Section 4 Detect and Induce Currents

What Do You See?

Learning Outcomes

In this section, you will

- **Explain** how a simple galvanometer works.
- **Induce** current using a magnet and coil.
- **Describe** alternating current.
- **Appreciate** accidental discovery in physics.

What Do You Think?

For 10 years after Hans Christian Oersted discovered that a current produces a magnetic field, scientists struggled to try to find out if a magnet could produce a current.

- **How would you explore whether a magnet could produce a current?**
- **What equipment will you need for your investigation?**

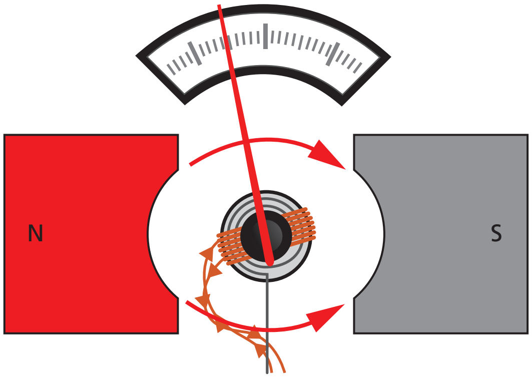
Write your answer to these questions in your *Active Physics* log. Be prepared to discuss your ideas with your small group and other members of your class.

Investigate

In this *Investigate*, you will use a *galvanometer* to determine if an electric current is generated when a bar magnet is inserted into a solenoid. You will explore how the relative magnet and coil speed determines the strength and direction of the current generated.

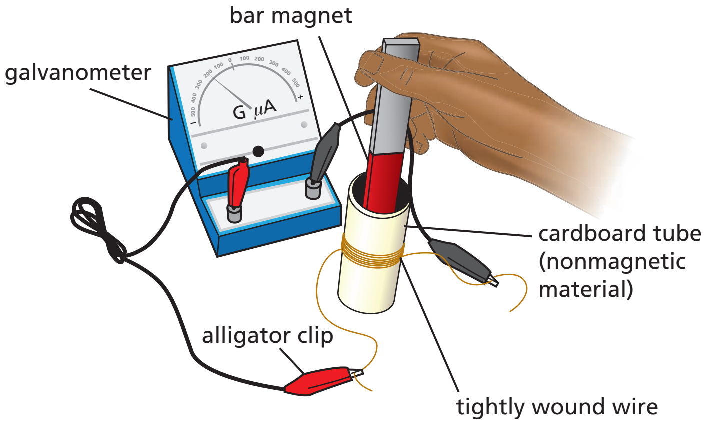
1. In a previous section, you saw that a small loop of a current-carrying wire experienced a force and rotated when placed near a magnet.

If a needle is attached to the small loop to show the amount of rotation, you have a meter that can measure very small currents. This is called a galvanometer. It is similar to the way in which a speedometer in a vehicle works. As the vehicle's tires turn, a small current goes through a coil and the speedometer needle rotates to show your vehicle's speed.



If a galvanometer is not available, you can make one as you did in *Section 1* by using a compass to detect the presence of a current. Instead of a needle showing the presence of the current, your compass needle will deflect in the presence of a current.

2. Connect a commercially made galvanometer or your homemade galvanometer to a solenoid wound on a hollow core of nonmagnetic material, such as a clear plastic or cardboard tube. For example, 25 turns of wire on a cardboard tube should work well. The cardboard tube must be big enough for a magnet to pass through. If you like, you can remove the coil from the cardboard tube, tape the wires together, and then tape the coil to a table so it sits on its edge (like a wheel, and the bar magnet will be in the position of the wheel's axle).



3. Hold a bar magnet in one hand and the solenoid steady in the other hand. Rapidly plunge one end of the bar magnet into the hollow core of the solenoid, stopping it inside. Another person should hold the galvanometer steady so that it will not be disturbed. Be sure to keep the galvanometer as far away from the magnet as possible. Watch the galvanometer during the sequence. You may need to practice this a few times.

   a) Write your observations in your log.

4. Remove the magnet from the solenoid with a quick motion, and watch the galvanometer during the action.

   a) Record your observations.

   b) A current is produced! Causing a current by moving a magnet near a coil is called inducing a current. What happens to the direction of the current compared to what you observed in *Step 3*?

5. Modify and repeat the last two steps to answer the following questions:

   a) What, if anything, about the induced current changes if the opposite end of the bar magnet is plunged in and out of the solenoid?

b) How does the induced current change if the speed of the magnet is changed?

c) When the magnet is not moving (stopped), what is the amount of induced current?

d) When the magnet is held stationary and the solenoid is moved back and forth over and around it, what is the effect on the induced current?

e) What is the effect of moving both the magnet and the solenoid simultaneously in opposite directions?

f) What is the effect of holding the magnet firmly inside the solenoid and moving both of them back and forth together?

6. Substitute an electromagnet for the permanent magnet. Place the electromagnet into the solenoid.

a) When the electromagnet is not moving, what is the amount of the induced current?

b) The current in the electromagnet is maintained by the battery or the rotation of the hand generator crank. While carefully watching the galvanometer, stop the current. Did you observe an induced current?

c) While carefully watching the galvanometer, create a current. Did you observe an induced current?

d) A current has a magnetic field associated with it. As the current is created, the magnetic field lines move out from the electromagnet to fill the space surrounding it. These magnetic field lines move past the wires in the solenoid. Even though there is no movement of the electromagnet, there is a movement of the field lines past the wires of the solenoid. Draw a series of sketches showing how field lines move past the wires.

Physics Talk

PRODUCING A CURRENT USING A MAGNET

Generating Electricity

In this *Investigate*, you were able to produce electricity by moving a magnet within a coil of wire. You created electrical energy by physically moving the bar magnet through the coil. When neither the magnet nor the coil moved relative to each other, no electricity was generated. A device that produces electricity is called a **generator**. When you produced electricity, you used the **galvanometer** as a detector.

Previously you have used a hand-cranked generator to produce electricity. A closer inspection of the hand-cranked generator shows that inside the generator, you either move a magnet through a coil or move the coil past the magnet. Inducing a current shows the conversion of mechanical energy to electrical energy to mechanical energy. The movement of the generator handle or magnet is an example of mechanical energy.

Physics Words

generator (electric): a device that produces electricity.

galvanometer: an instrument used to detect and measure an electric current.

In both cases electrical energy was produced. This electrical energy was converted to mechanical energy when the needle on the galvanometer moved.

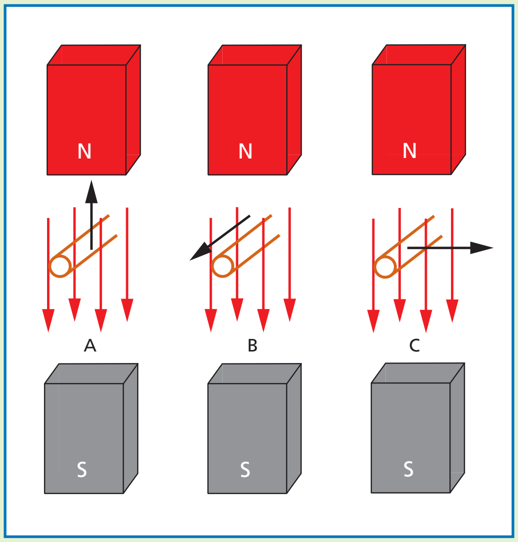
A current is created or induced when a magnet is moved in and out of a solenoid. The current flows back and forth, changing direction with each reversal of the motion of the magnet. Such a current is called an **alternating current**, and you may recognize that name as the kind of current that flows in household circuits. It is frequently referred to by its abbreviated form, **AC**. It is the type of current that is used to run most electric motors in home appliances.

Physics Words

alternating current (AC): an electric current that changes direction cyclically.

When you observed the movement of the permanent magnet and solenoid, you noticed that some movements induced more current than other movements. It is easier to understand the creation of a current if you think of a set of invisible threads made of wax to signify the magnetic field produced by permanent magnets. The very thin wax threads fill the space and connect the north pole of one magnet with the south pole of the other magnet. If the moving wire is imagined to be very thin and very hot, the question you must ask is whether the hot wire melts through the wax threads as it moves. If the wire moves in such a way that it melts through the field lines, then a current is generated. If the wire moves in such a way that it does not melt through the field lines, but instead slides along between the threads, then no current is generated.

Look at the diagrams at the right of the magnetic fields and moving wires. In all three cases, the magnetic field lines are vertical and point from the north pole of the upper magnet to the south pole of the lower magnet. In case A, the wire is moving up and down. Since it does not cut through and "melt" the magnetic field lines, no current is induced in the wire.

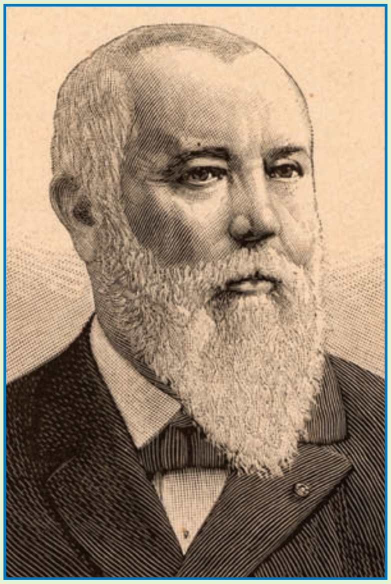


In case B, the wire is moving in and out along the direction of the wire itself. Again, since it does not cut through and "melt" the magnetic field lines, no current is induced in the wire. In case C, the wire is moving horizontally. When it does this, it cuts through and "melts" the magnetic field lines, so current is induced in the wire. There's one more detail that is very important. If the wire is moving to the right as in case C, the negative current flows along the wire out of the page. If the wire is moving to the left in case C, the negative current flows along into the page. In other words, when the wire moves so as to cut through or "melt" the magnetic field lines, the direction of the induced current in the wire reverses if the direction the wire is moving reverses.

Accidental Discoveries and the History of Physics

The history of science is filled with discoveries that have led to leaps of progress in knowledge and applications. This is certainly true of physics and, in particular, electricity and magnetism. These discoveries "favor" the prepared mind. Oersted's discovery in 1820 of the magnetic field surrounding a current-carrying wire already has been mentioned. Similarly, Michael Faraday discovered electromagnetic induction in 1831. Faraday was seeking a way to induce electricity using currents and magnets. He noticed that a brief induced current happened in one circuit when a nearby circuit was switched on and off. This is similar to your investigation of the current induced when you turned the electromagnet on and off. One story is that Faraday turned the circuit on expecting a continuous effect. Instead there was a very short current in the second circuit that stopped almost immediately. After waiting for some time while nothing happened, he disappointedly turned the main circuit off only to be surprised by another brief flow of current in the second circuit. After a flash of thought he excitedly turned the switch on and off repeatedly and found that as long as he kept switching the main circuit, then the second circuit's current continued to flow. Both Oersted and Faraday are credited for taking advantage of the events that happened before their eyes, and pursuing them.

About one-half century after Faraday's discovery of electromagnetic induction, which immediately led to the development of the generator, another event occurred. In 1873, a Belgian engineer, Zénobe Gramme, set up a demonstration of DC generators at an exposition (a forerunner of a world's fair) in Vienna, Austria.


Zénobe Gramme (1826 – 1901) was a Belgian engineer.

Steam engines were to be used to power the generators, and the electrical output of the generators would be demonstrated. While one DC generator was operating, Gramme connected its output to the output of another generator that was not operating. The shaft of the inactive generator began to rotate—because it was acting as an electric motor! Although Michael Faraday had shown as early as 1821 that rotary motion could be produced using currents and magnets, in other words a "motor effect," nothing useful resulted from it. Gramme's discovery, however, immediately showed that electric motors could be useful. In fact, the electric motor was demonstrated at the same Vienna exposition where Gramme's discovery was made. A fake waterfall was set up to drive a DC generator using a paddle wheel arrangement, and the electrical output of the generator was fed to a "motor" (a generator running "backward"). The motor was shown to be capable of doing useful work.

Zénobe Gramme invented the first useful electrical motor.

A motor converts electrical energy into mechanical energy. You used an electric current (electrical energy) to turn a loop of wire (mechanical energy). A generator converts mechanical energy into electrical energy. You pushed a magnet (mechanical energy) through a coil and produced an electric current (electrical energy.)

Checking Up

1. When a magnet is moved into and out of a coil of wire, what happens to the direction of the electric current produced?
2. In order to generate an electric current by moving a wire through a magnetic field, which way must the wire be moved?
3. What did Zenobe Gramme do to make the first practical DC motor start working?

Active Physics Plus

+Math	+Depth	+Concepts	+Exploration
	◆◆	◆◆	◆◆

Investigating Factors that Affect the Strength of the Current Induced

In your investigation, you examined the current induced in a coil from a moving magnet. Two aspects of the motion varied: the direction and speed of the magnet.

It is interesting to examine how other factors affect the induced current.

a) Design an experiment that keeps all factors the same except the number of turns in the coil. It is best to test coils with a very different number of turns.

The goal is to find a quantitative relationship between the size of the induced current and the number of turns in the coil.

b) Design an experiment that keeps all factors the same except the strength of the magnet. It might be difficult to know how the strengths of magnets compare, but you might use the number of staples or paper clips it can pick up as a guide.

c) Design an experiment that keeps all factors the same expect the orientation of the magnet relative to the coil. You have already examined what happens when the positions of the poles of the magnet are reversed. In this experiment, examine what happens when the magnet is oriented at several different angles.

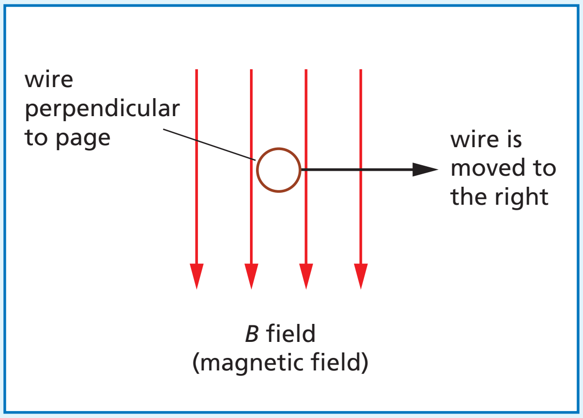
Lenz's Law

A current-carrying wire in a magnetic field experiences a force that moves the wire. This is the basis of the electric motor. A moving wire cutting across magnetic field lines induces a current. This is the basis of the electric generator. It seems that it may be possible to give a wire a tiny push and have the wire move. The wire's movement would then cause a current. The current would then make the wire move some more. More movement induces more current and then more movement and more current forever.

Conservation of energy implies that this cannot happen. You cannot get more and more energy out of a system without putting more and more energy into it.

The dilemma is solved by considering the directions of the force and the direction of the induced current. The left-hand rule for determining the direction of the force is to place your thumb in the direction of the electron current and your outstretched fingers in the direction of the magnetic field. The force on the wire is perpendicular to your palm.

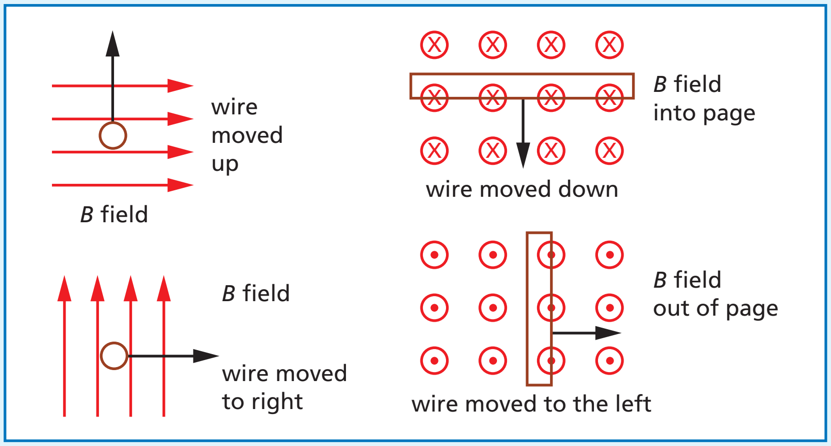
As the wire in the diagram is moved to the right, a current is created. For the sake of argument, imagine that the current could be into the page or out of the page. If the current were into the page, the force on the wire would be to the right. This would then move the wire more to the right and produce more current into the page. This is the "lots of energy for nothing" scenario described earlier.



The alternative is what really happens. As the wire in the diagram is moved to the right, a current is created. This current is out of the page. If the current is out of the page, the force on the wire would be to the left. This would then stop the wire's movement and no more current would be created. If you did want to create more current, you would have to push harder to the right to overcome the force due to the current in the magnetic field.
More current requires more force and more electrical energy requires more mechanical energy. This is consistent with the principle of conservation of energy.

The principle of conservation of energy is implied in Lenz's law, which describes the direction of the induced current: When a current is induced in a wire, the direction of the current must be such as to oppose the change that produced it.

Below are some diagrams where currents are induced in a wire. Determine the direction of the induced currents using Lenz's law and the left-hand rule.

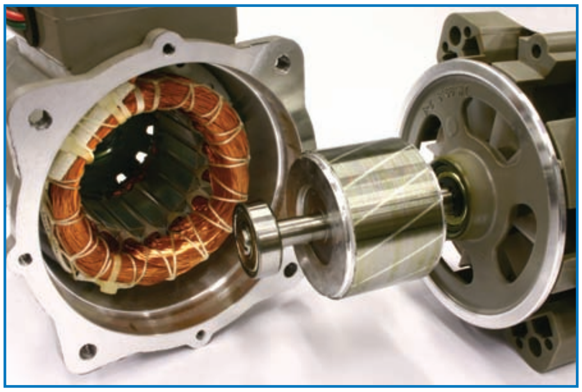


What Do You Think Now?

At the beginning of this section, you were asked

- **How would you explore whether a magnet could produce a current?**
- **What equipment will you need for your investigation?**

How would you answer these questions now? Michael Faraday was famous for his lectures for children at the Royal Academy. Imagine that you are Faraday and were about to show your students the surprising new fact that electricity can be created with magnetism. How would you set up the equipment for the experiment and what would you say as you performed the experiment?



Physics
Essential Questions

What does it mean?
How does the connection between electricity and magnetism allow you to make a motor out of a coil and a magnet? How do induced currents allow you to make a generator out of a coil and a magnet?

How do you know?
What did you observe that showed you a moving magnet can induce a current in a coil?

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Electricity and magnetism	Symmetry	* Parsimonious - maximum of generality for minimum of primary concepts

* Physics seeks to explain as many observations as possible with the same theory. What is it about a current causing a coil near a magnet to move and a moving magnet inducing a current that prompts you to think they might have the same explanation?

Why should you care?
You are going to construct a toy motor and/or generator. Why are you sure that what you observed in this section will be important when you do this?

Reflecting on the Section and the Challenge

In this section, you discovered that you can produce electricity. A current is produced or induced when a magnet is moved in and out of a solenoid. The mechanical energy of moving the magnet or the handle of the generator (which moves the coil) is converted into electrical energy. Part of your *Chapter Challenge* is to explain to the children how a motor operates in terms of basic principles of physics or to show how electricity can be produced from an external energy source. This section will help you with that part of the challenge.

Physics to Go

1. An electric motor takes electricity and converts it into movement. The movement can be a spinning fan, a washing machine, or a DVD player. The galvanometer may be thought of as a crude electric motor. Discuss that statement, using forms of energy as part of your discussion. Movement is one form of mechanical energy.

2. The galvanometer detects the amount and direction of the electric current. Explain how the galvanometer works.

3. How could the galvanometer be made more sensitive, so that it could detect very weak currents?

4. An electric generator takes motion and turns it into electricity. The electricity can then be used for many purposes. The solenoid and the bar magnet in this section could be thought of as a crude electric generator. Explain the truth of this last statement, referring to specific forms of energy in your explanation.

5. Imagine repeating the investigation in such a way that you would be able to see only the galvanometer and not the solenoid, the magnet, and the person moving the equipment. Would you be able to tell from the galvanometer whether the magnet is being moved, or the solenoid is being moved, or both are being moved? Explain your answer.

6. In generating electricity in this section, you moved the magnet or the coil. How can you use each of the following resources to move the magnet?

   a) wind

   b) water

   c) steam

7. ***Preparing for the Chapter Challenge***

   If the toy you are going to have the child assemble has a generator as part of the design, it should not develop more than 10 V (volts) for safety reasons. Make a list of the things you should consider in the design of the generator that will determine the amount of voltage the generator can put out. What should you include in the kit list to allow the student to test the generator to see if it is working properly when it is assembled?

Inquiring Further

Household Currents

Find out about the 120 V (volt) AC used in United States home circuits. If household current alternates, at what rate does it surge back and forth? Write down any information about AC that you can find and bring it to class.