SECTION 3

Building an Electric Motor

Section Overview

In this section, students explore ways to improve a motor's performance. After observing how a permanent magnet interacts with a current-carrying coil of wire, students begin to build a simple motor out of a battery, wire, a permanent magnet, and two supports. The *Physics Talk* discusses the force acting between a magnet and a current-carrying wire, and students apply their knowledge to solve problems, design possible toys using motors, and explain how an electric motor works.

Background Information

Motors convert electrical energy to mechanical energy. They operate in most electrical devices that have moving parts that spin or rotate. Motors function because of the interaction between moving charges in a wire and a magnetic field. In the motor, either a current-carrying coil of wire or a permanent magnet is connected to an axle. The current-carrying coil is an electromagnet because it induces a magnetic field. This induced magnetic field interacts with a magnetic field that is fixed within the motor, either due to a permanent magnet or an electromagnet within the motor. As these two magnetic fields push each other, the coil of wire on the axle spins. When a stationary magnetic field is aligned north to south with the rotating field, the force will no longer induce a spin. Hence, the electromagnet needs to be turned on and off at the correct times, or the current that is producing the magnetic field needs to switch mid-turn in order to keep the coil rotating about the axle. This rotational motion of the coil and axle is what causes the fan blades on a rotor to turn in an electric fan or the rotor in a toy helicopter to spin. Motors are used in many devices such as blenders, electric toothbrushes, electric windows, garage door openers, and electric-can openers. The interaction between moving charge and magnetic fields is used in electric guitars, door bells, speakers, automatic street light signals, crosswalk signals, telephones, and so on.

Crucial Physics

- Current-carrying wires and magnets interact with each other and exert a force on each other. The strength of the force depends on the strength and direction of each object's magnetic field.
- Motors convert electrical energy in the current-carrying wires into the kinetic energy of motion. The motor's kinetic energy may then be converted to potential energy in any number of ways. The motion is caused by the interaction between the magnetic field produced by a current-carrying coil and a magnetic field of a permanent magnet or electromagnet.
- A device known as a commutator allows the magnetic field of a direct current to change directions during the coil's rotation to provide a constant force between the magnetic field of the coil and the magnetic field of the motor's poles.

Learning Outcomes	Location in the Section	Evidence of Understanding
Observe the force on a current-carrying wire.	***Investigate*** Step 1	Students record their observations of how a magnet and a current-carrying coil interact.
Build, operate, and **explain** the operation of a motor.	***Investigate*** Steps 2 and 3 ***Physics Talk*** ***Physics to Go*** Questions 5 and 6 ***Inquiring Further***	During the *Investigate,* students build and operate a simple electric motor. The class discusses the basic principles behind the motor in the *Physics Talk*. Explanations on how motors operate are required in the *Physics to Go* questions and considerations of how they are started are expanded upon in the *Inquiring Further.*
Describe the force on a current-carrying wire as the interaction between the magnetic fields of the wire and the external magnet.	***Investigate*** Step 1.b) ***Physics Talk*** ***Physics to Go*** Questions 5 and 6	Students construct an explanation for their observations between a current-carrying coil and a permanent magnet. This interaction is discussed during the *Physics Talk*. Students use their knowledge of the forces between a current-carrying wire and a magnet to describe and explain how a motor works.

NOTES

Section 3 Materials, Preparation, and Safety

Materials and Equipment

PLAN A		
Materials and Equipment	**Group (4 students)**	**Class**
Magnet, large bar	1 per group	
Scissors	1 per group	
DC hand-operated generator	1 per group	
Magnet, ceramic ring	1 per group	
Safety pin, large	2 per group	
Rubber band, #64, pack		1 per class
Sandpaper, 60 grit	1 per group	
Battery, D-cell, alkaline	1 per group	
AA alkaline battery	1 per group	
Tape, masking		6 per class
Wire, #24, magnet, 60-ft roll		1 per class
Straw, drinking, transparent, pkg 100		1 per class
Styrene-foam cup, 12 oz		40 per class

Time Requirement

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

Teacher Preparation

- Make a demonstration motor so that students can see that it is possible, and show them that it does work. Try to build it exactly the same way as it is in the student text, and anticipate the different problems that students might encounter.
- One variation you might want to try is to add a switching mechanism. This may be done by placing a short length of an ice pop stick under one of the safety pins as a pivot point and moving the rubber band above that point. Thus, the lower end of the safety pin must be pinched to make it touch the battery. Pinch it and the motor starts. Let it go and the motor stops.
- Have spare parts available for students to use if they are having difficulty, including extra ring magnets, sandpaper, and batteries.

Safety Requirements

- Caution students that the motor circuit can get quite hot if the coil is not rotating. If they are squeezing the safety pins in their hands while the loop is stationary, the pins may become very hot after a few seconds.
- Students should wear safety goggles.

Materials and Equipment

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Magnet, large bar	1 per group	
Scissors	1 per group	
DC hand-operated generator	1 per group	
Magnet, ceramic ring	1 per group	
Safety pin, large	2 per group	
Rubber band, #64, pack		1 per class
Sandpaper, 60 grit	1 per group	
Battery, D-cell, alkaline		1 per class
AA alkaline battery	1 per group	
Tape, masking		6 per class
Wire, #24, magnet, 60-ft roll		1 per class
Straw, drinking, transparent, pkg 100		1 per section
Styrene-foam cup, 12 oz		40 per class

Time Requirement

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

Teacher Preparation

- Make a demonstration motor so that students can see that it is possible, and show them that it does work. Try to build it exactly the same way as it is in the student text, and anticipate the different problems that students might encounter.
- One variation you might want to try is to add a switching mechanism. This may be done by placing a short length of an ice pop stick under one of the safety pins as a pivot point and moving the rubber band above that point. Thus, the lower end of the safety pin must be pinched to make it touch the battery. Pinch it and the motor starts. Let it go and the motor stops.
- Have spare parts available for students to use if they are having difficulty, including extra ring magnets, sandpaper, and batteries.

Safety Requirements

- Caution students that the motor circuit can get quite hot if the coil is not rotating. If they are squeezing the safety pins in their hands while the loop is stationary, the pins may become very hot after a few seconds.
- Students should wear safety goggles.

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Reading comprehension Understanding motion from a diagram	***Physics Talk***	**Augmentation** • Students who are visual learners will benefit from the diagrams in this section, but these same students may have a difficult time visualizing the movement of the wire loop from a still picture, especially if they struggle with reading comprehension and have a difficult time understanding the diagram descriptions. Use a real-life model or a web-based simulator to show students a model in motion. Ask students to read the diagram descriptions aloud and then use the moving model to explain each step in their own words. • Some examples of web-based simulators can be found by conducting an Internet search on the key words "electric motor, simulation."
Understanding essential concepts Using academic vocabulary	***Checking Up*** ***Physics to Go*** Question 6	**Augmentation** • In order to be successful with the *Chapter Challenge*, students need to be able to use the new physics vocabulary in their own writing and explanations. Students need many opportunities to practice using the vocabulary and receive feedback about their understanding of the words. Require that students use at least three vocabulary words every time they are answering the *Checking Up* questions. Students can refer to the list in the *Physics Corner* at the beginning of the chapter. • To scaffold this investigation, tell students who may struggle with vocabulary which words they need to use. For these questions, students could use magnetic fields, electromagnets, energy transfer, and DC current. • Remind students to refer back to the *Investigate* and *Physics Talk* when they are trying to answer these questions. Check to see which students follow these directions. If students do not flip back to these sections, give them a one-on-one reminder with help to locate the needed pages. **Accommodation** • Provide a graphic organizer with illustrations to help students answer each question. For example, provide an illustration of a wire that is perpendicular to the magnetic field lines and ask students to use the illustration to describe what happens when a DC current is sent through the wire. • If students struggle to answer or provide incorrect answers to these questions, provide direct instruction to review how a motor works. Students cannot move on with the chapter until they understand this essential concept.
Designing a toy	***Physics to Go*** Question 3	**Augmentation** • Designing a toy may be an overwhelming task for some students, especially if they are still struggling to understand how electric motors work. Complete a group brainstorm of toys that use a motor. Most students will follow through with an idea if they have one before they leave class, but they are less likely to try something if they are confused and lacking confidence. **Accommodation** • Allow students who are struggling to understand how electric motors work to design one toy instead of three and bring them to class for feedback from you and their peers.

Strategies for Students with Limited English-Language Proficiency

Learning Issue	Reference	Augmentation
Higher-order thinking	***Physics Talk***	The distinction between science and technology can be difficult to understand. If technology is "the process by which humans modify nature to meet their needs and wants," what is science in relation? Have students think about that question, and challenge them to see if they can come up with something like this: "Science is the process of studying and learning about how nature behaves. It is the application of scientific knowledge that allows humans to develop technologies to meet their needs."
Vocabulary comprehension	***Physics Talk***	Students may benefit from a review of the term "electron." It is defined as "a negatively charged particle with a charge of 1.6×10^{-19} C and a mass of 9.1×10^{-31} kg." Help students remember that electrons are the charged particles that move in current-carrying wires, creating an electric current.
Understanding concepts		Part of performing science investigations and studying how nature behaves includes recognizing patterns and similarities in behavior. Review the phrase: "like charges repel, and opposite charges attract." Ask students if they can come up with a similar statement about magnetism. By now they should recognize that "like poles repel, and opposite poles attract."

Two important aspects of learning a new language are speaking and writing in that language. Some ELL students will be self-conscious and shy about speaking in front of their peers, while others will be less reluctant to try. Be sure to encourage all ELL students to speak in class, and give them opportunities to write on the board. Over time, the shy students will become increasingly less self-conscious about speaking in front of their classmates.

With that in mind, hold a class discussion to review *Section 3*. Call on ELL students to answer or address the bulleted items below.

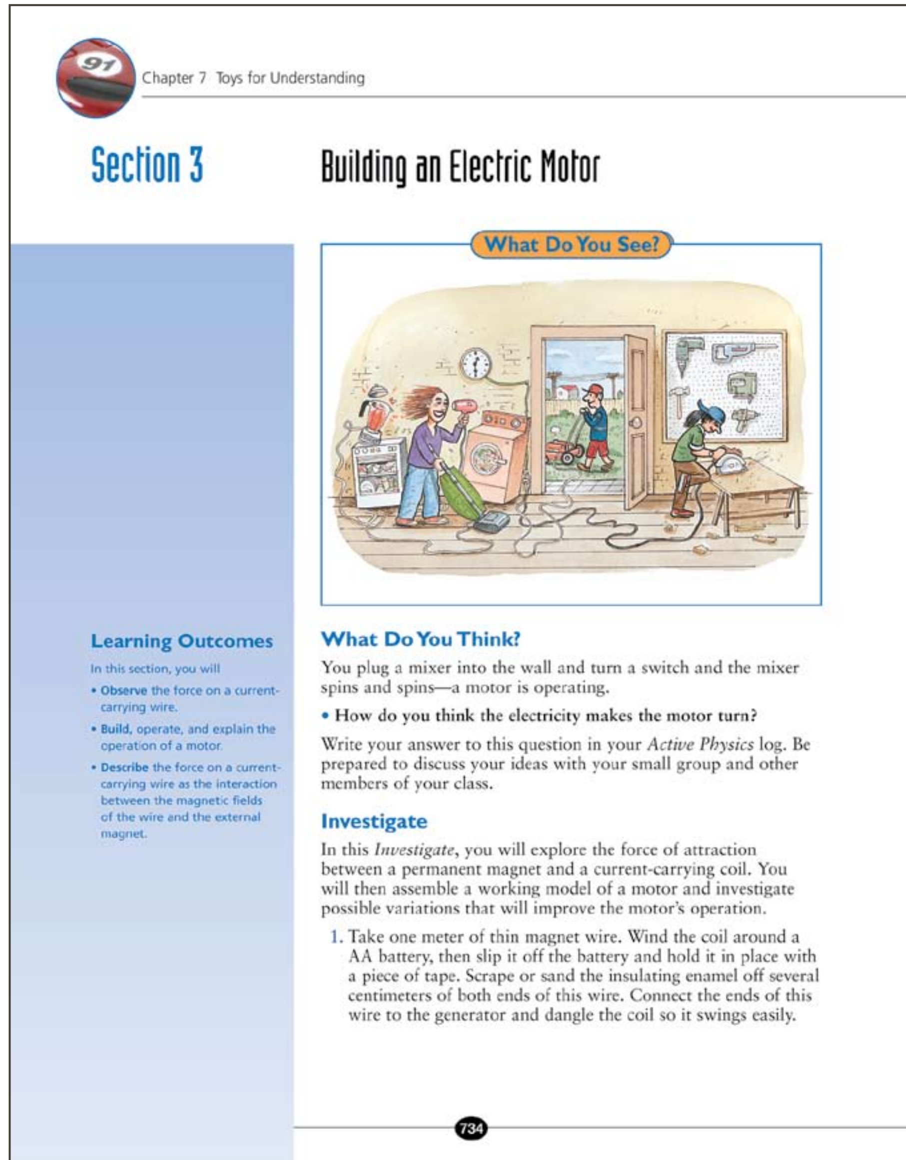
- Name three variables that can be changed to increase the output of a motor. *(Increase the current in the coil, increase the number of turns of wire in the coil, and increase the strength of the magnet.)*
- What is the basic principle behind how an electric motor works? *(A current-carrying wire creates a magnetic field that interacts with the magnetic field of a magnet to create motion.)*
- State the following equation in words: $F = IlB$ *(The force on a current-carrying wire equals the amount of current in the wire multiplied by the length of the wire in a magnetic field, times the strength of the magnetic field.)*
- What are the two ways to describe one tesla? *(One newton second per coulomb meter, and one newton per ampere meter.)*

SECTION 3

Teaching Suggestions and Sample Answers

What Do You See?

Have students consider the illustration and the title of the section. The girl blow-drying her hair and vacuuming at the same time, the man mowing his lawn, and another girl intently operating an electric tool are some of the images that will most likely capture your class's attention. Encourage students to see how the artist unifies all the images of this illustration to convey the physics concepts that will subsequently be covered in this section. Ask students what they think the illustration shows and what the image might have to do with the title of this section. Some students may say that motors are inside some of the electrical devices shown.


97 Chapter 7 Toys for Understanding

Section 3 Building an Electric Motor

What Do You See?

Learning Outcomes

In this section, you will

- **Observe** the force on a current-carrying wire.
- **Build**, operate, and explain the operation of a motor.
- **Describe** the force on a current-carrying wire as the interaction between the magnetic fields of the wire and the external magnet.

What Do You Think?

You plug a mixer into the wall and turn a switch and the mixer spins and spins—a motor is operating.

- **How do you think the electricity makes the motor turn?**

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 explore the force of attraction between a permanent magnet and a current-carrying coil. You will then assemble a working model of a motor and investigate possible variations that will improve the motor's operation.

1. Take one meter of thin magnet wire. Wind the coil around a AA battery, then slip it off the battery and hold it in place with a piece of tape. Scrape or sand the insulating enamel off several centimeters of both ends of this wire. Connect the ends of this wire to the generator and dangle the coil so it swings easily.

734

Students' Prior Conceptions

By building an electric motor and investigating interactions with a permanent magnet, students will recognize that movement of an electric charge—a current—creates a magnetic field. This fosters student understanding of magnetic fields and forces.

1. **Students do not understand the role of resistance.** Unfortunately, embedded in this section is the naïve precept about resistance and current. This affects students' understanding of conduction within a wire; how the molecular constitution of a wire contributes to its low resistivity; and ultimately how mechanical energy put into the system with the hand-cranked generator affects the strength of the magnetic field. As students list ways to improve the performance of the motor, you may highlight how a change in the type of characteristics (wire diameter or composition) and the length of the wire constituting the coil may affect the resistance and thus, the current. This should reinforce the concept of the strength of the magnetic field of an electromagnet being dependent on the current.

Ask students which devices shown have electric motors. Consider using an overhead projector during the discussion.

What Do You Think?

Have students consider the question, record their ideas in their log, and discuss them in groups. Facilitate a discussion on students' ideas. Ask students to provide reasons for their ideas and any experimental evidence they have. Note students' misconceptions and address these at appropriate times during the section. Consider asking them the connection between the illustration and the *What Do You Think?* question. Let students know that this is their chance to record their answers and ideas without restraint, and to brainstorm different aspects of this question to explore how electric motors work.

Investigate

1.

Number (gauge) 24 magnet wire seems to work well for this investigation.

What Do You Think?

A Physicist's Response

To understand how electricity makes a motor turn, you need to understand how a motor works. A motor consists of a current-carrying coil of wire that is free to rotate about an axis and a permanent magnet. When current runs through the coil, it induces a magnetic field, which interacts with a fixed magnetic field. This interaction causes the current-carrying coil to be pushed or pulled, rotating the coil, until its induced magnetic field aligns itself with the fixed magnet's field. Once the fields are aligned, the coil will stop spinning. In order for the coil to spin continuously, either the current has to be switched back and forth mid-turn in order to keep the coil rotating, or the current has to be turned on and off, allowing the coil to continue a half-turn before it is turned on again.

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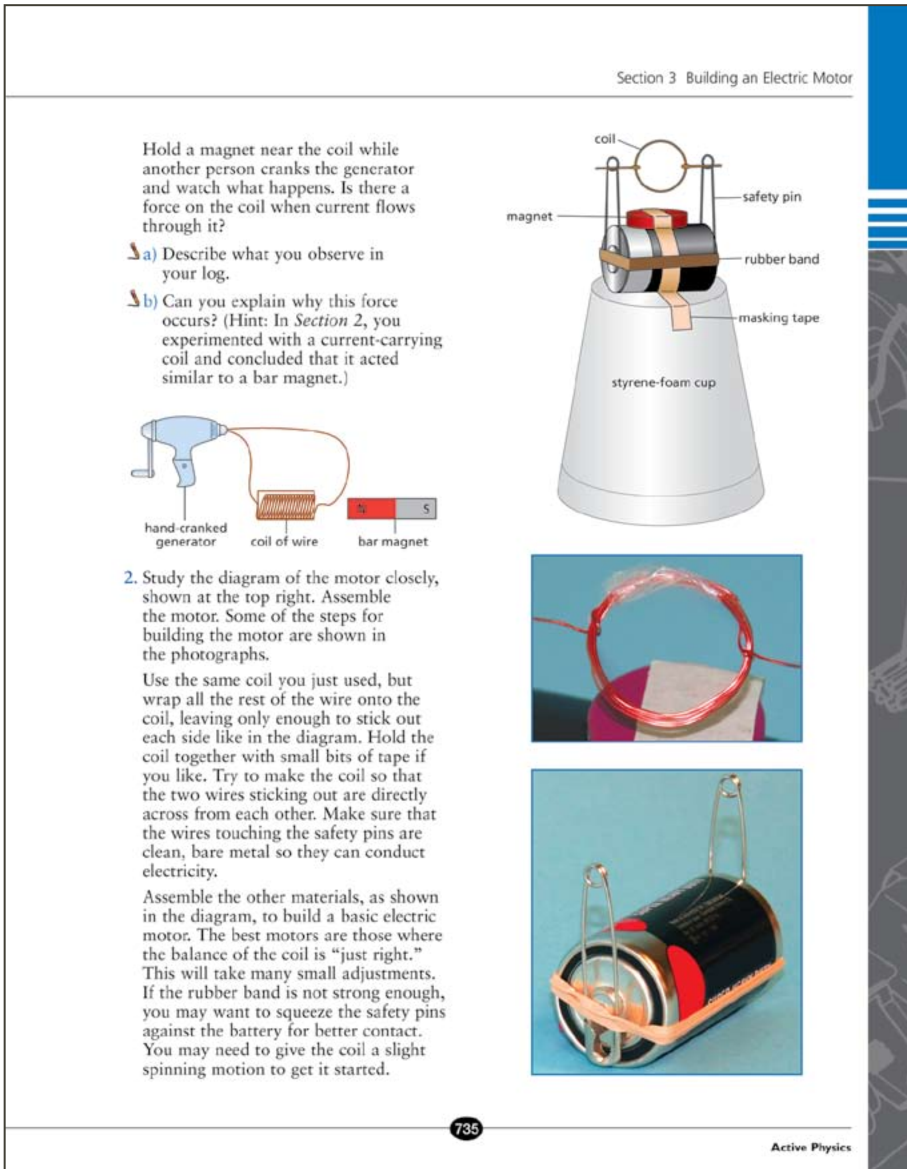


Hold a magnet near the coil while another person cranks the generator and watch what happens. Is there a force on the coil when current flows through it?

a) Describe what you observe in your log.

b) Can you explain why this force occurs? (Hint: In *Section 2*, you experimented with a current-carrying coil and concluded that it acted similar to a bar magnet.)

2. Study the diagram of the motor closely, shown at the top right. Assemble the motor. Some of the steps for building the motor are shown in the photographs.

Use the same coil you just used, but wrap all the rest of the wire onto the coil, leaving only enough to stick out each side like in the diagram. Hold the coil together with small bits of tape if you like. Try to make the coil so that the two wires sticking out are directly across from each other. Make sure that the wires touching the safety pins are clean, bare metal so they can conduct electricity.

Assemble the other materials, as shown in the diagram, to build a basic electric motor. The best motors are those where the balance of the coil is "just right." This will take many small adjustments. If the rubber band is not strong enough, you may want to squeeze the safety pins against the battery for better contact. You may need to give the coil a slight spinning motion to get it started.

1.a)

Students will see repulsion or attraction between the bar magnet and the coil, depending upon the polarity of the coil and the magnet.

1.b)

Explanations should include that the solenoid has an induced magnetic field when a current is flowing in it, and that this induced field interacts with the field of the bar magnet.

2.

Building the motor requires a careful balance of the coil students assemble. When students have almost completed the coil, the end of the wire can be twisted once around the assembled coil on each side to hold the turns in place. The wires should come out of opposite sides of the coil as shown in the text and be balanced as best possible. When students place the coil in the safety pin loops, they should see the coil "lock into position" as a current flows through the coil and it is attracted to the cylindrical magnet that is placed on the battery. Taping the magnet down is optional, since it should stick to the battery case. If the coil does not "lock in," try to squeeze the safety pins by hand to improve the connection. If the coil still does not appear to have current flowing, have students remove the wire loop and sand its ends some more. Once the loop has locked in, give it a twist to help start the rotation of the coil, which then should continue to rotate. If it does not rotate, have students check the coil balance, and make sure the ends of the coil are in good contact with the safety pins.

Teaching Tip

If students still are having difficulty with making the motor operate, you may wish to switch to a "homopole" motor. Conduct an Internet search on homopole motors. Consider showing a video of its construction to the class. The motor is very simple to construct, and extremely reliable to operate. Make sure students wear safety goggles.

CHAPTER 7

3.a)

Students may list any of a series of appliances, including refrigerators, washers, dryers, mixers, clocks, and so on.

3.b)

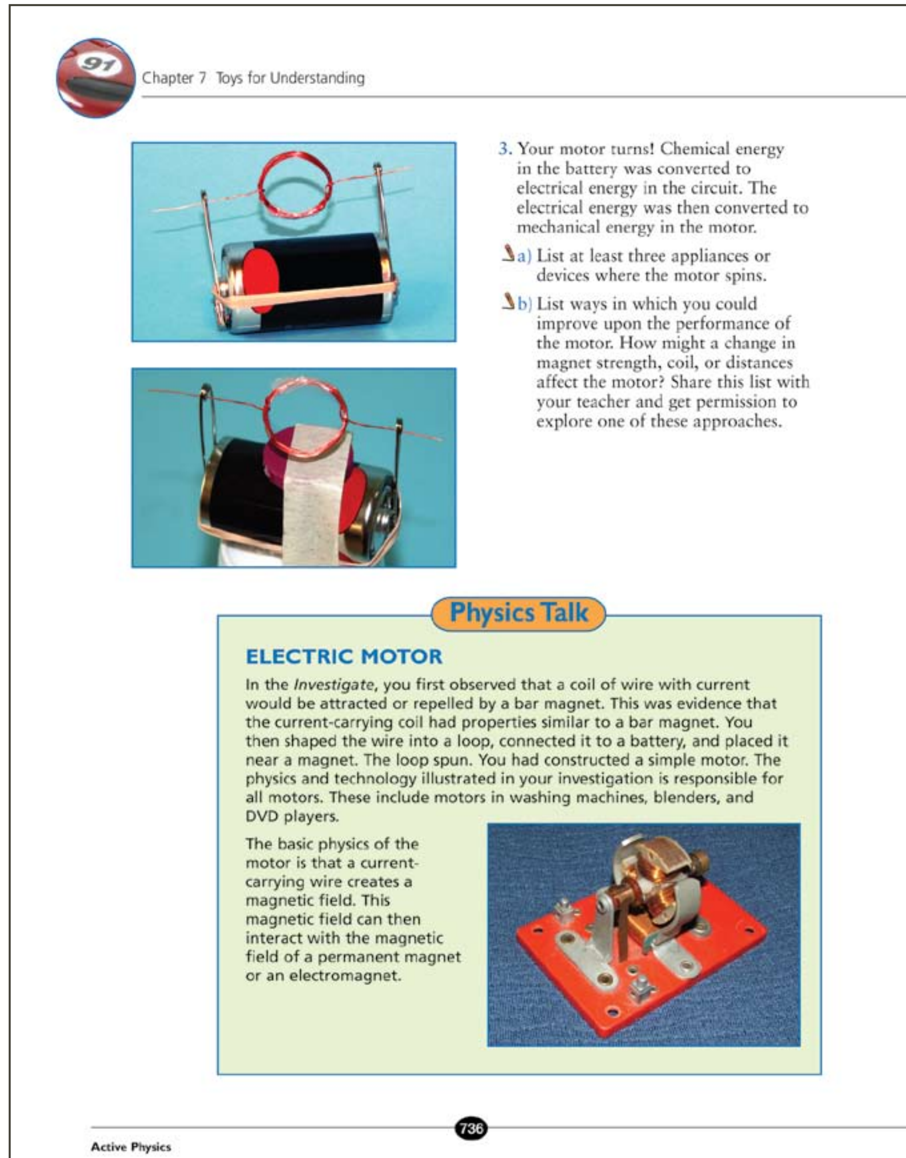
Students' lists may consist of things such as using a bigger (or smaller) coil, connecting two batteries in series or parallel, and adding magnets either above or below the coil. Briefly discuss students' observations and responses.

Physics Talk

This *Physics Talk* describes how a coil of wire with current would be attracted or repelled in a magnetic field produced by a bar magnet. It also introduces the technology of commutators.

Review the interaction between a current-carrying wire and a magnet. Describe how they push or pull on each other because the current-carrying wire induces a magnetic field that interacts with the magnet's field. Emphasize that this is the basic physics of a motor, which consists of a current-carrying coil that is free to rotate and a permanent magnet or an electromagnet.

Describe the current-carrying wire going between the two poles of the horseshoe-shaped magnet and the upward force acting on it. Discuss technology and the definition provided in the student text. Go through the diagrams in the student text that describe the forces felt on a current-carrying coil as it rotates through the


91 Chapter 7 Toys for Understanding

3. Your motor turns! Chemical energy in the battery was converted to electrical energy in the circuit. The electrical energy was then converted to mechanical energy in the motor.

a) List at least three appliances or devices where the motor spins.

b) List ways in which you could improve upon the performance of the motor. How might a change in magnet strength, coil, or distances affect the motor? Share this list with your teacher and get permission to explore one of these approaches.

Physics Talk

ELECTRIC MOTOR

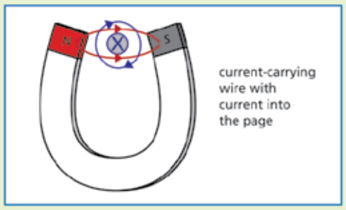
In the *Investigate*, you first observed that a coil of wire with current would be attracted or repelled by a bar magnet. This was evidence that the current-carrying coil had properties similar to a bar magnet. You then shaped the wire into a loop, connected it to a battery, and placed it near a magnet. The loop spun. You had constructed a simple motor. The physics and technology illustrated in your investigation is responsible for all motors. These include motors in washing machines, blenders, and DVD players.

The basic physics of the motor is that a current-carrying wire creates a magnetic field. This magnetic field can then interact with the magnetic field of a permanent magnet or an electromagnet.

Active Physics 736

magnetic field of a horseshoe magnet. Emphasize that the only part of the loop that feels a force is the part that is not parallel to the field lines. When the current is momentarily turned off, the loop switches direction. In this way, the coil continues its rotational motion in one direction.

Discuss the variables of the motor that can be changed to alter the output of the motor: the strength of the current in the coil, the number of turns of the coil, and the strength of the magnetic field of the fixed magnet.



In the diagram at right, a current-carrying wire is placed between the poles of a horseshoe magnet. Notice that the current-carrying wire is perpendicular to the magnetic field lines of the horseshoe magnet. The magnetic force of the wire and the horseshoe's magnetic field create a force on the wire. A force on the wire pushes it up. If the current were to stop, the magnetic field of the wire no longer exists and the wire would drop due to gravity. If the current were to resume, the wire would jump up. Turning the current on and off repeatedly would cause the wire to jump up and fall down repeatedly. This illustrates the physics of the motor.

In *Technically Speaking: Why All Americans Need to Know More About Technology*, technology is defined as "the process by which humans modify nature to meet their needs and wants." Nature produces a force on a current-carrying wire in the presence of a magnetic field. Humans take this physics principle of nature and build motors to exploit the physics for their benefit.

Rather than having a single wire move up and down, a motor has a coil of wire that can spin. In the following diagrams, you can see how the coil spins.

Diagram 1: The current in the left-hand section of the loop creates an upward force. The current in the right-hand section of the loop creates a downward force. The part of the loop that is parallel to the field lines of the horseshoe magnet does not experience a force.

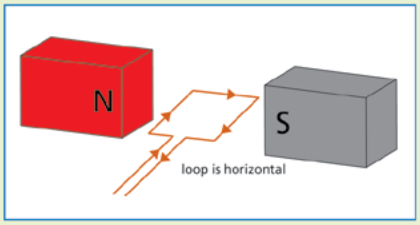


Diagram 1 – Loop is horizontal.

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Diagram 2: The loop pivots to this position. The force is momentarily zero and the loop continues to pivot due to its momentum. The loop would then experience forces that would make it rotate in the opposite direction. A clever technology called a commutator switches the direction of the current in the coil. You will learn about commutators later.

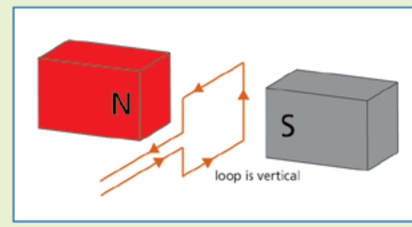

Diagram 2 – Loop is vertical.

Diagram 3: Since the current has been reversed, once again, the current in the left-hand section of the loop creates an upward force. The current in the right-hand section of the loop creates a downward force. The motor continues to spin.

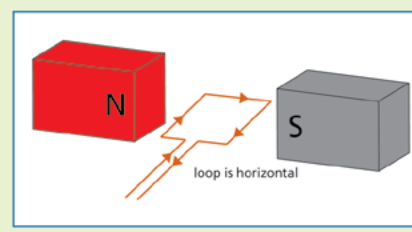

Diagram 3 – Loop is horizontal.

The force on a current-carrying wire in a magnetic field is actually a force on the moving electrons within the wire. This physics concept is not only used in motors. It can also explain how the images are created in some television sets and computer monitors.

738

Active Physics

A number of parts of the motor can be changed if a larger motor is needed. You can increase the current in the coil. You can also increase the number of turns of wire in the coil. In addition, a stronger permanent magnet or a stronger electromagnet can also be used. Increasing any one or all of these elements will increase the output of the motor.

The motor that you investigated in this section is referred to as a direct current motor or DC motor. That is because the battery providing the current had a steady current in one and only one direction (direct current).

Checking Up

1. What occurs when a wire that is perpendicular to the magnetic field lines has a DC current sent through it?
2. What is the basic physics of an electric motor?
3. When the wire loop is in the position shown in diagram 2 for the motor, why does the loop continue to rotate?

Active Physics *Plus*

+Math	+Depth	+Concepts	+Exploration
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An Equation for Magnetic Force

In this section, you observed the force on a current-carrying wire. In physics, students often ask, "Is there an equation that can describe this?" In this case, the equation is just what you would expect:

$$F = IlB$$

where F is the force,
I is the current,
l is the length of the wire, and
B is the magnetic field.

You can produce a larger force with:

- a larger magnetic field (by increasing the strength of the magnet)
- a larger current (by increasing the current in the wire)
- an increase in the length of the wire (more turns)

The force on the wire is due to movements of the electrons in the wire. As mentioned in the *Investigate*, beams of electrons also experience this force. You make use of this force and deflection of electrons every time you watch television (except flat-panel models) or look at a computer monitor. Once again, as student physicists, you may ask, "Is there an equation that can describe this?" and once again the answer is "Yes."

Charges moving perpendicular to a magnetic field experience a force that can be expressed by the following equation:

$$F = QvB$$

where Q is the charge,
v is the velocity, and
B is the strength of the magnetic field.

Checking Up

1.

When a wire perpendicular to the magnetic field lines has a DC current through it, it experiences a force perpendicular to both the field lines and the current.

2.

An electric current in a coil free to rotate induces a magnetic field that interacts with a fixed field created by a permanent magnet or an electromagnet. Some students may state that when these fields interact, they push and pull the coil so that it begins to rotate. By adjusting the current (turning it off and/or switching its direction), the current-carrying coil can be continuously forced so that it rotates about an axis.

3.

In Diagram 2, the loop continues to rotate because the current is momentarily turned off, allowing the loop to continue rotating due to its momentum. If the current was not turned off, then the attraction between the induced magnetic field and the fixed field would hold the loop in place. When the current is reestablished, it is also reversed to keep the loop rotating in the same direction.

Active Physics Plus

This *Active Physics Plus* has questions designed to increase students' depth of understanding of problems involving the interaction between a moving charge and a magnetic field, and allows students to solve problems using algebra.

Discuss with the class the equation in the student text that describes the force between a current-carrying wire and a magnetic field. Emphasize that *l* is the length of the wire within the field. Describe the relationship between these variables and how the force on the wire could increase and decrease.

Describe how cathode-ray tubes that commonly were used to make TV screens and computer monitors use a beam of electrons that strike a phosphorescent screen. The position where the beam of electrons strikes the screen is controlled using the interaction between a moving charge and a magnetic field.

CHAPTER 7

Have a class discussion on the dimensional analysis of the equation relating force, charge, and field. Describe and demonstrate the left-hand rule, and have students practice it for different situations.

1.

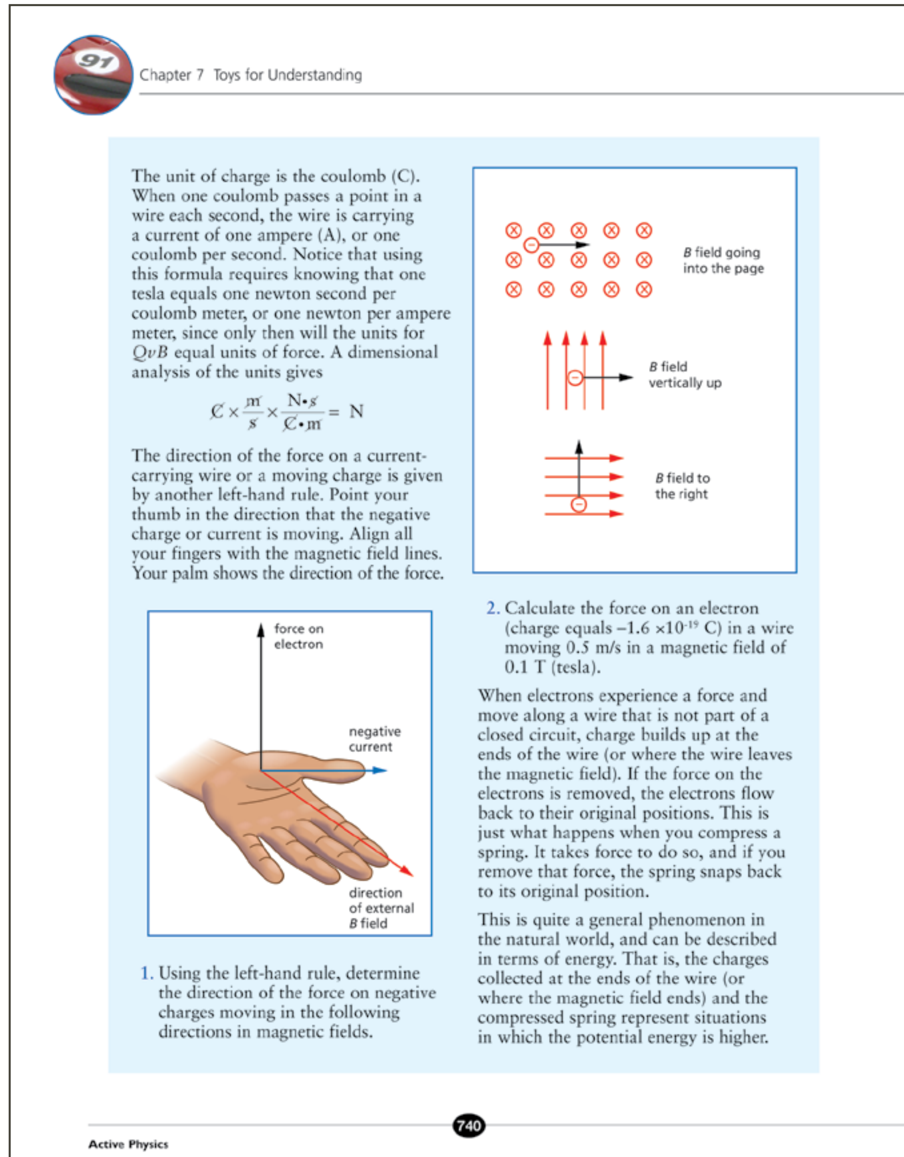
Students should use the left-hand rule to determine the force on the negative charges moving in a magnetic field.

- For the field going into the page and the negative charge moving to the right, the force on the charge is down.
- For the negative charge moving vertically up and the magnetic field to the right, the force on the charge is out of the page.
- For the negative charge moving to the right and the upward field, the force is into the page.

2.

$F = QvB =$
$(-1.6 \times 10^{-19}\ \text{C})(0.5\ \text{m/s})(0.1\ \text{T}) =$
$-8 \times 10^{-21}\ \text{N}$

Have a discussion on the analogy of a compressed spring with charges in a wire in a magnetic field. Describe the electric potential energy stored and the kinetic energy in terms of this analogy.


Chapter 7 Toys for Understanding

The unit of charge is the coulomb (C). When one coulomb passes a point in a wire each second, the wire is carrying a current of one ampere (A), or one coulomb per second. Notice that using this formula requires knowing that one tesla equals one newton second per coulomb meter, or one newton per ampere meter, since only then will the units for QvB equal units of force. A dimensional analysis of the units gives

$$\cancel{C} \times \frac{\cancel{m}}{\cancel{s}} \times \frac{N \cdot \cancel{s}}{\cancel{C} \cdot \cancel{m}} = N$$

The direction of the force on a current-carrying wire or a moving charge is given by another left-hand rule. Point your thumb in the direction that the negative charge or current is moving. Align all your fingers with the magnetic field lines. Your palm shows the direction of the force.

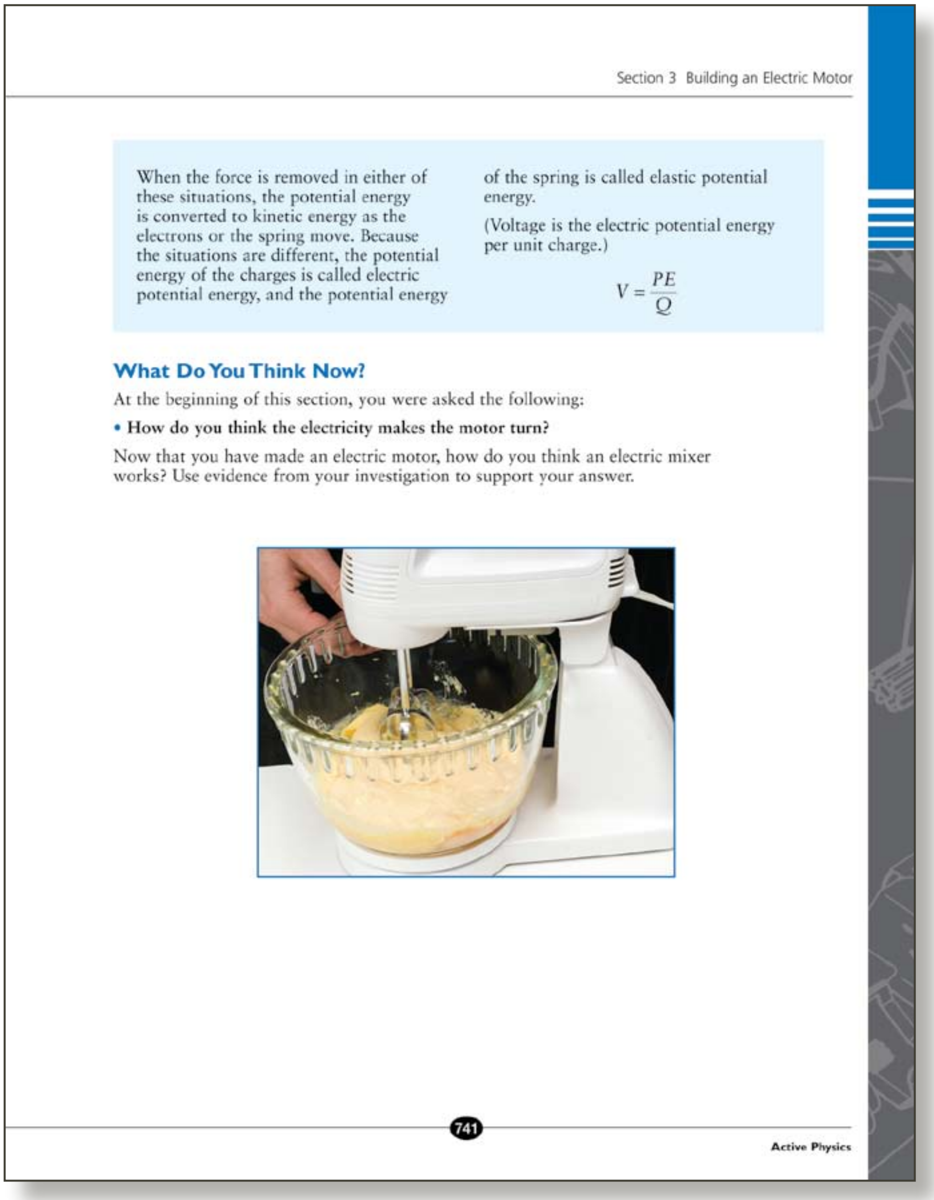
1. Using the left-hand rule, determine the direction of the force on negative charges moving in the following directions in magnetic fields.

2. Calculate the force on an electron (charge equals -1.6×10^{-19} C) in a wire moving 0.5 m/s in a magnetic field of 0.1 T (tesla).

When electrons experience a force and move along a wire that is not part of a closed circuit, charge builds up at the ends of the wire (or where the wire leaves the magnetic field). If the force on the electrons is removed, the electrons flow back to their original positions. This is just what happens when you compress a spring. It takes force to do so, and if you remove that force, the spring snaps back to its original position.

This is quite a general phenomenon in the natural world, and can be described in terms of energy. That is, the charges collected at the ends of the wire (or where the magnetic field ends) and the compressed spring represent situations in which the potential energy is higher.

740
Active Physics



When the force is removed in either of these situations, the potential energy is converted to kinetic energy as the electrons or the spring move. Because the situations are different, the potential energy of the charges is called electric potential energy, and the potential energy of the spring is called elastic potential energy.

(Voltage is the electric potential energy per unit charge.)

$$V = \frac{PE}{Q}$$

What Do You Think Now?

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

- **How do you think the electricity makes the motor turn?**

Now that you have made an electric motor, how do you think an electric mixer works? Use evidence from your investigation to support your answer.

What Do You Think Now?

Students should reflect on their earlier answers to the *What Do You Think?* question and revise them based on their current understanding of parallel circuits. Allow students to share their answers with each other and follow up with a whole-class discussion. Draw out misconceptions by prompting students with a few open-ended statements, letting students elaborate on these by getting them engaged in the discussion. You might want to provide students with *A Physicist's Response* to give them a better understanding of how electricity makes a motor turn.

Reflecting on the Section and the Challenge

Discuss the information students have investigated so far in the student text. Emphasize that the motor students constructed and their understanding of how it works is very important to the *Chapter Challenge*. Remind them that they will also have to design an interesting toy and explain how it works.

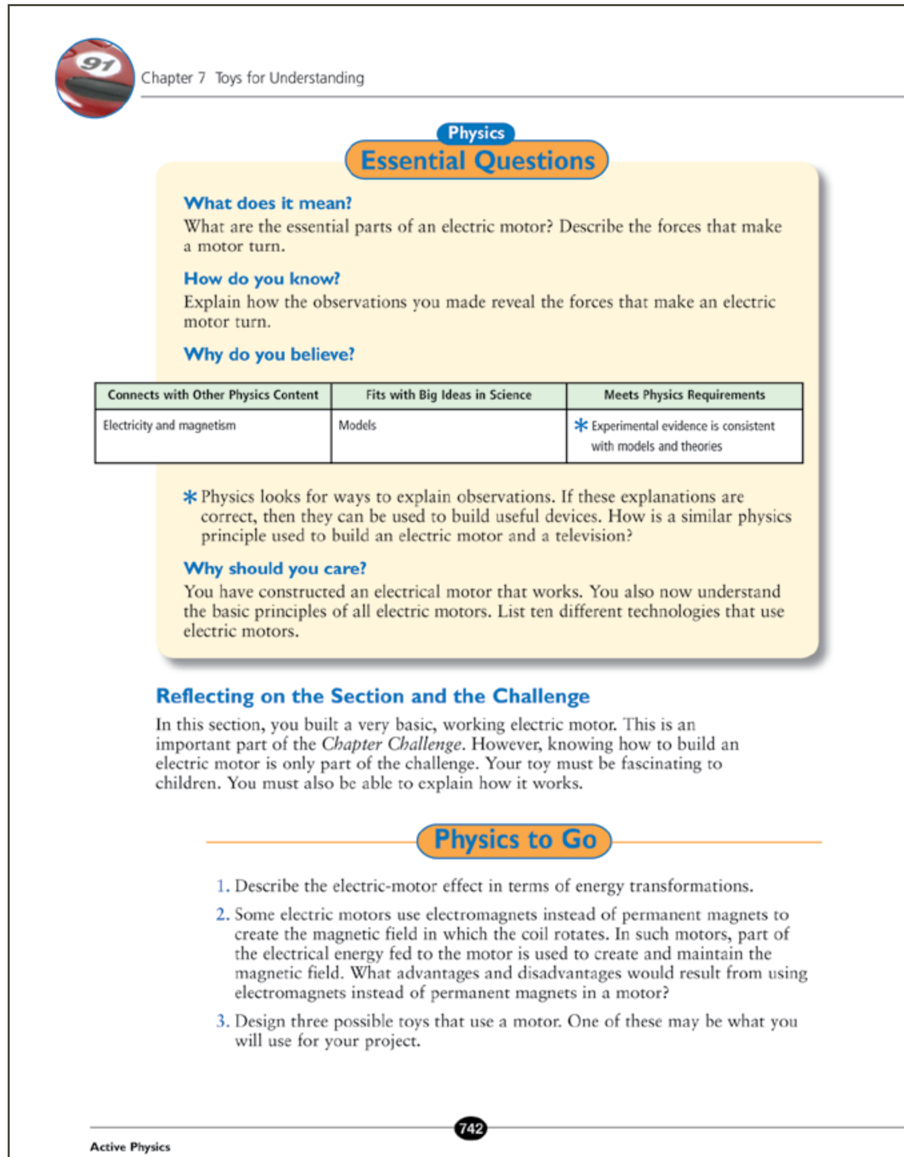
Physics to Go

1.

Students should describe how the electric motor transforms electrical energy into kinetic energy.

2.

The major disadvantage if an electromagnet is used instead of a permanent magnet in an electric motor, is that an energy source is required to maintain the external magnetic field in which the current-carrying coil moves. An advantage is that the magnetic field can be made very strong and may be turned on and off as needed. Also, its direction may be switched, changing the need for



Chapter 7 Toys for Understanding

Physics
Essential Questions

What does it mean?
What are the essential parts of an electric motor? Describe the forces that make a motor turn.

How do you know?
Explain how the observations you made reveal the forces that make an electric motor turn.

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 looks for ways to explain observations. If these explanations are correct, then they can be used to build useful devices. How is a similar physics principle used to build an electric motor and a television?

Why should you care?
You have constructed an electrical motor that works. You also now understand the basic principles of all electric motors. List ten different technologies that use electric motors.

Reflecting on the Section and the Challenge

In this section, you built a very basic, working electric motor. This is an important part of the *Chapter Challenge*. However, knowing how to build an electric motor is only part of the challenge. Your toy must be fascinating to children. You must also be able to explain how it works.

Physics to Go

1. Describe the electric-motor effect in terms of energy transformations.
2. Some electric motors use electromagnets instead of permanent magnets to create the magnetic field in which the coil rotates. In such motors, part of the electrical energy fed to the motor is used to create and maintain the magnetic field. What advantages and disadvantages would result from using electromagnets instead of permanent magnets in a motor?
3. Design three possible toys that use a motor. One of these may be what you will use for your project.

Active Physics 742

Physics Essential Questions

What does it mean?

A motor requires a magnet and a coil of wire that can rotate. A current must be present in the coil. The current-carrying coil sets up a magnetic field. This magnetic field is either attracted to or repelled by the magnet, causing it to rotate.

How do you know?

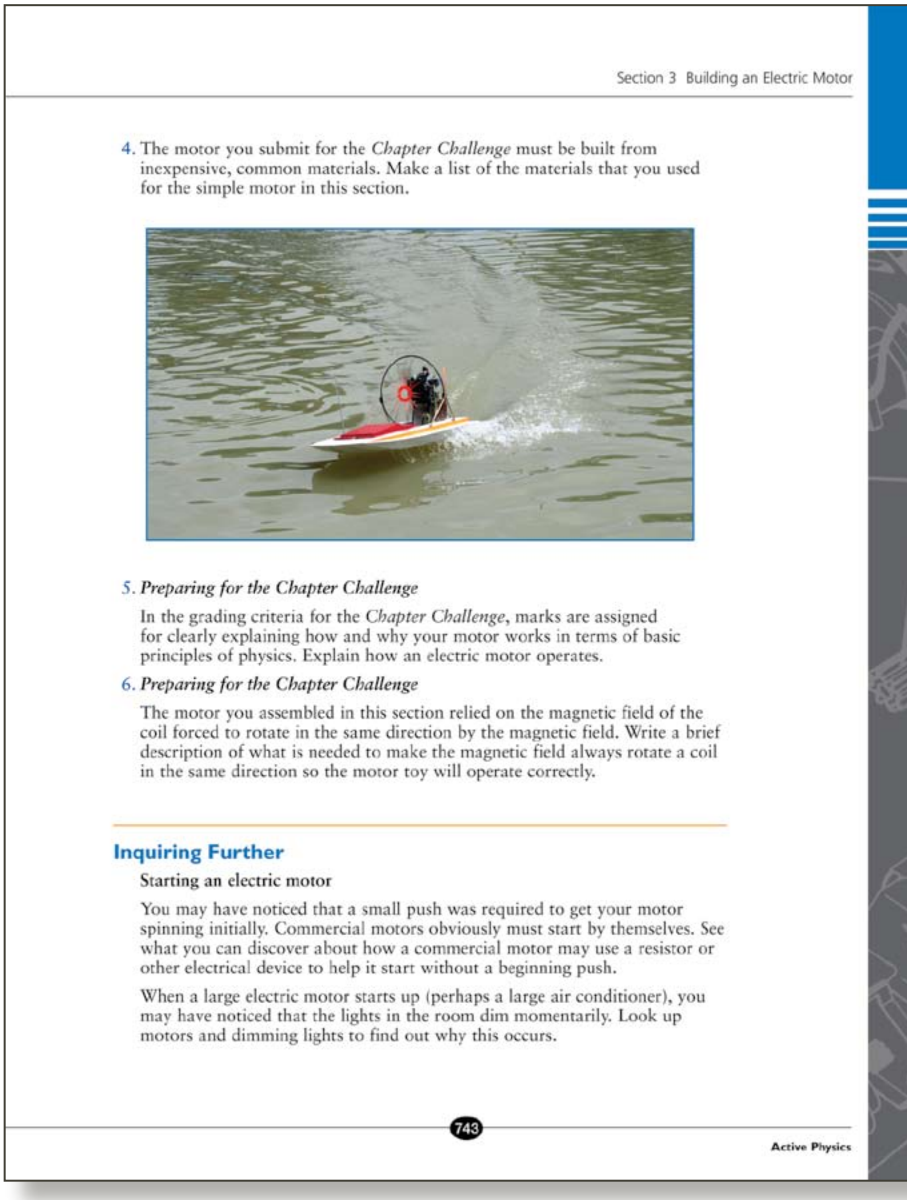
Because the coil of wire is accelerating as it moves in a circle, a force must be present.

Why do you believe?

The current-carrying wire is attracted or repelled by a magnet in a motor. The electron beam is deflected in the presence of a magnet.

Why should you care?

Ten different technologies that use motors are fans, washing machines, CD players, turntables, mixers, lawnmowers, drills, circular saws, rotors, and electric toothbrushes.



Section 3 Building an Electric Motor

4. The motor you submit for the *Chapter Challenge* must be built from inexpensive, common materials. Make a list of the materials that you used for the simple motor in this section.

5. *Preparing for the Chapter Challenge*

In the grading criteria for the *Chapter Challenge*, marks are assigned for clearly explaining how and why your motor works in terms of basic principles of physics. Explain how an electric motor operates.

6. *Preparing for the Chapter Challenge*

The motor you assembled in this section relied on the magnetic field of the coil forced to rotate in the same direction by the magnetic field. Write a brief description of what is needed to make the magnetic field always rotate a coil in the same direction so the motor toy will operate correctly.

Inquiring Further

Starting an electric motor

You may have noticed that a small push was required to get your motor spinning initially. Commercial motors obviously must start by themselves. See what you can discover about how a commercial motor may use a resistor or other electrical device to help it start without a beginning push.

When a large electric motor starts up (perhaps a large air conditioner), you may have noticed that the lights in the room dim momentarily. Look up motors and dimming lights to find out why this occurs.

743

Active Physics

the coil to be connected to a commutator.

3.

Students should design three toys, each using a motor.

4.

Students' lists should include a wire, an energy source such as a battery, and a magnet or electromagnet.

5.

Preparing for the Chapter Challenge

An electric motor works on the basic principle that a moving charge (current) interacts with a magnetic field. A current-carrying wire creates a magnetic field. This field can interact with a magnetic field of a permanent magnet or electromagnet. In a motor, the current-carrying wire is a coil that is free to rotate around an axis. When the coil's induced field interacts with the fixed field of the permanent magnet (or electromagnet), the coil is pushed on one side and pulled on the other. The coil of wire begins to rotate so as to align itself with the fixed magnetic field. The current is turned off before the coil is aligned, but the coil of wire continues to move because of its momentum. The current is then switched back on and reversed so that the coil is pushed in the same direction and continues to rotate about the axis.

6.

Preparing for the Chapter Challenge

In order for the coil to be forced to rotate in the same direction, the interaction between the coil and the magnetic field has to be removed before the coil's magnetic field aligns itself with the fixed magnetic field of the permanent magnet (or electromagnet). If the fields align, the coil will stop rotating. After turning off the current, the coil will continue to rotate because of its momentum. Then the current can be switched back on; however, to keep the force rotating the coil in the same direction, the current needs to be reversed. A device known as a commutator achieves this.

Inquiring Further

Starting an electric motor

Students should include information about how motors are started. Have a class discussion on students' responses and consider having students present to the class.

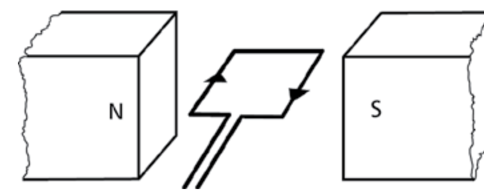
Motors may be started with an electric starter that employs a solenoid and large currents, or gear starters, or a pneumatic starter. Most items in the home use an electric starter. In the past, automobile engines were started with a hand crank; however, it was not the most convenient or safe method.

NOTES

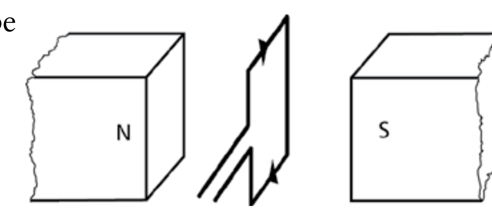
NOTES

SECTION 3 QUIZ

7-3a Blackline Master



1. The diagram on the right shows a loop of wire in a magnetic field with electrons flowing in the direction of the arrows. In the position shown the loop would
   a) be pushed upward.
   b) be pushed downward.
   c) be pulled to the left.
   d) rotate.



2. The loop in Question 1 is now turned 90° as shown on the right. In this position, the force on the loop would be
   a) to the left.
   b) to the right.
   c) upward.
   d) There is no net force in this position.

3. To make a motor from a current-carrying loop of wire in a magnetic field, the current must be reversed periodically. To do this, the motor uses a device called a(n)
   a) commutator.
   b) inverter.
   c) reversing loop.
   d) transient changer.

4. Which of the following changes to the loop or wire in the diagrams above would make the motor spin faster?
   a) Decreasing the current in the loop.
   b) Increasing the number of coils carrying current.
   c) Moving the magnets further away from the loop.
   d) Reversing the current in the loop.

5. If a loop of wire was wrapped around an iron core, the force acting on the loop when current flows through it would
   a) decrease.
   b) increase.
   c) remain the same.

SECTION 3 QUIZ ANSWERS

1. d) rotate. The force on the loop can be found by using the left-hand rule. The right side of the loop, near the south pole of the magnet, will feel an upward push. The left side of the loop, near the north pole, will feel a downward push. These forces acting on the loop cause the loop to rotate. The far end of the loop has a current in the direction of the field and does not feel a force on it because of this.

2. d) There is no net force in this position. The force on the top part of the loop is downward, and the force on the bottom part of the loop is upward. These forces do not rotate or move the coil of wire, although they may bend the wire loop slightly closer together. The reason it does not rotate the wire is that the induced magnetic field produced by the current-carrying coil is aligned with the external magnetic field. Note that the far end of the loop feels a force pulling it inward but not as strongly as the parts of the coil within the strongest parts of the external magnetic field.

3. a) commutator. The commutator reverses the direction of current during the rotation of the coil to allow for the coil to be pushed in the same direction.

4. b) Increasing the number of coils carrying current. Reversing the current does not change the strength of the interaction, only the direction. Moving the magnet further from the coil would reduce the strength of the interaction. Reducing the current would reduce the strength of the interaction.

5. b) increase. The force on the coil would increase because an iron core would increase the strength of the electromagnet the coil forms, and hence it would also increase the strength of the interaction between the coil and the field. Note however, that it would also increase the gravitational force on the rotating part.