

Section 5

AC and DC Currents



Learning Outcomes

In this section, you will

- **Describe** the induced current when a wire moves around a square in a magnetic field.
- Sketch the current during a cycle for both an AC and DC generator.
- **Compare** AC and DC generators in terms of commutators.

What Do You Think?

Batteries produce direct current. The electricity from wall sockets is alternating current.

• What is the difference between a direct current and an alternating current?

Write your answer to this question in your *Active Physics* log. Be prepared to discuss your ideas with your small group and other members of your class.

Investigate

In this *Investigate*, you will observe a demonstration on the workings of AC and DC generators. By watching the motion of a galvanometer connected to the generators, you will be able to determine whether the generator is AC or DC. You will then try to design a device that extracts the current from these generators without tangled wires.

1. In the last section, you observed that a current was induced when a coil moved in the vicinity of a magnet. This effect is used in an electric generator. When you moved the magnet into the coil, the current was in one direction. When you moved it out of the coil, the current was in the opposite direction. If you repeated this over and over again, your movements would be generating an alternating current. An *alternating current* is a current that changes directions. A *direct current* is a current that is in a single direction, like the current from a battery where the negative current always flows from the negative terminal to the positive terminal.

Your teacher will explain and demonstrate a hand-operated, alternating current (AC) generator. During the demonstration, make the observations necessary to answer these questions:

- ▲ a) When the AC generator is used to light a bulb, describe the brightness of the bulb when the generator is cranked slowly, and then rapidly. Write your observations in your log.
- b) When the AC generator is connected to a galvanometer, describe the action of the galvanometer needle when the generator is cranked slowly, and then when it is cranked rapidly.



2. The key to constructing an AC generator is to have the coil of wire rotate in a circle. You can see in the generator shown that the crank wheel has a belt that turns the coil in a circle. The coil has two ends that must supply the current to the light bulb.

If the ends of the wire were connected to any device, the wires would get tangled very quickly.

One solution is to have the wires touch "slip rings." Each end of the wire maintains contact with only one slip ring. The current can then travel from the slip rings to the bulb.

Below is a diagram of a single loop of wire rotating in a magnetic field.



- ▲a) Try to design a device using pencils or straws and pieces of paper that demonstrates how the slip rings keep the wires from getting tangled while not losing electrical contact. Describe your design in your log.
- 3. In *Section 4*, you observed that when you moved the magnet into the coil, the current was in one direction. When you moved the magnet out of the coil, the current was in the opposite direction. This is similar to what is happening with the slip rings. The current leaves through the first slip ring during one part of the rotation, but enters through the first split ring during another part of the rotation. This is an alternating current.
- 4. To get a direct current from the rotating coil, it is necessary to have a different arrangement. Imagine the following: The current from one end of the wire exits the first slip ring. Connect the part of the wire where the current exited to the second slip ring during the part of the rotation when the current is entering the wire.

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Chapter 7 Toys for Understanding



So, when the wires change sides, the current reverses, but the wire also changes slip rings at the same time, canceling the effect of the reverse curent. This would provide a direct current. Changing the connection during every cycle can be done with a mechanical device called a commutator.



▲a) Try to design a device using pencils or straws and pieces of paper that demonstrates how the "split-ring" commutator in the diagram keeps the wires from getting tangled while not losing electrical contact and changes the contact between the wires during each part of the cycle. Record your design in your *Active Physics* log.

- 5. Your teacher will demonstrate a handoperated, direct current (DC) generator. During the demonstration, make the observations needed to answer these questions:
- ▲a) When the DC generator is used to light a bulb, describe the brightness of the bulb when the generator is cranked slowly, and rapidly. Write your observations in your log.
- b) When the DC generator is connected to a galvanometer, describe the action of the galvanometer needle when the generator is cranked slowly, and rapidly.

GENERATING ELECTRICITY

AC Generator

The key to constructing an AC generator is to make the wire go around in a circle so that it can keep moving while still between the two magnets. To make things easier, assume the wire is going around in a square instead of a circle. The diagrams show the wire moving in four directions as it goes around the square. The



wire looks like a small circle in the diagrams because the view is along the wire (like looking at the eraser end of a pencil so all you see is the eraser).

Physics Talk

Remembering that a current is induced when the moving wire cuts the magnetic field lines, a current is induced in diagrams B and D. These currents will be in opposite directions because the movements of the wire are reversed.

To better understand the current produced by a generator, it is useful to sketch a graph of the current as it varies during a cycle of the wiring going around the square. The vertical axis represents the current induced in the wire and the horizontal axis represents time during one cycle. The time from 0 to $\frac{1}{4}$ fraction of a cycle is shown in sketch A. The time from $\frac{1}{4}$ to $\frac{1}{2}$ fraction of a cycle is shown in sketch B. The time for $\frac{1}{2}$ to $\frac{3}{4}$ is

shown in sketch C. The final time from ¾ to 1 is shown in sketch D.

If the wire moved around a circle instead of a square, the current would no longer jump from one value to another, but would vary smoothly for the entire cycle. There still would be times that the current would flow in one direction and other times that the current would flow in the other direction. There would also be two times during the cycle when the current would be zero.

An alternating current (AC) generator does not have a single wire but has a loop of wire. To keep the loop from getting tangled, a pair of slip rings provides an electrical contact as the wire spins. The diagram below shows one construction for a coil of wires and the slip rings.







Physics Words

direct current: an electric current in only one direction.

transformer: a

device that transfers electrical energy from one circuit to another through electromagnetic induction and, in the process, changes voltage from one value to another.

DC Generator

A direct current (DC) generator also has a loop of wire rotating in the magnetic field. A commutator switches the direction of the current during the cycle so that the current is always in the same direction. Although the current is always in the same direction, it is not a constant current. Half cycles of the induced current look like half cycles in the AC generator.

A split-ring commutator can reverse the current at the appropriate positions of the rotation. Notice in the diagram at the right how the wire slides along one half of the split ring. Just as the induced current changes the direction, the wire leaves that half of the split ring and begins contact with the other half of the split ring. This produces the DC current.



Power Transformers

Devices powered by electricity may use batteries, rechargeable batteries, or power cords. The voltage of the wall outlets in the United States is 120 V AC. However, many electrical devices, like audio players or radios, require 6 V. When these devices are powered by a wall outlet, a **transformer** must change the 120 V to 6 V. A transformer is a device that transfers electrical energy from one circuit to another through electromagnetic induction. In the process, it changes (or transforms) voltage from one value to another.

A simple transformer consists of two coils of wire, separated from one another (electrically insulated). They are arranged so that a current in one coil (called the primary coil) will induce a current in the other coil (called the secondary coil). The diagram shows a step-down transformer. Notice that the wires in the primary coil do not touch the wires in the secondary coil. When the electrical current is generated in the primary coil, a magnetic field is created. These magnetic field lines expand around the primary coil. As they expand, their magnetic field lines pass through the secondary coil, producing the current there. The current is produced in the secondary coil because a changing magnetic field across a wire produces a current, as you observed in *Section 4*. When the current in the primary coil changes direction, the magnetic field lines collapse and then expand with their north pole and south pole reversed.

A transformer can be a step down or step up transformer. The ratio of the number of turns in the primary coil to the secondary coil is equal to the ratio of voltages. By varying the number of coils in the primary and secondary coils, the transformer can step-down or step-up the voltage. The voltage can be stepped down by



making the number of turns in the secondary coil less than the number of turns in the primary coil. The voltage can step up by making the number of turns in the secondary coil greater than the number of turns in the primary coil.

It would appear that by merely making more turns of the wire, you can increase the electrical energy. This is not true. The increase in voltage is accompanied by a decrease in the current. Since electrical power is the product of voltage and current (P = VI), the power or electrical energy per second remains the same while the voltage changes.

Power transformers only work with alternating current. To induce the current in the secondary, the magnetic field must be in constant motion. This can only occur if the magnetic field expands and contracts in the primary coil. This can be accomplished with alternating current.

Generators for Cities

Most of the electrical energy in the United States is produced in large power plants. When Michael Faraday first discovered how to induce electricity in the 1830s, many people were skeptical about the value of electricity. Today it is hard to imagine a world without electricity.

Our society needs to create huge amounts of energy to satisfy our residential and industrial needs. Almost all our electrical energy is generated with giant coils of wire and giant electromagnets. The relative motion between the wires and magnets can be accomplished by

water dropping over a natural waterfall (like Niagara Falls) or over a humanmade dam. The motion can also be caused by the wind. More windmill farms are being built, and there is also talk about using the ocean tides to produce the required relative motion.

Most of the large power plants use steam to move the turbines. Water is converted to steam by burning coal, oil, natural gas or by the fission of nuclear materials. The steam from this boiling water is then used to turn the turbines. Each method of generating electricity has both positive and negative consequences.



Checking Up

- 1. How is the current produced by an AC generator different from the current produced by a DC generator?
- 2. Describe the operation of a split-ring commutator in a DC generator.
- 3. In an AC generator, how many times a cycle is the current zero?

Wind and water are renewable forms of energy. However, some people are concerned that wind generators may alter the velocities of global surface wind and cause temperature increases. Others worry about the environmental implications of building dams to use water energy.

Oil and coal are nonrenewable sources in that it takes too much time for these materials to be generated within Earth. Oil comes from the decay of plant material from 50 million years ago. Once the oil (or coal) is used, it will be another 50 million years to create new oil (and coal).

Some people are concerned that increased use of coal will increase our atmospheric carbon dioxide. Other people are concerned that dependence on foreign oil is politically dangerous. Nuclear energy raises concerns about safety, storage of used radioactive fuel, and nuclear proliferation by nations and terrorists. Solar energy requires photovoltaic cells to convert sunlight to electricity. If too much of the land surface is covered by farms of these cells, it is possible that Earth's temperature may increase, since most of the solar energy hitting photovoltaic cells eventually turns into heat.

Energy use is a major economic and political issue. As student physicists, you will be responsible for helping to find ways to use energy responsibly and to ensure that the economies of our country and the world can continue to grow.

Active Physics

+Math	+Depth	+Concepts	+Exploration	Dluc
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Rotating Coils in Electrical Generators

 Although the straight-wire electrical generators discussed in this section are useful in understanding how electrical generators work, they are not a practical design. It is much easier to construct an electrical generator with a rotating coil instead of a moving straight wire. The single rotating wire also had its limitations. The current varied from zero to a maximum value and then back to zero for a moment. If you had two coils that were oriented perpendicular to each other, one coil would be inducing a maximum current while the other would be momentarily inducing no current.

- a) Create a graph showing the induced current from a pair of coils that are perpendicular to one another.
- b) Try a similar exercise where you have three coils at angles of 60 degrees to each other.
- c) Extend this exercise to additional coils.
- d) What are the benefits of having multiple coils of wire rotating? What are the detriments of having multiple coils of wire?

What Do You Think Now?

At the beginning of this section, you were asked the following:

• What is the difference between a direct current and an alternating current?

How would you explain the difference now based on what you have learned in this section? How do the designs of AC and DC electrical generators differ?



What does it mean?

What are the essential parts of a generator? How does an AC generator differ from a DC generator?

How do you know?

Describe the observations you made that contrasted the current from an AC and DC generator.

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Electricity and magnetism	Models	* Experimental evidence is consistent with models and theories

* Physics seeks to help you to understand how nature works. Once you understand how nature works, it is possible to use this understanding to design useful devices. What did you have to understand about electrical currents and magnets in order to design an electrical generator?

Why should you care?

You now can design your own electrical generator. What parts must every electrical generator have?

Reflecting on the Section and the Challenge

In the last section, you found that moving a wire past a magnet or moving a magnet past a wire could produce electricity. In this section, you refined that knowledge. By creating a loop that moves by a magnetic field, you created a constantly changing current. The current not only varied in magnitude, but also changed directions. This is called an alternating current. Through the use of a split-ring commutator, the alternating current could be turned into a direct current. Although the current still varied in magnitude, it did not reverse direction. Part of your challenge will be to explain the operation of your toy. This section should help you in that part of the challenge.



Physics to Go

- 1. What is the purpose of an electric generator?
- 2. How does a direct current differ from an alternating current? Use graphs to illustrate your answer.
- 3. In an electric generator, a wire is placed in a magnetic field. Under what conditions is a current generated?
- 4. Draw a graph of the induced current similar to the one you drew for an AC generator, but assume the coil is rotating in the opposite direction, starting at position I.
- 5. Preparing for the Chapter Challenge

The toy you will be designing may have a generator as part of the kit. The child who will be using the kit will have to decide if the generator will operate as a DC or an AC generator. What extra parts should you include in the generator to allow the material you supply operate in either DC or AC mode? What instructions should you give to the recipient to explain the difference between AC and DC electricity to allow for the proper choice?

Inquiring Further

Investigating Hertz

Investigate the answers to these questions:

- What does it mean to say that household electricity has a frequency of 60 Hz?
- Heinrich Hertz was a nineteenth-century German physicist. Find out about the unit of measurement named after him, the hertz, abbreviated Hz. Write a brief report on what you find.
- Have you ever heard a sound caused by 60 Hz AC being emitted from a fluorescent light or a transformer? What does it sound like, and can you explain why it occurs?
- Look at a catalog or visit a store where sound equipment is sold, and check out the "frequency response" of speakers—what does it mean?