# SECTION 5

# AC and DC Currents

## Section Overview

Students observe demonstrations of alternating current and direct current generators and are introduced briefly to how these generators are constructed. They design a model slip ring used in AC generators to show how the connections with the wires are made without getting tangled or losing contact. Students also design a device using pencils or straws and pieces of paper that shows how the split rings work in DC generators. AC and DC generators are discussed in the *Physics Talk*, as well as the induced current in a coil moving along a square and circular path in a magnetic field. Students also learn about renewable and nonrenewable energy sources and apply their knowledge to solve problems involving AC and DC generators.

## Background Information

The principles of electromagnetic induction introduced in *Section 4* are applied to AC and DC generators in *Section 5*. It is suggested that you read the *Background Information* for *Section 4* if you have not already done so. It is also suggested that you read the detailed treatment of AC and DC generators presented in the *Physics Talk* section of *Section 5* before conducting the *Investigate* with students.

In the *Inquiring Further* of this section, the hertz is introduced as a unit of frequency and applied to AC electricity. A common misconception about this unit of measurement is shown when a frequency of, for example, 60 Hz is expressed as 60 cycles per second or 60 vibrations per second. While it is true that terms such as "cycles," "vibrations," or other descriptive nouns may enhance communication, it is essential to recognize that, by definition $1 \text{ hertz} = (\text{second})^{-1} = 1/\text{second}$.

Therefore, the mathematically appropriate way to express frequency in an equation is, for example, $60 \text{ Hz} = 60/\text{s}$; descriptive words such as "cycles" or "vibrations" are not included because they are not included in the formal definition of the hertz as a unit of measurement. Carrying such descriptive terms in the numerator for frequency leads to trouble with dimensional analysis of units because the terms do not cancel. Within calculations involving equations, it is best to express Hz as reciprocal seconds. Electric power plants in the United States are required to maintain 60 Hz as the precise frequency of AC voltage distributed on the power grid. The reason for maintaining a dependable frequency is that many devices, such as clocks and motors, are designed to operate in synchronization with that frequency, or a multiple thereof. It should also be recognized that one complete AC cycle of $1/60 \text{ s}$ duration contains two pulses of current, one in each direction. Therefore, the "pulse frequency" of 60 Hz electricity is 120 Hz; sometimes it can be heard being emitted from electrical devices as a "hum" corresponding to a pitch of 120 Hz.

The changing magnetic fields associated with AC current are the basis for the transformer, which, as its name implies, changes the voltage and current in an AC circuit from one value to another. As AC current goes through its sinusoidal rise and fall, the associated magnetic field rises and falls along with the voltage change. In a solenoid, this means that the magnetic field is never constant, but is continually rising, then falling, then reversing direction as it starts to rise to a peak and then falls back to zero before the process repeats itself. When two coils are placed in proximity, (one connected to a source of AC electricity—called the primary, and one without any power—called the secondary) the constantly changing magnetic field provides the basis for developing a voltage in the unpowered coil. The voltage developed in the unpowered coil (the secondary) depends upon the rate of change of magnetic flux passing through the coil, which is expressed in $V = -\Delta\Phi/\Delta t$, as discussed in the Background Information for *Section 4*. The two coils of a transformer typically are wrapped around an iron core, which serves as a concentrating device for the magnetic flux of the powered coil. As a result, there is almost 100% flux linkage between the primary and secondary coils. The voltage developed in the secondary depends upon the number of turns ($N$) of wire in the secondary. The voltage in the primary is expressed through the relationship $N_p/N_s = V_p/V_s$, where the subscript "p" is for the primary and "s" is for the secondary.

Conservation of energy dictates that the power in the secondary can never exceed the power in the primary. Thus, for the perfect transformer without losses, $P_p = P_s$. Because power $P = VI$, the equation can be written as $V_p I_p = V_s I_s$. Solving for $V_p/V_s$ gives $V_p/V_s = I_s/I_p = N_p/N_s$. This shows that the current in the secondary decreases as the voltage increases. Thus, a transformer increases the voltage in a circuit at the expense of the current.

Transformers are used extensively by the electric power industry to raise and lower voltage. Electricity generated by steam turbines of the power company is of the order of 11,000 V. This is then stepped up to 115 kV or higher and transmitted to local transformers, which step the voltage back down to 13,000 V for local distribution. This is further stepped down for household use to 220 V.

High voltage AC current is the preferred method of transporting power around the country because of reduced line loss to the resistance of the wires in comparison with lower voltage electricity.

## Crucial Physics

- An alternating current is a current that changes direction periodically.
- A direct current is a current that is in a single direction.
- An AC generator consists of a coil of wire rotating in a uniform magnetic field. The coil makes contact with the external circuit through a set of slip rings.
- A DC generator consists of a coil of wire rotating in a uniform magnetic field. The coil makes contact with a commutator, which periodically reverses the direction of current flow from the coil. As the induced current in the coil begins to switch direction, the connection switches, resulting in the induced current having one direction.
- In the transformation of mechanical energy to electrical energy, turbines usually provide the mechanical energy required to run the generator. Steam, falling water, and wind, among other sources may power modern turbines. The electric power developed by the generators is then transmitted to its point of use. This flow of power is the basis for our present day society.

| Learning Outcomes | Location in the Section | Evidence of Understanding |
|---|---|---|
| **Describe** the induced current when a wire moves around a square in a magnetic field. | ***Physics Talk*** | Students read that the induced current produced in a wire moving along the perimeter of a square cuts through a magnetic field. |
| **Sketch** the current during a cycle for both an AC and DC generator. | ***Physics to Go***<br>Questions 2 and 4 | Students draw graphs to describe the differences between the induced AC and DC currents that can be generated. Students graph the induced alternating current for a loop going around in the opposite direction as that described in the *Physics Talk*. |
| **Compare** AC and DC generators in terms of commutators. | ***Investigate***<br>Steps 2.a) and 4.a)<br><br>***Physics Talk***<br><br>***Physics Essential Questions***<br><br>***Physics to Go***<br>Questions 2, 4, and ***Preparing for the Chapter Challenge*** | Students construct models of the split-ring commutator of a DC generator and a slip ring of an AC generator. Students discuss and describe the differences between AC and DC generators. |

NOTES

# Section 5 Materials, Preparation, and Safety

## Materials and Equipment

| PLAN A and PLAN B | | |
|---|---|---|
| **Materials and Equipment** | **Group (4 students)** | **Class** |
| Scissors | 1 per group | |
| Galvanometer, 0-500 ma | 1 per group | |
| AC/DC demonstration generator | | 1 per class |
| Straw, drinking, transparent, pkg 100 | | 1 per class |

## Time Requirement

- Allow one class period or 45 minutes to complete the *Investigate* portion of this section.

## Teacher Preparation

- Assemble the required material. If a large demonstration galvanometer is available, it should be used during the *Investigate* portion of the section to allow students better visibility.
- Limitations on equipment will most likely require that this activity be performed as a whole-class demonstration. Large, low-voltage demonstration generators that have exposed parts and are capable of generating either AC or DC current are available from science suppliers. Many can be powered through the coils and run as motors, as well as serving as AC or DC generators. Such a device or the equivalent is needed for this investigation, and may also be used in *Section 3* as a demonstration of how a commercial motor works.
- Construct a large scale mock-up of both slip rings and a commutator to demonstrate to the students generator connections to the external circuit.

## Safety Requirements

- When running the hand generator with a galvanometer in the circuit, ensure there is a resistance such as a light bulb included in the series to limit the current through the galvanometer. Similar precautions should be taken with a demonstration galvanometer. Although the needle of the galvanometer may not move significantly off zero when the AC mode of the generator is used, significant power may still be delivered to the galvanometer coil and cause a burnout.

NOTES

# Meeting the Needs of All Students

## Differentiated Instruction: Augmentation and Accommodations

| Learning Issue | Reference | Augmentation and Accommodations |
|---|---|---|
| Understanding and interpreting graphs | ***Physics Talk***<br><br>***Physics to Go***<br>Questions 2 and 4 | **Augmentation**<br>• After students have an opportunity to look at the graph of the current induced by an AC generator, give them a second chance to observe a galvanometer that is attached to a working AC generator. Ask them to describe the movement of the galvanometer related to the graph. Students should be able to make an explicit connection between the galvanometer readings and the shape of the graph before moving onto a DC generator and repeating the process.<br>• Ask students to draw a sketch of a galvanometer and the corresponding current reading on at least four points of the graph.<br>• Students may have misconceptions about the difference between a positive and negative current. Ask students what positive and negative current means. If there are misconceptions, clarify the concept before moving on.<br>**Accommodation**<br>• Provide a graph that includes sketches of galvanometers and corresponding current readings. Ask students to describe the relationship between the graph and the galvanometer readings. |
| Reading comprehension | ***Physics Talk***<br>Generators for Cities | **Augmentation**<br>• Students often skim through reading if the purpose is not clear or if they are having a difficult time understanding the content. This section is not vital to the *Chapter Challenge*, but it does make an explicit connection to a real-life current event for students. Require students to spend time with this text by asking them to come up with a pros and cons list for water, wind, solar, nuclear, and fossil fuel energy. Developing a pro/con list requires students to use higher-level thinking skills. The list also can be used to further compare and contrast the topics at hand because students will have an organized list of information to synthesize. |
| Describing how an electric commutator works | ***Checking Up***<br>Question 2<br><br>***Physics to Go***<br><br>***Preparing for the Chapter Challenge*** | **Augmentation**<br>• Students may be able to verbally describe that the current in a DC generator flows in one direction because of a commutator, but they may still be struggling to understand how a commutator works.<br>• Use as many visual models as possible to aid students' understanding.<br>• Students may need to answer this question in small groups or as a large group with some direct instruction. |

## Strategies for Students with Limited English-Language Proficiency

| Learning Issue | Reference | Augmentation |
|---|---|---|
| Vocabulary comprehension | ***Investigate*** Step 4 | Instead of defining "commutator" for students, allow them to use the device while working through the steps of the *Investigate*, and then challenge them to come up with a definition on their own. Have them write a definition in their *Active Physics* logs and then check their definitions with a dictionary. |
| Vocabulary comprehension | ***Active Physics Plus*** Question 1.d) | Students should be able to figure out the meaning of the word "detriments" from context. If they have difficulty, or feel the need for further clarification, have them look up the term in the dictionary. |
| Higher-order thinking | ***Physics Talk*** Generators for Cities | Citizens as well as scientists need to make energy-related decisions for their communities. To make responsible decisions, citizens need to be well informed about the issues. For a few days, as you work through this section, have students look for and bring in newspaper or magazine articles about various ways of generating electricity. Review the content briefly every day. As you wrap up work on the section, hold a class debate. Choose two ways of generating electricity for your community and divide students into two teams: one supporting one way of energy generation and the other supporting the other way. Give one team four minutes to present its position in favor of one way to generate electricity, and the other team two minutes for rebuttal. Then allow the second team four minutes to present its point of view and the first team two minutes for rebuttal. Encourage students to include financial, environmental, and political considerations in their comments. Finally, hold a class vote: Which method of generating electricity would your students choose for their community? |

Venn diagrams help students compare and contrast. Ask students to design a Venn diagram to show similarities and differences between alternating current and direct currents. Have them draw two intersecting circles and give them the labels "AC" and "DC." (Note: This Venn diagram will likely be quite large. Have students design it on a piece of 11" × 17" paper turned sideways, and be sure the two outer sections are large enough for several entries. The overlapped part of the diagram need not be very large.) Have students place similarities between the currents in the overlap, and characteristics that belong to only one category or the other in the appropriate circle.

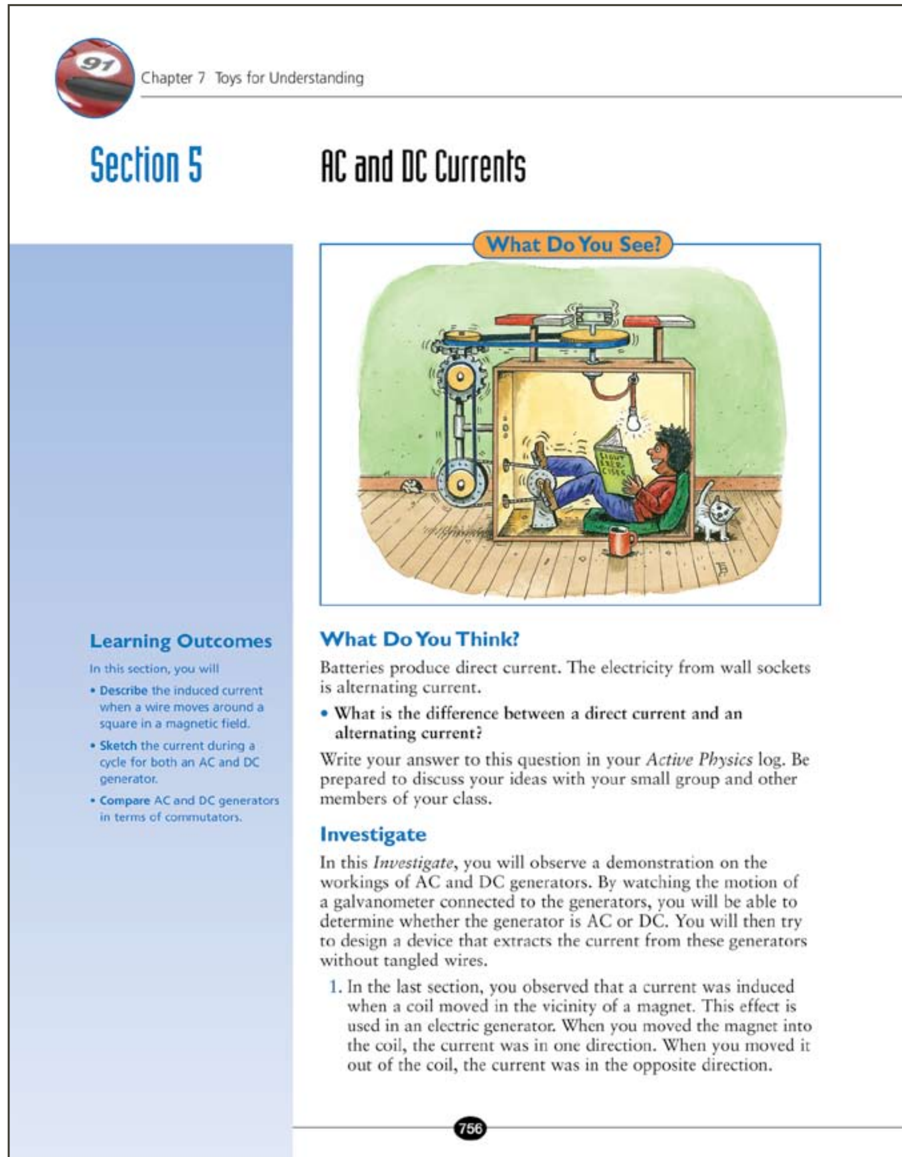
DC was first introduced in *Section 3*, and AC in *Section 4*. Encourage students to include any pertinent information from those sections in their diagrams, as well as information from *Section 5*. Students' diagrams should include all of the following information: (1) definitions of AC and DC; (2) how each type of current affects a galvanometer; (3) a description and/or labeled illustration of an AC and a DC generator; (4) proper use of a commutator; (5) a sketch/graph of a cycle of each type of current; and (6) some uses of each type of current (some of this information should be in the overlapped part of the diagram).

# SECTION 5

# Teaching Suggestions and Sample Answers

## What Do You See?

This *What Do You See?* illustration offers many interesting points of discussion on the generation of electricity. You might want to point out how the belt loops around the wheels connect the wires to the light bulb. Ask students what is providing the electricity to light the bulb in the illustration. Most students should recognize that the mechanical energy being supplied to the generator is from the person pedaling. Ask students what would happen to the light if the person stopped pedaling, or if he pedaled faster. Use an overhead of the illustration to help focus the discussion and record students' responses. Have students write a brief response to



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What Do You See?

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.

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## Students' Prior Conceptions

If students have studied *Electricity for Everyone*, they will have confronted and hopefully altered some of their prior conceptions on simple circuits. This section challenges them to review misconceptions regarding batteries and focuses on the flow of current and its composition.

1. **Batteries and cells have electric charge stored in them. A battery is a constant current source, regardless of resistance of the circuit. The current through the battery is independent of the rest of the circuit.** You should underscore the concept that batteries produce direct current and encourage students to draw this current as it passes through the elements in a circuit. Reviewing Ohm's law and how current, voltage, and resistance relate to each other in simple circuits will call attention to these misconceptions and enable students to move on to AC current and away from the idea that batteries have energy stored within them.
2. **Direction of current and order of elements matters in simple circuits.** Have students measure the circuit current containing several devices, then reorder the components and measuring the current again. This process may be repeated several times until students are convinced that the order is irrelevant. A test of student understanding could then be performed by reversing the current flow by reversing the battery connection to detect if students realize this also is irrelevant.
3. **More devices on a series circuit means more current in it because devices "draw" current.** It is prudent for you to review the relationship between voltage, current,

what they understand from the image and how the title of the section reveals the purpose of this illustration.

## What Do You Think?

Ask students to write down their answers in their *Active Physics* logs. Find out what students know about alternating and direct currents. Emphasize the connection between the *What Do You See?* illustration and the *What Do You Think?* section. Encouraging students to participate in a whole-class discussion will reveal how you can tailor your lesson plan to address their needs. Record their initial ideas so that you can refer to them at appropriate times during the *Investigate*.

**What Do You Think?**

**A Physicist's Response**

An alternating current is a current that reverses its directions in a periodic way. A direct current maintains one direction, although its amount may vary.

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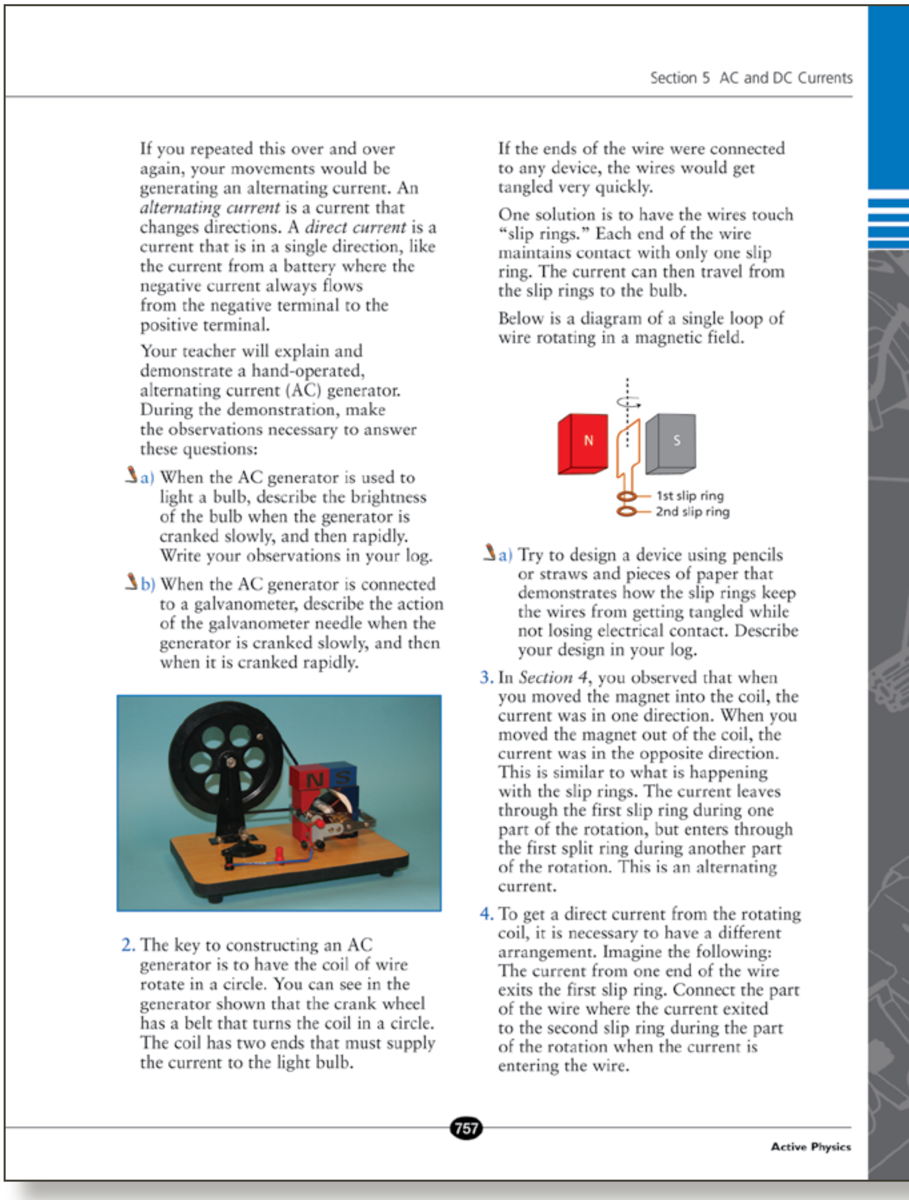
and resistance, independent of whether the source of electrical energy provides for a DC or an AC current. This misconception arises from nonscientific language that persists in the general public and in the media when speaking about devices powered by a circuit. Have students connect a simple series circuit with one resistor and measure the current. Ask them to predict what will happen to the reading on the ammeter when a light bulb is added in series, and then have them test their prediction. Increasing devices increases the total resistance of a series circuit. This alters the transfer of energy in both series and parallel circuits; however, current is conserved. You must emphasize this when students say that something, such as electrons and the flow of electrons, is used up by devices in a circuit.

4. **The Electric Company supplies the electrons for your household current.** Students sometimes believe that the current produced at the power plant, which may be miles away, provides electrons that flow along wires for those many miles from the source to the application in a home or school circuit. You need to highlight that electric current is not a flow of electrons from the source to the device. The collisions among and between electrons enable them to be carriers of charge along wires and within a circuit. The analogy of water in a very long garden hose is particularly apt in this situation. If a garden hose is full of water and pressurized, the water immediately begins to flow when the valve on the end is open (analogous to an electric circuit). This is particularly important in AC electricity, since the current flow reverses direction every $1/120^{th}$ of a second.

# NOTES





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.



## Investigate

**Teaching Tip**

Students may have difficulty visualizing how slip rings and commutators work. Use a piece of 12 gauge or lower wire to form a stiff loop to show how the ends can make contact on a ring (like the inside of a soft drink can with the top and bottom cut off) as the loop spins.

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### 1.a)

When the AC generator is cranked slowly, the light bulb winks on and off (or brightens and dims) at regular intervals. When the generator is cranked quickly, the light bulb is on continuously, although there may be a little bit of "flicker" and the brightness varies slightly.

### 1.b)

When the AC generator is connected to a galvanometer and then spun slowly, the needle oscillates back and forth on either side of zero. When the generator is cranked quickly, the needle seems to stay at the zero mark and vibrates rapidly.

### 2.a)

Students should be able to understand that a wire sliding inside a ring maintains contact and can still rotate with the coil without tangling. Students should design a model to show and describe how the slip rings work. Show an example of slip rings to students.

### 3.

Students read the section.

**4.a)**

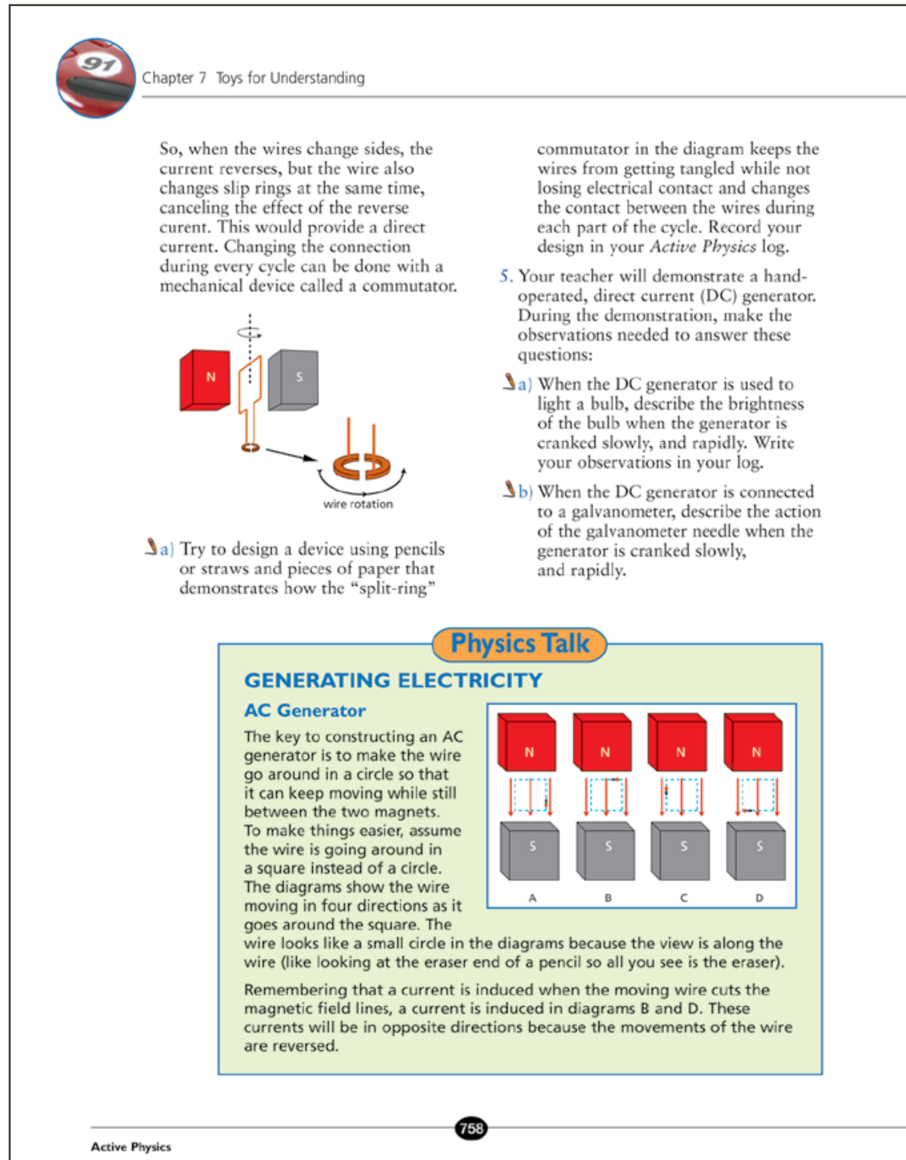
Students may be able to discern from the diagram that when the current reverses, the connection does also, if a single commutator ring is split in half and connected to opposite sides of the circuit. Students should design a model to show and describe how the split-ring works. Show an example to students of a split-ring.

**5.a)**

When the DC generator is connected to the light bulb, the bulb will flicker (brighten and dim) when the generator is cranked slowly, but will stay on with less of a flicker when the generator is spun quickly.

**5.b)**

When the DC generator is cranked slowly and connected to the galvanometer, the galvanometer will go up to a low value on one side, and oscillate around that point. When the generator is cranked faster, the galvanometer reading will be higher on the same side, and oscillate less noticeably (almost steady).



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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 current. 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 hand-operated, 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.

Physics Talk

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).



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.

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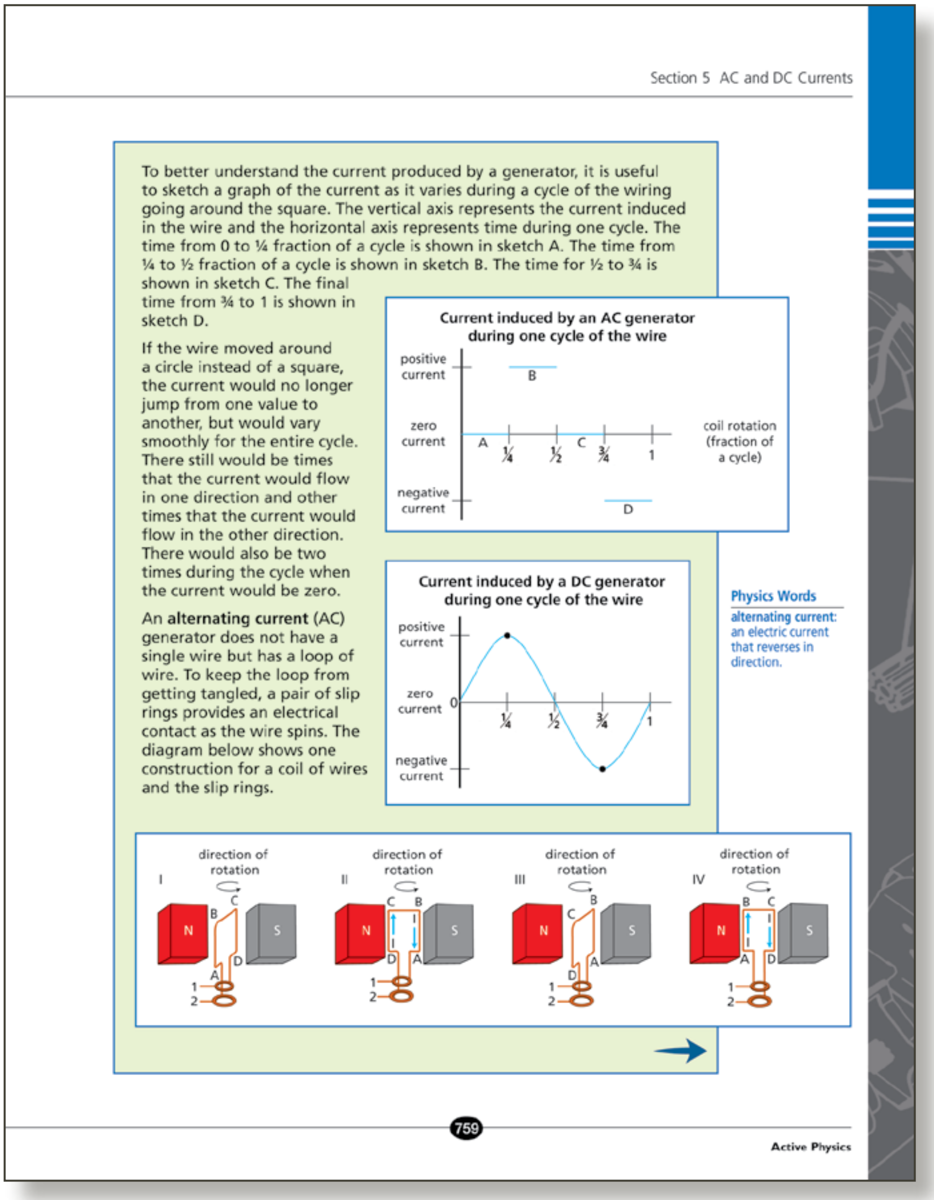
Active Physics

## Physics Talk

This *Physics Talk* describes how a coil of wire traverses the magnetic field in the production of alternating currents and direct currents by generators. Students read how currents are induced in AC and DC generators and how transformers change the voltage. A description of renewable and nonrenewable energy sources also is provided.

Discuss each step of a wire going along the square path shown in the student text. Demonstrate for students what this might look like using a single strand of wire (or something like a pencil to represent the wire). Discuss the slip rings of the AC generator and describe how currents are induced using a model. Describe the graph presented in the student text for the square path and that for a circular path. Emphasize that the current induced alternates direction in a periodic way, and hence is called an alternating current.

Discuss with students the DC generator and the corresponding graph in the student text. Describe the split-ring commutator used and show students a model of how it works or have them describe it with the models they developed. Emphasize that direct



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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 ¼ fraction of a cycle is shown in sketch A. The time from ¼ to ½ fraction of a cycle is shown in sketch B. The time for ½ to ¾ 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**

**alternating current:** an electric current that reverses in direction.

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current can change in value but maintains the same direction.

Discuss transformers, which can lower or raise (step down or up) the voltage and only work with alternating currents. Describe how a simple transformer works by inducing a current in a secondary coil due to a current going through a nearby primary coil. Describe how the changing current in the primary coil produces a changing magnetic field. If this changing magnetic field passes through the secondary coil, it induces a current in the secondary coil. Emphasize that energy is conserved—if the voltage is decreased and the current increases.

Describe how electrical energy is produced in power plants and discuss the various renewable and non-renewable energy sources that can be used to produce electricity, as well as their consequences.

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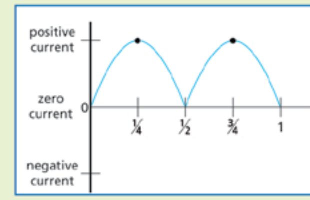
**7-5a Blackline Master**

**Physics Words**

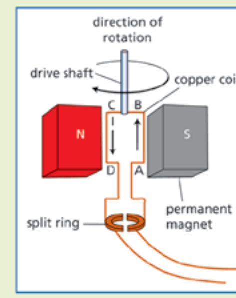
**direct current:** an electric current in only one direction.

**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 conduction. 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,

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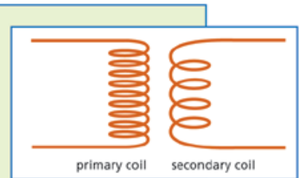
the magnetic field lines collapse and then expand with their north pole and south pole reversed.




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 human-made 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.**

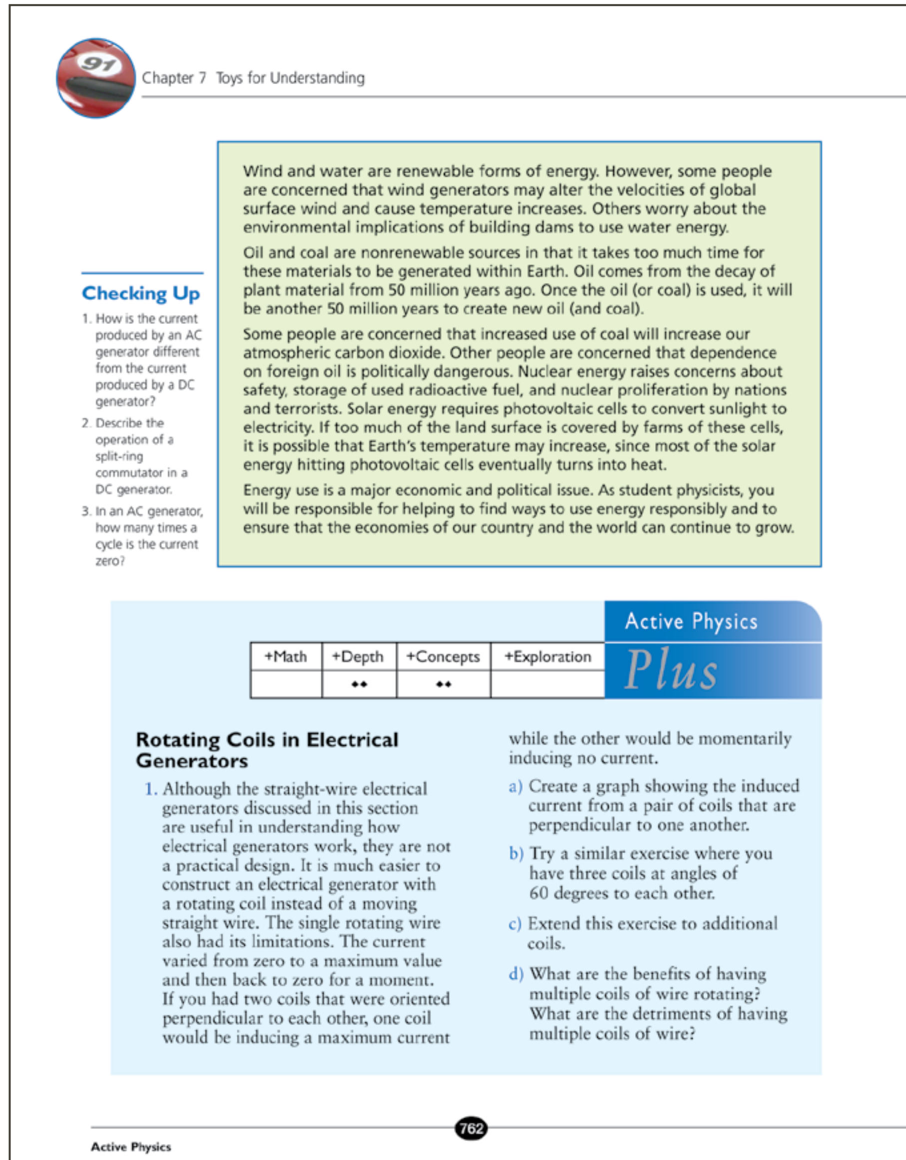
The current produced by an AC generator changes direction periodically, and the generator uses slip rings so that each end of the rotating coil can spin around to maintain contact to keep the circuit closed. The DC generator produces a direct current, which varies in strength but does not change direction.

**2.**

A split-ring commutator is two nearly half rings, (a ring split through its diameter) with leads attached to it. The coil of wire in a DC generator has leads that make contact to each half ring. As the coil rotates, it leaves one of the half rings and makes contact with the other, reversing the input and output wires as the current in the coil reverses direction. This results in the current leaving the generator maintaining one direction. The split-ring reverses the direction of the induced current, resulting in a current of one direction.

**3.**

In an AC generator, the current is zero twice during each cycle.



Chapter 7 Toys for Understanding

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.

**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?

**Active Physics Plus**

| +Math | +Depth | +Concepts | +Exploration |
|---|---|---|---|
| | •• | •• | |

**Rotating Coils in Electrical Generators**

1. 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?

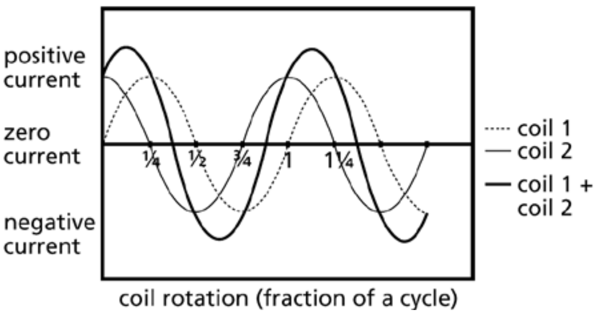
Active Physics 762

## Active Physics Plus

This *Active Physics Plus* is geared toward increasing students' depth of understanding of generators.

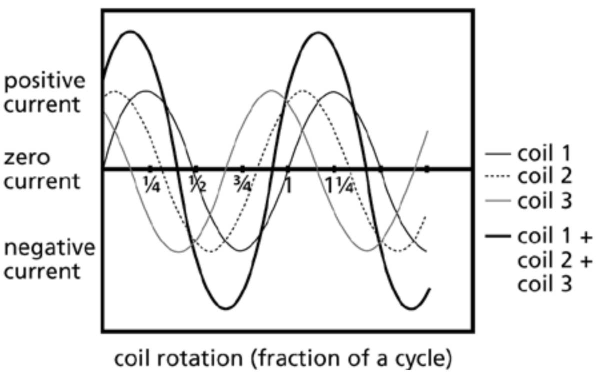
**a)**

**Induced current from a pair of coils**




**b)**

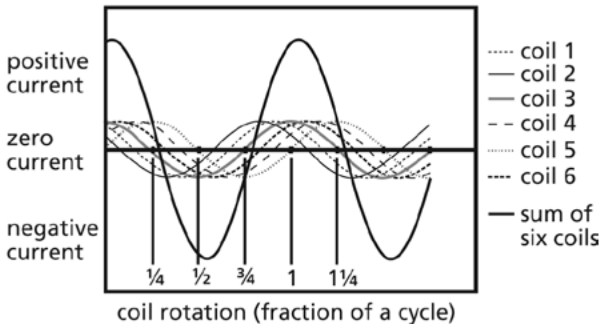
**Induced current from three coils**




**c)**

Students should sum more than three single wires, each out of phase with the rest. Below is an example of six coils each 30° apart.

**Induced current from six coils**




**d)**

Having multiple coils increases the overall amplitude of the current induced, however, it becomes more complicated to set up the coils. For example, adding a positive and negative contribution may yield an overall current of zero.

NOTES

## What Do You Think Now?

Revisit the *What Do You Think?* questions, and review students' initial ideas. Then ask students how they would answer these questions now using what they know about AC and DC generators and the currents they induce. Ask students how AC and DC generators differ. Students should describe how an AC generator uses slip rings so that the loop (or coil) has leads that are in constant contact with one slip ring. Students should describe a DC generator as having a split-ring commutator that switches the input and output, thus causing the current to be in the same direction. Consider presenting *A Physicist's Response* to students.

NOTES

### 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?

#### Physics Essential Questions

**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.



## Reflecting on the Section and the Challenge

Ask students to read this section and reflect on the differences between AC and DC generators. Briefly review and have students summarize what they learned through the *Investigate* and the *Physics Talk*. Emphasize to the class that part of the challenge will be to explain how their toy will operate using a motor and/or generator. Consider revisiting the *What Do You See?* illustration and ask students to describe how their knowledge of electricity has evolved with each part of this section.



## Physics Essential Questions

### What does it mean?

The essential parts of a generator are a coil of wire and a magnet. The AC generator has slip rings. The DC generator has a split-ring commutator.

### How do you know?

The current generated from both the AC and DC generator varied from a maximum to zero. The DC generator had the current in one direction only. The AC generator had the current changing directions during each cycle.

### Why do you believe?

It was necessary to understand how a current can be induced from its relative motion with respect to a magnetic field.

### Why should you care?

Every electric generator must have a wire and a magnet (permanent magnet or electromagnet). It must also have something that can supply mechanical energy to achieve a relative motion between the wire and the magnet.

## Physics to Go

**1.**

Electric generators transform mechanical energy into electrical energy.

**2.**

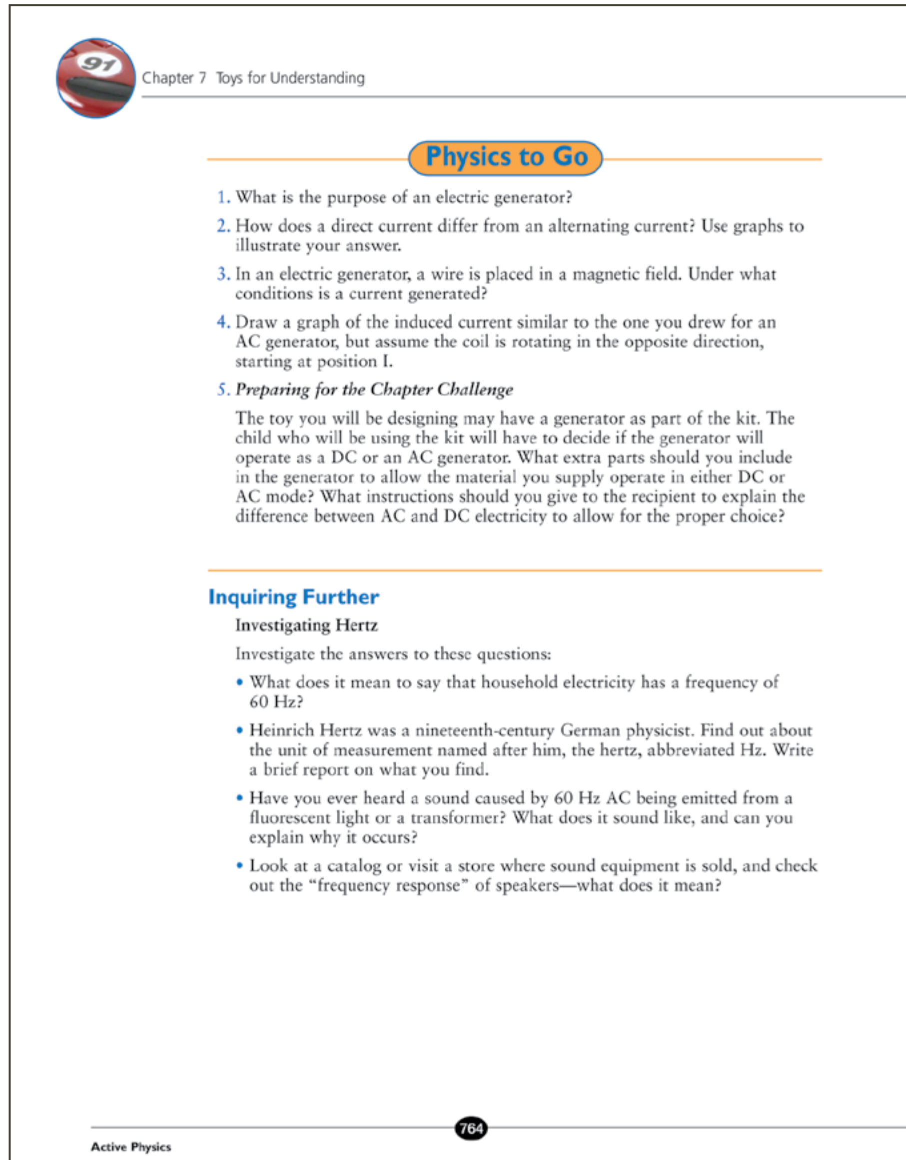
A direct current may change values but does not change direction. An alternating current changes value and direction in a periodic way. Students should sketch graphs similar to those in the *Physics Talk* used to describe the alternating current produced by an AC generator and the direct current produced by the DC generator.

**3.**

Current is generated when the wire cuts through the magnetic field lines.

**4.**

Students' graphs should look similar to the following:



Chapter 7 Toys for Understanding

**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?

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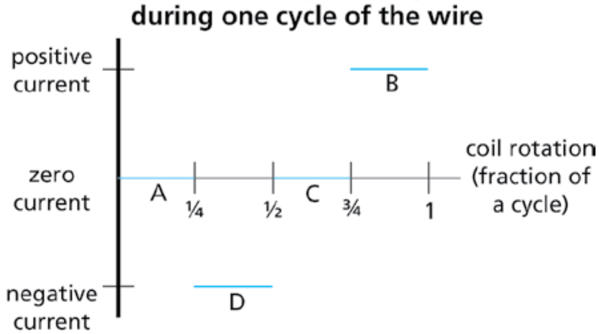
Active Physics

**Current induced by an AC generator during one cycle of the wire**




**5.**

### *Preparing for the Chapter Challenge*

Students should describe adding either a set of slip rings for an AC generator or a split-ring commutator for a DC generator. Students should construct a list of materials and a set of instructions that explain the difference between AC and DC electricity that will provide the child who receives the toy with enough information to determine which type of generator to use.

## Inquiring Further

**Investigating Hertz**

Students should research the answers to the questions listed. Responses should include the following:

- 60 Hz means 60 cycles occur per second.
- One hertz (1 Hz) is equal to one cycle per second. A cycle is something that repeats itself. Some students may include that the hertz is the unit used for frequency, which is the inverse of the period of a cycle.
- Sound occurs because of a vibration (oscillation) that travels through matter. When the induced oscillating magnetic field interacts with a transformer or a fluorescent light, it may set up a resonant frequency with the device, causing it to hum.
- Speakers vibrate to transform electromagnetic energy to sound energy. Frequency response is supposed to describe the range of frequencies or musical tones that a speaker can reproduce.



NOTES

## SECTION 5 QUIZ

**7-5b** **Blackline Master**

1. An AC generator is connected to a galvanometer, and the generator then starts to spin. As the speed of the generator increases, the reading on the galvanometer

   a) first goes back and forth, and then settles to read the maximum current.

   b) first goes back and forth, and then settles to zero current.

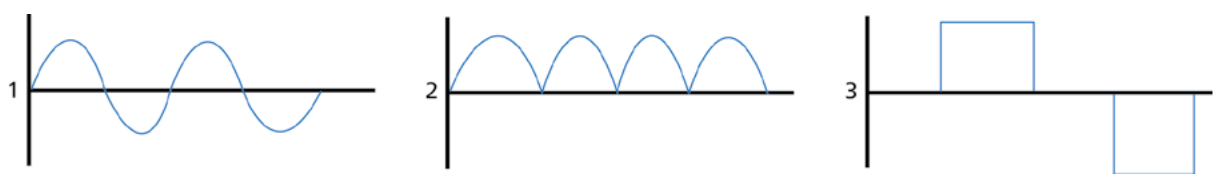
   c) starts out at zero and gets larger the faster the generator spins.

   d) starts out at the maximum current value.

2. The physical structure of a generator most closely resembles that of a

   a) motor.
   b) galvanometer.
   c) voltmeter.
   d) solenoid.

3. The graphs at right show the current flowing out of a generator as a function of time. Which statement below correctly correlates the type of generator with the correct graph?




   a) 1 is a DC generator and 3 is an AC generator.

   b) 2 is an AC generator and 3 is a DC generator.

   c) 2 and 3 are both DC generators and 1 is an AC generator.

   d) 1 is an AC generator and 2 is a DC generator.

4. To make an AC generator into a DC generator, which of the following is used?

   a) A galvanometer.

   b) A split-ring commutator.

   c) A transformer.

   d) Nothing is needed; the generator must simply be spun the opposite way.

5. What is needed in a circuit to light a light bulb with an AC generator?

   a) A galvanometer.

   b) A solenoid.

   c) Nothing; the bulb will light fine when connected to the generator.

   d) You cannot light a light bulb with an AC generator.

## SECTION 5 QUIZ ANSWERS

1. b) first goes back and forth, and then settles to zero current. As the speed of the generator increases, the galvanometer responds to more input values, averaging out more of the induced current. As the time for a cycle of the alternating current reaches the response time of the galvanometer, the galvanometer reads zero since it sums the positive and negative contributions of the alternating current.

2. a) motor. A generator is just a motor in reverse. Although a solenoid and a galvanometer both work on the same electromagnetic principles, their goal is not to transform electrical energy to mechanical energy or mechanical energy to electrical energy.

3. d) 1 is an AC generator and 2 is a DC generator. The AC generator produces an alternating current that periodically changes direction. The DC generator produces a current that can fluctuate in value but always goes in the same direction. Graph 3 could depict the induced current for a single wire traversing a square path. Although this could still be considered a generator because mechanical energy is transformed to electrical energy, it is not one of the choices.

4. b) A split-ring commutator. A split-ring commutator reverses the input and output, thus keeping the direction of the current the same during the rotation of the coil of wire.

5. c) Nothing; the bulb will light fine when connected to the generator. A generator transforms mechanical energy to electrical energy that can then be used to, for example, light a bulb.