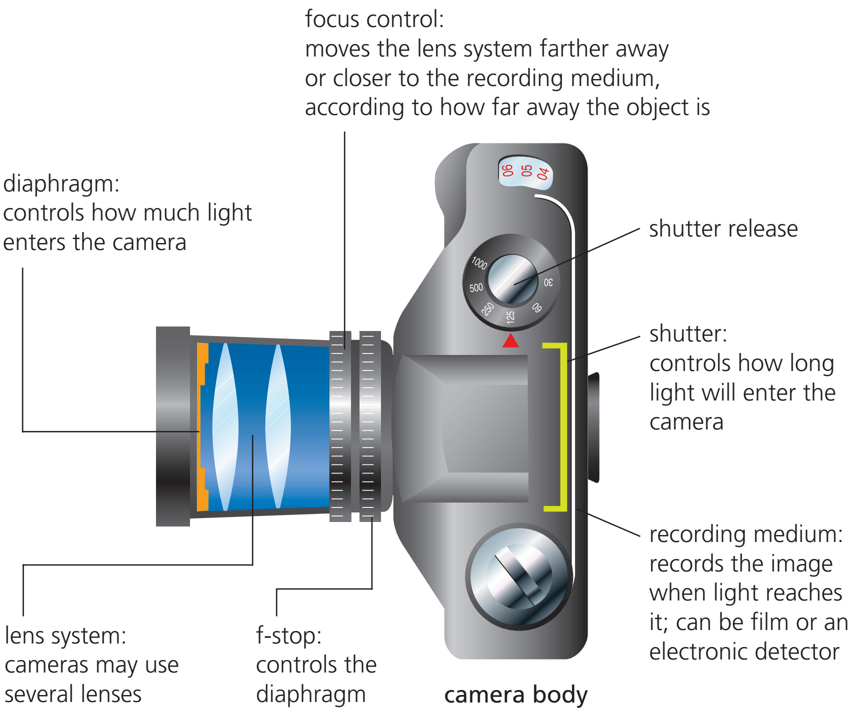


Figure 2
A camera

The Cornea and the Lens: Gathering Light

The eyeball is surrounded by a tough, white outer layer called the **sclera**. Six muscles are attached to the sclera. These muscles allow the eye to look up and down and from side to side. The front part of the sclera, known as the **cornea**, is colourless and transparent so that light can enter the eye. Both the human eye and a camera use a convex lens to gather light from an object and produce an image of the object. In the eyes about 80 % of the refraction of light takes place as the light passes through the cornea. The lens then refines the refraction to focus the image. A camera uses a set of lenses to achieve the same effect.

LEARNING TIP

Active readers know when they learn something new. Ask yourself, "What have I learned about the human eye that I did not know before?"

The Iris: Controlling the Amount of Light

Think about walking into a dark room or theatre. At first you cannot see well, but your eyes become adjusted to the dark and you begin to see better. What actually happens is your pupils become larger. The **pupil** of the eye is the "window" through which light enters the lens. The pupil looks black because most of the light that enters the eye is absorbed inside. The size of the pupil is controlled by the **iris**, a ring of muscle that contracts and relaxes automatically to regulate the amount of light entering the eye (**Figure 3**). The iris is the coloured part of the eye.

Figure 3
The iris controls the size of the pupil, thus regulating the amount of light that enters the eye.

The diaphragm of a camera has the same function as the iris (**Figure 4**). Photographers must control both the diameter of the diaphragm and the exposure time (how long the shutter is open) to get a high-quality photograph.

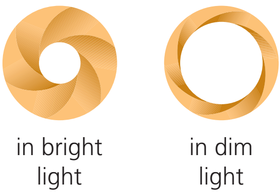


Figure 4
The diaphragm of a camera controls the amount of light that enters the camera.

Ciliary Muscles: Controlling the Focus

If you look at printing held a few centimetres from your eyes, you will notice that it is blurred—the printing is out of focus. Your eyes can focus clearly on objects as close as about 25 cm and as far away as you can see. The lens is held in place behind the pupil by a band of muscles called the **ciliary muscles**, which are attached to the lens by thin ligaments.

When you look at a distant object, light rays entering the eye are nearly parallel and do not have to bend very much to produce an image on the retina. The ciliary muscles are relaxed and the lens is in its normal shape (**Figure 5(a)**).

Light rays from nearby objects, however, enter the eye at an angle. These light rays have to refract, or change direction, more than those from distant objects, to produce an image on the retina.

As you learned in Chapter 11, a lens with greater curvature (a fatter lens) causes a greater refraction of light. To focus on nearby objects, therefore, the shape of the lens has to change to refract light more. The ciliary muscles contract, forcing the lens to become thicker or "fatter." The lens is shaped by the appropriate amount to refract the light so that the image of the nearby object is focused on the retina (**Figure 5(b)**). As people get older, their lenses and muscles become less flexible, which reduces their ability to control the focus and see close objects clearly.

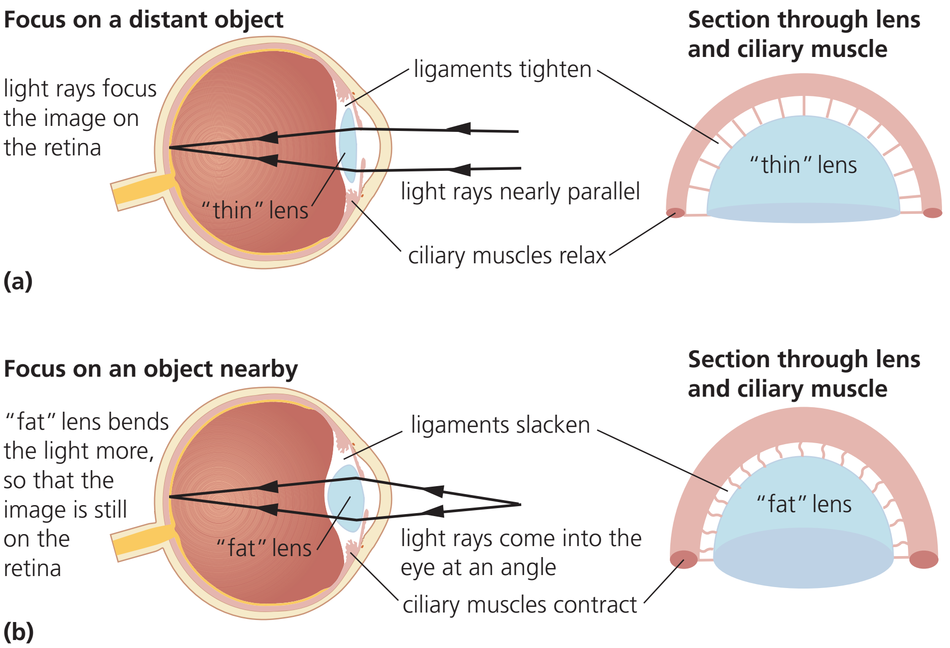


Figure 5
The shape of the lens is changed by the ciliary muscles to produce a clear image on the retina.

In a camera, instead of changing the shape of the lens, the whole lens system is moved back and forth to find the correct distance from the recording medium to produce a clear image.

The Retina: Producing an Image

In the eye, the image is produced on the **retina**, the light-sensitive layer on the inside of the eye. The retina has many blood vessels and nerves, and two types of light receptor cells, called rods and cones because of their shape when examined under a microscope. In most eyes, there are about 120 million **rods**, which are sensitive to the level of light, and about 6 million **cones**, which are sensitive to colour. Rods can detect dim light. They allow us to see during the night and in other dark conditions. Vision during these conditions is in black and white or shades of grey. Cones detect bright light and allow us to see colour and detail during the day and other bright conditions.

The rods and cones transform light into nerve signals. The nerve signals are sent through the **optic nerve** to the brain to interpret. In the area where the optic nerve and blood vessels connect to the retina, there are no rods or cones. This area is known as the **blind spot.**

In a camera, the image is produced on either a chemical film (to be developed later) or a digital device (which can be transferred to a computer).

LEARNING TIP

Making study notes is important for learning and remembering. Read this section again and look at the headings. Turn each heading into a question and then read to answer it. Record your answers as point-form notes under each heading.

TRY THIS: Finding Your Blind Spot

Skills Focus: predicting, observing, communicating

If an image produced by the eye falls on the area of the retina where the optic nerve connects with the back of the eye, the image cannot be seen. Because there are no light receptor cells in this area, no signals are sent to the brain. This area is referred to as the blind spot. To demonstrate the blind spot, follow these steps.

1. Hold this book at arm's length, with the symbols in **Figure 6** directly in front of you. Close your right eye, and focus on the cross with your left eye. You will still be able to see the dot.
2. Slowly bring the book toward you, while maintaining your focus on the cross.

(a) Describe what you observe as you move the book closer to your face.

(b) Explain your observations using a diagram.

(c) Why are two eyes better than one?

Figure 6

Images in the Eye and a Camera

As you can see in **Figure 7**, the image of an object is real and inverted in both the eye and a camera. You may think it strange that the image is inverted in your eye, but your brain is able to flip images. Your brain interprets the signals it receives from your eyes, and you perceive the images to be upright.

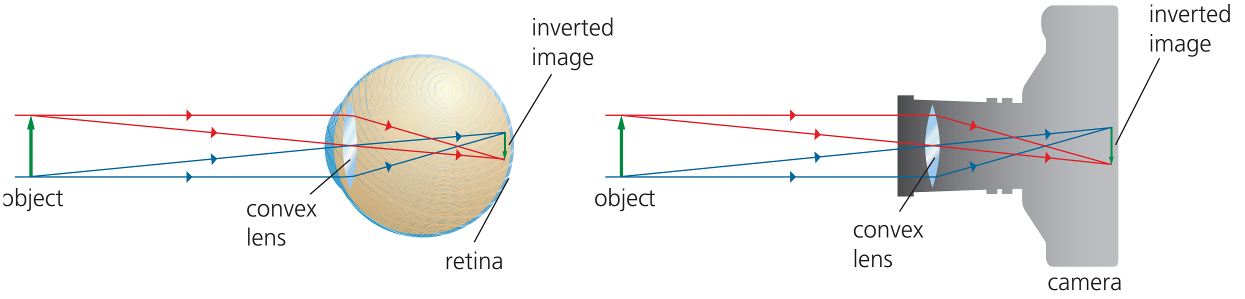


Figure 7
Light and lenses produce real images in the human eye and in a camera.

12.1 CHECK YOUR UNDERSTANDING

1. Copy **Table 1** into your notebook, and then complete the boxes that have question marks.

Table 1

Function of part	Camera part	Eye part
?	?	convex lens
controls the amount of light entering	?	?
?	?	ciliary muscles
records the image	?	?

2. Compare and contrast the image that is formed on the film of a camera and the retina of the eye.
3. Where does refraction occur in the human eye?
4. When your eyes feel tired from looking at close objects, it helps to look at distant objects for a few minutes. Why do you think this helps?

12.2 Vision and Vision Problems

Do you ever have trouble reading a road sign or seeing what your teacher writes on the chalkboard at the front of the class? Do the words seem blurry? If so, you probably have a vision defect. A large percentage of people between the ages of 15 and 30 experience some deterioration in their vision.

Fortunately, several corrective technologies are now available to help people who have common vision defects. How many of your friends wear eyeglasses or contact lenses? Have any had corrective surgery?

Normal Vision

During an eye test, a patient stands 6 m away from the eye chart (**Figure 1**) and, with one eye at a time, attempts to read as many lines as possible. The optometrist then compares the patient's vision with normal vision.

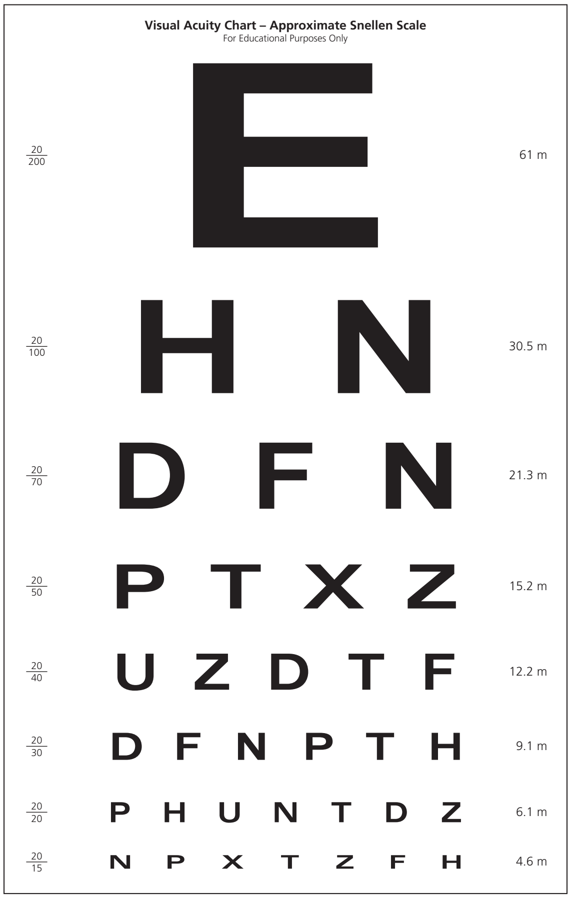


Figure 1
The Snellen Eye Chart is used to compare a person's vision with normal vision. (This picture of the chart is not the proper size to test your vision.)

DID YOU KNOW?

Tell Me What You See

The wall chart that you read when you visit an eye doctor was devised in 1862 by ophthalmologist Dr. Hermann Snellen. To this day, it is referred to as the Snellen Eye Chart.

You have probably heard the phrase "20/20 vision." This phrase has been used for a long time and has been commonly accepted as a way of referring to normal vision. When we say that people have 20/20 vision, it means that when they are standing 20 feet away from an eye chart, they can see the detail that should normally be seen at this distance. Today, of course, we use the metre rather than the foot as a unit of measurement to measure distance. In SI, **normal vision** can be referred to as 6/6. This indicates what can normally be seen at 6 m. The phrase "6/6 vision" does not mean perfect vision—it refers to how clear or sharp vision normally is at 6 m. For example, a person with 3/6 vision needs to be 3 m away from the eye chart to see the detail that can normally be seen at 6 m. A person with 10/6 vision can see at 10 m what can normally be seen at 6 m. Thus, a person with 10/6 vision has better than normal vision.

When you have normal vision, the eye produces an image on the retina (**Figure 2**). The image is upside down and reversed from left to right, compared with the actual object. As you have learned, however, the brain has no difficulty interpreting the image properly.

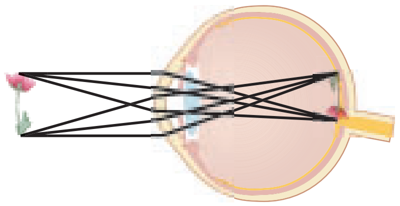


Figure 2
When vision is normal, the cornea and the lens refract light to produce a clear image on the retina.

Common Vision Defects

There are numerous conditions and diseases of the eye that can affect vision. The most common vision defects involve an inability of the eye to focus an image properly on the retina. These defects are known as **refractive vision problems**. The two most common refractive vision problems are myopia and hyperopia.

Myopia

A person with **myopia** (nearsightedness) can see nearby things clearly, but cannot focus on distant objects. This is caused when the eyeball is too long from front to back or when the focusing mechanism refracts light too much. As a result, the image is formed in front of the retina and is not clear (**Figure 3**). Myopia affects about a third of the population.

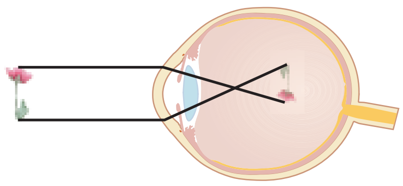


Figure 3
The focal point in the eyes of a nearsighted person is in front of the retina.

Hyperopia

Hyperopia is the opposite of myopia. A person with **hyperopia** (farsightedness) can see distant objects clearly but has difficulty focusing on objects that are close up. The eyeball is shortened from front to back or the focusing mechanism does not refract light enough. As a result the image is focused behind the retina and is not clear (**Figure 4**). Hyperopia affects about a quarter of the population.

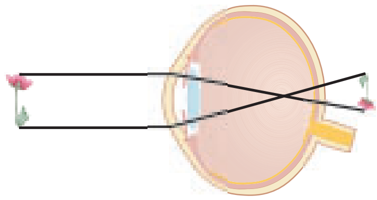


Figure 4
The focal point in the eyes of a farsighted person is behind the retina.

Other Refractive Vision Problems

Another common refractive problem, which often occurs along with nearsightedness and farsightedness, is **astigmatism**. Astigmatism is a condition in which the cornea has an irregular curvature. Normally, the cornea is evenly curved in all directions. In an eye with astigmatism, the cornea is curved more in one direction—it is shaped more like a football than a basketball. Light entering the eye is focused on two focal points, and, therefore, vision is blurred at any distance.

You have undoubtedly seen people holding reading material at arm's length in order to read it. These people are suffering from an age-related vision defect. Like other parts of the body, the eyes weaken with age. When a person reaches their 40s, the lens and the cornea lose some of their elasticity and cannot change shape as easily. This inability to focus on either nearby or far away objects is known as **presbyopia**.

Corrective Measures

There are several different ways to correct vision defects. The type of method used depends on what the problem is, and what a person is comfortable with.

Corrective Lenses

Think back to the question at the beginning of this section. How many people do you know who wear eyeglasses or contact lenses? Optical technology has progressed tremendously. Today, the use of corrective lenses is more widespread and has benefited more people than any other health technology.

The use of corrective lenses probably began with the early Egyptians and Romans, who discovered that a glass bowl filled with water magnified objects and made them easier to see. An understanding of how light behaves when it passes through a lens has led to the development of technologies that can correct refractive vision problems.

There are two main types of corrective eyewear: eyeglasses and contact lenses. Both involve a specially designed lens that is placed in front of the eye to correct the eye's focusing problem. The lens ensures that the image is focused on the retina rather than in front of or behind it.

In nearsightedness, the light is refracted too much and the image is focused in front of the retina. A concave lens placed in front of the eye spreads the incoming light. When the light passes through the cornea and the lens, it is focused properly on the retina (**Figure 5**).

In farsightedness, the light is not refracted enough by the cornea and lens, and the image is focused behind the retina. A convex lens is placed in front of the eye to refract the light slightly more before it enters the eye. The result is an image that is focused at the proper distance on the retina (**Figure 6**).

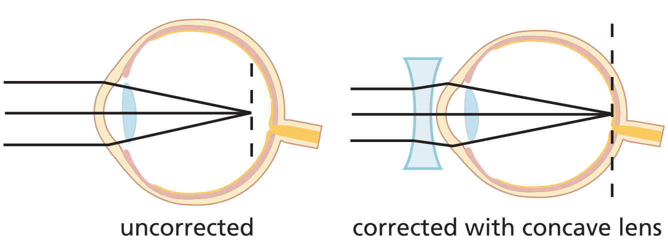


Figure 5
Nearsightedness (myopia) is corrected with a concave lens.

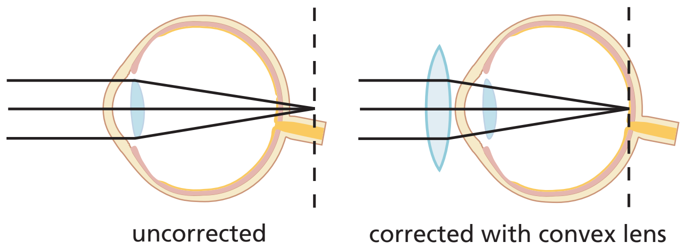


Figure 6
Farsightedness (hyperopia) is corrected with a convex lens.

Contact lenses work like eyeglasses (**Figure 7**). A small lens is placed directly on the surface of the cornea to spread or refract light before it enters the eye.

The earliest eyeglasses were designed with only function in mind. Modern eyewear, however, is not only concerned about correcting vision problems but also about fashion. You can now change the appearance of your eye colour with contact lenses or give yourself a special look with trendy eyeglasses.

Figure 7
For most people who require corrective lenses, contact lenses are more comfortable and convenient than eyeglasses.

Surgery

In recent years, surgery has been used as a more permanent solution to refractive vision problems. The most common form of surgery is laser surgery. In laser surgery, a very fine beam of light from a laser reshapes the cornea to adjust the focal point so that images are focused on the retina.

12.2 CHECK YOUR UNDERSTANDING

1. Explain what is meant by "normal vision." Is it possible to have better than normal vision? Explain.
2. Using a simple sketch, describe the vision problem of a person with myopia.
3. Why are eyeglasses referred to as "corrective lenses"?
4. Name and briefly describe the common solutions to refractive vision problems.

PERFORMANCE TASK

Does your device have a corrective lens similar to what humans need to fine tune the focusing of the image?

Laser Eye Surgery

The first applications of lasers in medicine were for general and cosmetic surgery. In the past two decades, lasers have been developed to correct refractive vision problems surgically.

An excimer laser is a high-intensity beam of light in the ultraviolet part of the electromagnetic spectrum. Unlike other lasers, excimer lasers do not produce a lot of heat. They change solids into gases, not by heating but by breaking the bonds that hold the molecules together. Excimer lasers can be used to remove extremely thin layers of human tissue accurately by vaporizing it (**Figure 1**).

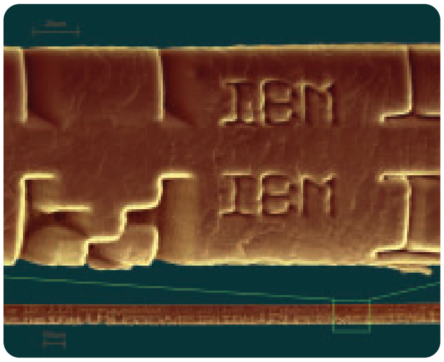


Figure 1
An excimer laser was used to carve this image in a human hair.

An American ophthalmologist, Dr. Steven Trokel, patented the process of using excimer lasers for eye surgery. He performed the first laser eye surgery in 1987. In a relatively short length of time, equipment and techniques have improved significantly and laser eye surgery has become a realistic and safe alternative to eyeglasses and contact lenses.

Types of Refractive Surgery

Surgery aimed at improving the focusing power of the eye is called refractive surgery. Since the cornea focuses most of the light, refractive surgery involves changing the shape of the cornea, thereby changing its focusing ability.

The two most common refractive surgeries are LASIK and PRK. Both use an excimer laser to modify the shape of the cornea so that it focuses light properly to produce a clear image on the retina.

LASIK (Laser-Assisted In situ Keratomileusis) is a procedure that permanently changes the shape of the cornea. In LASIK eye surgery, a flap is cut in the cornea and is folded back, out of the way (**Figure 2**). A laser is then used to remove a precise amount of corneal tissue underneath the flap to produce the required shape. The flap is then laid back in place.

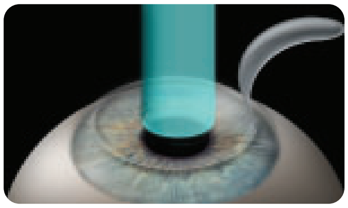


Figure 2
In LASIK eye surgery, a flap of the cornea is folded back.

PRK (Photorefractive Keratectomy) was originally the most common type of laser eye surgery. In PRK eye surgery, no flap is used. The excimer laser removes material directly from the surface of the cornea to reshape it properly (**Figure 3**).

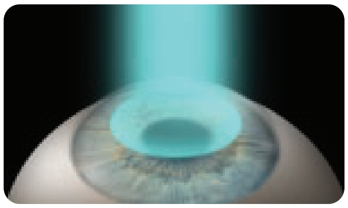


Figure 3
In PRK eye surgery, the cornea is not folded back.

Laser surgery can be used to correct myopia, hyperopia, and astigmatism. Although many people consider laser surgery to be a miracle technology, it cannot reverse the aging process that causes presbyopia.

Inquiry Investigation 12.3

INQUIRY SKILLS

- ● Questioning
- ● Hypothesizing
- ● Predicting
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Evaluating
- ● Communicating

Mixing the Colours of Light

As you learned in Chapter 10, Isaac Newton discovered that white light can be split into spectral colours and that spectral colours can be put together to produce white light. One place where Newton's discoveries have practical applications is the theatre. Colour spotlights can be used to change what you see on the stage.

Question

(a) Read the Procedure, and write a question for this Investigation.

Hypothesis

(b) Write a hypothesis for this Investigation.

LEARNING TIP

For help with writing a question and a hypothesis, see "Questioning" and "Hypothesizing" in the Skills Handbook section **Conducting an Investigation**.

Experimental Design

By making and checking predictions, you will learn how to predict the results of overlapping different colours of light. **Figure 1** shows the colours you will use in this Investigation.

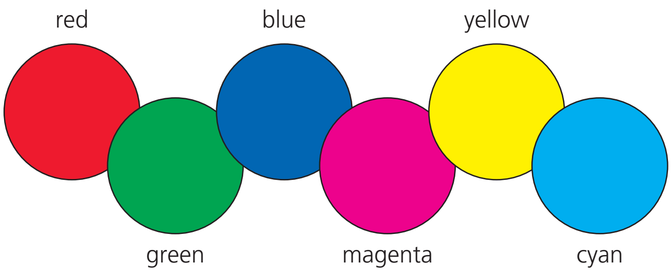


Figure 1

(c) Design a table to record your predictions and observations. Have your teacher approve your table before beginning the procedure.

Materials

- 3 ray boxes
- 6 colour filters (red, green, blue, yellow, cyan, and magenta)
- white screen

Do not touch the light bulb in the ray box or look directly into the light.

Procedure

1. Set up two ray boxes so that the two light beams overlap on the screen. Obtain red, green, and blue filters. Predict the colour that will result when the colours of light in each set overlap:

- Set A: green and red
- Set B: green and blue
- Set C: blue and red

Record your predictions in your table.

Step 1

2. In a darkened room, put the filters for Set A in the ray boxes. Observe the result when the colours overlap. Record your observations in your table.

3. Repeat step 2 using the filters for Set B and then Set C.

Step 2

4. Remove the colour filters from the ray boxes. Add a third ray box to your set-up. Make sure that the light beam from the third ray box shines on the same spot as the other two light beams. Predict the colour that will result when the following colours of light overlap:

- Set D: red, blue, and green

Record your prediction in your table.

Step 4

5. Use the three ray boxes and filters to test your prediction. Record your observations.

6. Obtain yellow, cyan, and magenta filters. Predict the colour that will result when the colours of light in each set overlap:

- Set E: blue and yellow
- Set F: red and cyan
- Set G: green and magenta

Record your predictions in your table.

Step 6

7. Test your predictions using two ray boxes. Record your observations.

PERFORMANCE TASK

Are certain colours of light more important than others in your optical device? Does the device control the brightness of light? Does the brightness of light affect the device?

Analysis

(d) Summarize your observations in a diagram.

(e) Which of the sets produced white light?

Evaluation

(f) Did your results support your hypothesis? Explain.

Colour Vision 12.4

You have observed that only three overlapping colours—red, green, and blue—are needed to produce what you see as white light. It seems that orange, yellow, and violet are not needed, but they are all part of natural white light. Why is this? The explanation is in the design of the human eye.

Seeing in Colour

You have learned that there are colour detectors called cones in the retina of the eyes. There are three types of cones. One type of cone is sensitive to red light, a second type is sensitive to blue light, and a third type is sensitive to green light. Our eyes combine signals from these cones to construct all the other colours. When light that contains red, blue, and green light enters our eyes, we see it as white (**Figure 1(a)**). When light that contains red and green light enters our eyes, we see it as yellow (**Figure 1(b)**). When light that contains only blue light enters our eyes, only the blue cones send signals to our brain and we see the light as blue (**Figure 1(c)**).

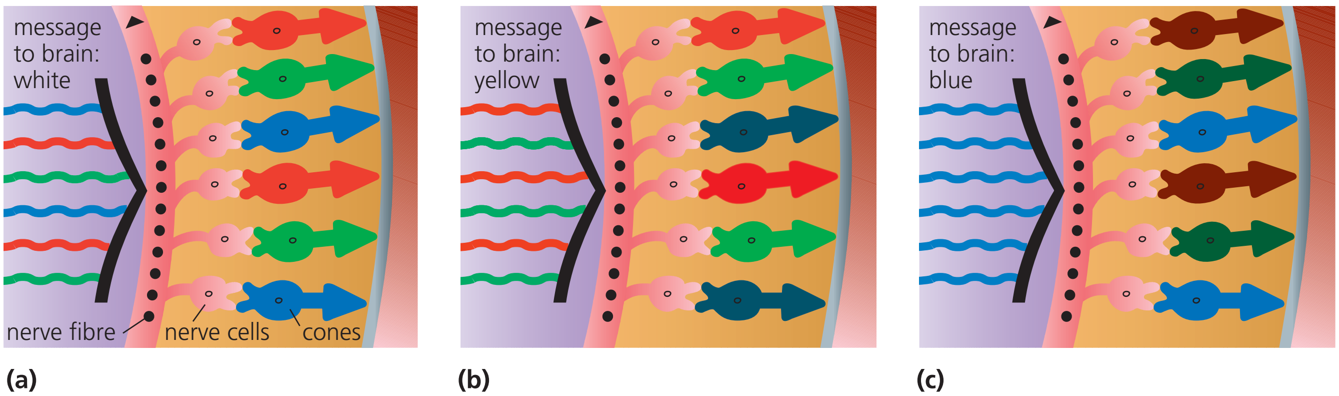


Figure 1
Cones in your retinas tell you what colour of light is entering your eyes.

You can observe evidence that the cones detect red, blue, or green. When you stare at a blue object for a long time, the cones that are sensitive to blue become tired. If you then look at a white surface, the tired sensitive-to-blue cones do not react to the blue in the white light. The cones sensitive to red and green, however, do react. As a result, you see yellow, which is a combination of red and green, instead of white.

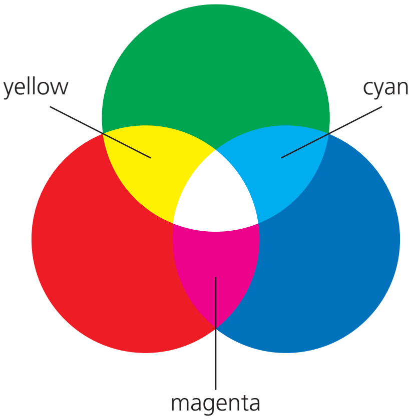


Figure 2
Combining any two primary light colours produces a secondary light colour. Combining all three primary light colours produces white light.

Primary and Secondary Colours of Light

The process of adding together colours of light to produce other colours is called **additive colour mixing.** Studying additive colour mixing will help you understand human colour vision.

The **primary light colours** are the three colours of light that our cones can detect. The colour that results when any two primary light colours are combined is called a **secondary light colour**. There are three secondary light colours: cyan, yellow, and magenta (**Figure 2**). For example, when blue light and green light overlap, we see cyan.

Complementary light colours are any two colours of light that produce white light when added together. For example, magenta and green are complementary colours. Magenta is created by mixing blue light and red light. Therefore, when magenta light and green light overlap, all three of the primary light colours are present and we see white light.

TRY THIS: See What Your Cones See

Skills Focus: observing, communicating

In this activity, you will test your cones.

1. Copy the outer box and black square of the rectangle in **Figure 3**. Stare at the black square of the rectangle on this page for at least 45 s. Then stare hard at the black square in your copy of the rectangle for the same length of time.

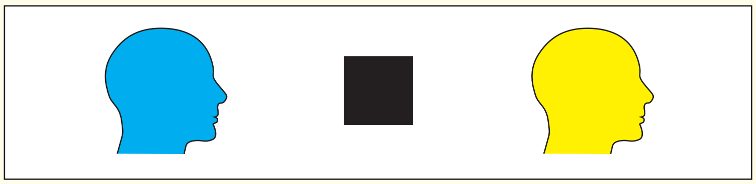


Figure 3

(a) On your copy of the rectangle, indicate the colours you saw and roughly where they appeared.

(b) Explain what you saw.

LEARNING TIP

Work with a partner. Complete the test for red-green colour blindness. How did your six million cones react? Explain what you saw to your partner. Did your partner see anything different?

Colour Blindness

When you look at the pattern of coloured dots in **Figure 4**, do you see a number? Do any of your classmates see something different? Patterns such as this one are used to test for colour blindness.

People with colour blindness are not blind to colours, but are unable to distinguish certain shades of colours clearly. Some of the cones at the back of their eyes do not respond to the light received. One example is red-green colour blindness. A person with red-green colour blindness may have difficulty distinguishing something red against a green background, especially from a distance.

Red-green colour blindness is a fairly common condition in males. It affects about 8 % of the male population, but only about 0.4 % of the female population. Consider the difficulties that a person with colour blindness might have. The colours of traffic lights would be hard to see. Certain jobs that require normal colour vision, such as photography and colour printing, would not be possible for a person with colour blindness. In other jobs, such as airline pilot or ship's officer, colour blindness might pose a safety risk. Colour blindness is not always a disadvantage, however. Hunters with colour blindness can often see prey against a confusing background better than hunters with normal colour vision. Similarly, soldiers with colour blindness are often able to see through camouflage that others cannot.

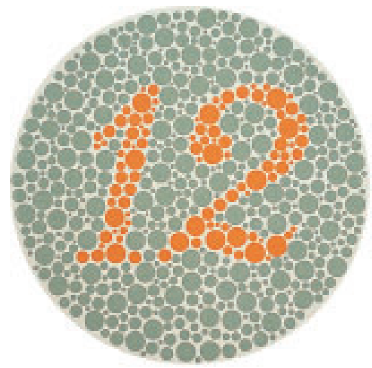


Figure 4
This pattern is used to test for red-green colour blindness.

12.4 CHECK YOUR UNDERSTANDING

1. What are the primary light colours and the secondary light colours?
2. State the complementary light colour of
   (a) red
   (b) green
   (c) magenta
   (d) yellow
3. Explain why overlapping two complementary colours produces white light. Use a diagram in your answer.
4. Which cones in the human eye must be activated in order to see the following colours?
   (a) yellow
   (b) cyan
   (c) white
5. (a) If you stare intently at a bright green square and then look at a white surface, what will you see? Explain why this happens.
   (b) Predict and explain what will happen if you stare at a bright cyan square and then look at a white surface.
6. Scientists have evidence that certain animals, such as bees, can see ultraviolet radiation, which is invisible to human eyes. Create an imaginary additive colour theory for an animal that can see much more of the electromagnetic spectrum than we can see.

LEARNING TIP

Active readers know how to use text features to quickly locate relevant information. Locate the information needed to answer the Check Your Understanding questions by scanning the text for headings and vocabulary.

PERFORMANCE TASK

Is coloured light important in your optical device? Is white light split into its component colours or are primary or secondary light colours combined to produce a different colour?

12.5 Career Profile: Research Scientist

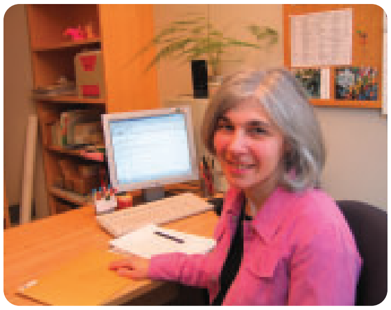


Figure 1
Dr. Marilyn Borugian

Dr. Marilyn Borugian (**Figure 1**) is a senior scientist at the B.C. Cancer Research Centre. She is conducting research to develop ways to measure light exposure at night so future research can answer the question, "Does shift work increase cancer risk?"

The human body produces a hormone known as melatonin. Melatonin regulates sleep patterns, as well as strengthens our immune system. It is produced mainly during the night and early morning hours, the dark part of the 24 hour day.

Most people are asleep during the night and early morning when melatonin is produced in their bodies. About 30 % of Canadians, however, are involved in shift work that requires them to be exposed to light during the hours when melatonin is normally produced. This interferes with the production of melatonin. The critical question is "Does shift work increase cancer risk?" The hypothesis is that exposure to light at night interferes with the production of melatonin, which in turn weakens the immune system and increases the risk of cancer.

Figure 2
A lux meter measures light levels. These meters are often used by photographers to measure light levels and adjust camera settings.

The research monitored the light exposure of shift workers over a seven day period during winter and summer. Participants wore a device called a lux meter (often called a light meter), which measures light levels at regular intervals (**Figure 2**). A saliva test on the participants was used to determine their melatonin levels.

The results showed that shift workers were exposed to light in irregular patterns. Shift workers had lower-than-normal melatonin levels during sleep periods, and higher-than-normal melatonin levels on arising and during work, when compared to people who worked during the day.

"Most people understand our need for bright light, and its effect on mood, such as in the case of seasonal affective disorders, but the flip side is that we also need darkness to remain healthy. We have become a 24 hour society, where fast-food restaurants, grocery stores, and many other industries operate around the clock," says Dr. Borugian. "This is an issue that affects many Canadians, and while there are many cancer risk factors that we can't do anything about, such as age and inherited factors, we might be able to modify work schedules to reduce the impact on shift workers."

Light and Human Behaviour

Most people welcome sunlight. It not only brightens the day but a person's mood as well. There is scientific evidence that a sunny-day mood is determined by your body's chemical response to light or its absence.

Scientists know that sunlight affects human behaviour in a number of ways. In most cases, sunlight affects us in ways that we are not conscious of. For example, our bodies manufacture vitamin D when skin is exposed to sunlight. Vitamin D is necessary for the absorption of calcium, a mineral essential in building strong teeth and bones. Vitamin D may also stop the growth of some cancer cells and prevent them from spreading.

The shortening of daylight time in the fall can cause a form of psychological depression known as seasonal affective disorder (SAD). It is estimated that around 6 % of people experience some symptoms of SAD, which include mood changes, low energy, change of sleeping habits, increased eating and weight gain, difficulty concentrating, and spending less time in social activities. A student with SAD may have trouble studying and completing assignments, be less motivated, and get lower grades. These behavioural changes usually start in the fall when the days shorten, and continue until spring when the days get longer. Because of the seasonal variation in the length of daylight, SAD is more common in areas that are farther away from the equator. The length of daylight does not vary as much near the equator.

The decrease in the length of daylight causes changes in body chemistry. Experts believe that two hormones—melatonin and serotonin—are involved. Melatonin, a hormone that regulates sleep cycles, is produced by the pineal gland in the brain during the dark hours of the day. Levels of melatonin are increased when the daily period of darkness increases during fall and winter. Serotonin is produced by the brain when a person is exposed to sunlight. Serotonin levels are likely to decrease when the hours of sunlight are decreased. The combination of higher levels of melatonin and lower levels of serotonin will bring on the symptoms of SAD in some people during the fall and winter months.

The symptoms of SAD can be treated with light therapy, also known as phototherapy. For less severe symptoms, light therapy might involve simply spending more time outdoors during the winter months. For more serious conditions, a full-spectrum light (the full visible spectrum) that simulates daylight is used. The individual sits in front of the light for a short period (usually less than an hour) every day (**Figure 1**). They also have to look at the light occasionally because the light has to be absorbed through the retinas of the eyes in order to be effective. In most cases, light therapy reverses SAD in a few days.

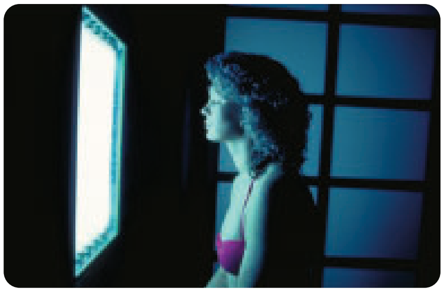


Figure 1
A person can read, work, or do other activities while undergoing light therapy.

12.6 A Telescope for Every Wave

Just as there are many different wavelengths in the electromagnetic spectrum, there are many different telescopes that can be used to view the objects that emit these wavelengths. No matter how different an X-ray telescope may look from Galileo's original model, the optical principles that operate them are the same.

LEARNING TIP

You can use a table to help you organize information for studying. Make a three-column table with the headings "Reflecting Telescopes," "Radio Telescopes," and "X-Ray and Gamma Ray Telescopes." As you read the pages of this section, record important information under the appropriate heading in your table. Write the information as point-form notes.

The First Telescopes

The principles of light refraction and magnification that make telescopes possible were known in the time of the ancient Greeks. The modern telescope first made its appearance in the early 1600s. **Figures 1** and **2** show early designs by Italian scientist Galileo Galilei and German astronomer Johannes Kepler.

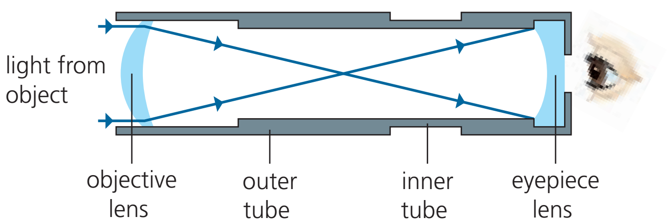


Figure 1
Galileo's telescope consisted of a convex lens for the objective lens and a concave lens for the eyepiece lens.

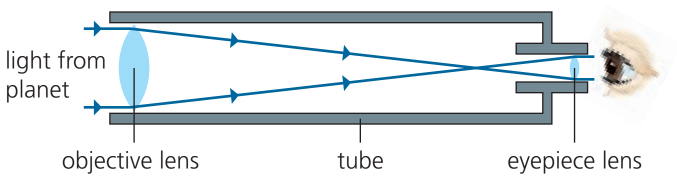


Figure 2
Kepler's telescope was the first refracting telescope. It used convex lenses for both the objective lens and the eyepiece lens.

The Reflecting Telescope

If a glass lens is too big, its edges may break under the heavy weight. To overcome this problem, designers began building reflecting telescopes that used a concave mirror rather than a convex lens to gather light (**Figure 3**).

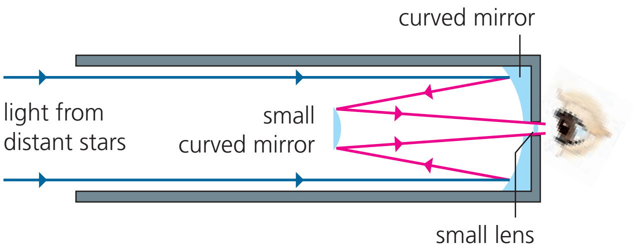


Figure 3
This design was invented by James Gregory, a Scottish mathematician who lived in the 17th century. Another refracting telescope design, still used today, was invented by Isaac Newton.

Radio Telescopes

Radio waves can be detected by concave reflectors called radio telescopes (**Figure 4**). Recall that radio waves have longer wavelengths than waves of visible light. This is why radio telescopes tend to be much larger than telescopes that gather visible light.

Figure 4
Because a large mesh is not transparent to radio waves, the radio telescope is not as solid as a light telescope.

X-Ray and Gamma-Ray Telescopes

X-ray wavelengths are so short that they penetrate ordinary mirrors. X-ray mirrors must be coated with a heavy metal, such as gold or beryllium, to reflect the rays. Gamma-ray wavelengths are even shorter than X-ray wavelengths and penetrate any mirror, no matter how heavy the metal is. Gamma rays must be "caught" in a special crystal in order to obtain an image (**Figure 5**).

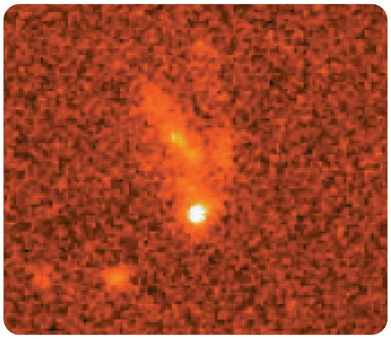


Figure 5
Even when gamma rays are properly caught in crystal to produce an image, the image tends to be fuzzy.

Location Is Everything

Today, the most powerful Earth-based telescopes are found in observatories (**Figure 6**, on the next page). These telescopes track objects in the sky as Earth rotates. The digital images they record are later analyzed by astronomers using computers.

Stars do not really twinkle. The twinkle effect is caused by Earth's atmosphere, which also interferes with certain kinds of radiation. The Hubble Space Telescope (**Figure 7**) was launched into space to avoid this interference.

Figure 6
Gemini North is a part-Canadian observatory built at an altitude of 4300 m atop Mauna Kea in Hawaii. The mirror in the Gemini North reflecting telescope has a diameter of about 8 m.

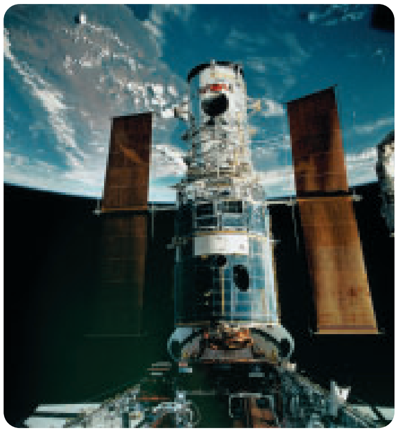


Figure 7
The Hubble Space Telescope, in orbit around Earth, still uses Newton's basic telescope design.

12.6 CHECK YOUR UNDERSTANDING

1. How would you increase the magnification of Galileo's telescope without changing its basic design? What limitations in its design does this suggest?
2. What advancement in design led to an improvement in Galileo's magnifier?
3. What advantages would a concave mirror have over a convex lens in the construction of a telescope?
4. When an object is viewed through Galileo's or Kepler's telescope, the object appears to be encircled by several rings of different colours. This effect does not occur when the same object is viewed through Gregory's or Newton's telescope. Why? (*Hint*: Remember that white light is actually made up of many different wavelengths.)
5. Compare the structure and use of a classroom microscope with the structure and use of an astronomical refracting telescope.
6. Why are observatories usually built on mountaintops?

PERFORMANCE TASK

If your chosen optical device is a telescope, what type is it? How are the lenses or mirrors arranged?

No More Twinkle, Little Star

A problem that has faced astronomers since the invention of the telescope is atmospheric distortion. Scientists have discovered a way to eliminate this distortion in Earth-based telescopes.

You have undoubtedly seen "twinkling" stars. Light from the stars refracts as it passes through hot and cold air mixing in the atmosphere. Because the air is constantly moving and changing, the amount of refraction changes too, and the stars appear to twinkle.

This atmospheric distortion limits the detail that can be seen by Earth-based telescopes. One of the reasons for putting the Hubble Space Telescope into orbit was to eliminate the effect of Earth's atmosphere and overcome this problem. For Earth-based telescopes, astronomers have chosen locations that minimize the atmospheric distortion—high mountains overlooking oceans. Two of the best locations are the dormant volcano Mauna Kea in Hawaii (**Figure 1**) and the Andes Mountains in Chile.

Scientists and engineers have developed a technique called adaptive optics to compensate for atmospheric distortion. They use mirrors or lenses that can be deformed or bent to change the path of light in a telescope. A very simple version of adaptive optics is found in many video cameras and some digital cameras to compensate for the shaking of a hand-held camera. The adaptive optics for telescopes are much more precise and expensive!

Figure 1
The Gemini North Observatory on Mauna Kea in Hawaii.

One such system, the Altair system, was designed and built at the National Research Council's Herzberg Institute of Astrophyics in Victoria, British Columbia. Altair was installed on the Gemini North Telescope on Mauna Kea in Hawaii in 2003. This large, modern telescope, with its 8 m mirror, can collect 11 times more light than the Hubble Space Telescope. With the Altair adaptive optics, Gemini produces images that are three times as clear as those from Hubble (**Figure 2**). The Altair system samples starlight, determines how the atmosphere distorted it, and then uses its deformable mirror to "straighten out" the starlight. The amount of bending of the mirror is only a few microns (thousandths of a metre). To keep up with the random movement of the atmosphere, the adjustment is performed 1000 times every second.

With the Altair system doing the unromantic job of "taking the twinkle out of the stars," astronomers on Earth can now study the gas swirling around a black hole, take images of planets orbiting other stars, and study the formation of stars in dust clouds.

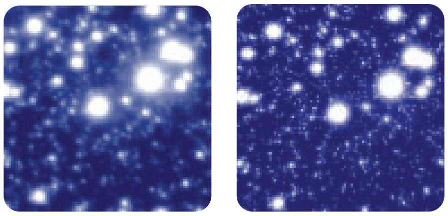


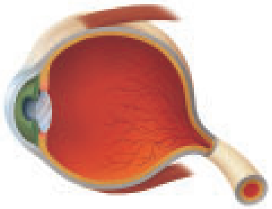
Figure 2
Gemini images without (left) and with (right) the Altair adaptive optics.

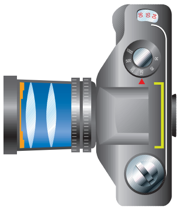
Review Light and Vision

Key Ideas

The human eye and a camera function in a similar way.

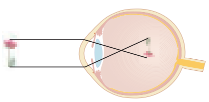
- The amount of light entering the eye is controlled by the iris. The amount of light entering a camera is controlled by the diaphragm.
- In the human eye and a camera, light is focused by a lens.
- In the eye, a real, inverted image is produced on the retina. In a camera, a real, inverted image is produced on a film or electronic detector.

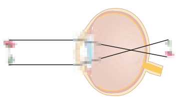




There are several vision problems, some of which can be corrected by technology.

- Normal vision, called 6/6 vision, refers to the level of detail that should normally be seen from a distance of 6 m.
- The most common vision problems are refractive vision problems, in which the image is not focused properly on the retina.
- The four most common refractive vision problems are myopia, hyperopia, astigmatism, and presbyopia.
- Refractive vision problems can be corrected by lenses (eyeglasses or contact lenses) or laser surgery.





The eye has special structures that enable us to see colours.

- Special cells called rods and cones convert light to nerve signals that the brain interprets as images.

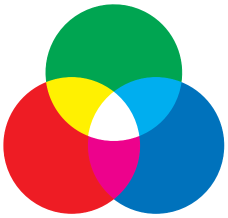
Vocabulary

sclera, p. 342
cornea, p. 342
pupil, p. 342
iris, p. 342
ciliary muscles, p. 342
retina, p. 344
rods, p. 344
cones, p. 344
optic nerve, p. 344
blind spot, p. 344
normal vision, p. 347
refractive vision problems, p. 347
myopia, p. 347
hyperopia, p. 347
astigmatism, p. 348
presbyopia, p. 348
additive colour mixing, p. 354
primary light colours, p. 354
secondary light colour, p. 354
complementary light colours, p. 354

- Rods are sensitive to the level of light and enable us to see black and white or shades of grey in dim light conditions.
- Cones operate in bright light conditions and enable us to see detail and colour.

White light is made up of six main colours, which can be combined in different ways to produce many colours.

- Only three primary light colours—red, blue, and green—are required to produce what we see as white light.
- Primary colours can be combined to produce secondary light colours. Red and green produce yellow, blue and green produce cyan, and red and blue produce magenta.
- Combinations of primary and secondary colours that produce white light are said to be complementary light colours.



Telescopes have been designed to use different parts of the electromagnetic spectrum.

- There are two types of telescopes—refracting telescopes, which use lenses, and reflecting telescopes, which use mirrors, to gather and focus light.
- Light telescopes receive energy or light from the visible spectrum. Radio, X-ray, and gamma-ray telescopes receive energy from the non-visible parts of the electromagnetic spectrum.

Review Key Ideas and Vocabulary

1. Which of the following combinations of light does not produce white light?
   (a) red light + blue light + green light
   (b) red light + cyan light
   (c) blue light + yellow light
   (d) red light + blue light
   (e) green light + magenta light
2. A person can read a book with no problem but requires glasses when driving a car. Which refractive vision problem does the person most likely have?
   (a) myopia
   (b) presbyopia
   (c) hyperopia
   (d) astigmatism
   (e) all of the above
3. What colour would you see in each numbered part of **Figure 1**?

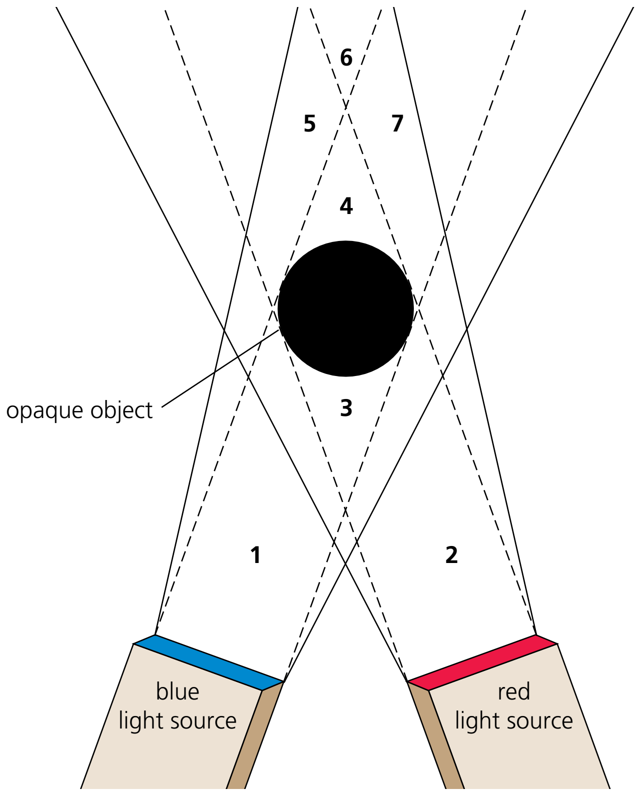


Figure 1

4. Name the parts of the eye that are responsible for
   (a) gathering light
   (b) controlling the amount of light
   (c) focusing light
   (d) producing an image
5. Use your knowledge of colour mixing to explain how the eye sees colours.
6. Fill in each blank with the word or phrase that correctly completes the sentence.
   (a) The complementary light colour of cyan is ___?___.
   (b) If you look through a green filter at a magenta object, you see the colour ___?___.
7. Explain how we can see black objects if they do not reflect any light.
8. What is a major disadvantage of using a lens to gather light in a telescope?
9. Do all telescopes detect visible light? Explain your answer.

Use What You've Learned

10. Suppose that you are standing at a bus stop reading a newspaper. Describe what happens to the ciliary muscles, the lenses, and the pupils in your eyes as you look up to see the bus approaching in the distance.
11. Explain the difference between myopia and hyperopia. Use diagrams to show how eyeglasses can correct each condition. Explain your diagrams in your own words.
12. Describe how you would investigate several coloured light bulbs to determine which visible colours each light bulb emits.

13. Sometimes the colour of something you buy in a store looks different in sunlight. This happens because stores often use fluorescent lights, which emit more blue light than red light. How would fluorescent lights affect the colours of items such as clothing, cosmetics, and decorating supplies? Design a system that would avoid this problem.
14. Imagine that you are looking at an oncoming car through Kepler's telescope. What would be odd about the image? Suggest a way to modify Kepler's design to correct the oddity. Under what circumstances would the oddity not matter?
15. Radio waves can penetrate even a thick cloud cover. What might interfere with the radio-wave reception capabilities of a telescope?
16. Compare the automatic functions of the human eye with the automatic functions of a camera.
17. The design of colour-television screens and computer monitors is based on additive colour mixing. Using electronic and print resources, research the process that is used to produce colours in these devices. Describe your findings.

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18. Canada has part ownership of large observatories in Hawaii and Chile. Research the features, uses, and discoveries of one of these observatories. Report your findings.

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Think Critically

19. Energy is needed to produce artificial light. Usually, electrical energy is used. Electricity generation is expensive and sometimes damaging to the environment. Identify a common use of light that you think we could do without. Explain why.
20. Some of our emotional responses to different colours have been identified through research. Think of commercials and advertisements that capture your interest. How is colour used to influence you? What are the benefits and abuses related to the use of colour?
21. What effect might the hole in the ozone layer have on the receptivity of a UV telescope?

Reflect on Your Learning

22. Write one or two paragraphs about the importance of vision in your everyday life. In your reflection, consider the perspective of a person who is visually impaired or blind.
23. Take a position for or against the following statement: "Vision is your most important sense." Write a list of arguments to support your position. Find a partner who took an opposite position, and discuss your arguments.
24. Think about your favourite colour. Why is it your favourite? Do you think colour can affect your mood or your attitude?

Visit the Quiz Centre at

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