12.2 Technologies That Use Light

Here is a summary of what you will learn in this section:

- Cameras collect and focus light in order to form an image.
- Microscopes are made of two convex lenses that are arranged to make magnified images of objects.
- Refracting telescopes use lenses to collect and focus light, whereas reflecting telescopes use mirrors for the same process.
- A telephoto lens magnifies a distant object. A wide-angle lens provides a large field of view.

Figure 12.21 An amateur astronomer uses a telescope to view the Milky Way galaxy.

The Invention of the Telescope

Some of the most fascinating discoveries of the last few hundred years have come about thanks to astronomers observing the sky with telescopes (Figure 12.21). Telescopes are fairly common now as shown in Figure 12.22, but when the telescope was first invented its existence was kept secret.

The first documented invention of a telescope was by the Dutch spectacle-maker Hans Lippershey. When one of his apprentices held up two lenses in front of his eyes, he was surprised to find that distant objects appeared even closer than when looking through only one lens. Lippershey placed the lenses at either end of a tube and in 1608 took his invention to the Dutch government. The Dutch government realized that telescopes could give a great advantage in warfare, so they decided to keep the invention a secret. The secret was not well kept, however, and within a year, lens crafters all over Europe were building and selling small telescopes.

Hans Lippershey himself helped spread the news of the telescope to the most famous and productive scientist of his time — the Italian astronomer and physicist Galileo Galilei. Galileo obtained one of Lippershey's telescopes and within a few months improved the design and built what was then the most powerful telescope in the world, able to magnify objects up to 30 times. He turned his telescope to the sky and became the first person in history to see mountains on the Moon.

Figure 12.22 Coin-operated telescopes are available in some scenic locations for the public to use.

Technology Development Continues

Galileo also discovered that four moons orbited the planet Jupiter. His discovery provided evidence that the Sun was the centre of the solar system rather than Earth. This started a race to build the best telescope possible. Larger lenses were used to capture more light and increase magnification. Thin lenses have better optical properties than thick ones but need to be spaced farther apart, so telescopes became both wider and longer. The largest early telescopes were much too large to hold, and in some designs one lens would be mounted on the roof of a building while the other lens was placed on the ground. Many sizes, shapes, and arrangements of lenses were tried, but eventually every design came upon the same insurmountable problem. Lenses refract different colours of light differently. Just as a prism can split sunlight into a rainbow, even the best lenses refract different colours of light in different ways. For example, this resulted in the image of a planet being surrounded by circles of different colours.

A new design was needed. By the late 1700s, another great scientist, Isaac Newton, had designed a telescope in which the large convex lens normally placed at the front of the telescope was replaced with a large concave mirror placed at the back of the telescope (Figure 12.23). This type of telescope was difficult to build because the technology needed to grind a mirror to the correct shape was not well developed. However, the advantages were great because mirrors were much lighter than lenses and they did not absorb some of the light, as big lenses had a tendency to do. This same design is used by all the largest and most powerful telescopes today.

Figure 12.23 Sir Isaac Newton's reflecting telescope

D30 *Quick Lab*

Extending Human Vision

Purpose

To appreciate the value of extended vision

Procedure

1. Choose a photograph in this student book that was taken using a telescope and that you think reveals important information about its subject.
2. Choose a photograph in this book that was taken using a microscope and that you think reveals important information about its subject.
3. Choose your favourite photograph in this student book.
4. Share your choices with members of your group Discuss your reasons for each of your choices.

Question

5. Consider all the choices your group has presented. Which image gives information that has had the most important effect on society? Explain why.

Cameras

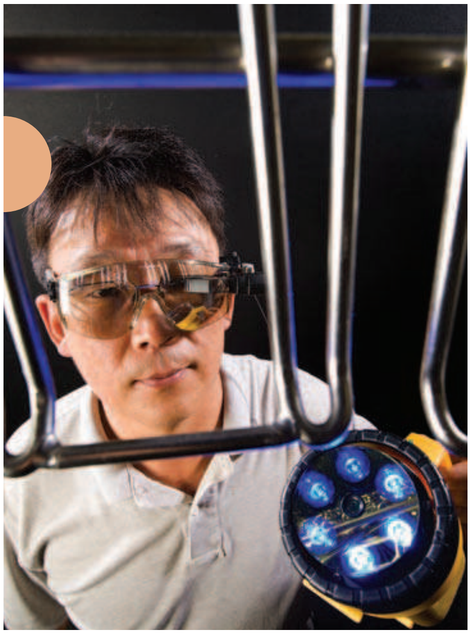

Figure 12.24 This portable imaging device is equipped with a head-mount display for inspecting the sanitation of food-processing equipment.

Our view of ourselves, our planet, and our universe has grown enormously by learning how to extend our vision. Laser light and fibre optics have allowed us to transmit light within the human body. Microscopes have allowed us to see a world of structures and organisms that was completely unknown just a few hundred years ago. Using telescopes, we have observed stars exploding in deep space, temporarily outshining nearby galaxies containing billions of stars. We can record images of all these very large and very small subjects using cameras.

The recent increased availability of small, inexpensive, and low-power cameras has had important social effects. Because they are incorporated into cellphones and mobile digital devices, cameras can be taken almost anywhere and images can be transmitted almost instantly around the world. This widespread use of cameras has raised concerns about privacy, but it has allowed easier communication between communities of people in different locations.

Cameras are also used in industrial applications, such as automated vision systems to ensure quality control (Figure 12.24). For example, the Canadian Food Inspection Agency uses colour digital photography to monitor food colour and compare it with the colours of good quality food. If the colour of the food product does not match an acceptable stored value, an alarm goes off and the food product is manually inspected.

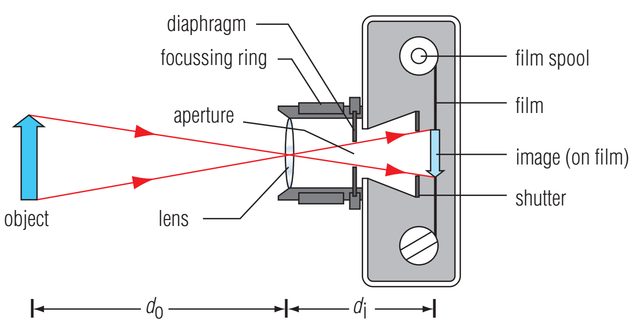

Figure 12.25 The parts of a simple camera that uses film

Parts of a Camera

A **camera** is basically a lightproof box with a lens at one end to form a real, inverted image on a light detector or light-sensitive plate or film (Figure 12.25). For a distant object, the image distance d_i is equal to the focal length of the lens. For nearer objects, the lens must be moved farther from the light detector so that the image is still focussed. A **shutter** controls the length of time light is allowed in. The **diaphragm** is the part of the camera that controls the aperture. The **aperture** is the opening that the light passes through, much like how the iris controls the pupil in the human eye. A large aperture is helpful in low light situations or when the subject of a photograph is far away. The larger the aperture, the greater the amount of light that can be collected by the camera.

Suggested Activity
D32 Inquiry Activity on page 493

Suggested STSE Activity
D33 Decision-Making Analysis on page 494

Almost all cameras use a convex lens to refract light rays onto a light detector, such as a charge-coupled device (CCD), that records the image. The image is usually recorded digitally and can be produced as a paper photograph, as an image for display on a monitor, or as a moving image or video. The image is stored on a memory chip and can be transferred to a computer, printer, or other electronic device.

Types of Lenses

The farther away an object is, the dimmer it is and the fewer the light rays that can reach the camera. A **telephoto lens** increases the amount of light that is collected and magnifies a distant object. A telephoto lens has a long focal length, which is why it protrudes so far in front of the camera (Figure 12.26).

The opposite of a telephoto lens is a **wide-angle lens**, which captures a wider angle of view (Figure 12.27). The shape of a wide angle lens is more spherical and has a shorter focal length than a telephoto lens. Cellphone cameras usually have a wide-angle lens.

Figure 12.26 A telephoto lens magnifies distant objects.

Figure 12.27 A photograph of the aurora borealis taken using a wide-angle lens

Digital Images

When the light detector in a digital camera records an image, it does so by registering different parts of the image on many thousands or millions of different detectors. Each tiny area of the image is assigned a single colour and brightness (Figure 12.28). These tiny picture elements are known as **pixels**. When the pixels are combined, an apparently continuous image is produced. The greater the number of pixels, the more closely the image resembles the original object.

WORDS MATTER

"Pixel" is formed from pix, which is a slang expression meaning pictures, and el, which is short for elements.

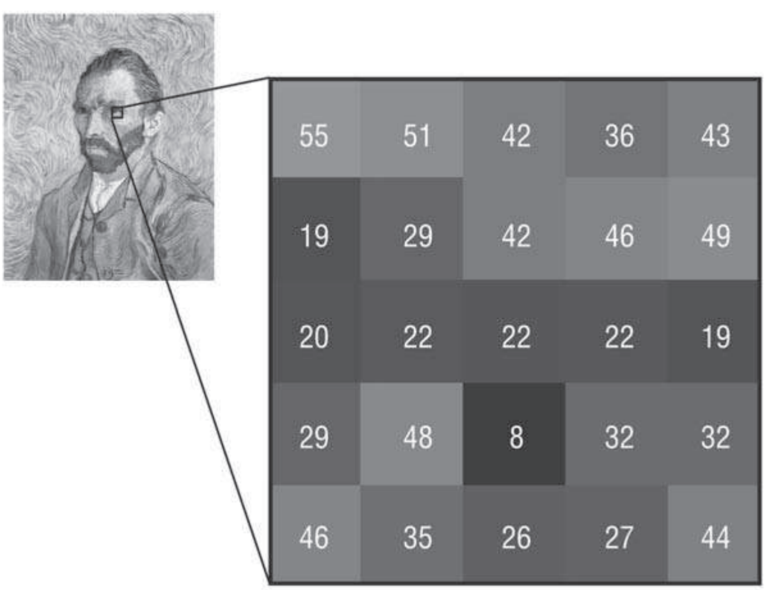

Figure 12.28 A digital image is made by combining thousands of individual pixels.

Digital Image Manipulation

Digital cameras can produce a range of optical effects, from highly detailed and realistic to manipulated and abstract. Because every image is composed of pixels, each of which is stored as a series of numbers, it is possible to manipulate the images by using software to change the values of the numbers stored for every pixel. For example, sometimes people's eyes appear bright red in photographs (Figure 12.29). This is because light from the camera flash passes into the eye, reflects off the red blood vessels inside of the eye, and then passes out again through the pupil. The red in the photograph can be removed using image editing software.

Image editing software allows many changes and improvements to the images captured by a camera. You can brighten the colours, remove unwanted objects in the photograph, sharpen or soften images, change colours, or even take objects from one photograph and add them to another. For example, you can take a photograph of yourself and insert it into a photograph of a scene from a foreign land that you have never visited. All of these changes allow increased creativity in making images more realistic or less realistic. However, manipulating images also raises concerns when the changes are applied to images in mass media such as magazines and newspapers.

Suggested STSE Activity
D34 Decision-Making Analysis on page 495

Figure 12.29 A digital image can be modified using software.

Learning Checkpoint

1. What is the difference between a shutter and an aperture?
2. (a) What is an advantage of widespread camera use?
   (b) What concerns have been raised over widespread camera use?
3. How does the focal length of a wide-angle lens compare to the focal length of a telephoto lens?
4. How is a digital image produced from pixels?

Microscopes

Some of the most important advances in health care during the last few hundred years have been the result of our ability to view the microscopic world, both directly through microscopes and indirectly through images. One of the first discoveries made using a microscope was that there were living things so tiny that they could not be seen with the unaided eye. The discovery was made by Antonie van Leeuwenhoek, a Dutch amateur scientist in the 1600s. Although his microscopes were very simple in design and had only one lens, van Leeuwenhoek used them to look at things like pond water, blood, and the plaque from his own teeth. What he saw astounded him. He wrote about his discoveries of "little animalcules" which were really the first descriptions of microscopic items such as bacteria, algae, and red blood cells. Van Leeuwenhoek's discoveries surprised the scientific world. Up until then, people had no idea there were organisms so small that you could not see them.

These discoveries confirmed one of the single most important health improvements in human history: the importance of washing hands. Prior to these discoveries, people did not realize that doctors moving from patient to patient in hospitals were spreading micro-organisms. The progress of entire plagues could be checked simply by having good sanitation.

WORDS MATTER

The suffix "-scope" is derived from the Greek verb meaning to view. In modern usage, a scope means an instrument for viewing. The prefix "micro-" means tiny, "tele-" means distant, and "peri-" means around or above. A microscope is for viewing tiny objects; a telescope is for viewing distant objects; and a periscope is for viewing objects above the scope.

Parts of a Microscope

In a **compound microscope**, a pair of convex lenses causes a small object to appear magnified when viewed through the eyepiece. The specimen is placed on a glass slide and then illuminated with a light source. Light travels through the objective lens, which is a convex lens at the bottom of the tube close to the specimen. Like a simple magnifying glass, the lens forms an upright enlarged image of the object when the object being viewed is less than one focal length from the lens. By using a second convex lens in the eyepiece, a magnification of hundreds or thousands of times can be achieved. Notice in Figure 12.30 that the light rays from the object converge inside the microscope and then diverge again. This crossing over of the light rays causes the image to become inverted. As a result, when you look through a microscope, the image is upside down.

Another type of microscope that uses light is the confocal microscope, which uses a laser beam to light the specimen. The image of the specimen is then digitally enhanced so it can be viewed on a computer monitor.

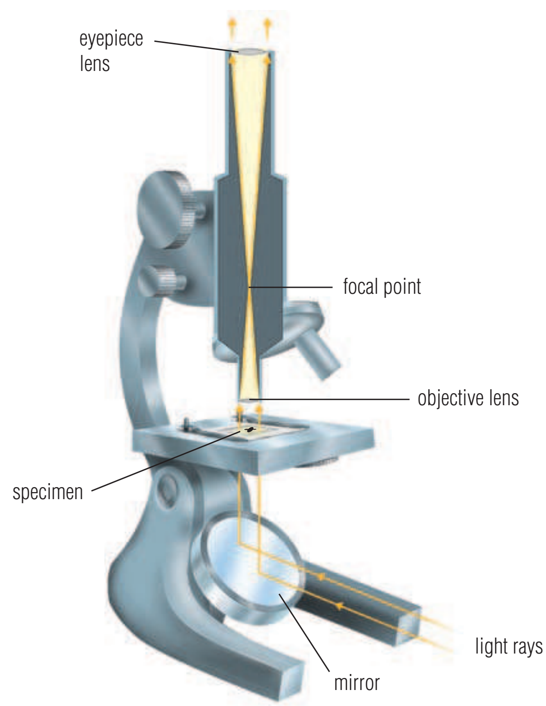

Figure 12.30 A compound microscope allows you to see great detail by combining the power of at least two lenses.

During Writing — Thinking Literacy

Evaluating Information

Background information is never the whole story when you are analyzing an issue or situation. You need to make a final judgement or evaluation of the situation by telling your readers what is most important and why they should care about the topic. Make recommendations about what should be done.

Telescopes

A **telescope** is an optical device that provides enlarged images of distant objects. The lenses and mirrors in a telescope collect light from distant objects and focus it so the objects can be viewed directly or recorded using a charge-coupled device. There are two main reasons why it is difficult to see an object that is far away. One reason is that any distant object appears very small. But there is another equally important reason, which is that the farther away an object is, the dimmer it becomes. Recall that we see an object because light rays radiate off it and pass into our eyes. The more light rays that reach our eyes, the brighter the object appears. At greater distances, fewer light rays reach our eyes.

A telescope uses either a concave mirror or a convex lens that is much larger than human eyes so that it can gather more light. This is why some telescopes are so large — not to magnify better, but to collect more light. There are two main types of telescopes: refracting telescopes and reflecting telescopes.

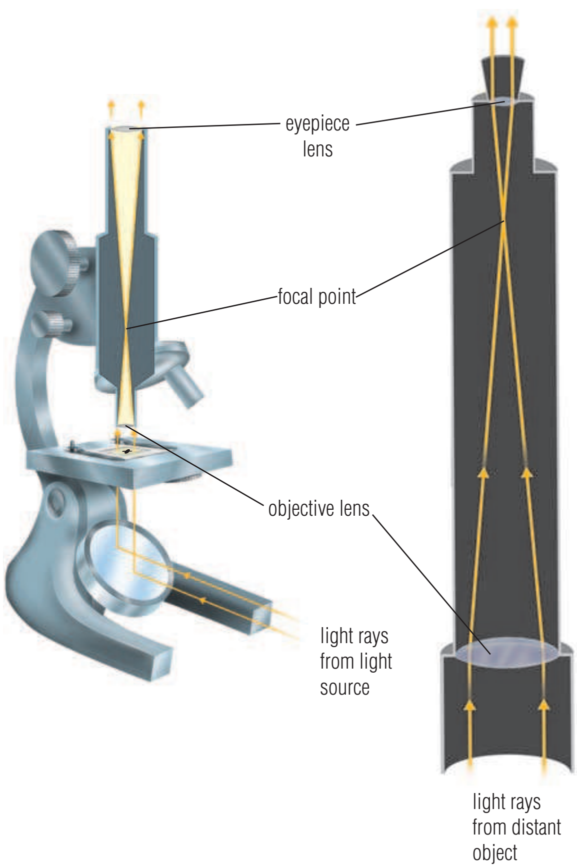

Figure 12.31 A microscope and refracting telescope have a similar design.

Refracting Telescopes

A **refracting telescope** is similar in design to a microscope, in that they both have two lenses, one on each end of a long tube. However, unlike a microscope, the objective lens in a telescope is the larger lens. Because the object viewed with a telescope is far away, the objective lens has a very long focal length. This is more suitable for focussing light rays that are almost parallel when they strike the lens, which is how light rays arrive at the telescope when coming from an object a great distance away. This also explains why refracting telescopes can be very long. The rays refracted by the objective lens need a long distance before they converge, as in the diagram in Figure 12.31.

Refracting telescopes are often used by amateur astronomers because of their portability. However, refracting telescopes are rarely used for astronomical research because very large lenses are heavy and can sag under their own weight. Another disadvantage is that lenses absorb some of the light that passes through them.

Binoculars

Using a combination of several mirrors and lenses, it is possible to make a refracting telescope more compact. For example, **binoculars** are two short refracting telescopes attached together as shown in Figure 12.32. The two telescopes are made shorter by using prisms inside that act as mirrors to redirect the path of light rays.

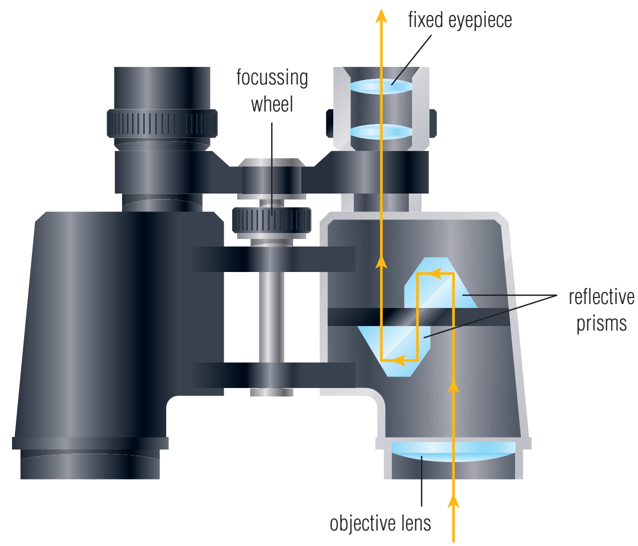

Figure 12.32 Binoculars have two reflective prisms on either side to make the arrangement more compact.

Reflecting Telescopes

The largest telescopes are built using mirrors because mirrors do not absorb light. In a **reflecting telescope**, light enters from one end of a tube and then reflects off of a concave mirror toward a small plane mirror. This small mirror directs the light into an eyepiece, camera, or other instrument (Figure 12.33).

One of the largest telescopes, the Gemini North telescope is located in Hawaii and is operated by Canada and six other countries The Gemini North telescope has a flexible mirror 8 m in diameter that can be adjusted in microseconds to correct for disturbances in the atmosphere that would cause blurry images (Figure 12.34). Together with a second telescope, called Gemini South, located in Chile, the entire sky can be viewed.

Figure 12.34 The Gemini North telescope in Hawaii is one of the largest telescopes in the world.

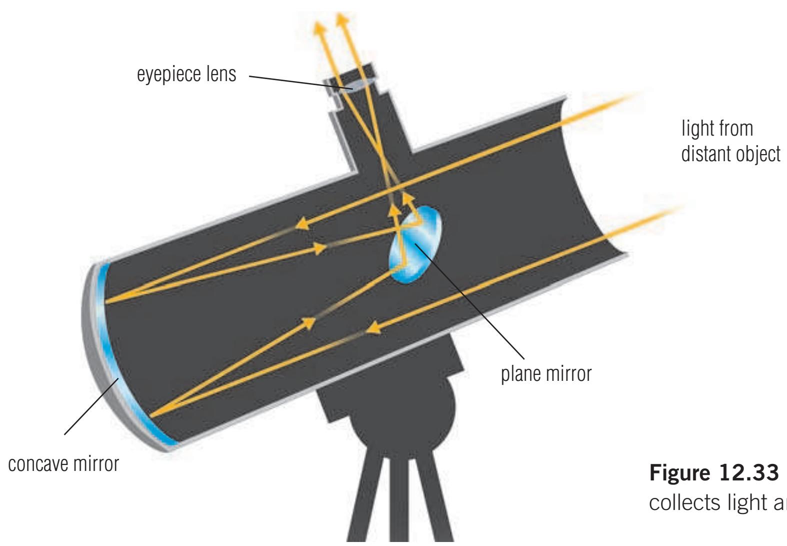

Figure 12.33 In a reflecting telescope, a large concave mirror collects light and causes it to converge.

Learning Checkpoint

1. What lenses are used in a compound microscope?
2. Why is the image you view through a microscope upside down?
3. Why are some telescopes very large?
4. What are two main types of telescopes?
5. How are binoculars made more compact than telescopes?

Lasers

WORDS MATTER

The word "laser" is an acronym that stands for "**l**ight **a**mplification by **s**timulated **e**mission of **r**adiation."

A **laser** is an optical device that produces a form of light in which all the light rays are almost perfectly parallel, all have the same wavelength, and all of the wave crests and troughs are exactly lined up. Laser light is very different from incandescent light, which is usually a jumble of different wavelengths with the wave crests and troughs arranged randomly (Figure 12.35).

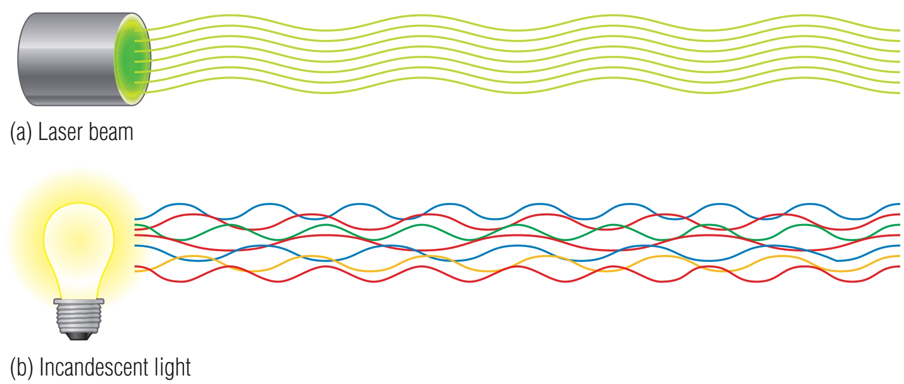

Figure 12.35 (a) In laser light, the light waves are parallel, have the same wavelength, and have wave crests and troughs aligned. (b) In ordinary light, different wavelengths (colours) of light are combined randomly.

Laser light is used in communications, consumer electronics, bar code readers, and DVD players, where information on the DVD is encoded in a manner similar to bar codes but in a microscopic size. You may also be familiar with lasers used in entertainment (Figure 12.36).

Lasers used in different applications vary tremendously in brightness. However, all lasers are bright enough to do permanent damage to the retina of your eye, which is why you should never look directly into a laser beam, even briefly. The brightness of a laser depends on the power used to generate the light, the colour of the light, and how well it remains in a tight beam. Very little energy is needed to operate lasers compared to other forms of light production. For example, an outdoor laser show can shoot bright laser beams using less energy than is needed in a standard household light bulb. The difference between the two is that all the energy in a laser is concentrated into a single beam. Stadium lasers are safe to view because they are kept at a distance and not directed straight into an audience.

Figure 12.36 Lasers are often used in light shows.

Lasers in Medicine

Lasers are used as a diagnostic tool in medicine to detect cancer. Many forms of cancer produce chemicals that leave the cancer cells and enter the bloodstream. By taking a sample of blood and shining laser light through the blood, it is now possible to detect certain kinds of cancers before they cause symptoms or grow large enough to be detected by an X-ray.

Colours of Laser Light

Because our eyes are more sensitive to green light than red or blue, a green laser beam appears brighter to us than a laser beam of a different colour (Figure 12.37). Although laser beams are more tightly concentrated than ordinary light beams, they still spread out. In fact, a laser beam may be several kilometres in diameter by the time it reaches the Moon. Astronauts from the Apollo missions left mirrors on the Moon. The mirrors are used with lasers to measure the distance between Earth and the Moon.

670 nm	diode
650 nm	diode
635 nm	diode
633 nm	helium-neon
568 nm	krypton
532 nm	diode
514 nm	argon
488 nm	argon
473 nm	diode
458 nm	argon
416 nm	krypton
410 nm	diode

Figure 12.37 Some common colours of laser light. The column on the left shows the wavelengths of light produced by the various types of lasers listed on the right.

Photonics

In the wave model of light, different colours of light have different wavelengths. Another way of modelling how light travels is by thinking of light as a series of many tiny packets of energy called **photons**. In this model, the colour of light is related to the amount of energy carried by each photon. It has been found, for example, that a photon of blue light carries more energy than a photon of yellow or red light. A photon of ultraviolet light carries even more energy than a photon of blue light, which is why ultraviolet light can damage skin, whereas blue, yellow, or red light cannot. Both the wave and the photon models of light each account for some properties of light. However, both models are needed to account for all of the properties.

Technologies that make use of the way in which light travels as photons are called **photonics**. Photonic technologies are used in many applications including laser technologies, digital cameras, solar energy generation, and computers with components that use light instead of electricity.

Take It *Further*

Canadian scientists are guiding the building of the world's largest optical telescope, the Thirty Meter Telescope (TMT). The 30-m mirror in the telescope will actually be made of many smaller mirrors. and the telescope will be nearly 100 times more sensitive than existing telescopes. Find out more about Canada's role in building the TMT. Begin your research at ***ScienceSource***.

Digital Cameras

The widespread availability of tiny, inexpensive still and video cameras has occurred partly due to photonics technologies in image capture. Just as a solar cell absorbs photons of light to produce electricity, millions of tiny, individually wired cells can be grouped together on a grid to detect many different photons at one time. Combining all of these detectors at once creates an image. The most common form of detector is a charge-coupled device (Figure 12.38).

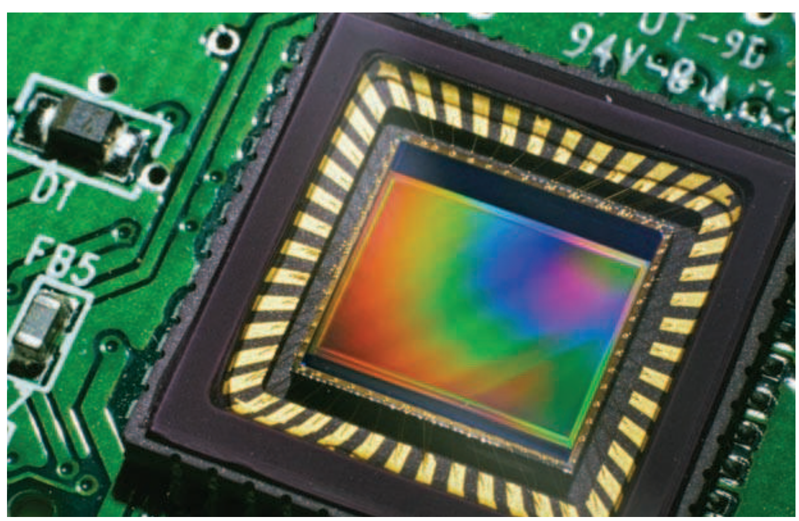

Figure 12.38 A charge-coupled device (CCD)

Figure 12.39 Long rows of solar cells

Solar Cells

Solar cells convert sunlight directly into electrical energy (Figure 12.39). When a photon of sunlight is absorbed by an atom of a metal, such as lithium, an electron within the atom receives the energy of the light. This permits the electron to move away from the atom along a circuit. The flow of electrons in the circuit is electric current.

Solar cells have existed for many decades. Recent emphasis on renewable and clean energy production has inspired intensive research into new and widespread applications for high-efficiency solar cells.

Optical Computers

Traditional computers use electronic components to perform their functions through the movement of electrons in electric circuits. In an optical computer, photons take the place of electrons and optical switches and components do the calculating and other functions within the central processing unit of the computer. Optical computing is currently in an intensive research and development phase. Optical computers are expected to be much smaller but also to operate much faster than electronic devices.

D31 **STSE** *Science, Technology, Society, and the Environment*

Digitally Edited Photographs

Before photographs appear in a newspaper or magazine, a photo editor removes any "noise" including dust or distracting elements. Removing a distracting element might mean taking out a tree branch that is obscuring part of a statue, or it might mean removing a building or cars from the background. Photographs of people are often airbrushed to smooth out skin features. Sometimes, an editor also adds elements to a photograph, such as increasing the size of a crowd gathered to watch an event or adding fireworks to a night sky. These changes mean that the photographs you view in a magazine or newspaper may no longer be accurate portrayals of the events they capture.

1. Take the approach that digital editing is acceptable. Develop an argument that supports your position from the point of view of:

   (a) the editor of a news magazine

   (b) the editor of a fashion magazine

2. Take the approach that digital editing is only sometimes acceptable. Explain when it should be allowed.