TOPIC 4

The Energy Connection

What does the word "energy" mean to you? One definition of energy is "the ability to do work." Does that definition seem to apply to electricity? Electric motors certainly use electric energy to do work on objects by moving them. Energy, however, has another important characteristic: it appears in many forms. Some electrical devices, such as light bulbs and stoves, are designed to change electric energy into other forms of energy, such as light and heat. Other technology is able to transform heat, light and energy of movement (kinetic energy) into electrical energy. In this Topic, you will investigate a variety of forms of energy, and discover how they can be converted directly into electricity, and how electricity can be converted directly into other forms of energy.

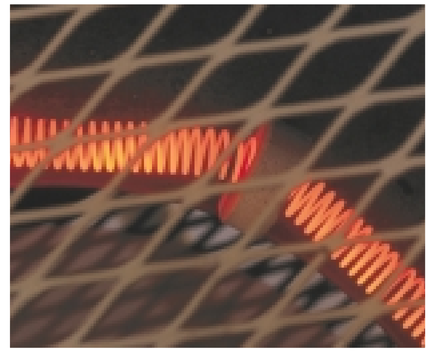


Figure 4.23 Heating elements convert electric energy into thermal energy. What other devices can you name that perform a similar energy conversion?

Find Out ACTIVITY

Something to Electricity: Electricity to Something

In your day-to-day life you encounter many devices that do useful tasks by converting electrical energy into some other form of energy. There are also many types of equipment that convert another form of energy into electricity.

Materials

reference materials (books, Internet, periodicals)
paper
pencil

Procedure ✷ Analyzing and Interpreting

1. Copy the table at right into your notebook.
2. Think of familiar devices that convert electrical energy into some other form. Choose examples that cover a variety of forms of energy, and use them to fill in the table.
3. Choose one type of energy conversion and find out more about how it is achieved. Then choose a device that is designed to accomplish this conversion, and prepare a detailed explanation of how it works. Use a format specified by your teacher.
4. Present your findings about an energy-conversion device to the rest of the class. Discuss similarities and differences among the various conversion devices.

Device	Energy Conversion	
	Starting form	Final form
	electricity	
	electricity	
		electricity
		electricity

What Did You Find Out?

1. How does your list compare with that of your classmates? Add several more examples from their lists to your list.
2. Which type(s) of energy conversion occur most frequently in your list? Suggest a reason why this is so.

Word CONNECT

The movement of molecules within a substance produces thermal energy. *Heat* is defined as thermal energy that is transferred from a warmer substance to a cooler one.

Electricity and Heat

In appliances such as a stove or hair drier, electric energy is converted to heat as moving charges meet the resistance of a metal conductor. You observed this process in Find Out Activity: Resistance Roadblock in Topic 3. The opposite process is also possible.

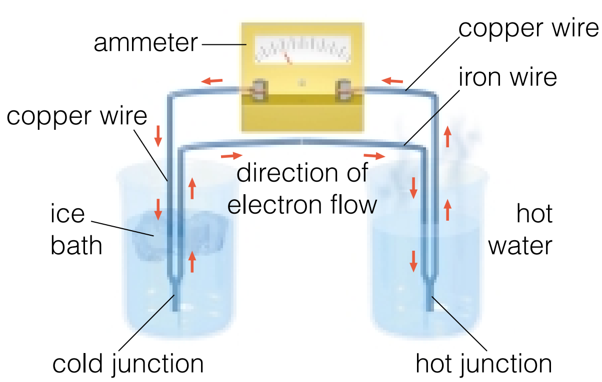
Heat can be converted directly to electric energy using a **thermocouple**. A thermocouple is a loop of two wires made of different types of metals. The wires are wrapped together at both ends, or "junctions." When one junction is heated, a small electric current is produced. If the temperature difference between the junctions is increased, the current increases. For example, one junction might be cooled while the other is heated. If the positions of the hot and cold junctions are reversed, current will flow in the opposite direction.

The basic principle of the thermocouple was discovered by Thomas Johann Seebeck in 1821, and was named the Seebeck Effect. Seebeck originally concluded that any two metals could be used. However, it is now known that not every combination of metals works in thermocouples. Copper and constantan (a copper nickel alloy), or iron and constantan, are the most common metals used in modern industrial thermocouples.

Individual thermocouples produce only a small amount of current. They are widely used to obtain accurate temperature measurements where regular liquid thermometers cannot be used.

DidYouKnow?

If you hook the two wires leading from a thermocouple to a battery, one junction will get hot and the other will get cold.



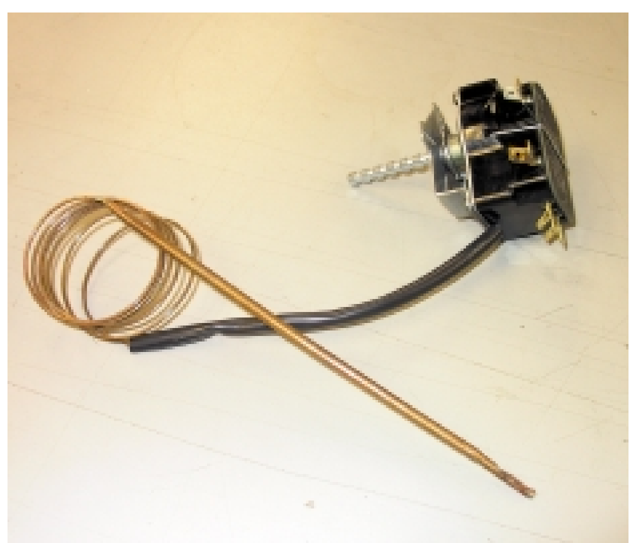


Figure 4.24 Thermocouples are rugged and can measure high temperatures. They are used as sensors in safety and control devices for furnaces, hot water heaters, and electric ovens.

A **thermo-electric generator** is a device based on a thermocouple that converts heat directly into electricity without moving parts. Heat from a gas burner or another heat source moves through several thermocouples connected in series — a *thermopile* — creating a potential difference. Thermopiles are extremely reliable, low-maintenance devices. They are used in remote locations to generate limited quantities of electrical energy that are sufficient to power, for example, emergency communications equipment.

On one side of the thermopile, a gas burner or other heat source is installed. The opposite side is kept cool by components such as aluminum cooling fins or heat pipe assemblies. Operating generators generally maintain temperatures of approximately 540°C on the hot side and 140°C on the cold side. The heat flow through the thermopile creates a steady flow of electricity. Individual thermo-electric generators can range in output size from 15–550 W and can be combined to produce up to 5000 W.

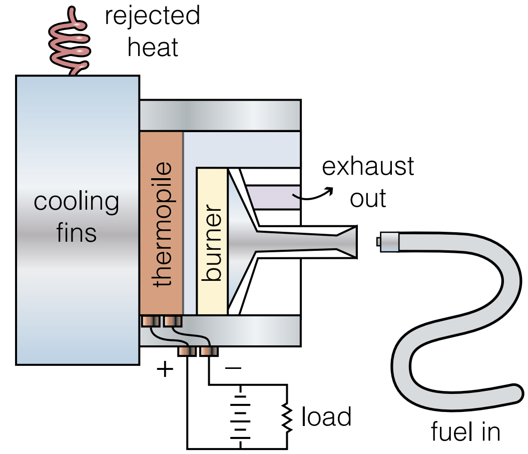


Figure 4.25 Thermo-electric generators such as this are manufactured by Global Thermoelectric, an industry-leading company based in Calgary.

Electricity to Motion

How can sound be produced by tiny electric watches or the paper-thin sound modules in "talking" greeting cards? There is no room in these devices for even the smallest loudspeaker. Instead, sound is produced when an electric current causes vibrations in a tiny crystal — the piezoelectric effect. *Piezo* in Greek means pressure or push. When a piezoelectric crystal such as quartz or Rochelle salt is connected to a potential difference, the crystal expands or contracts slightly. Any material touching the crystal experiences pressure, which can create sound waves or vibrations. This link between electricity and pressure was first investigated in 1880 by two young French scientists, Pierre and Jacques Curie, who were 21 and 24 at the time.

Modern researchers have developed non-crystalline materials that move in response to an electric current. Such materials have many potential uses. For example, using a flexible polymer (plastic) with this property, Joseph Bar-Cohen, an American physicist, has created a robotic hand with four "fingers." When a voltage is applied, the plastic "fingers" bend, gripping any small object between them. Bar-Cohen's experimental device can lift only 10 g, the mass of a small ball point pen, but it is inexpensive, durable, and light.

Cool Tools

A scanning tunnelling microscope (STM) is one of the few machines capable of producing images of individual atoms. Parts of an STM must make incredibly small movements of only a few nanometres (10^{-9} m). The motion is produced by piezoelectric ceramic wafers, which move very slightly when a low voltage is applied to them.

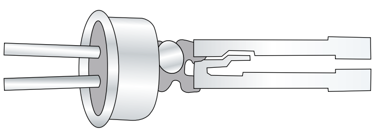
Motion to Electricity

A barbecue "spark" lighter uses the piezoelectric effect in reverse. While a piezoelectric crystal is being compressed or pulled, a potential difference builds up on opposite sides of the crystal. Conductors attached to the crystal can connect it to a circuit, where the crystal acts as a source of electric energy. In a barbecue lighter, this creates a spark. Devices such as crystal microphones and some types of pressure sensors use the changing voltage from a piezoelectric crystal to control much larger electric currents in amplifiers and recording equipment.

Figure 4.26 Squeezing the handle of a barbecue spark lighter slams a tiny hammer against a piezoelectric crystal, generating a potential difference of thousands of volts and a miniature lightning bolt across the spark gap.

Did You Know?

In 1927, Warren Morrison, a Canadian engineer working for Bell Laboratories in the United States, invented the quartz clock and revolutionized the way time was kept. The most common crystals are quartz crystals. Quartz is a piezoelectric material, and quartz crystals vibrate when a voltage from a battery is applied to them. Quartz watch crystals act as miniature tuning forks that vibrate 32 768 times per second. Other types of crystals vibrate at more than 50 million times per second.



Find Out ACTIVITY

Flashing Rocks

The piezoelectric effect produced by certain types of crystals can be observed as flashes of light as two crystals (rocks) are hit together. This activity allows you to experience piezoelectricity first hand.

Safety Precaution

Materials

2 large quartz (quartzite) crystals, preferably smooth and clear crystals or white quartzite pebbles
safety glasses or goggles
a very dark room or heavy blanket

Procedure Performing and Recording

1. Put on your safety glasses.
2. Select two pieces of quartz and either enter a darkened room or duck beneath a heavy blanket that does not allow light to penetrate.
3. Strike the two crystals together with a glancing blow.
4. Record your observations.

What Did You Find Out? Analyzing and Interpreting

1. What did you observe when the crystals were hit together?
2. Using your knowledge of piezoelectricity, attempt to explain your observations.
3. Describe a known application for what you have seen or invent an application of your own.

Electricity to Light

Using electricity to produce light seems like a pretty simple matter. In incandescent light bulbs, a filament made of a high-resistance metal glows brightly when an electric current passes through it. In fluorescent or neon bulbs, the electric current causes a gas or vapour to glow brightly. Piezoelectric crystals can produce light when they are hit together.

Some recent types of flashlights, bicycle lights, and toy lights do not have a light bulb. Instead they have light-emitting diodes (LEDs), solid-state electronic components that glow when electricity flows through them. LEDs use only a fraction of the power of a traditional bulb and last for years as opposed to months. How do they work? The heart of the LED is a tiny semiconductor chip that is often protected by a transparent plastic case. Unlike regular light bulbs, LEDs work only when connected to a circuit in one direction.

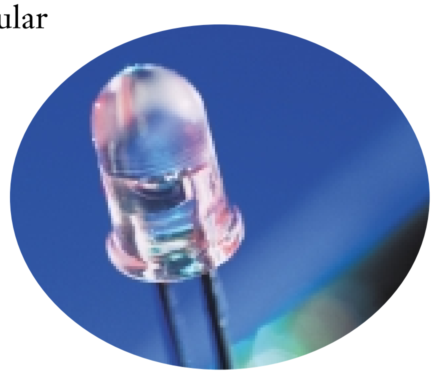


Figure 4.27 The plastic package of this light-emitting diode is about the size of a grain of rice, but all the light is produced from a microscopic area in the centre of the package.

Did You Know?

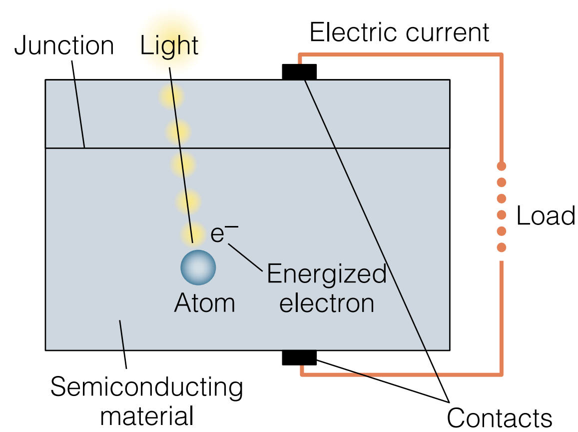
Thousands of miniature LEDs form the liquid-crystal and flat-panel displays used in many portable computers and hand-held "digital assistants." The displays use organic light-emitting liquids, which emit light when an electric current passes through them. The colour of light emitted depends on the particular type of material used. In order to observe the light emitted by an organic LED, at least one of the electrodes must be transparent.

Light to Electricity

As traditional methods of producing electricity are becoming more expensive and causing increased concerns about pollution, using light to produce electricity could play a large role in our future (see figure 4.28). The *International Space Station* is powered entirely by an electricity-generating solar array that will eventually cover an area of approximately 0.5 ha.

The device that is most commonly used to produce electricity from light is called a photovoltaic (PV) cell, or solar cell. Photovoltaic cells are made of semiconducting materials such as silicon. When light strikes the cell, some light is absorbed by the semiconductor material, breaking electrons loose and allowing them to flow freely. Metal contacts on the top and bottom of the PV cell allow this electric current to be drawn off for external use in devices such as calculators, water heaters, or emergency roadside telephones. Because voltage and current of an individual cell are limited, solar cells are usually combined to form modules, which are in turn combined to form arrays.

Figure 4.28 Light hitting an individual photovoltaic cell transfers energy to electrons, starting a current through the load. A rooftop solar array can power a house.



Find Out **ACTIVITY**

Show Me the Light!

How much electricity can be produced by photovoltaic cells (solar cells)? What factors affect the output of a photovoltaic cell? Investigate these questions as you perform this activity.

Materials

1–3 small photovoltaic cells
ammeter or milliameter
plug-in light source
wires with alligator clips
meter stick
protractor

Safety Precautions

If your light source uses an electric bulb, handle it carefully. Light bulbs are fragile and can get hot enough to burn you.

Procedure

Initiating and Planning
Performing and Recording

1. Work with your group to formulate a hypothesis that identifies one factor that you think affects the amount of current produced by a photovoltaic cell or cells. Predict how the current will change when this factor increases and decreases.

2. Design a simple investigation to test your hypothesis. Then carry out the investigation using the materials supplied.

3. Collect results from at least two other groups that investigated different factors.

4. Record your results and the results collected from your classmates in an appropriate format.

Analyzing and Interpreting

What Did You Find Out?

1. For the investigation carried out by your group, what were the manipulated and responding variables?

2. What were the manipulated variables in other groups' investigations?

3. Based on your findings, which variable or variables had the greatest effect on the electrical current produced by the cell? Suggest a reason why.

4. In addition to the factors investigated by groups in your class, name at least three other factors that might affect the ability of a photovoltaic cell to produce electricity.

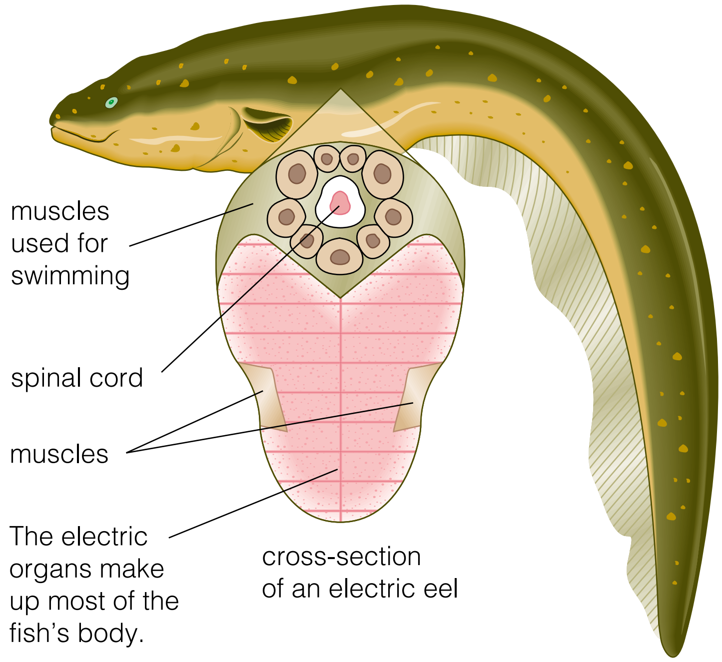
Extension

5. Based on the data you collected, describe features you would include if you were to design a home powered by photovoltaic cells.

6. What are the main reasons why some people *are* currently choosing photovoltaics as a home power source, and the main reasons why other people *are not* using solar power?

Did You Know?

Many fish have electric organs that can produce a large voltage. They use this electric energy to detect enemies, navigate, and possibly to communicate. These animals are said to be electrogenic and electroreceptive. The South American fresh water eel, *Electrophorous electricus*, can generate the largest voltage of any fish. The electric organ consists of thousands of flat, specialized muscle cells, called electroplaques, which make up about 40% of the eel's mass. Each cell generates a voltage of about 0.15 V. Because the cells are connected in series, the electric organ can generate a total voltage of about 600 V. The eel releases a burst of electric energy, lasting about 3/1000 of a second, to stun prey. This "electric shock" causes the prey to stop breathing and drown. Then the eel consumes its meal.



TOPIC 4 Review

1. Describe at least three ways in which usable light can be produced from electricity.
2. How does a thermocouple work? Give two examples of uses for thermocouples.
3. What happens to a piezoelectric crystal when it is squeezed? Give one example of how this phenomenon can be applied.
4. What would happen if an electric current were passed through a piezoelectric crystal? Describe an application for this phenomenon.
5. Photovoltaic cells produce electricity from light. Describe two concerns or problems a homeowner might face in a house powered entirely by photovoltaics.