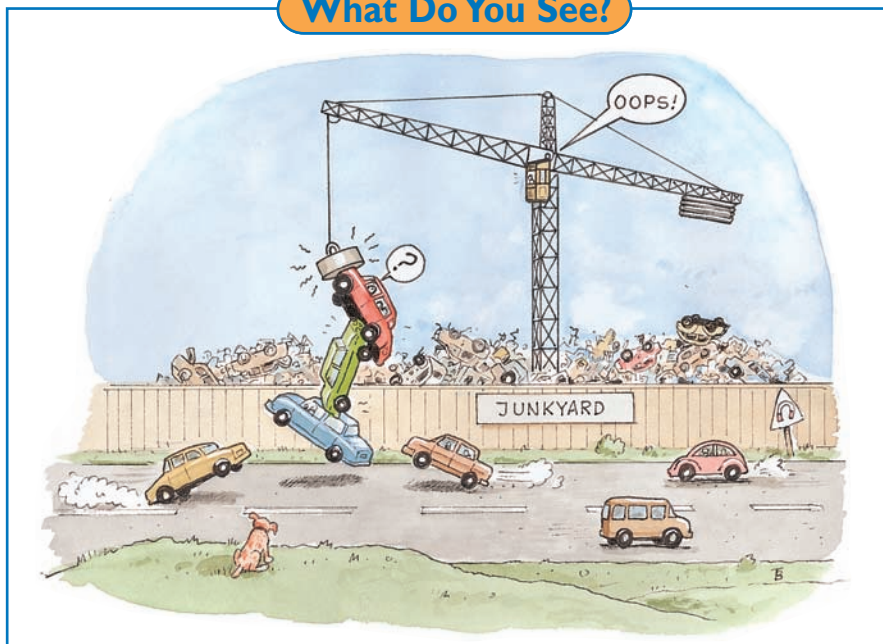




## Section 2

## Electromagnets

### What Do You See?



### Learning Outcomes

In this section, you will

- **Describe** the magnetic field of a current-carrying solenoid.
- **Compare** the magnetic field of a solenoid to the magnetic field of a bar magnet.
- **Identify** the variables that make an electromagnet strong or weak and explain the effects of each variable.

### What Do You Think?

Large electromagnets are used to pick up cars in junkyards.

- How does an electromagnet work?
- How could it be made stronger?

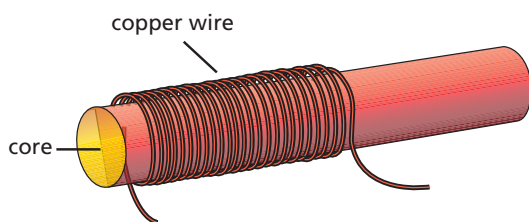
Write your answer to these questions in your *Active Physics* log. Be prepared to discuss your ideas with your small group and other members of your class.

### Investigate

In this *Investigate*, you will map the magnetic field of a current-carrying coil of wire (a *solenoid*) and compare it to that of a bar magnet. You will then determine how the number of turns, current size, and core material affect the strength of the magnetic field of a solenoid.

1. Wind 50 turns of wire on an end of a drinking straw to form a *solenoid* as shown in the diagram on the next page. It is better to put all of the turns at the same place on the straw rather than spread them out along the straw. Put some tape over the solenoid to keep the wires in place. Use sandpaper to clean the insulation from a short section of the wire ends down to bare metal.

2. Connect the wires from the DC generator to the wires of the solenoid. Bring one end of the solenoid near the magnetic compass and crank the generator to send a current through the solenoid. When current flows through the solenoid, you will have an *electromagnet*. Observe any effect on the compass needle. Try several orientations of the electromagnet to produce effects on the compass needle.



- a) Record your observations in your log.
  - b) Compare your observations to those you made with the bar magnet.
  - c) How can you tell the “polarity” of an electromagnet? That is, how can you tell which end of an electromagnet behaves like the north pole of a bar magnet?
3. Predict what you can do to change the polarity of an electromagnet.

- a) Write your prediction in your log.
  - b) Test your prediction. Record your results and compare them to your prediction.
4. Hang a paper clip or staple from a thread and see if your drinking-straw solenoid can pull it slightly to one side.
  - a) Record your observations in your log.
5. There are a number of variables that you can change to determine the effect on the strength of the electromagnet.

- You can replace the core of the straw from air to an iron nail.
- You can change the number of turns of wire.
- You can change the amount of current through the wire.

Decide which of these variable changes you will investigate.

- a) Design an investigation of the effect of the variable on the strength of the electromagnet. Record the steps of your investigation.
- b) After your teacher approves your procedure, carry out your investigation. Record the results in your log.

## Physics Talk

### ELECTROMAGNETS

A single current-carrying wire produces a magnetic field. In this section, you investigated what happens if the current-carrying wire is wrapped into a coil. You observed that this coil, also called a **solenoid**, behaved like a bar magnet. You had produced an **electromagnet**. (An electromagnet is any magnetic field created by a current. A solenoid is an electromagnet in the shape of a cylinder.) That is, it affected a compass in the same way that a bar magnet affects a compass. The diagrams on the following page show how the magnetic field consisting of loops of wire add up to make a stronger magnetic field than a single wire.

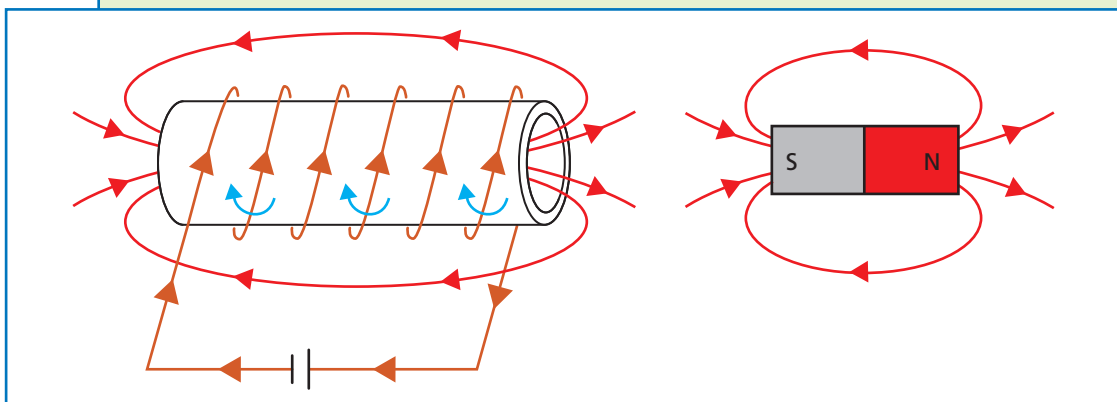
### Physics Words

**solenoid:** a coil of wire wrapped around a core of some material that provides a magnetic field when an electric current is passed through the coil.

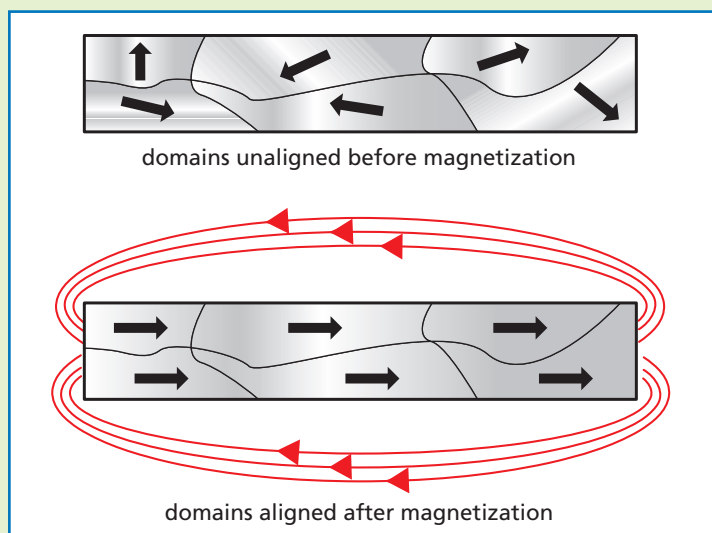
**electromagnet:** any magnetic field created by a current.



By combining many loops, the total magnetic field of the solenoid resembles the magnetic field of the bar magnet.



The magnetic field of the solenoid increases in strength when an iron nail is inserted into the core of the solenoid. One model that could explain this introduces the concept of magnetic domains. These domains are tiny bar magnets that exist within iron. At most times, these domains point every which way. The number of domains that point up is the same as the number that point sideways and down. The magnetic field of the solenoid causes these magnetic domains to align. When more and more of them align, the total strength of the solenoid increases. The magnetic field is no longer just due to the current-carrying solenoid but is also due to the sum of the strength of the aligned magnetic domains.



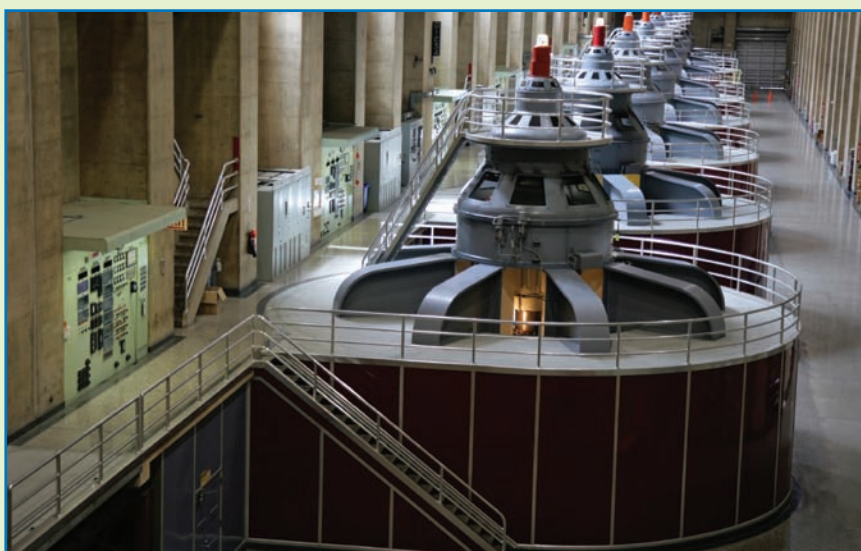
“Soft iron” works well as the core of an electromagnet. Soft iron is a processing term. It means the iron that has not been “hardened” by heat treatments, added ingredients, or other processes.

It is not soft to the touch. Iron is a magnetic material, but in soft iron the material is made up of small domains, each with its magnetic field pointing in a different direction. So by itself, soft iron does not make a good permanent magnet, because the fields from all the differently oriented domains cancel each other out. But if soft iron is placed in the magnetic field produced by something else, the magnetic field causes many of the domains to line up in the same direction, with their north poles in the direction of the magnetic field. This causes the soft iron to be a strong magnet, but only as long as it is in the magnetic field of something else.

It does not take a strong magnetic field to line up most of the domains of soft iron. The magnetic field due to the lined-up domains can often be 1000 times larger than the magnetic field that caused most of the domains to line up.

This magnetic domain model also helps to explain where the magnetism of a bar magnet comes from. The bar magnet has aligned magnetic domains. Some magnets are more permanent than others. This depends on the ability of the domains to remain aligned. Dropping a magnet can rotate some of the domains, causing the magnet's strength to diminish. Heating a magnet can also cause the domains to rotate, also diminishing the magnet's strength.

Magnets (either permanent magnets or electromagnetic magnets) are found in all motors and generators. A motor converts electricity into movement such as a fan or a clothes dryer spinning. A generator converts motion into electricity. The knowledge about magnets from *Sections 1* and *2* will help you understand and explain how to build motors and generators.



### Checking Up

1. What does the magnetic field of a solenoid most closely resemble?
2. Why does soft iron by itself not make a good magnetic material?
3. Why does adding an iron nail to a solenoid increase the strength of the magnetic field so dramatically?



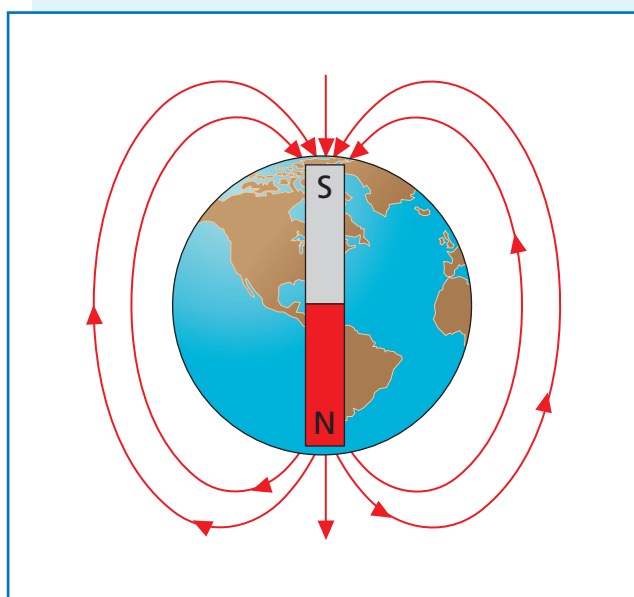
## Active Physics

+Math	+Depth	+Concepts	+Exploration
	♦	♦	♦

*Plus*

## The Magnetic Field of Earth

The magnetic field of Earth is similar to the magnetic field of a huge bar magnet inside Earth with its south magnetic pole near the north geographic pole and its north magnetic pole near the south geographic pole.



As shown in the diagram, at any point on the surface of Earth, the magnetic field is always directed toward the north geographic pole. Although the magnetic field resembles that of a bar magnet inside Earth, there is strong evidence that such a bar magnet does not exist.

First, all magnetic materials lose their ability to be permanent magnets at some high temperature. The temperatures deep inside Earth are much too high for any known material to be a permanent magnet.

Second, there is a huge amount of evidence pointing to the fact that the magnetic field of Earth has reversed its direction many times over the history of Earth. A permanent magnet cannot do this. Scientists' best hypothesis for the cause of Earth's magnetic field is that movement of material inside Earth, powered by Earth's rotation, generates currents that produce a magnetic field similar to an electromagnet.

1. Design and conduct an experiment to compare the strength of a bar magnet with the strength of Earth's magnetic field using only a compass and a ruler.
2. A dip needle is similar to a compass, but instead of being able to rotate in the horizontal plane, the needle is able to rotate in a vertical plane. Assuming you oriented the vertical plane of the dip needle along the north-south direction, what angle would you expect it to point if you were located at the north geographic pole? What if you were located at the Equator?
3. If you were doing this experiment in your classroom, in what direction (roughly) would the needle point?

## What Do You Think Now?

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

- How does an electromagnet work?
- How could it be made stronger?

How would you answer these questions now? Use your observations from the *Investigate* to explain how there are a number of variables of a solenoid that you can change to determine the effect on the strength of the magnetic field.

### Physics

## Essential Questions

### What does it mean?

What is an electromagnet?

### How do you know?

How can you increase the strength of an electromagnet?

### 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

\* Imagine a bar magnet and current-carrying solenoid were put into identical boxes so you could not see what is inside. Describe an experiment you could conduct outside the boxes that would tell you which one is which.

### Why should you care?

A motor requires a strong magnet. Strong permanent magnets can be quite large and heavy. What factors can be changed in an electromagnet to increase its strength?

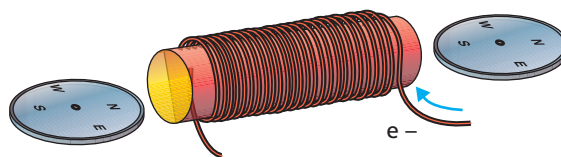
## Reflecting on the Section and the Challenge

An electromagnet, often constructed in the shape of a solenoid, and having an iron core, is the basic moving part of many electric motors. In this section, you learned how the amount of current and the number of turns of wire affect the strength of an electromagnet. You will be able to apply this knowledge to affect the speed and strength with which an electric motor of your own design rotates.



## Physics to Go

1. Explain the differences between permanent magnets and electromagnets.
2. Which of the following will pick up more paper clips when the same electric current is sent through the wire:
  - a) A coil of wire with 20 turns, or a coil of wire with 50 turns?
  - b) Wire wound around a cardboard core, or wire wound around a steel core?
3. The diagram below shows an electromagnet with a compass at each end. Copy the diagram and indicate the direction in which the compass needles point when a current flows through the electromagnet in the direction shown in the diagram.



4. Explain the conditions necessary for two electromagnets to attract or repel one another, the way that permanent magnets do when they are brought near one another.
5. Explain what you think would happen if you made an electromagnet, with half of the turns of wire on the core going in one direction, and half in the opposite direction.
6. *Preparing for the Chapter Challenge*

Your instructions for the toy a child will assemble may include making a solenoid by wrapping a hollow core with wire. What instructions would you give the child to ensure that the solenoid is strong enough to work as an electromagnet, strong enough to pick up pieces of iron and repel a permanent magnet?

## Inquiring Further

1. **Variables affecting the behavior of an electromagnet**

Identify as many variables as you can that you think will affect the behavior of an electromagnet, and design an experiment to test the effect of each variable. Identify each variable, and describe what you would do to test its effects. After your teacher approves your procedures, do the experiments. Report your findings.

## 2. Use of permanent magnets and electromagnets

Find out how both permanent magnets and electromagnets are used. Do some library research to learn how electromagnets are used to lift steel in junkyards, make buzzers, or serve as parts of electrical switching devices called “relays.” For other possibilities, find out how magnetism is used in microphones and speakers within sound systems, or how “super-strong” permanent magnets make the small, high-quality, headset speakers for today’s portable MP3 players possible. Prepare a brief report on your findings.



## 3. Magnetic levitation

Do some research to find out about magnetic levitation. “Maglev” involves using super-conducting electromagnets to levitate, or suspend objects such as subway trains in air, thereby reducing friction and the “bumpiness” of the ride.

- What possibilities do “maglev” trains, cars, or other transportation devices have for the future?
- What advantages would such devices have?
- What problems need to be solved? Prepare a brief report on your research.