

Imagine depending on battery-powered flashlights to light a sports field for a night game. Not likely? Batteries are fine for portable power, but they cannot supply the quantities of electricity required for outdoor lighting equipment, heavy appliances, and large industrial machinery.

Most of our electricity comes from the conversion of mechanical energy. Mechanical energy is associated with any system with moving parts — for example, a rotating windmill, spinning turbines in thermo-electric, nuclear, or geothermal power plants, or the moving water of rivers or tides. A device that converts mechanical energy into electric energy is called an **electric generator**. The operation of a generator depends on a relationship that surprised early scientists — electricity and magnetism are related.

Electric Current-Generating Tube

Using a magnet and a coil of wire to produce an electric current is the basic principle of electric generators. In this Activity you will have the opportunity to investigate factors that affect the current produced by a simple generator.

Materials

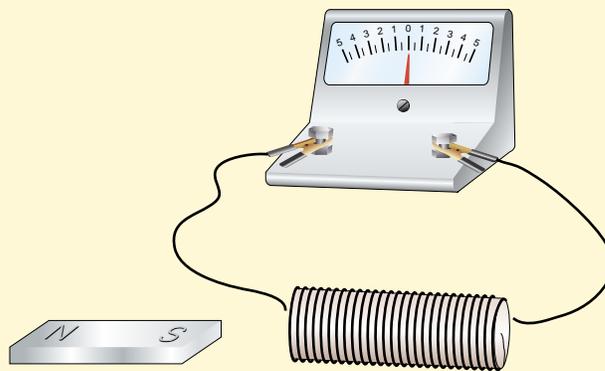
5 m of insulated copper wire (about 26 gauge)
cardboard tube
galvanometer or milliammeter
ammeter
powerful bar magnet

Procedure Performing and Recording

1. Leaving about 15 cm for a lead at the end of the wire, make a coil of about 25 turns by wrapping the wire around the cardboard tube. Remove the tube from the coil.
2. Strip the insulation off each end of the wire. Then connect the wire to the ammeter.
3. While closely monitoring the meter, insert one end of the bar magnet into the coil of wire and then pull it out. Record any movement of the meter needle that you observe.
4. Next, record the effect on the meter needle when you:

Find Out ACTIVITY

- (a) vary the speed with which you move the magnet inside the coil of wire
- (b) vary the speed with which you move the magnet over the outside of the coil
- (c) move the coil over the magnet while the magnet remains still
- (d) move the magnet outside the coil in different directions



What Did You Find Out? Analyzing and Interpreting

1. How does the magnet's speed affect the current that is produced?
2. How does the position of the coil or magnet affect the current produced?
3. What combination of conditions generates the largest current?



Figure 4.33 Hans Christian Oersted (1777–1851) was a Danish physicist who wanted to show that there was no relationship between electricity and magnetism, but he observed just the opposite.

Electricity to Magnetism

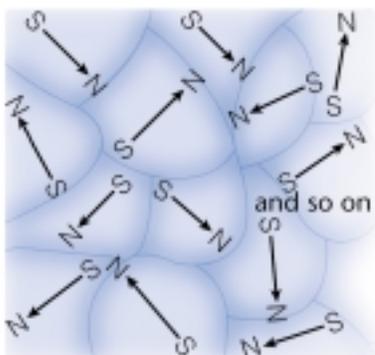
The idea for the first electric generators dates back to a discovery by Hans Christian Oersted and André-Marie Ampère in 1820. They noticed a relationship between electricity and magnetism. Oersted observed that a compass needle turned when it was near a wire carrying electric current. The amount of deflection depended on how much electric current was flowing in the wire. When the direction of the current was reversed, the needle of the compass moved in the opposite direction. As soon as the current was interrupted, the magnetic effects ceased.

Electromagnets

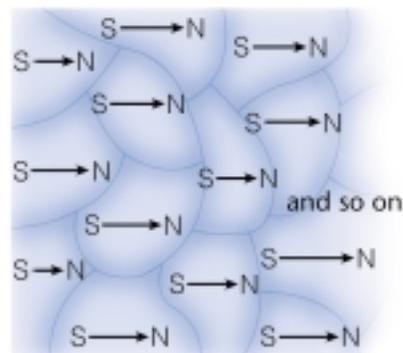
When a soft iron core is inserted into a coil of wire and a current is passed through the wire, an even stronger temporary magnet called an **electromagnet** is created (see Figure 4.34). When electric current flows in the coil, one end of the core becomes a magnetic north pole and the other the south pole. When more coils of wire are wrapped around the iron core, the strength of the magnet increases. Increasing the current also results in a stronger magnet. If the direction of the current is reversed, the polarity of the magnet is also reversed. When the current is turned off, the iron core loses its magnetic properties.

The strength of an electromagnet depends greatly on its core material. Iron cores are much more effective than other metals, wood, or plastics at producing strong electromagnets.

Michael Faraday (1791–1867) is credited with discovering the basic principles of electromagnetism. Faraday became interested in chemistry and physics while reading science texts as he apprenticed as a bookbinder. At 21, he was accepted as a laboratory assistant to chemist Humphrey Davy. Faraday's experiments form the basis of modern electromagnetic technology and electrochemistry. He introduced terms such as “ion,” “electrode,” “cathode,” and “anode” to science, and invented the idea of lines of magnetic force. The farad, the unit for stored electric charge, is named in his honour.



unmagnetized material



magnetized material

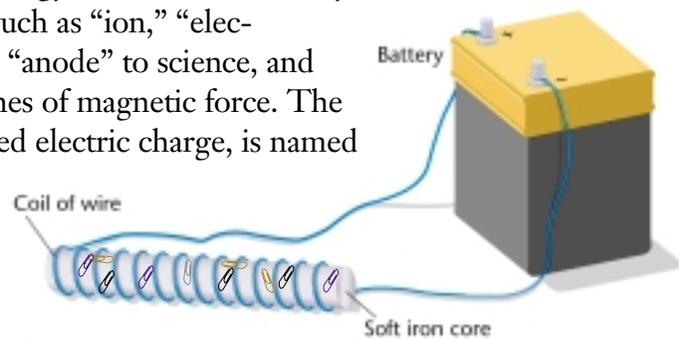


Figure 4.34 A simple electromagnet consists of an electric power source connected to a wire coiled around a soft iron bar.

DidYouKnow?

Individual atoms behave like tiny magnets, each having a north and south pole. Atoms in materials like iron, cobalt and nickel, group together into *magnetic domains*, in which all the north poles face the same way. Unmagnetized objects have domains that are randomly arranged. Their magnetic effects cancel out. Domains in a magnet or electromagnet, however, are aligned, so the resulting magnetic effects are strengthened. Magnetic domains in iron line up very easily, so iron is an effective core for electromagnets.

- ☀ Initiating and Planning
- ☀ Performing and Recording
- ☀ Analyzing and Interpreting
- ☀ Communication and Teamwork

The Attractive Electromagnet

Using the basic principles upon which electromagnets operate, you can produce surprisingly strong magnetic effects. In this investigation you will assemble and test a circuit that creates and controls a strong electromagnet.

Challenge

Using the materials supplied, design an electromagnet that will allow your group to transport the largest possible number of metal objects a specified distance in a fixed time.

Apparatus

- 5 cm iron nails
- 10 cm iron nails
- paper clips
- iron bolts and nuts
- straight pins
- 1.0 m and 0.5 m lengths of insulated copper magnet wire, such as #26 AWG
- D-cells (2 per group)

Safety Precautions



Design Specifications

- A. The D-cells and wire may be used to construct one or two electromagnets.
- B. You may use either a single 1.0 m length, or two 0.5 m lengths of magnet wire.
- C. Your electromagnet(s) may be constructed from any or all of the supplied materials.
- D. Each group will have 2 min to lift and transport as many metal objects as possible from a table, across a 4 m space, and into a collecting container, using only their electromagnet(s).
- E. You may not touch the metal objects with your hands to help your electromagnet lift, transport, or drop them.

Plan and Construct

- 1 With your group, plan and then construct your electromagnet.
- 2 Plan how to use your electromagnet to pick up, transport, and drop metal objects. Test your strategy and modify it if necessary.
- 3 Test your electromagnet as your teacher directs.

Evaluate

1. Calculate the total number of points your electromagnet earned during its trial.

Metal object	Point value
straight pin	2
paper clip	4
iron nut	8
iron bolt	12

2. How did you make your electromagnet as powerful as possible?
3. How did you release objects from the electromagnet? How effective was this method? How could it be improved?

Extend Your Skills

4. If your school has computer probeware, develop and test an alternative way of measuring the strength of your electromagnet. You may wish to use a force probe or a magnetic field sensor.

Magnetism to Electricity

Experiments such as the one you have just done show that magnetic effects can be produced by electric currents. The opposite process is also possible. Electric effects can be produced using a magnet, as you observed at the beginning of this Topic. Michael Faraday and an American scientist named Joseph Henry made this discovery in 1831. Working independently, they found that a voltage developed in wires that were moved at an angle to a nearby magnet. The same thing happened when the magnet moved at an angle to a stationary wire. If the motion stopped, or if the magnet and wire moved parallel to each other, no voltage developed.

Faraday and Henry extended their experiments by connecting the wire to a load. Now an electric current flowed in the circuit, but only as long as either the wire, or the magnet, or both were moving (Figure 4.35). Wrapping the wire into a coil around the magnet increased the current, as you have observed.

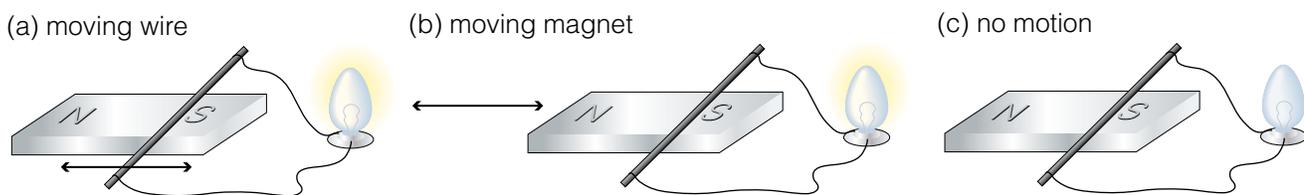


Figure 4.35 Relative motion between a wire and magnet causes a current to flow in a circuit connected to the wire.

Today, we say that a potential difference (voltage) is “induced” in a wire when there is relative motion between the wire and a nearby magnet. When the wire is connected to a circuit, an “induced current” flows. This connection between magnetism and electricity was used to develop motors, generators, and other electrical technology long before scientific theories were developed to explain the relationship.



Current-carrying coils around this experimental Tokamak nuclear fusion chamber turn it into a gigantic electromagnet. Gas molecules with a temperature of more than 10 000 000°C are suspended and compressed by the magnetic effects.

Extremely powerful electromagnets have many other uses. Experimental maglev (magnetic levitation) trains use the repulsion between electromagnets on the train cars and electromagnets mounted between the tracks to suspend the entire train above the track, reducing friction and increasing efficiency.

In hospitals, patients are wheeled inside gigantic electromagnets in MRI (magnetic resonance imaging) equipment. As atoms in the patient’s body are twisted by the powerful magnets, they emit radio signals that can be detected, analyzed, and assembled into images by computer. MRI equipment can produce detailed images of soft body tissues that cannot be examined using X rays.



What's in a Generator?

This AC generator, the most common form, has a coil of wire that rotates inside a stationary field magnet (see Figure 4.36). The coil is rotated by an external force, which is usually supplied by steam, falling water, or wind. Most large generators use electromagnets rather than permanent magnets.

As wires in the coil rotate, electrons begin to move along the wire in one direction. After one-half revolution of the wire loop, each side of the coil passes near the opposite pole of the magnet. The electrons in the coil start moving in the other direction. The direction of the current from the generator changes twice with each revolution. Electricity produced by this type of generator is called **alternating current** (AC) because it changes direction, or “alternates” (see Figure 4.37).

In North America, generators turn at a controlled speed, providing alternating current that changes direction 120 times per second. On a graph, the current has a wave shape, with 60 complete waves each second, so we describe it as 60 Hertz (60 Hz), or 60 cycle AC.

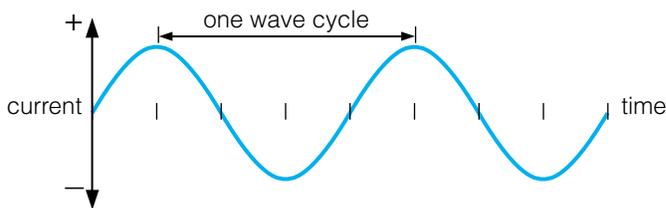


Figure 4.37 Current from an AC generator constantly varies in size and direction. Positive and negative values on the graph represent the opposite directions of the current flow.

Why do most power plants produce alternating current rather than direct current? One reason is that it is relatively easy to increase or decrease the voltage of alternating current. In order to travel long distances efficiently through transmission lines, the voltage is increased. For consumer use, voltage must then be decreased. This process involves transformers, which will be discussed in more detail in the next Topic.

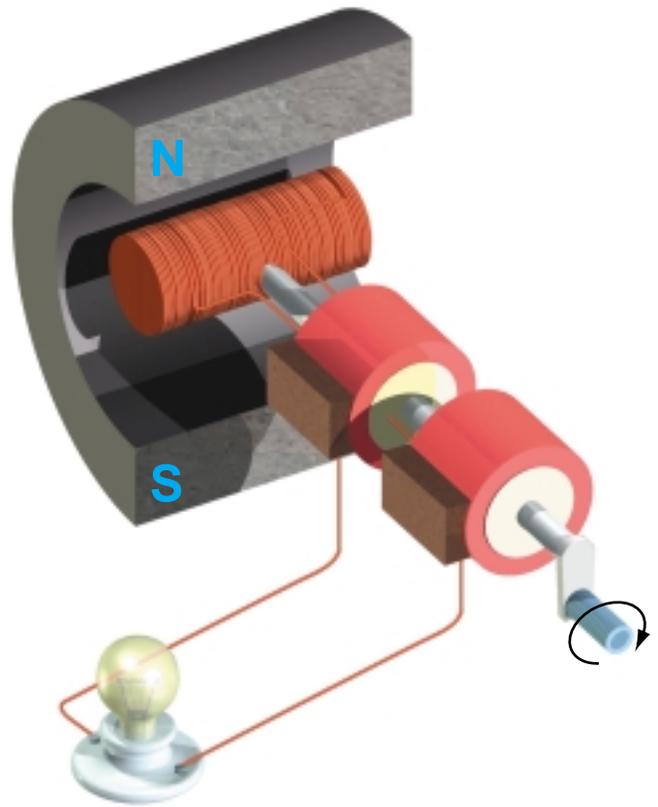


Figure 4.36 In this AC generator, electric current is produced when a coil of wire is rotated inside a magnet. (As you know, current can also be produced when a magnet is rotated within a coil of wire.) In this hand-cranked model, everything attached to the shaft rotates as a unit.

Word **CONNECT**

Generators that produce alternating current are also called *alternators*. Car electrical systems often use an alternator to generate AC, which is then converted to direct current for the motor's ignition system. Multiple choice tests present you with several *alternative* answers. A sports team may have practices and games on *alternate* nights. What is the common feature of words and phrases based on “alternate”?

DC Generators

Generators can also produce direct current (DC), or current in only one direction. A generator that produces direct current is often called a **dynamo**. In a dynamo, the armature (rotating loop of wire) is connected to the outside circuit by a split-ring **commutator** (Figure 4.38A).

To visualize how the commutator operates, study the four parts of Figure 4.38B. (The red dot on the armature lets you track its rotation.) In position 1 the brushes touch the metal split rings, so electrons flow from and return to the armature. When the armature and commutator rotate to position 2, insulating gaps in the commutator momentarily stop the electric current. As the gaps move past the brushes, current resumes (position 3). At this point, the direction of charge flow in the armature has reversed, but so has the connection through the commutator. As a result, current continues through the load in a constant direction. The same sequence of events repeats continuously as the armature keeps rotating past position 4.

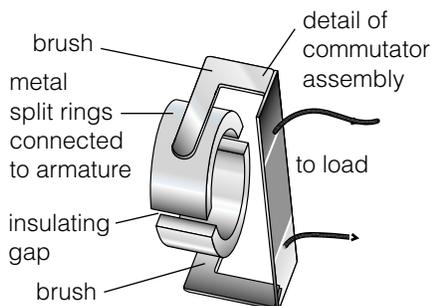
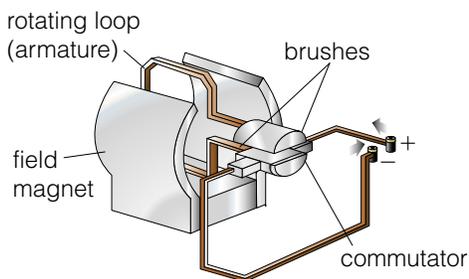


Figure 4.38A A typical DC generator has a split-ring commutator so it sends current through a circuit in only one direction.

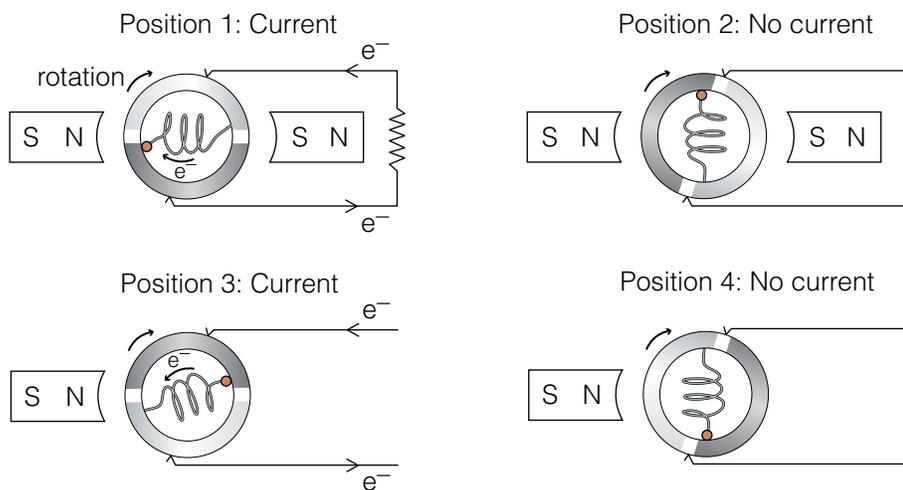


Figure 4.38B These end views of the DC generator in Figure 4.38A show the changing position of the two halves of the commutator. Current through the load is not constant, but it is one-directional.

DidYouKnow?

The current electricity that is produced by a DC generator is not the same as that produced by a battery. Although both devices produce an electric current in one direction only, the DC produced by the generator is pulses of current that coincide with the spinning of the generator. Batteries produce a smooth continuous current.

Electric Motors: Electric to Mechanical Energy

An electric motor can be constructed in exactly the same way as a generator. Instead of *producing* electricity, however, a motor *uses* electric energy to make a coil of wire spin between the poles of a magnet (the “field magnet”). This occurs because the coil (armature) is connected to a source of electric energy. Current flowing through the coil turns it into an electromagnet, which is rotated by magnetic forces from the field magnet. The fundamental law of all magnets — opposite poles attract and like poles repel — is the basis upon which electric motors function.

DC Motors

In one common design for DC motors, a rotating wire coil (an armature) becomes an electromagnet as current flows into it through a splitting commutator. The armature is attracted and repelled by stationary field magnets near it, so it begins to rotate. The commutator acts as a switch, cutting off and then reversing the direction of current flow to keep the armature turning.

- electrons flow to the right from the battery to the commutator into the armature
- the north pole of the armature is repelled by the top of the field magnet and attracted by the bottom of the field magnet
- the armature begins to rotate clockwise (the yellow dot lets you follow the rotation)

- the commutator cuts off the current so the armature does not stall as it passes close by the field magnets
- the momentum of the spinning armature keeps it moving clockwise

- the commutator reverses the direction of current through the armature
- the ends of the armature reverse their magnetic polarity
- the top of the armature is again repelled by the top of the field magnet and attracted by the bottom of the field magnet
- the force on the armature continues to rotate it clockwise

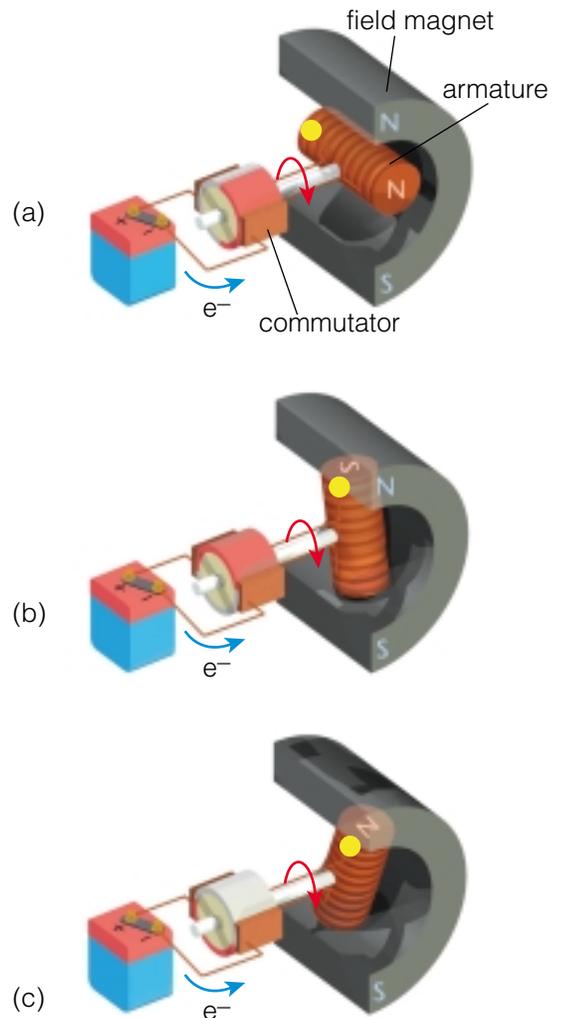


Figure 4.39 A DC motor is rotated by magnetic forces between the field magnets and the armature, which acts as an electromagnet.

- ☀ Initiating and Planning
- ☀ Performing and Recording
- ☀ Analyzing and Interpreting
- ☀ Communication and Teamwork

Let's Get Motoring!

The principles by which an electric motor works are relatively simple. Constructing one from simple components can be tricky. At times, you may find you need to fine-tune certain components in order to ensure your motor works.

Challenge

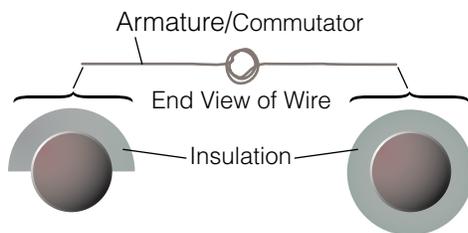
Following the specifications, construct a working electric motor using only the simple materials supplied. Troubleshoot and adjust your motor until it meets the design specifications.

Apparatus

- 1 D-cell
- 2 large paperclips
- 1 wide rubber band
- 1 plastic, paper, or Styrofoam™ cup (250 to 500 mL)
- 60 cm of enamel-coated magnet wire
- 1 rectangular or round ceramic magnet (about 1 cm thick and at least 3 cm long)
- 2.5 cm diameter wooden dowel or broom handle
- masking tape
- fine sandpaper



Note: You can make a split-ring commutator by removing insulation completely from one end of the coil wire. At the other end, remove insulation from around only half the wire, as shown.



Safety Precautions



Design Specifications

1. You can use only the materials supplied.
2. Your motor must run continuously for at least 10 s.

Plan and Construct

1. Decide how you will construct your motor, using the illustrations as a guide.
2. Build the motor and test it. Modify the motor until it operates successfully.
3. Draw a scientific diagram of your motor, labelling each part and the material used to build it.

Evaluate

1. Score your motor's success using the table below.
2. Describe problems you encountered in this activity and the steps you took to overcome them.

Extend Your Skills

3. Based on your experience in this investigation, make a list of at least four troubleshooting instructions that would assist students constructing this motor in the future.

Evaluation Criteria		
Level of success	Criterion	Score Points
1	coil moves but does not rotate	1
2	coil rotates less than one-half turn	2
3	coil rotates one-half to one turn	5
4	coil rotates more than one turn but for less than 10 s	7
5	coil rotates continuously for 10 s	10

AC Motors

Electric motors found in larger appliances, such as dishwashers, washing machines, garage door openers, and furnaces, operate on alternating current. AC motors have a rotating core, or **rotor**, made up of a ring of non-magnetic conducting wires connected at the ends and held in a laminated steel cylinder. Surrounding the rotor is a stationary component called a **stator**. In its simplest form, the stator is a two-pole (north and south) electromagnet. More complex stators resemble a ring of many electromagnets, each with a north and south magnetic pole. When an AC motor is turned on, the attraction and repulsion between the magnetic poles of the stator and the rotor causes the rotor to spin.

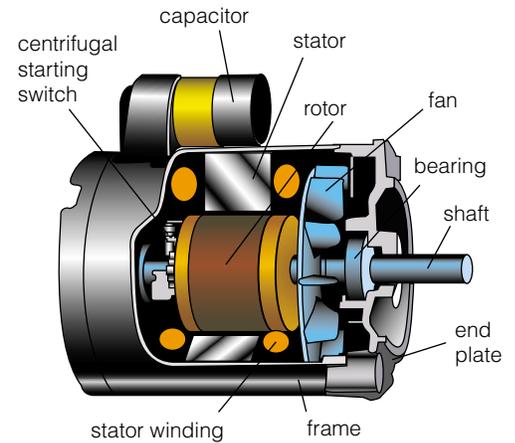
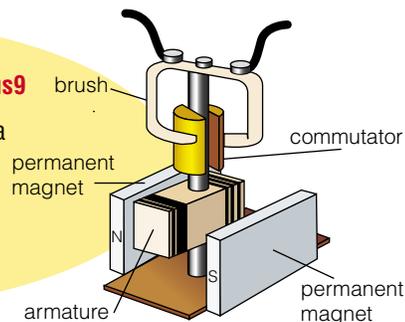


Figure 4.40 AC motors such as this one are used in a variety of larger appliances.

INTERNET CONNECT

www.mcgrawhill.ca/links/sciencefocus9

The St. Louis motor was designed to teach how a DC motor works. For plans to build a working St. Louis motor, go to the web site above, and click on **Web Links** to find out where to go next.



The St. Louis motor

TOPIC 6 Review

1. Who first observed the connection between magnetism and electricity? What did this person observe that led to the discovery?
2. Describe at least *two* ways in which an electromagnet can be made stronger.
3. What is the difference between AC and DC? How is each type of current usually produced? Why do we use AC in our homes?
4. In what ways are electric generators and motors similar? In what ways are they different?
5. What is the function of brushes and a split-ring commutator? Where are these items used?
6. Describe what parts the following components play in the operation of a DC motor: commutator, brushes, permanent magnets, and armature.