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

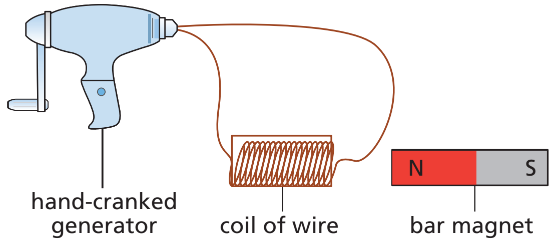
In this *Investigate*, you will explore the force of attraction between a permanent magnet and a current-carrying coil. You will then assemble a working model of a motor and investigate possible variations that will improve the motor's operation.

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.

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.

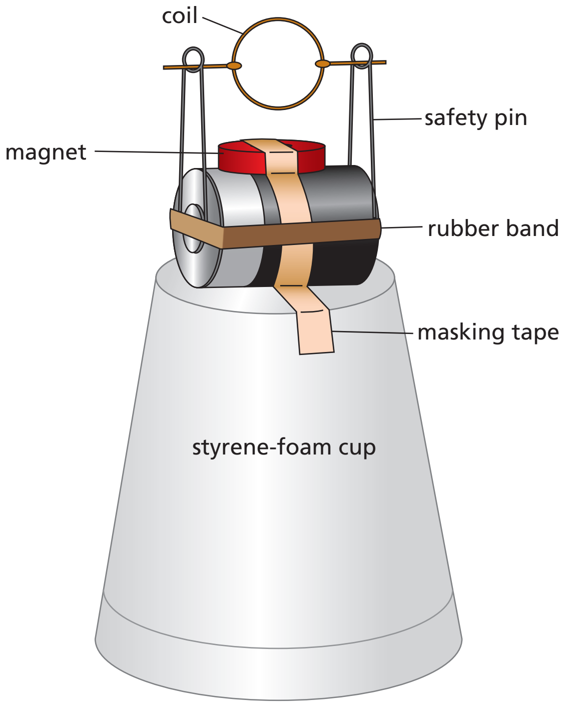
b) Can you explain why this force occurs? (Hint: In *Section 2*, you experimented with a current-carrying coil and concluded that it acted similar to a bar magnet.)

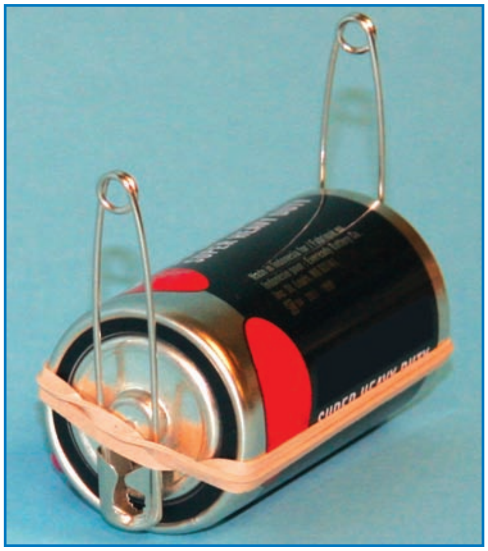


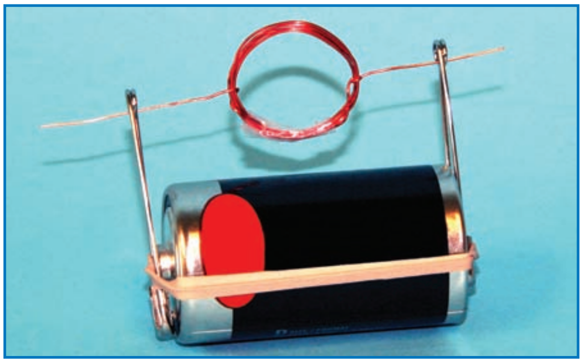
2. Study the diagram of the motor closely, shown at the top right. Assemble the motor. Some of the steps for building the motor are shown in the photographs.

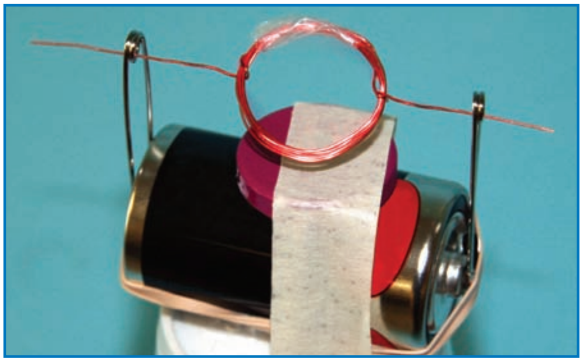
Use the same coil you just used, but wrap all the rest of the wire onto the coil, leaving only enough to stick out each side like in the diagram. Hold the coil together with small bits of tape if you like. Try to make the coil so that the two wires sticking out are directly across from each other. Make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









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.

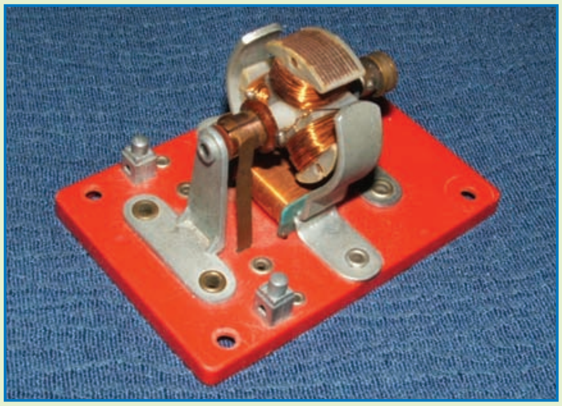
   b) List ways in which you could improve upon the performance of the motor. How might a change in magnet strength, coil, or distances affect the motor? Share this list with your teacher and get permission to explore one of these approaches.

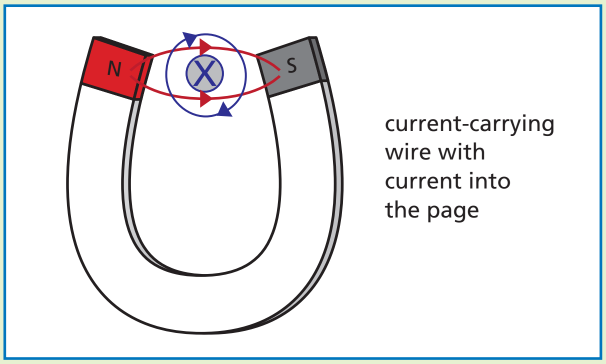
Physics Talk

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.





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.

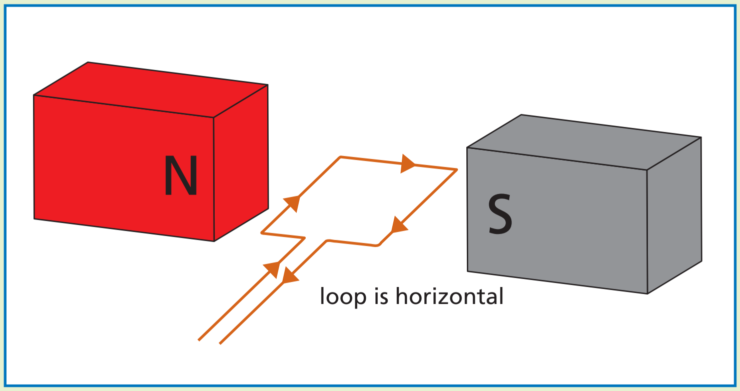


Diagram 1 – Loop is horizontal.

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.

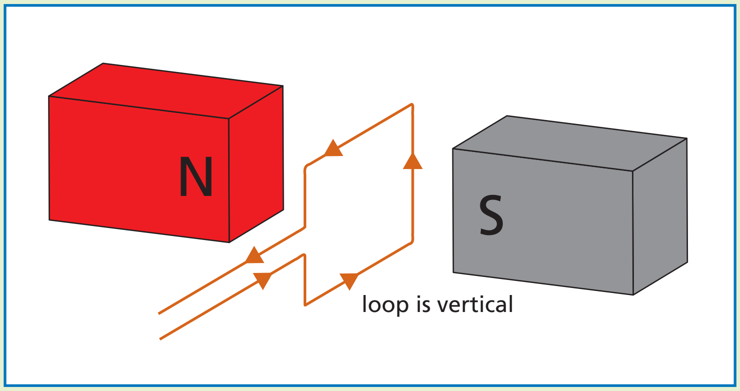


Diagram 2 – Loop is vertical.

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.

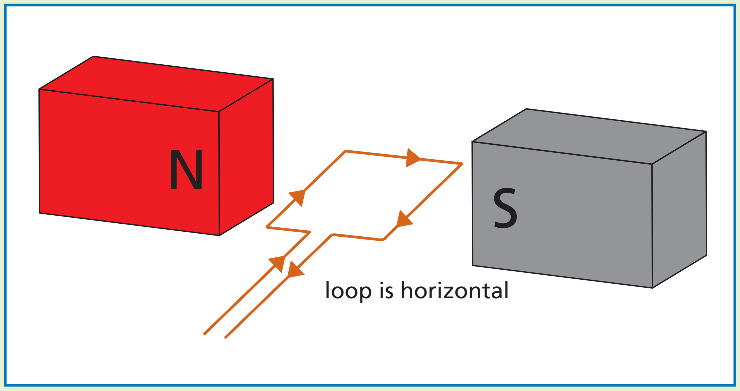


Diagram 3 – Loop is horizontal.

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.

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
◆◆	◆	◆	

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,

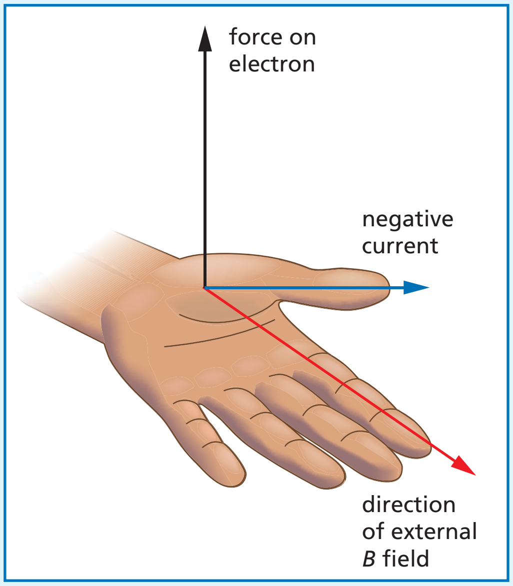
v is the velocity, and

B is the strength of the magnetic field.

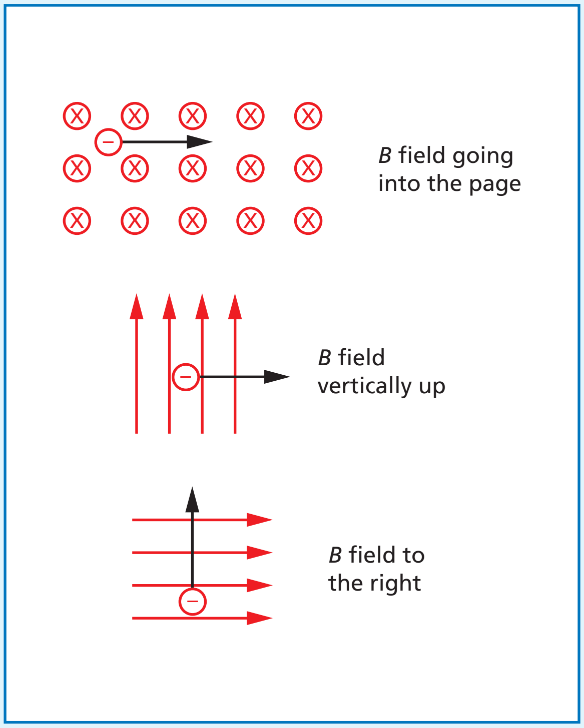
The unit of charge is the coulomb (C). When one coulomb passes a point in a wire each second, the wire is carrying a current of one ampere (A), or one coulomb per second. Notice that using this formula requires knowing that one tesla equals one newton second per coulomb meter, or one newton per ampere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

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

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.

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.

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.

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***

   a) 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.

   b) 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.