Key Terms
incandescence
fluorescence
luminescence
phosphorescence
chemiluminescence
bioluminescence
wavelength

10.1 Sources and Nature of Light

The zebrafish in **Figure 10.1** are emitting (giving off) light, similar to the algae shown on page 400. But there are some important differences. First, the algae emit light at the end of the day, after storing energy from the Sun. The fish only emit visible light when they are exposed to ultraviolet light. Second, the algae emit light naturally. The fish are genetically engineered to make them glow. They were developed as a novelty for aquariums. Some environmentalists are concerned that some of these genetically modified fish might escape into streams and ponds and disrupt the populations of natural fish. They believe that laws should be passed to prevent the sale of these fish.

Types of Light Emissions

There are many sources of light. Some sources of light are natural, for example, the Sun. Some sources of light are artificial, such as candles and light bulbs. Notice that these light sources are related to heat. Light from hot objects is made up of many different colours mixed together. This type of light is referred to as "white light." Light, however, can be emitted from sources that are not hot, such as the micro-organisms mentioned earlier and the fish in **Figure 10.1**. These sources of light often emit one main colour of light.

For all light sources, whether natural or artificial, atoms within the materials must absorb some form of energy. After absorbing energy, the atoms are considered to be in an excited state. Then, almost immediately, the excited atoms release the energy. The energy they release is often in the form of light.

Figure 10.1 Researchers implanted a gene from jellyfish into these zebrafish to make them fluorescent. You will learn about fluorescence on page 405.

Figure 10.2 Incandescent light bulbs are usually frosted to make a softer light. A clear bulb is shown here so that you can see the glowing filament.

incandescence light emitted from a material because of the high temperature of the material

Light from the Sun

The most abundant source of light is the Sun. In previous science courses, you may have learned that the hydrogen atoms in the Sun's core have so much energy that when they collide, they sometimes combine, or fuse, to form helium. Such reactions are called *fusion reactions*.

A tremendous amount of energy is released during fusion reactions. This fusion energy is transmitted to the gases on the outer layers of the Sun. When these excited atoms release some of their excess energy, they emit light. Fusion energy is a form of nuclear energy.

Light from Incandescence

For many years, the most common source of light in the home has been the incandescent light bulb. The term **incandescence** [pronounced in-can-DES-ence] means light that is emitted by a very hot object. An incandescent light bulb has a tiny tungsten wire, as shown in **Figure 10.2**, that gets very hot and glows brightly when electric current runs through it. Thus, electrical energy generates the heat that excites the atoms.

An incandescent bulb is inefficient at producing light. Only about 5 percent of the electrical energy used in an incandescent bulb becomes light. The remaining 95 percent is lost as heat. If you were using an incandescent light bulb for heat, it would be 95 percent efficient. Incandescent light bulbs are gradually being replaced by light sources based on newer technologies.

Light from Electric Discharge

Some streetlights, like the one in **Figure 10.3A**, are yellowish. Streetlight bulbs emit light from a heated gas, or vapour, instead of a heated wire. This process is called *electric discharge*. A common form of electric discharge bulb is the sodium vapour bulb. As shown in **Figure 10.3B**, the electric discharge bulb has an electrode at each end. A drop of sodium with a small amount of mercury are placed in the bulb. Most of the air is removed from the bulb, and then some of the sodium and mercury form a vapour in the bulb. An electric current passes through the vapour and excites the atoms. When the excited atoms release their energy, they emit the light that you see as a characteristic yellow.

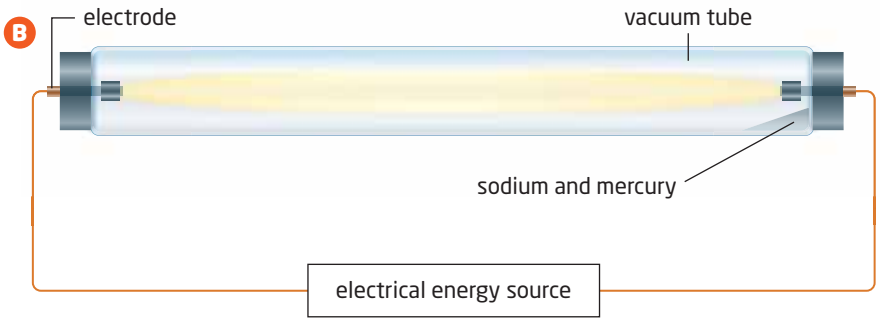


Figure 10.3 **A** The yellow light that is emitted by many streetlights is produced by excited sodium atoms. **B** Electric charges move rapidly between the electrodes, colliding with the atoms in the vapour and exciting them.

Fluorescence

The long tubular fluorescent bulbs shown in **Figure 10.4A** have been available for many years, and now the compact fluorescent bulbs shown in **Figure 10.4B** are readily available.

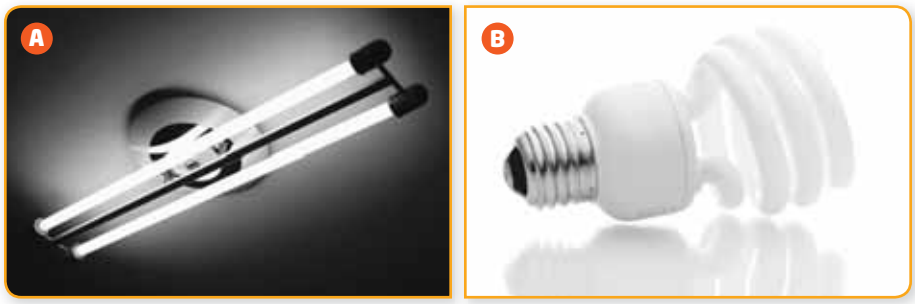


Figure 10.4 **A** Businesses, industries, and schools have been using the long tubular fluorescent bulbs to light large rooms for a long time. **B** Consumers are now using the newer compact fluorescent bulbs in lamps in their homes.

How a Fluorescent Bulb Works

A fluorescent bulb is an electric discharge tube with an electrode at each end, as shown in **Figure 10.5**. The bulb contains mercury vapour along with an inert gas, such as argon. Recall that argon is one of the noble gases that appear in column 18 of the periodic table.

The inside of a fluorescent bulb is coated with a powdery substance called phosphor. When electrical energy charges the electrodes, they emit electrons. The electrons travel through the gas, from one electrode to the other. As the electrons travel through the gas, they collide with atoms of mercury and excite these atoms. The excited mercury atoms release their excess energy in the form of ultraviolet light, which human eyes cannot see. The energy of the ultraviolet light is absorbed by the phosphor, which emits visible light. The visible light that is emitted in this way is called **fluorescence** [pronounced flor-ES-ence].

Study Toolkit

Interpreting Diagrams
The caption and labels in **Figure 10.5** can help you understand the source of fluorescence. The labels identify the main parts of the diagram. What does "Hg" stand for?

fluorescence light that is emitted during exposure of the source to ultraviolet light

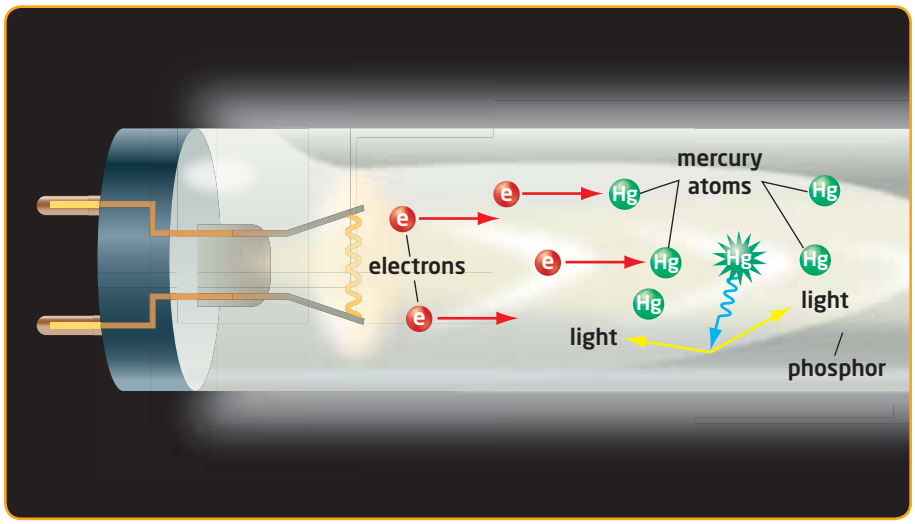


Figure 10.5 In a fluorescent bulb, the excited mercury atoms emit their excess energy in the form of ultraviolet light. The energy of the ultraviolet light excites atoms in the phosphor lining of the tube, causing them to emit visible light.

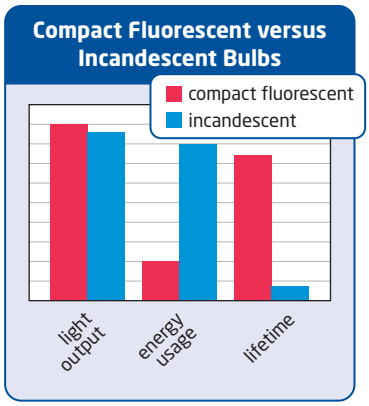


Figure 10.6 Compact fluorescent bulbs are more efficient than incandescent bulbs. Although their purchase price is higher, their lifetime costs are lower because they use less electricity and last longer.

Efficiency of Fluorescent Lighting

Fluorescent lighting is more efficient at producing light than incandescent lighting. For example, a compact fluorescent bulb is 20 percent efficient; that is, 20 percent of the energy it uses is converted into light. Compact fluorescent bulbs last much longer than incandescent bulbs. **Figure 10.6** compares these properties of compact fluorescent and incandescent bulbs. Because of the mercury in fluorescent bulbs, many municipalities accept these bulbs in their hazardous waste centres to keep these bulbs out of landfill.

Uses of Fluorescence

Fluorescent materials are found in many places. **Figure 10.7** shows several.

Many body fluids contain fluorescent molecules. Forensic scientists use ultraviolet lights at crime scenes to find blood, urine, and semen (all fluorescent).

The tongue's natural fluorescence changes when abnormal tissue is present. A dentist or hygienist can shine a blue light in the mouth and look through a special filter to detect unhealthy oral tissue, which appears as very dark spots.

Fluorescent materials are used in many types of documents. Banks, businesses, and other organizations have detectors that use ultraviolet lights to check legal documents, admission tickets, currency, and clothing for counterfeit documents and money.

Some theatre performers use paint with fluorescent dyes. When the theatre is dark and only ultraviolet light is shining on the performers, all the audience can see is the fluorescent light coming from the paint.

Figure 10.7 **A** Forensic investigators can detect fluorescent biological fluids using an ultraviolet lamp. **B** The unhealthy tissue is the dark area. **C** Fluorescent materials are used in some paper currencies. **D** The hands of these performers look like they are floating when you can only see the fluorescent paint.

Types of Luminescence

Luminescence [pronounced loo-mi-NES-ence] is light that is generated without heating the object. The energy used to excite the atoms can come from a variety of sources. Fluorescence is a type of luminescence because the energy used to excite the phosphor in a fluorescent bulb is ultraviolet light. Phosphorescence, chemiluminesence, and bioluminesence are types of luminescence.

Phosphorescence [pronounced fos-for-ES-ence] is similar to fluorescence, except the excited atoms in a phosphorescent material retain the energy for several minutes or even a few hours. Therefore, phosphorescent materials glow long after they have absorbed ultraviolet light. Many glow-in-the-dark objects contain phosphorescent materials.

luminescence the emission of light by a material or an object that has not been heated; for example, fluorescence

phosphorescence light that is emitted due to exposure of the source to ultraviolet light, and that continues to be emitted for some time in the absence of the ultraviolet light

Chemiluminescence

Chemiluminescence [pronounced CHE-mi-loo-mi-NES-ence] is light that is generated by the energy released in a chemical reaction. The light that you see in glow sticks, such as those in **Figure 10.8A**, is an example of chemiluminescence. **Figure 10.8B** shows how a glow stick works.

chemiluminescence light that is produced by a chemical reaction without a rise in temperature

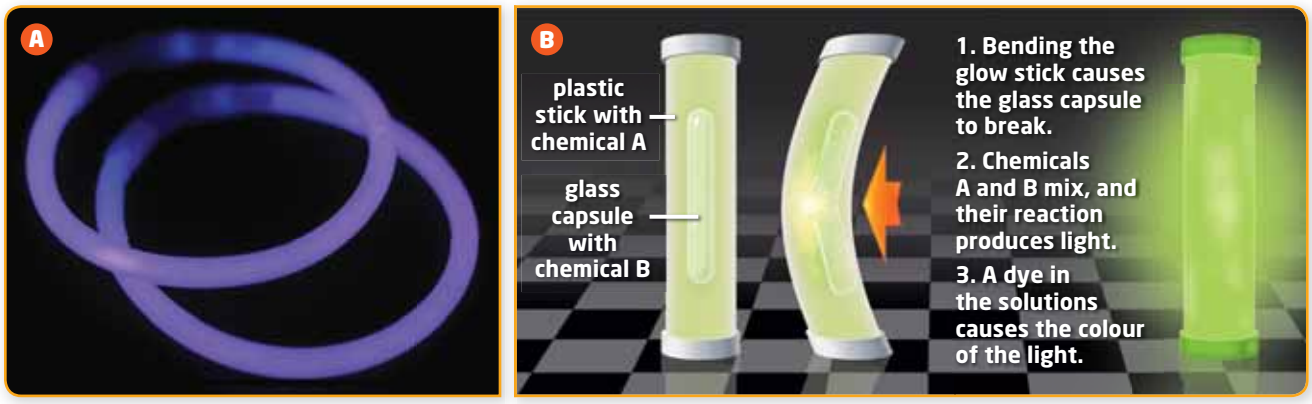


Figure 10.8 **A** You have probably seen many of these glow sticks in the form of bracelets or necklaces. **B** When chemicals A and B mix, the reaction produces light.

Bioluminescence

Bioluminescence [pronounced BIH-OH-loo-mi-NES-ence] is light that is produced by living organisms. Chemical reactions in the living cells produce the light. Bioluminescence is common in marine organisms, as shown in **Figure 10.9** on page 408.

bioluminescence light that is produced by a biochemical reaction in a living organism

Learning Check

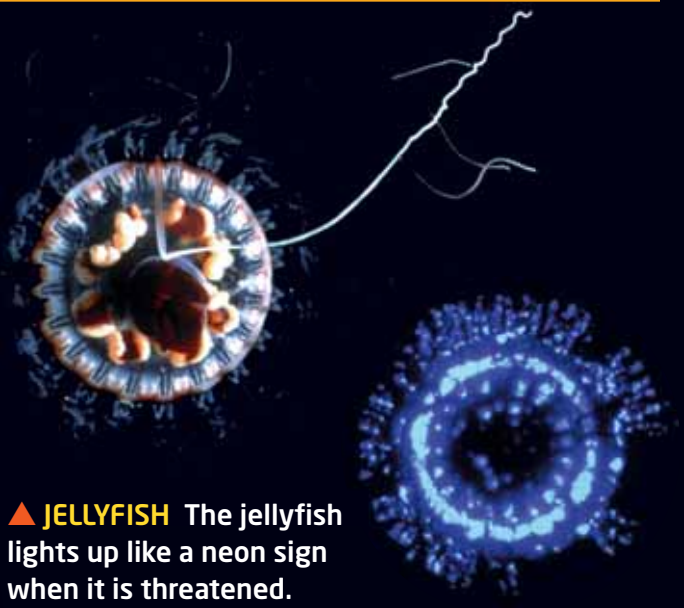
1. What does *excited atom* mean, and what happens after an atom is excited?
2. Explain the meaning of *incandescence*.
3. Use a diagram to explain how fluorescence works.
4. Do you think living organisms should be genetically modified so they can be used for ornamental purposes?

NATIONAL GEOGRAPHIC

VISUALIZING BIOLUMINESCENCE

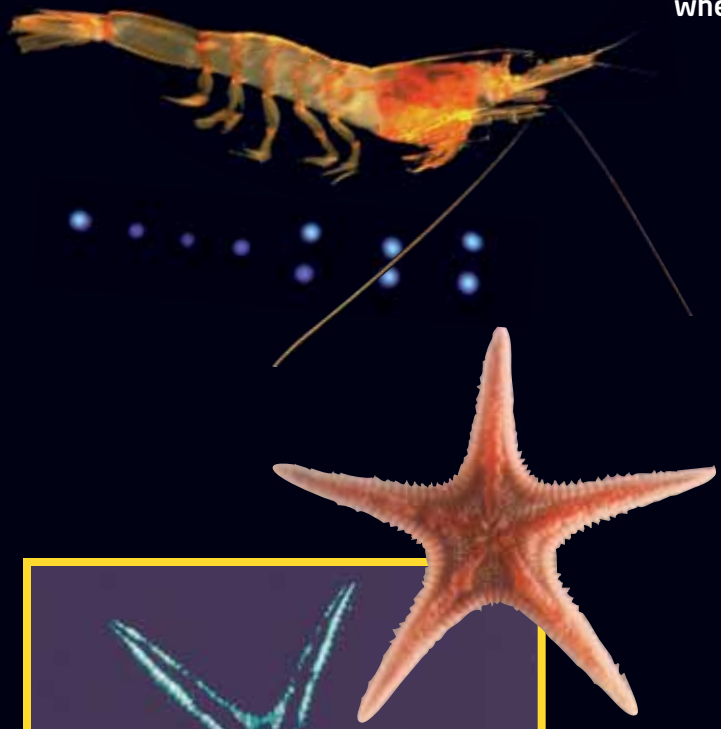
Figure 10.9

Many marine organisms use bioluminescence as a form of communication. This visible light is produced by a chemical reaction and often confuses predators or attracts mates. Each organism below is shown in its normal and bioluminescent state.



▼ **KRILL** The blue dots shown below the krill are all that are visible when it bioluminesces. The krill may use bioluminescence to confuse predators.

▲ **JELLYFISH** The jellyfish lights up like a neon sign when it is threatened.



◀ **BLACK DRAGONFISH** The black dragonfish lives in the deep ocean where light does not penetrate. It has light organs under its eyes that it uses like a flashlight to search for prey.

▲ **DEEP-SEA SEA STAR** The sea star uses light to warn predators of its unpleasant taste.

The Nature of Light

Light is the only form of energy that can travel like a wave through empty space and through some materials. Light behaves like a special kind of wave, called an *electromagnetic wave*.

Electromagnetic waves are very similar to water waves. Both types of waves involve the movement of energy from one point to another. In water waves, the energy causes water molecules to go up and down, so the shape shown in **Figure 10.10A** is produced. Note that **wavelength** is defined as the distance from one crest (or trough) to the next.

wavelength the distance from one crest (or trough) of a wave to the next crest (or trough)

Electromagnetic waves are invisible and can travel through a vacuum. They do not need particles in order to travel. They travel through a vacuum, such as space, at the speed of light (3.00×10^8 m/s). Electromagnetic waves are more complicated than water waves because they involve electric and magnetic fields. But scientists model electromagnetic waves with the same shape as a water wave, as shown in **Figure 10.10B**.

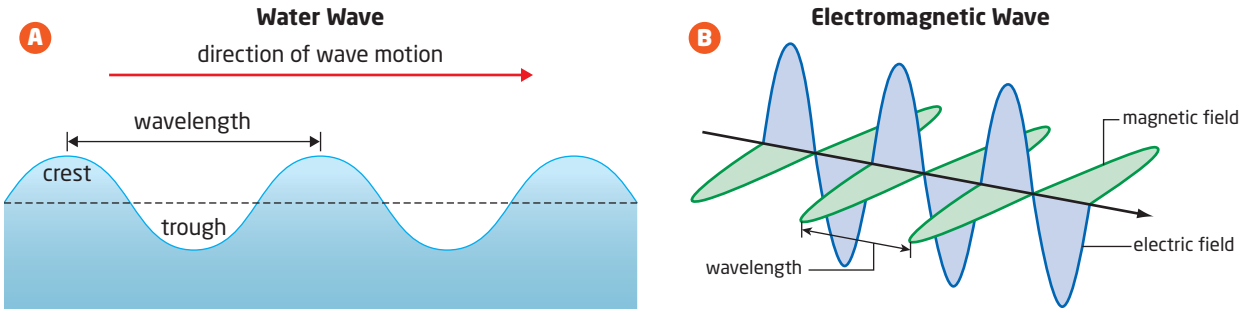


Figure 10.10 Water waves (part **A**) and electromagnetic waves (part **B**) are modelled by the wave patterns shown here.

The Electromagnetic Spectrum

Figure 10.11 shows the electromagnetic spectrum. The *electromagnetic spectrum* is a diagram that illustrates the range, or spectrum, of electromagnetic waves, in order of wavelength or frequency. Notice that the colours of light are just different wavelengths of light. The colour red has the longest wavelength of visible light, which is 700 nm (nm is the symbol for nanometre, or 10^{-9} m). Violet has the shortest wavelength of visible light, which is 400 nm.

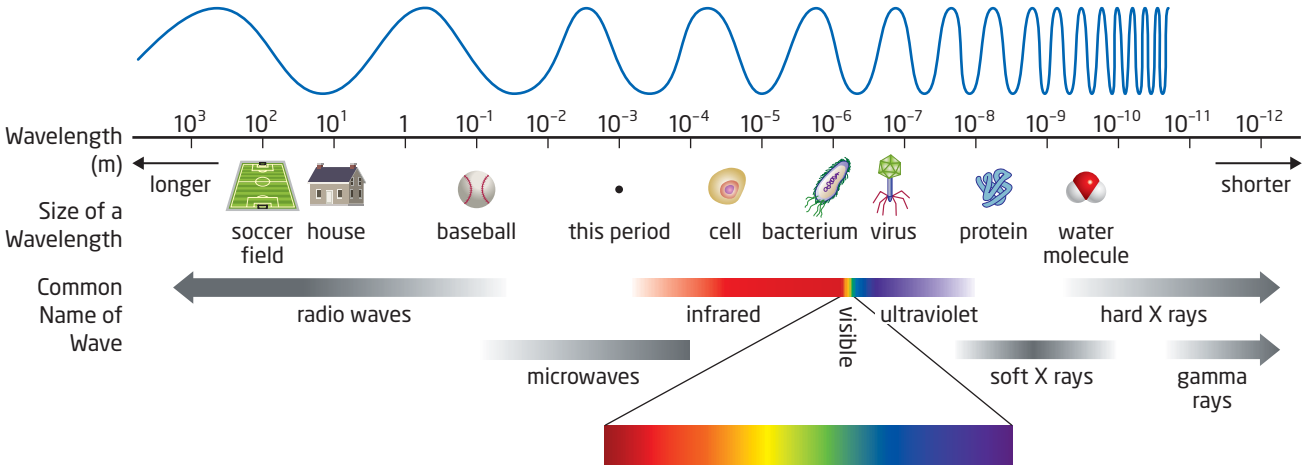


Figure 10.11 Notice that visible light makes up only a very small portion of the electromagnetic spectrum. That portion has been expanded in this diagram to show the range of colours.

Section 10.1 Review

Section Summary

- Incandescence is light that is emitted from an object because the object is very hot.
- Luminescence is light that is emitted in the absence of heat. Fluorescence, phosphorescence, chemiluminescence, and bioluminescence are all forms of luminescence.
- Light is transmitted in the form of electromagnetic waves. Visible light makes up only a small part of the electromagnetic spectrum.
- Light is used in many technologies. For example, blue light, with a special filter, is used to detect oral cancer.

Review Questions

C **1.** Review **Figure 10.5**. Draw a diagram that shows the steps to convert electrical energy to light in a fluorescent light bulb. Number the steps in your diagram. State what occurs in each step.

K/U **2.** State one advantage and one disadvantage of using an incandescent bulb.

K/U **3.** Use a Venn diagram to compare phosphorescence and fluorescence.

K/U **4.** Describe one difference between chemiluminescence and bioluminescence.

A **5.** Examine the firefly in the photograph below. Use your knowledge of light sources to explain what might be happening in the photograph.

K/U **6.** Redraw **Figure 10.11** to show the regions of visible and invisible electromagnetic waves. Label the regions in your drawing.

K/U **7.** Which region of the electromagnetic spectrum has short wavelengths? Describe some objects that you have learned about that have similar lengths.

A **8.** Choose a light technology from this section, and explain how the technology benefits society.

Fireflies can produce their own light.