Figure 2.18 shows the light rays coming from the fish bending as they leave the water. Our eyes assume that light travels in straight lines. If you trace the light rays that reach the eye backward in a straight line, you will find that they do not lead to the fish. Instead, the light from the fish in deep water appears to be coming from shallower water, thus fooling you into grabbing where the fish is not.

How Light Refracts

When light travels at an angle from one medium (substance) to another, it bends or refracts. You might be surprised to learn that **refraction** is due to changes in the speed of light. In space, light travels at around 300 000 km/s. Space is a vacuum, and there are no particles to get in the way of light and slow it down. However, just like a student trying to move from class to class when the hallways are full, it's impossible to move at top speed when particles (students) get in the way. What happens when light suddenly slows down as it hits a medium? If it strikes a medium of different density at an angle, it refracts.

How does this happen? Imagine light travelling like the line of skaters in Figure 2.20. Initially, they are all travelling at the same speed. In front of skaters C, D, and E, lies a patch of rough ice that will cause them to slow down. If the rest of the skaters continue to skate at the original speed, the result is a bend in the line. The same thing happens with light. When part of a beam of light slows down and the rest keeps going, the beam of light will bend.

Figure 2.19 This object is not really bent.

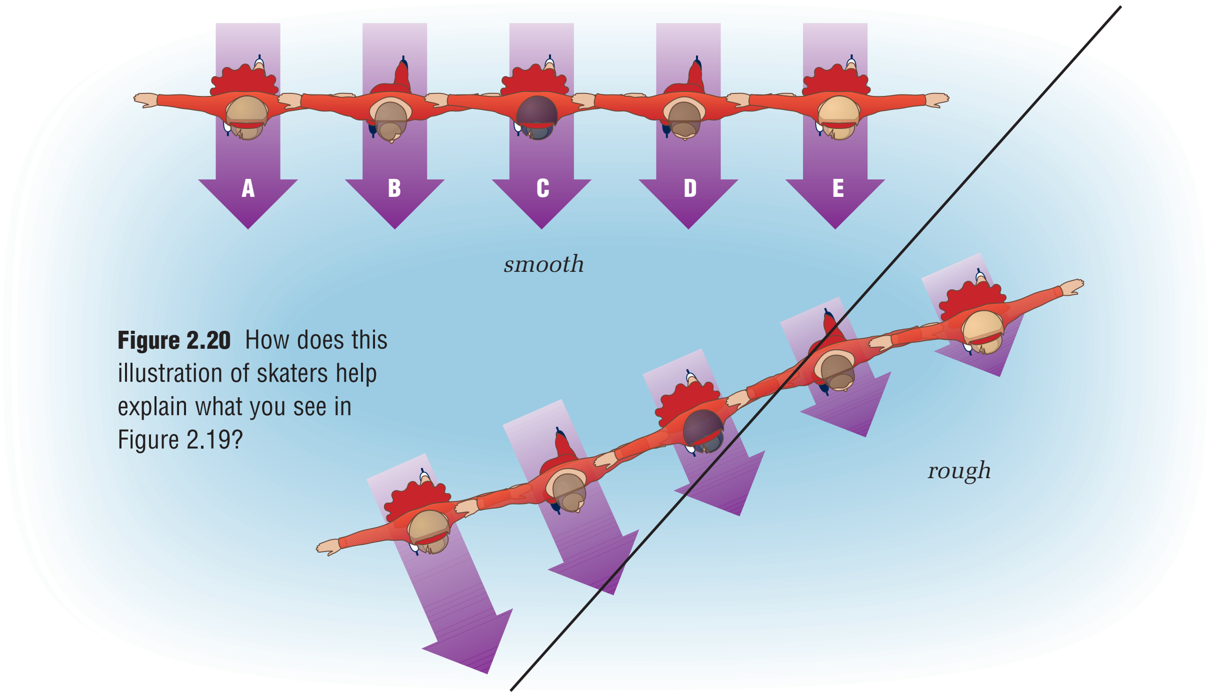

Figure 2.20 How does this illustration of skaters help explain what you see in Figure 2.19?

Inquiry Activity

FROM AIR TO SOLIDS

The Question

What happens to light when it passes from air through different transparent solids?

Materials & Equipment

- glass block
- paper
- pencil
- ruler
- protractor
- ray box with a single slit opening
- transparent plastic block

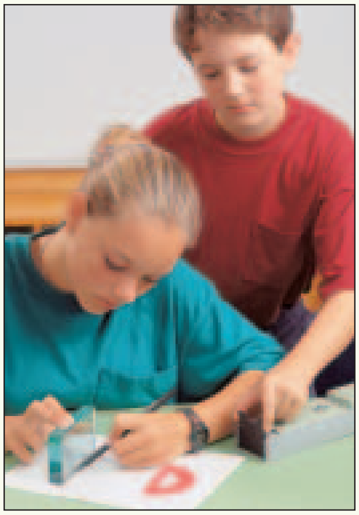

Figure 2.21 Tracing around the glass block

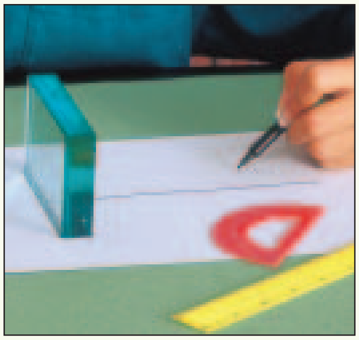

Figure 2.22 Drawing the normal

Procedure

1 Place the glass block on a piece of paper and trace around it as in Figure 2.21. Mark a point near the middle of the front edge of the block and draw a normal at right angles to this point, Figure 2.22.

2 Direct a ray of light from the ray box so that it shines along the normal. The point where the ray enters the block is the point of incidence.

3 Mark the exit point where the ray leaves the glass. Join the incident and exit points. This is the refracted ray.

4 Adjust the ray box so that the light ray strikes the glass at the same point of incidence, but this time at an angle from the normal.

5 Again, trace the incident ray, and mark the point where it leaves the block. Draw the refracted ray again and make sure to label them.

6 Repeat steps 4 and 5, each time using different angles for the incident ray.

Collecting Data

7 Complete each refracted ray on the paper using a ruler to join the point of incidence to the exit point. Make sure all rays, incident and refracted, are labelled correctly. Add arrows to the rays to indicate their direction.

8 Use your protractor to determine the angle of incidence and the angle of refraction in each case. Note that these angles are measured from the normal. Organize all the angles in a table with the headings "angle of incidence" and "angle of refraction" and list the rays in order by their angle of incidence.

9 Repeat steps 1 through 8 with the plastic block and a new sheet of paper. Predict how refraction will change using the plastic block. Use the same angles of incidence you used for the glass block.

Analyzing and Interpreting

10 How does the incident angle compare with the refracted angle?

11 What happened when the ray entered the block along the normal?

12 What happened to the refracted ray as the angle of incidence was increased?

13 How did the refraction of rays in glass and plastic compare?

Forming Conclusions

14 What two factors affect how much light is refracted?

15 Which of the two substances, glass or plastic, refracts light more?

Refraction in Different Media

Light bends when it hits a new medium at an angle. The denser the new medium, the more the light slows down, and so the more it refracts. A diamond is much more dense than water, and so a diamond refracts light more than water does.

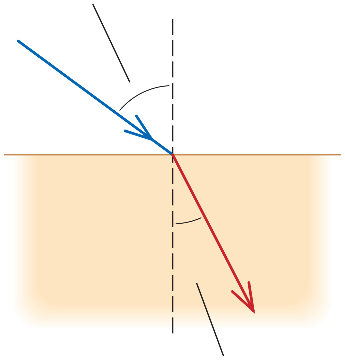

Figure 2.23 Ray diagram showing refraction

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Wet Road Ahead!

Have you ever been on a car trip on a hot sunny day and the road ahead seems wet? What you see is an optical illusion called a mirage. Investigate the role refraction plays in causing mirages.

Check and Reflect

1. What happens to light rays when they pass from one medium into another medium? Explain the process of refraction.
2. How does the type of medium affect refraction?
3. When would it be easier for a bear to catch a fish: as the fish swims or when it jumps in the air? Use your knowledge of how light travels in air and water to explain.
4. Why do objects at the bottom of an aquarium filled with water appear closer than they actually are?
5. The archer fish fires jets of water with its mouth at unsuspecting bugs on branches above the water. Explain in terms of how light travels, why these fish almost always “shoot” when they are directly beneath a bug. Why don’t they shoot at an angle?

Figure 2.24 Question 5

2.5 Lenses Refract and Focus Light

*info***BIT**

Wow! That's Intense!

Convex lenses bend parallel light rays to a single point. As a result, the concentrated light energy at that point is hot enough to burn skin and can start fires. Be very careful handling convex lenses, especially in sunlight.

In section 1.0, you learned that microscopes, telescopes, and binoculars take advantage of lenses to manipulate light. What is it about lenses that make them great at collecting and moving light around? The answer lies in their shape and the material they're made of.

A **lens** is a piece of curved glass or other transparent material. It is smooth and regularly shaped so when light strikes it, the light refracts in a predictable way. The most useful aspect of lenses is that the light rays that refract through them will sometimes form images.

Figure 2.25 A magnifying glass is a convex lens.

Concave Lenses

A **concave lens** is thinner in the centre than at the edges. As parallel rays pass through a concave lens, they are refracted away from the centre of the lens. So as light passes through a concave lens, the light rays diverge or spread out, and they will never meet on the other side of the lens.

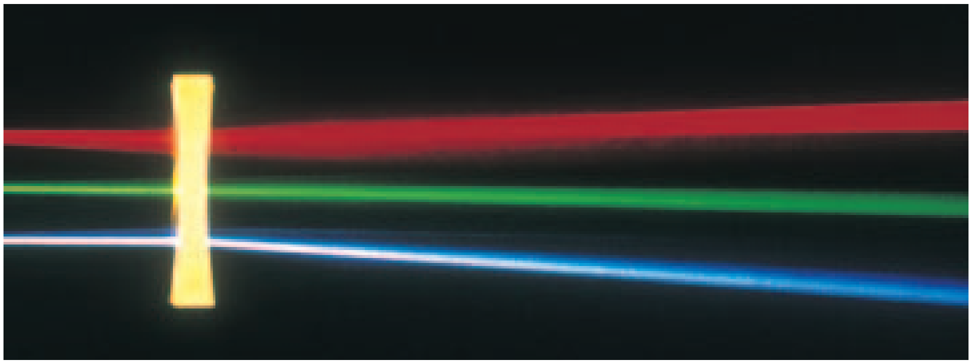

Figure 2.26 Concave lenses spread light out.

Convex Lenses

A **convex lens** curves outward and is thicker in the middle than at the edges. The technical name for a convex lens that curves outward on both sides is a double convex lens, but it's usually just called a convex lens. As parallel light rays travel through a convex lens, they are refracted toward the centre of the lens. So as light passes through a convex lens, the rays move toward each other. The light rays cross at the focal point of the lens. (By changing the curvature of the lens or the substance it is made of, you can alter the focal point.)

The ability to bring light rays together makes a convex lens useful for two reasons. First, it can act as a light collector, much like a concave mirror. This is why a convex lens is used in a refracting telescope. It collects and focusses starlight. (Look back at the diagram of a refracting telescope on page 184.) Second, a convex lens forms a **real image**. The light rays actually meet at a point, and the image can be projected onto a screen.

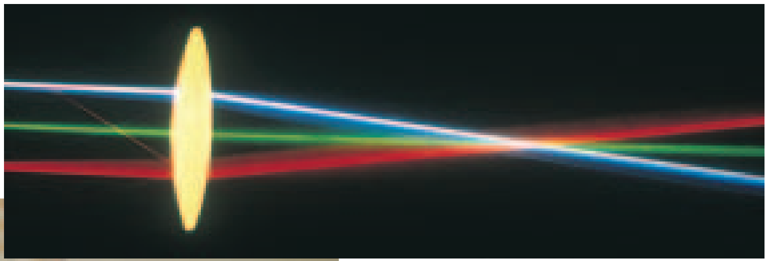

Figure 2.27 Convex lenses bring light rays together.

Figure 2.28 A real image can be projected onto a screen.

Depending on how close the object is to the convex lens, you can project images that are smaller or larger than the object. However, as you can see in Figure 2.28, there is one drawback to convex lenses. The image is upside down!

Inquiry Activity

Checking Out Images

Materials & Equipment

- cardboard stand
- sheet of unlined white paper
- tape
- light bulb and socket
- battery and wires
- convex lens
- modelling clay (to support the lens)
- metre-stick

The Question

How does the distance between an object and a convex lens affect the image formed?

The Hypothesis

Based on the question, form a hypothesis for this investigation.

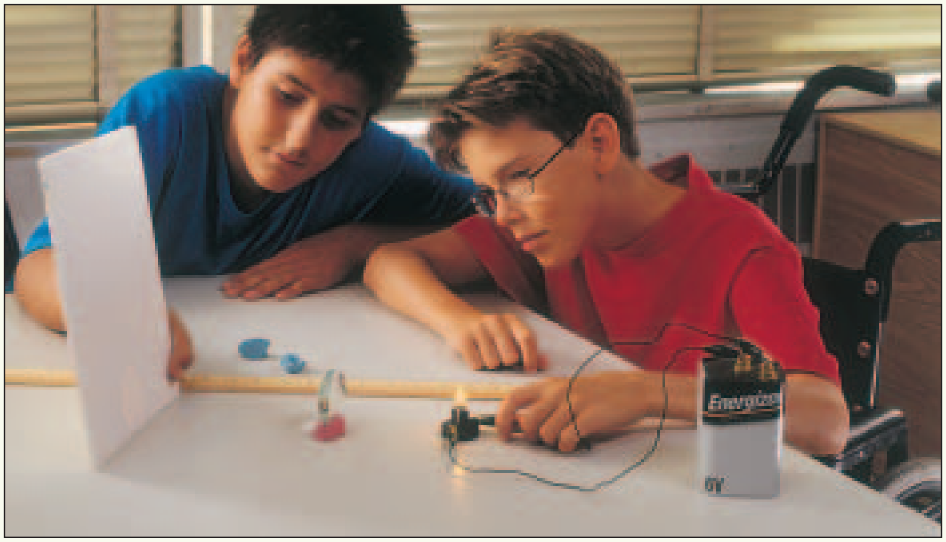

Figure 2.29 Finding the focal length of the lens

Procedure

1. Measure the height of the glass part of the bulb.
2. Tape the paper onto the cardboard stand. This is your "screen."
3. If your teacher has provided you with the focal length of the lens, you may skip this step. If you don't know the focal length of the lens, do the following to find the focal length:
   - Place the lens in between the stand and the lit bulb.
   - Move the screen and the bulb slowly inward, then outward, keeping the lens in the middle. At a particular distance, an upside-down bulb of the same size as the actual bulb will come into focus on the screen. Be patient! If you don't get the image the first time, keep trying.
   - Measure the distance between the bulb and lens. Divide this value by 2. This is the approximate focal length of the lens.
4. Record the bulb height and focal length in your notebook.
5. You are going to collect data on the size of the image of the bulb, as well as the distance of the bulb from the lens. Draw a data table like the one on the following page.

Distance from bulb to lens (cm)	Image position (upright or upside down)	Size of image (cm)

6 Place the bulb more than twice the focal length away from the lens. Move the screen until the image comes into focus.

Collecting Data

7 Record the following in your data table:
- distance from the bulb to the lens
- the position of the image (upright or upside down)
- the size of the image

8 Place the bulb just over one focal length away from the lens. Move the screen until the image comes into focus. Record the results as in step 7.

9 Repeat step 7 again but this time place the bulb less than one focal length away from the lens. Move the screen to attempt focus. If you cannot get an image on the screen, bend down and look at the bulb through the lens. Can you see an image of the bulb in the lens? If you see an image through the lens, estimate its size.

Analyzing and Interpreting

10 Is the image formed by a convex lens always upside down? If not, under what conditions is the image upright?

11 What happens to the size of the image as the bulb moves toward the lens? What happens to the image position?

12 What happens when the bulb is placed inside the focal length of the lens?

Forming Conclusions

13 Write a summary paragraph explaining how lens placement affects image size and location.

Applying and Connecting

Convex lenses are often used in projectors. You may have used a projector to give a slide or film presentation. What happens to the size of the image as the projector is moved closer to the screen? Explain this in terms of what you have learned about convex lenses. How do you think projectors overcome the "upside-down" problem?

Extending

Try repeating this experiment using lenses of different focal lengths.

Figure 2.30 Using a projector

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The Fresnel Lens

In 1822, Augustine Fresnel (pronounced Fray-nell) invented a lens that was much more efficient at collecting and directing light rays than other lenses used at the time. Find out more about the structure and function of Fresnel lenses.

Image Formation with a Convex Lens

The formation of an image by a convex lens depends upon how far the object is from the lens. The ray diagrams in Figure 2.31 help illustrate this. If the object is farther away than the focal point of the lens, as in diagrams A and B, the image appears upside down and smaller or bigger. Both of these images are real images. In diagram C, the image will appear upright and bigger, and forms on the same side of the lens as the object. When you use a magnifying glass, the object you're looking at appears to be bigger on the other side of the glass.

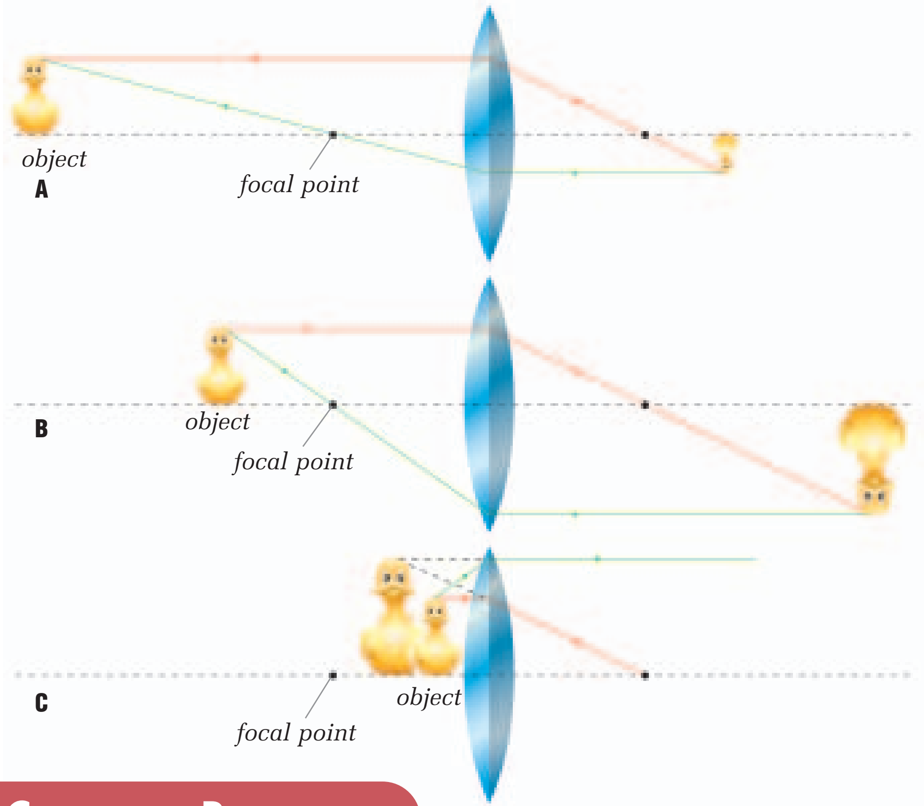


Figure 2.31 The formation of an image with a double convex lens depends on where you put the object.

Check and Reflect

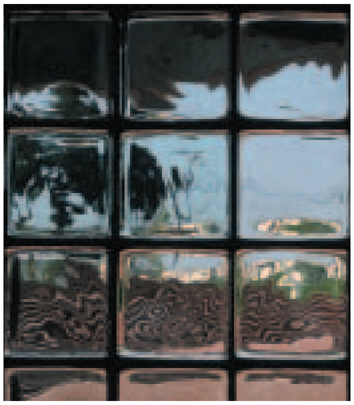


Figure 2.32 Question 4

1. Why are lenses useful for moving light around?
2. Draw a ray diagram that shows the path light rays take through a concave lens.
3. What kind of image is formed when an object is placed at the focal point of a convex lens?
4. Figure 2.32 shows the view through glass building bricks. How do these bricks let light through but still protect your privacy?
5. Suppose you wanted to examine closely the leaf of a plant. What type of lens would you choose? Would you use a lens combination? Explain.

Experiment ON YOUR OWN

LENS SWITCH-A-ROO

Before You Start ...

You now know how the size and position of images formed by a convex lens can change depending on the position of the object. Would the images be different if you used two convex lenses?

The Question

How does image formation vary when two convex lenses are used?

Design and Conduct Your Experiment

TOOLBOX

1 Make a hypothesis.

2 Decide on the materials and equipment you will need to test your hypothesis.

3 Are there any safety aspects you need to consider?

4 Plan your procedure. What steps do you have to go through to collect the data you need?

5 Write up your procedure and show it to your teacher.

6 Decide what your data collection table should look like and construct it.

7 Before you start your investigation, make predictions about the size and locations of the images.

8 Carry out your investigation and compare your results with your hypothesis. Was your hypothesis correct? If not, how would you explain your experimental result?

9 Compare your results with classmates who investigated similar questions. Were your results similar?

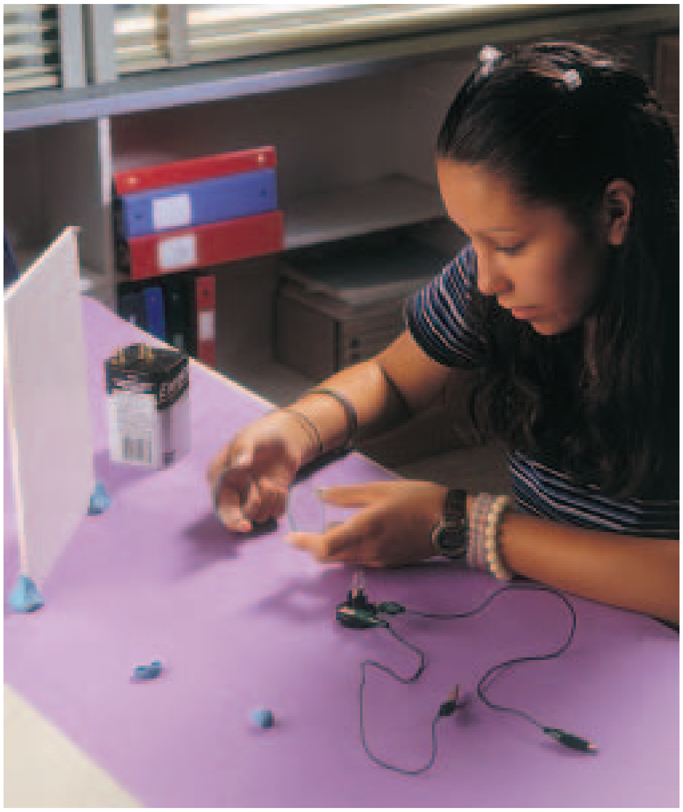


Figure 2.33 Think about how you will conduct your experiment.

10 Compare your experimental procedure with classmates who investigated similar questions. Identify some strengths and weaknesses of the different ways of collecting and displaying data.

11 Are there any questions or problems that came up during your experiment that would take more investigation to answer?

12 Outline how you would design an experiment to look into these questions or problems.

Careers and Profiles

SAY CHEESE!

Ray Boudreau is a professional photographer. His portfolio includes everything from corporate executives to members of the Royal Canadian Air Farce. In fact, he took many of the photographs that appear in this unit.

Q: When did you first become interested in photography?

A: My interest in photography began when I was 11 years old. A friend of the family gave me a little Kodak printing kit. After using it for the first time, I was hooked on it.

Q: What's the most challenging part of your job?

A: Each picture I take has its own photographic problem which I have to solve. It's a problem-solving business. Using my photographic knowledge to solve problems is fun for me.

Figure 2.34 Ray Boudreau is setting up for a photograph that appears in Cells and Systems.

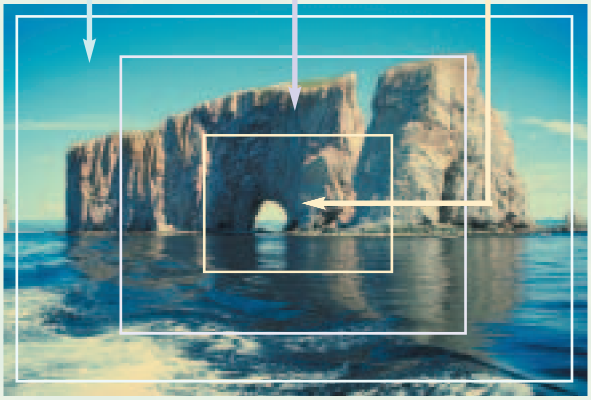
The camera Boudreau uses can be fitted with different lenses.

Each photographic lens uses a combination of convex and concave lenses.

Wide Angle Lens: Objects appear farther away than they really are.

Normal Lens: Objects appear as they would to your own eye.

Telephoto Lens: Objects appear closer than they really are.



Q: What was your most challenging photo?

A: I had to photograph the city of Toronto for the cover of a magazine. I rented a wide-angle lens and we went up in a helicopter. I was strapped in and I hung out of the helicopter and photographed the buildings from as close as we could get. The wide-angle lens made the tops of the buildings look really big and the bottoms look really small.

1. Do you think a photographer has to know about light and optical systems to do his or her job?
2. If you were a photographer, what part of the job would you find challenging?

Assess Your Learning

1. Use a labelled diagram to illustrate the law of reflection.

2. As Figure 2.35 indicates, it is possible to build a spy device with a long tube or milk carton. This could also be used to see over a crowd at a parade. Using a diagram, explain how mirrors are arranged in this device to make it an effective "spy tool." Make sure to indicate how rays of light would travel through the device.

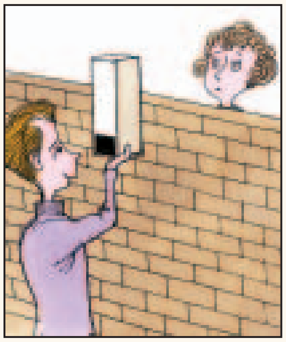


Figure 2.35 Question 2

3. Design a reading light that someone could use without bothering others in the room. (Hint: How could a mirror help?)

4. If you wanted to block out all of the light from your bedroom, what type of material would you use on the window? What would you use if you wanted to block out half of the light?

5. In Figure 2.36, the doll in the tank of water illustrates light from the doll reaching your eyes by three different paths. Explain what is happening to the light rays on those three paths.

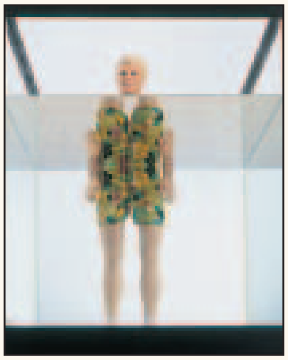


Figure 2.36 Question 5

6. Describe how you would project a bigger image with a double convex lens.

7. Why should the pages of a book be slightly rough rather than very glossy?

8. Trace Figure 2.37 into your book. Assume the light ray moved from substance A to B. Add an arrow to the light ray, draw a normal, and label the angles of incidence and refraction.

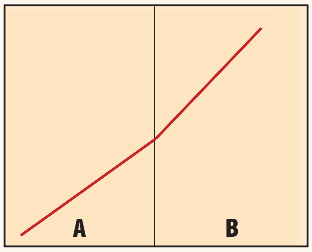


Figure 2.37 Question 8

Focus On THE NATURE OF SCIENCE

Scientists strive to gain knowledge of the natural world. Reflect back on what you have learned about how light behaves.

1. Why do you think it is important to learn how light reacts in nature?

2. How has the development of different types and applications of lenses and mirrors helped us to better understand our world?

3. How does an understanding of how light travels aid in the development of new technologies?

3.0 Light is part of the electromagnetic spectrum and travels in waves.*

Key Concepts

In this section, you will learn about the following key concepts:

- electromagnetic spectrum
- transmission and absorption of light
- colour and wavelength
- sources of light

Learning Outcomes

When you have completed this section, you will be able to:

- describe the characteristics and composition of sunlight
- explain the wave properties of light and the electromagnetic spectrum
- describe some of the technological applications of electromagnetic radiation
- recognize the dangers associated with certain forms of radiation
- evaluate, compare, and contrast different artificial and natural light sources
- describe how primary colours can be added to produce different colours and white light

The medical profession has changed incredibly in the last two centuries. Doctors have a number of different tools they can use to see inside the body without having to operate.

The endoscope is a combination camera/light source. The light is delivered through a thin, flexible fibre-optic cable. It allows the doctor to illuminate the inside of the digestive system and examine the structures clearly to identify any problems. The doctor views the image on a TV screen and can even perform operations this way.

Visible light is just one form of energy used by doctors to advance medical treatment. Lasers are used to make incisions in surgery. X-rays are used to view dense structures inside the soft tissue of our body. Gamma rays are used to treat cancer. Even microwaves have been used to shrink certain enlarged tissues. What do all of these forms of energy have in common?

For Web links relating to 3.0, visit **www.pearsoned.ca/scienceinaction**

* *Extension material*

3.1 The Wave Model of Light

An important part of science is developing models. Models are based on what we observe about the characteristics and properties of something. They help make it easier to understand complex concepts. Scientists commonly use the **wave model of light**.

Waves and light have two big similarities: they are both a form of energy, and they travel out in all directions. If waves describe light, then you need more information about how waves behave.

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Tsunami!
In 1771, a tidal wave, or tsunami, hit the coast of Japan. It was possibly 85 m high and had enough energy to toss a 750-t rock 2.5 km inland.

Properties of Waves

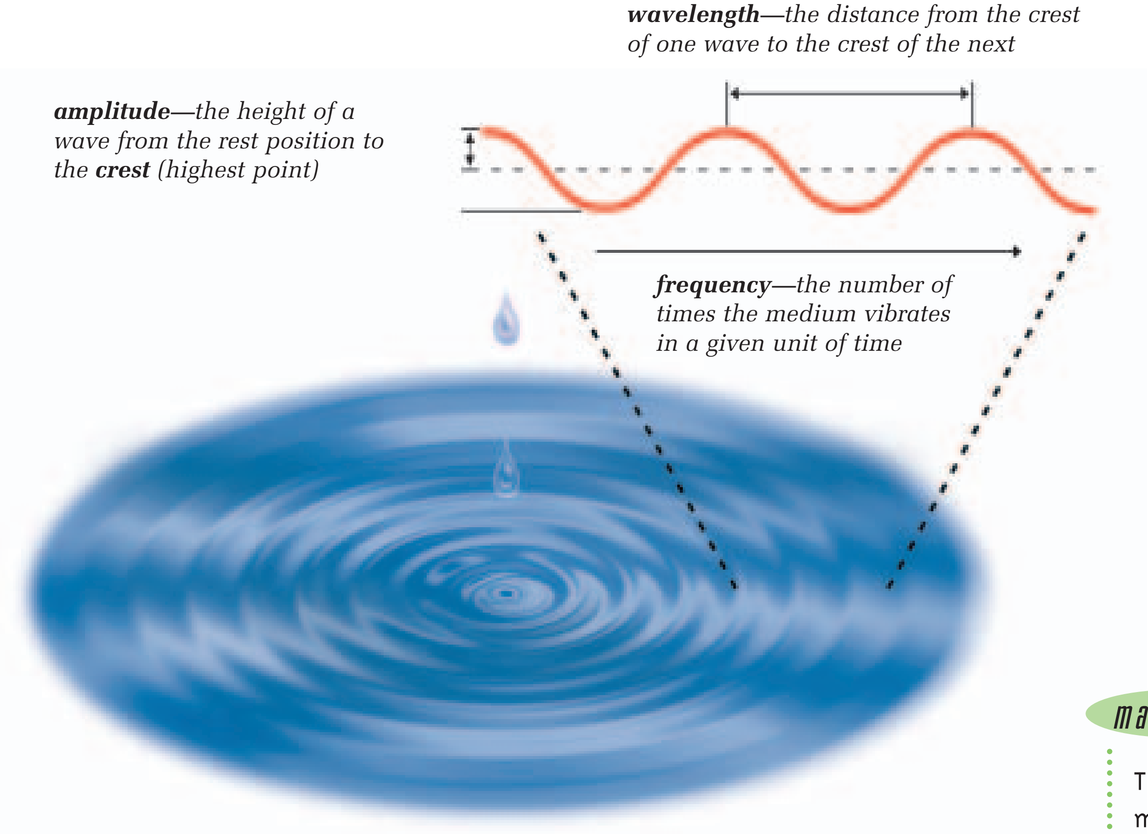

Figure 3.1 All waves have an amplitude, wavelength, and frequency.

All waves have a wavelength, but the wavelengths can vary widely. Think about sitting in the bath. You've probably created waves just for the fun of it. Suppose you were making one new wave every second. Would it take more or less energy to create three waves per second? It takes more energy.

When you create more waves per second, the frequency of the waves increases. As the frequency increases, you'll notice that the crests of each wave are closer to one another. So as more energy is put into making waves, the frequency of waves increases and the wavelength shortens.

mathLink

There is a mathematical relationship between the speed, wavelength, and frequency of a wave.

speed = wavelength × frequency

If the speed of a wave on a rope is 50 cm/s and its wavelength is 10 cm, what is the frequency of the wave?

Light Waves

As you learned in the first section, rainbows have fascinated people, especially scientists, for thousands of years. How are the colours of a rainbow formed? You always need sunlight to create a rainbow, so there must be some relationship between the white light of the sun and the coloured light of a rainbow.

Figure 3.2 Sunlight and raindrops are needed to form a rainbow.

Give it a **TRY** — ACTIVITY

What Is White Light Made Of?

Shine a light through a prism so that the light leaving the prism falls on an unlined piece of paper. What colours do you see? As you hold the prism and light steady, your partner will use coloured pencils to draw the colours on the piece of paper. Switch places with your partner. Again, trace the colours you see onto the piece of paper.

- What colours do you see on the paper? What is the order of the colours?
- Is it difficult to see where one colour ends and the next begins?
- Did the order of the colours on the paper ever change?
- The term *spectrum* means a range. How do you think this term is related to what you observed?

When you shine sunlight or white light through a prism as in Figure 3.3, the light refracts, and splits up into the colours of the rainbow. These colours form the **visible light spectrum**. Each colour of light is refracted at a different angle. So white light is made up of many different colours of light.

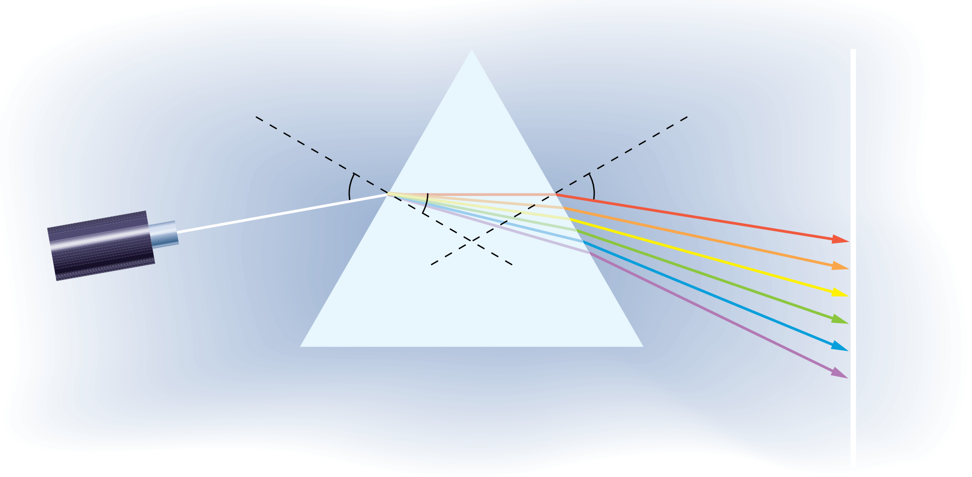

Figure 3.3 Refraction of white light through a prism. Each colour of light that makes up white light refracts at a slightly different angle.

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Two Pots of Gold?
When rainbows form, sometimes a secondary rainbow appears outside the first. Find out how the secondary rainbow occurs. Is the order of colour in the secondary rainbow the same as the first?

The colours of the spectrum can be explained using the wave model. Figure 3.4 shows that each colour of light in the visible light spectrum has a slightly different wavelength.

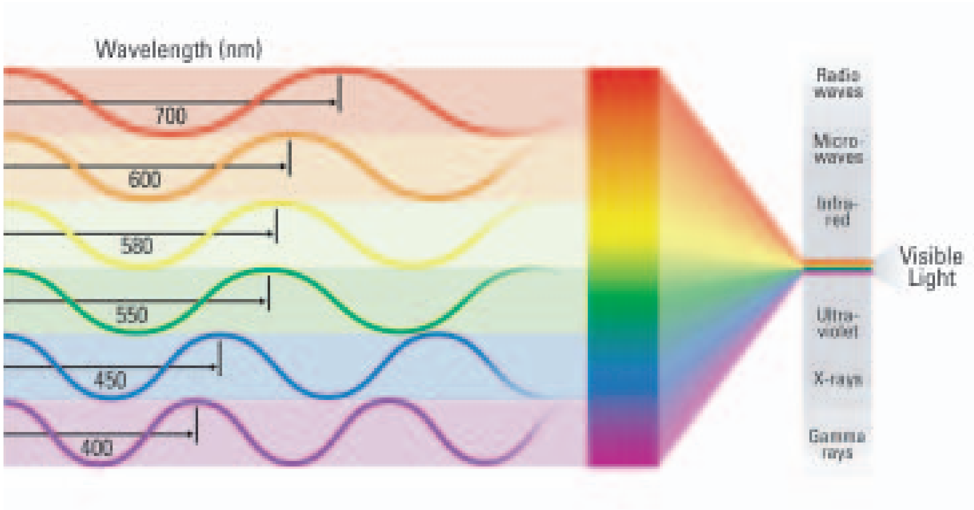


Figure 3.4 The visible spectrum has red light on one end, violet on the other, and all the other colours in between. Red light has a wavelength of 700 nm (nanometre)—as you move through the other colours, the wavelength shortens to 400 nm for violet light. These wavelengths are very tiny. A nanometre is one-billionth of a metre, so 700 nm = 0.000 000 7 m.

Check and Reflect

1. What properties do light and the waves in your bath share?
2. Create a concept map that links frequency, amplitude, and wavelength.
3. On a piece of graph paper, draw a diagram of a wave with an amplitude of 4 cm and a wavelength of 10 cm.
4. Draw a diagram to explain what happens to white light as it passes through a prism.

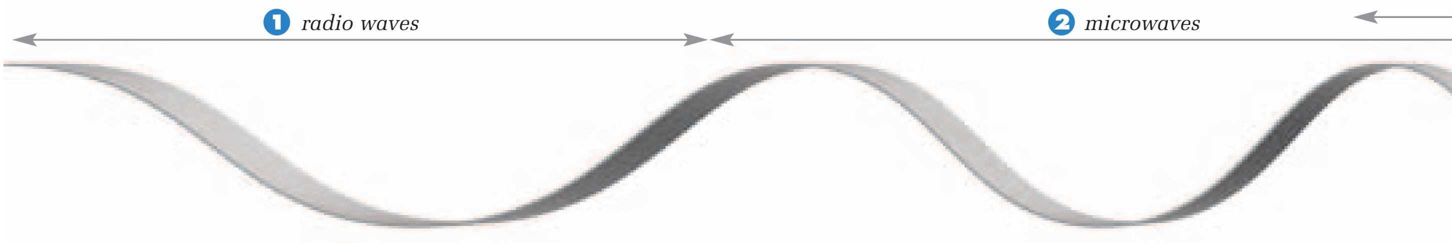
3.2 The Electromagnetic Spectrum

Imagine you are out for a walk in the park. The sun is shining down and there's not a cloud in the sky, but actually you are being drenched! Not by rain, but by energy. In addition to visible light, the sun sends out lots of different types of energy. Most of them you cannot see or feel.

The Invisible Spectrum

There is a whole world of energy that lies beyond our sense of

Uses of the Electromagnetic Spectrum



1 **Radio waves** are vital to communications around the world. Different wavelengths within the spectrum of radio waves are used to separate modes of communication. For example, FM radio waves are longer than AM radio waves. Searchers for extraterrestrial intelligence use radio antennas to scan space for radio signals that would indicate life on other worlds. They haven't found anything—yet.

2 **Microwaves** are shorter than radio waves. This means that the frequency of microwaves is higher than radio waves, and they carry more energy. When microwaves are used to heat food, they make the water particles in the food vibrate. This causes the food to heat up.

3 **Infrared waves** can't be seen but they are felt as heat. Special equipment can sense infrared radiation and detect hotter and cooler areas. Images of infrared radiation are called thermograms.

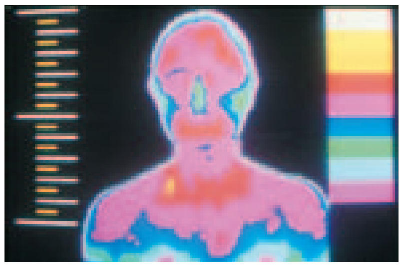


Figure 3.5 Electromagnetic radiation strikes Earth in many different forms.

vision. The wavelengths that make up visible light are just a small part of a very large range of **electromagnetic radiation**. The wave model works perfectly to explain the invisible parts of the **electromagnetic spectrum** (Figure 3.5). At the end of the spectrum with longer wavelengths than visible light, you find the low-frequency radio waves, microwaves, and infrared radiation. At the other end of the spectrum where the wavelengths are shorter and frequencies higher than visible light, you find ultraviolet radiation, X-rays, and gamma rays. Human eyes are not sensitive to either end of the electromagnetic spectrum that lies beyond visible light, so these rays remain invisible.

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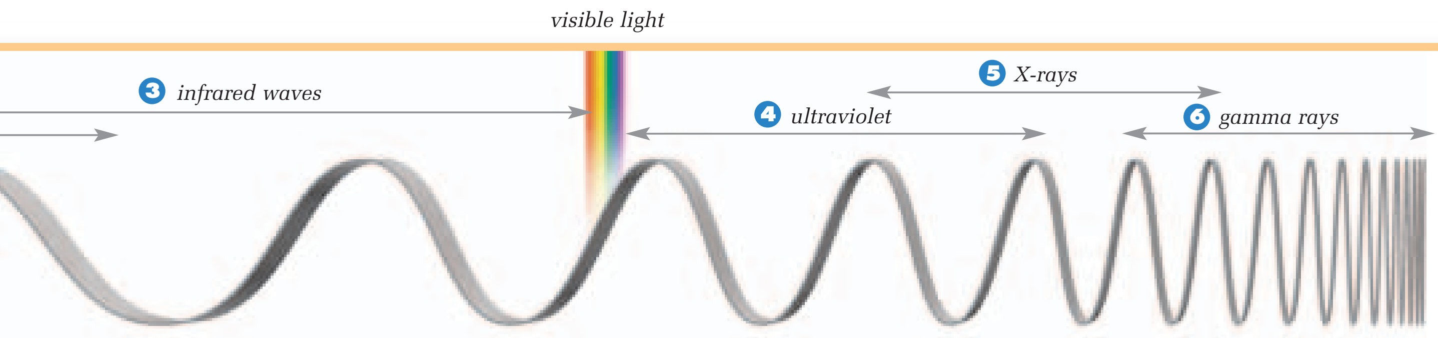
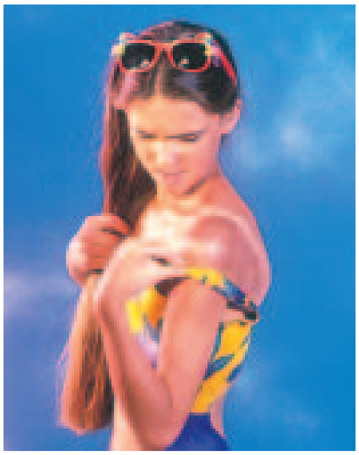
Not on the Same Wavelength

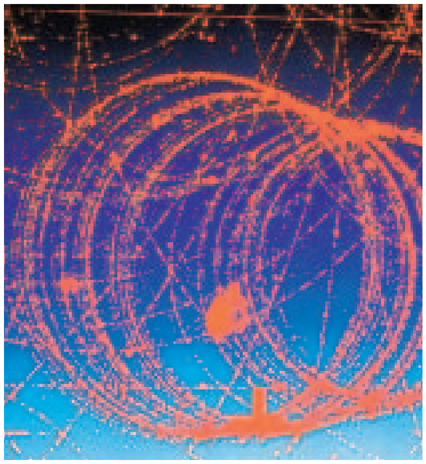
The longest wavelengths in the electromagnetic spectrum are long radio waves, at 100 km. The shortest are gamma rays, at 0.000 000 000 0001 mm



4 **Ultraviolet** (UV) **light** carries more energy than visible light and can burn the skin, increasing the risk of skin cancer. Most of the sun's UV rays are absorbed by Earth's ozone layer but it is still advisable to wear sunblock creams when outdoors. A sunblock provides an opaque layer that prevents UV rays from reaching your skin.



5 **X-rays** and **6** **gamma rays** both represent extremely high-energy radiation. Both these rays can penetrate tissues. Lower energy X-rays have difficulty passing through bone, making them useful for medical imaging. Gamma rays are used to kill cancer cells. Doctors always use very short bursts of these rays because long-term exposure can cause cancer. This is why X-ray technicians protect themselves and other parts of your body with lead aprons that X-rays cannot penetrate.



Cloud chamber showing radiation trails

Applications of Electromagnetic Radiation

Although we cannot see the invisible parts of the electromagnetic spectrum, these waves can be transmitted, reflected, and absorbed, just like visible light.

Radio Waves

Radio waves can be used in medicine to produce images of tissues deep inside the body. A magnetic resonance imaging (MRI) device sends short bursts of radio waves into the body. With the help of a magnetic field, the radio waves energize atoms and make them line up. When the radio pulses are turned off, the atoms return to their original orientation, releasing radio waves back to the machine. Different types of tissue release energy at different rates. The MRI uses these radio waves to construct a computer image of the tissue.

Figure 3.6 Magnetic resonance imaging is useful for examining the brain and spinal cord.

Microwaves

You may have heard the term ***radar*** before. The word is actually an acronym for **ra**dio **d**etection **a**nd **r**anging. Older radar devices used radio waves. Today, radar devices send out short bursts of microwaves in order to detect objects. Like visible light, microwaves obey the law of reflection, so some of the waves sent out by radar reflect off objects and return to the radar receiver. By knowing the speed of the microwaves and the time it took them to return, the receiver calculates how far away the object is. Radar is now an indispensable technology, allowing us to track ships, airplanes, and even weather systems.

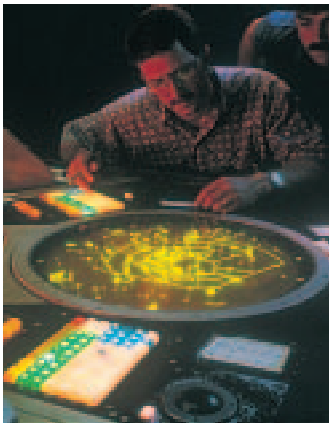


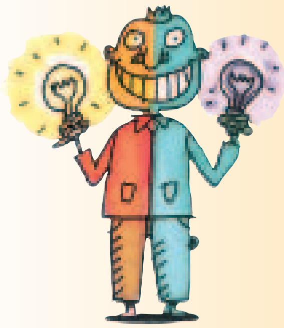
Figure 3.7 Air traffic controllers use radar to monitor planes landing and taking off at airports.

Give it a **TRY** ACTIVITY

GIVE IT A GLOW

Your teacher will provide you with a variety of materials and two light sources: a regular bulb and a black light bulb. The regular bulb emits infrared radiation (heat) as well as light. The black light bulb emits mostly ultraviolet light. Darken the room as much as possible and turn on the regular light bulb. One by one, hold the materials up to the light and note the appearance of each. Record your observations. Repeat the process using the black light.

- Which substances appear different under the regular light?
- Which substances appear different under black light?
- Why do you think that certain substances glow in the presence of ultraviolet radiation and not in the presence of infrared radiation? Discuss possible explanations with your classmates.



Ultraviolet Rays

Ultraviolet (UV) light is also a form of electromagnetic radiation. UV light has a higher frequency than visible light, so it carries more energy. Because the energy of UV rays is great enough to kill living cells, UV light can cause skin damage that can lead to cancer. This high energy level is useful to hospitals and food processing plants, which use ultraviolet lamps to kill micro-organisms on equipment.

Small doses of ultraviolet light can be beneficial to humans. Skin cells produce vitamin D, which keeps teeth and bones healthy. In order to create the vitamin, the cells need small amounts of UV light. Some babies are born with jaundice, a liver condition that causes yellowing of the skin. To treat the condition, newborns are placed under ultraviolet lamps.

Figure 3.8 This baby is being treated for jaundice under an ultraviolet light. The baby's eyes are covered because too much ultraviolet light could damage them.

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What's Cooking?

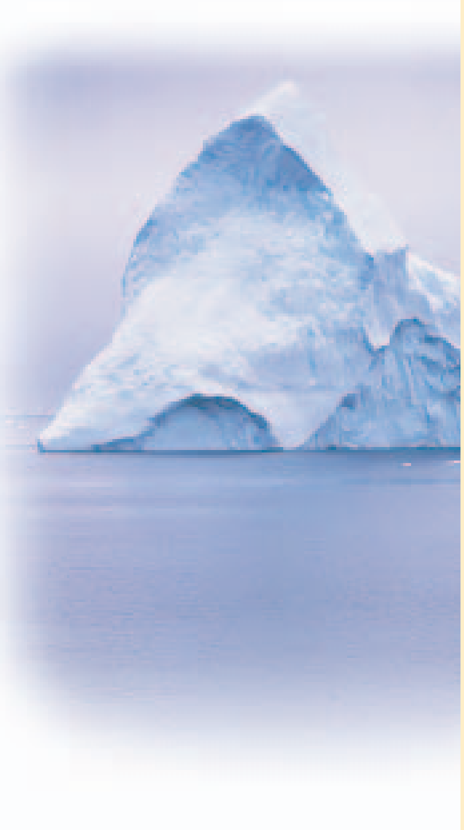
The microwave oven is an extremely useful application of microwave radiation. Did you know that the discovery that microwaves could cook food happened purely by accident? Use the Internet and other sources to find out more about the development of the microwave oven.

Gamma Rays

Gamma rays have the shortest wavelengths and highest frequency of the electromagnetic spectrum, and they contain the greatest amount of energy. Gamma rays can penetrate the body to a much greater extent than X-rays, and they can cause serious illness. But, like ultraviolet light, small amounts of gamma radiation can treat illnesses. Small doses of gamma rays are used in radiation therapy to kill cancer cells.

Figure 3.9 A person undergoing radiation therapy

Check and Reflect



1. Make a comparison chart of X-rays, radio waves, and visible light. How are they the same? How are they different?
2. Is the statement "the sun only gives off visible light" correct? Why or why not?
3. Why is it a good idea to wear a hat and sunblock creams when spending time in the sun?
4. Explain how radio waves can be used to determine the position of icebergs at sea.
5. Electromagnetic radiation can be used to treat cancer. What type of radiation would you use if you were the oncologist (cancer specialist)? Explain.
6. Many people operate their home electronics with remote controls. Using what you have learned about electromagnetic radiation, explain how a remote control might work.
7. When you go to the dentist, he or she sometimes takes X-rays of your teeth. Why does the technician put a lead apron over you, and why does he or she go behind a metal screen when taking the X-ray picture?

3.3 Producing Visible Light

Figure 3.10 Without sunlight, there would be no life on Earth.

Of the wide spectrum of electromagnetic radiation, visible light is probably the most important to us. Think about how often you are exposed to visible light. Where does most of it come from? How is it produced?

Look at the photos in Figure 3.11 and classify them as natural or artificial light sources. Artificial light sources are human made. Check how your classmates have classified the photos. Do you agree with them?

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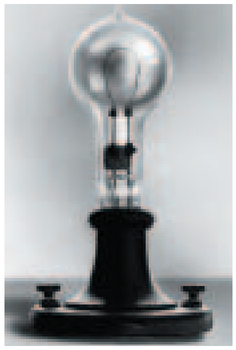
Bamboo Light



Thomas Edison was one of the first to design light bulbs in the late 1800s. His first bulbs didn't last that long, though. Edison used pieces of bamboo for the filament of the first light bulbs; these filaments would burn out after about 30 hours. Today, filaments are made of tungsten.

Figure 3.11 Natural and artificial light sources

Figure 3.12 Think how short winter days would be without any artificial light.

Artificial Sources of Light

Can you imagine how different your life would be without artificial sources of light? Think about how many times a day you flip on a switch and are greeted with light. Why is it now so easy to produce artificial light? What types of devices produce light?

Incandescent Light

At the heart of an **incandescent** bulb, there is a filament (thin piece of wire). When you turn it on, electrical energy flows through the filament, heating it to extremely high temperatures. As electricity flows through the filament, it causes the wire to glow white-hot. The light you see from the bulb is the filament glowing.

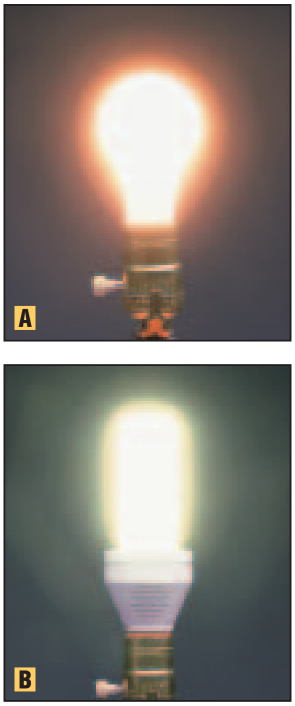


Figure 3.13 An incandescent bulb, A, and a fluorescent bulb, B

Fluorescent Light

A **fluorescent** bulb is a glass tube filled with a small amount of a gas such as mercury vapour. The inside of the bulb is coated with a white powder called **phosphor**. Electricity passes through a fluorescent bulb many times per second. Each time it passes through, it makes the gas in the bulb emit ultraviolet radiation. This ultraviolet radiation strikes the phosphor on the inside of the bulb, which then glows and emits visible white light. The emission of white light in this way is called fluorescing.

Phosphorescent Light

Phosphorescence is slightly different from fluorescence. In fluorescent lights, the phosphor emits light only while the ultraviolet light is hitting it. However, some substances have the ability to store energy from the radiation that hits them, and they can emit light for a long time after the source of radiation has stopped. This ability to emit light is known as **phosphorescence**. Phosphorescent materials are often used in novelty items because they will glow in the dark for some time after being energized by light. This also explains why glow-in-the-dark toys will eventually grow dim but can be re-energized simply by being held under a lamp for a few minutes.

INCANDESCENT VS. FLUORESCENT LIGHTS

Choosing an artificial light source depends on a number of things. Convenience, appearance, and durability all contribute to the choice of what light to use. The cost of operating the light is another factor. It may make sense to use a more expensive device if it costs less to run and lasts longer. These are some factors to consider when choosing between incandescent and fluorescent light bulbs.

Figure 3.14 Fluorescent lights are commonly used in offices and public buildings.

TRY This at Home

ACTIVITY

THE LOOK OF LIGHT

Check out the lighting around your home. You probably have incandescent and perhaps some fluorescent or halogen lights as well. Compared with sunlight, how would you describe the light from each of these light sources? Warm? Cool? Does each one have a slightly different colour? Look at objects lit by these lights. Do their colours appear different? If so, how are they different? Record your observations. Do the same thing with lights in public places such as malls and parking lots.

Inquiry Activity

Comparing Different Types of Light Bulbs

Materials & Equipment

- light bulbs: 60-W incandescent, 60-W halogen, and 15-W fluorescent (or any other variety of light bulbs that give off similar amounts of light)
- gooseneck lamps
- thermometer
- beaker
- water at room temperature
- test tube
- felt marker
- timer

Caution!
After bulbs have been turned on, do not touch them even after they have been turned off! They can reach very high temperatures. If there are not enough lamps for each group, your teacher will change the bulbs for you.

Figure 3.16 What lighting will keep this chick warm?

The Question

Which type of light bulb gives off the most heat?

The Hypothesis

Form a hypothesis for this investigation.

Procedure

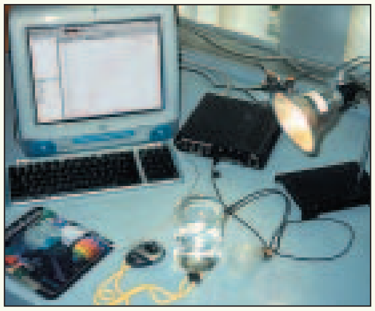


Figure 3.15 If available, consider using a computer interface.

1. Screw each of the three bulbs into a gooseneck lamp. Your teacher may have done this for you already by setting up lamps in different parts of the room. Do not turn them on yet.
2. Make a table for recording temperature data for each bulb. You will be taking readings every 30 s for 5 min.
3. Use the felt marker to draw a line about halfway up the test tube. Fill the tube with water from the beaker up to the mark.
4. Put the thermometer into the test tube. With one hand, hold the test tube around its top rim. Use your other hand to support the thermometer.
5. Have your partner start the timer and turn on the lamp. Hold the water-filled part of the test tube about 2 cm in front of the bulb you are testing. **Make sure the lamp is facing forward, NOT upward (see Figure 3.15). Never hold water above a lamp or light socket**. Be careful not to bump the bulb with your test tube. Very gently move the thermometer up and down in the water during the trial, to ensure it heats evenly.

Collecting Data

6. Every 30 s, record in your table the temperature shown on the thermometer. Continue doing this for 5 min.
7. Repeat the procedure described in steps 4 and 5 for the other two light bulbs. Before doing so, replace the water in the test tube with water from the beaker and let the thermometer cool down. Record temperatures in your table.

Analyzing and Interpreting

8. Construct a graph, using time as your manipulated variable and temperature as the responding variable. Plot the data for each of the bulbs on your graph.

Forming Conclusions

9. Write a summary statement that answers the question "Which type of light bulb gives off the most heat?"
10. The bulbs you tested produce similar amounts of light, but different amounts of heat. Where does the energy for the production of the heat come from?

Applying and Connecting

What type of lighting would you recommend for your school? an office building?

Energy-Efficient Light Bulbs

Most light bulbs should really be called "heat bulbs" because they produce far more heat than light, or more infrared radiation than visible light energy. Incandescent bulbs produce about 95% heat and only 5% light. When you were a child, you may have used an incandescent bulb to bake cakes in a toy oven! Fluorescent bulbs are much more efficient than incandescent bulbs, but they still release up to 80% of their energy as heat.

Natural Sources of Light

The most important natural source of light on Earth is the sun. There are, however, other natural sources of visible light. If you've ever walked through a meadow on a warm summer evening, you may have seen points of light flickering on and off. This flickering light is produced by fireflies. When living organisms produce their own light, it's called **bioluminescence**.

The firefly has a light-producing organ, or **photophore**, on the underside of its abdomen. The light produced by the photophore is created by a chemical reaction. Unlike electric light, this chemical light is very efficient because it gives off no waste heat. Because of this, bioluminescent light is often called cool light.

Fish that live deep in the ocean have to create their own light because no sunlight can reach that far down. Some produce light in the same way as fireflies do, but other fish have bacteria in their photophores that do the light-producing chemical reaction for them. The black sea dragon and the angler fish have a special long spine with a bulb on the end of it, filled with light-producing bacteria. The spine acts as a fishing rod, and the bulb as a lure, attracting smaller fish into their waiting jaws. Flashlight fish use light from their photophores to keep their school together as they swim. They can quickly turn their photophores off if a predator approaches.

Figure 3.17 A flashlight fish

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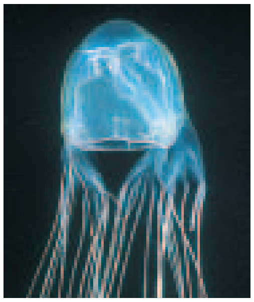
Glowing Organisms



Some algae, jellyfish, insects, crustaceans, fish, bacteria, and even earthworms produce light by bioluminescence. Find out more about species that produce light. Prepare a report on the organism and exactly how and why it produces light.

Check and Reflect

1. Explain how an incandescent light bulb works.
2. Your watch dial may have glow-in-the-dark numbers. Is this phosphorescence or fluorescence? Explain your answer.
3. Why would a business choose fluorescent instead of incandescent lights?
4. What is bioluminescence?