SECTION 1

The Electricity and Magnetism Connection

Section Overview

To investigate how two bar magnets interact with each other, students record their observations and map out the magnetic field lines of a bar magnet using a magnetic compass. They determine how a current-carrying wire interacts with a magnet by coiling the wire around a magnetic compass and connecting it in a closed circuit with a light bulb and a hand-cranked generator. Their observations support the idea that a current produces a magnetic field. Students consider the model of fields, the historical significance of Oersted's experiments, and how to determine the direction of the magnetic field produced in a current-carrying wire.

Background Information

A magnetic field is a model that depicts what force a compass would feel if it were placed at a certain location. For mapping out gravitational fields, scientists consider how much force and the direction of that force a test mass would feel if it were placed at various locations from a mass. Newton's universal law of gravitation states:

$$F_{12} = \frac{Gm_1m_2}{r_{12}^2},$$

where F_{12} is the force between the two masses, m_1 and m_2 are the masses of the objects (one being the test mass), and r_{12} is the distance between their centers of mass. The gravitational field is found by dividing this force by the test mass, or

$$\text{Gravitational field} = \frac{F_{12}}{m_2} = \frac{Gm_1}{r_{12}^2}$$

The direction is always toward the center of mass of the mass producing the field, in this case m_1.

To determine the electric field, observe the force on a test charge placed at a different location. Coulomb's law states:

$$F_{12} = \frac{kq_1q_2}{r_{12}^2},$$

where q_1 and q_2 represent the charges, k is a constant, and r_{12} is the distance between the charges. Dividing the force between the charge of interest and the test charge,

$$\text{Electric field} = \frac{F}{q_2} = \frac{kq_1}{r_{12}^2}.$$

The direction of the field points away from positive charges and toward negative charges.

A magnet always has two poles (north and south) associated with it. You cannot isolate one pole. Magnetism arises from the motion and spin of charge. Permanent magnets arise from the outer electrons of certain atoms having their spin property aligned. The magnetic field of a magnet can be determined by considering how a small bar magnet (i.e., a compass) interacts with the magnetic field of interest. For example, consider a U-shaped permanent magnet, which has a north and south pole close to each other. If a compass is placed in the field it aligns with the magnetic field.

The force on a moving charge in a magnetic field is given by

$F = qvB\sin\theta$, or in full vector form:

$$\vec{F} = q\vec{v} \times \vec{B}$$

where q is the positive test charge, v is the speed at which it is traveling, B is the magnetic field of the magnet, and θ is the angle between the velocity and the magnetic field vectors. The positive test particle will be deflected the most when it is traveling perpendicular to the magnetic field. It will not be deflected at all if it is traveling along or parallel to the field. Because the force acting on the charged particle is always perpendicular to its direction of motion, a magnetic field can never do work on the particle (or change its kinetic energy).

NOTES

Crucial Physics

- Electricity and magnetism are not two separate phenomena, but are intimately connected.
- Earth possesses a magnetic field. The south magnetic pole of Earth is located near the geographic North Pole and the north magnetic pole of Earth is located near the geographic South Pole.
- Magnets have two poles (north and south) and can attract and repel each other. The magnetic force acts at a distance (contact is not needed). Like poles repel, unlike poles attract.
- A magnetic field is a model used by scientists to describe the force the magnet producing the field would exert on an object in the field, such as a charge moving through the field, or a magnetic compass placed in the field. By convention, magnetic field lines are drawn away from the north pole of the magnet and toward the south pole of the magnet. A magnetic field may be mapped using a compass.
- A current-carrying wire (containing moving charges) produces a magnetic field. To find the direction of the magnetic field, place a magnetic compass near the wire. Alternatively, if you place your left-hand thumb in the direction of the electron current, your fingers wrap around the wire in the direction of the magnetic field.
- Magnetic fields from more than one source add together at every point in space, as vectors to determine both the magnitude and direction of the net magnetic field.

Learning Outcomes	Location in the Section	Evidence of Understanding
Map a magnetic field by using a magnetic compass.	***Investigate*** Part A, Step 4 ***Physics Talk*** ***Physics to Go*** Questions 1, 3, 5-6 ***Inquiring Further***	Students map out the magnetic field of a bar magnet using a magnetic compass. Magnetic fields are further described and discussed to include the magnetic field produced around a current-carrying wire. Students apply what they have learned to map out the magnetic field for various situations.
Look for a relationship between an electric current and a magnetic field.	***Investigate*** Part B, Steps 3-4 ***Physics Talk*** ***Physics to Go*** Questions 2-7	Students observe the deflection of a magnetic compass with a wire coiled around it when it is connected in a closed circuit and current flows through the coil of wire. They also observe that this deflection is dependent on the direction of the current. The *Physics Talk* discusses the direction and strength of the magnetic field produced by a current-carrying wire, and students apply their knowledge to various situations.

NOTES

Section 1 Materials, Preparation, and Safety

Materials and Equipment

PLAN A		
Materials and Equipment	**Group (4 students)**	**Class**
Magnet, large bar	2 per group	
Compass	1 per group	
Scissors	1 per group	
DC hand-operated generator	1 per group	
Alligator clip leads (singles)	2 per group	
Base for mini-light bulbs	1 per group	
Paper clips, pkg 100		1 per class
Sandpaper, 60 grit	1 per group	
Mini-light bulb	2 per group	
Tape, masking		6 per class
Wire, #24, magnet, 60-ft roll		1 per class
Piece of paper*	1 per student	
Pencil*	1 per student	

*Additional items needed not supplied

Time Requirement

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

Teacher Preparation

- Have one set of equipment pre-assembled to show students how to connect the generator and the bulbs.
- Prepare a transparency of *Part A, Step 4.c)* to ensure that students understand how to plot a magnetic field with a compass.
- Check all the compasses and magnets to ensure the correct end of the compass points north, and that the magnets have the correct number of poles in the correct positions. (Magnets that are stored incorrectly may reverse poles.)
- Warn students not to crank the hand generators very fast. The gears inside usually are nylon, and can be stripped.
- Test all the light bulbs to ensure they are working properly.
- Pre-cut the insulated wire to the correct lengths for use in *Part B*.

Safety Requirements

- Remind students that electricity can be dangerous. Although the currents and voltages are not likely to be harmful, the possibility for harm is there for students who may have heart or other bio-electrical problems.
- Light bulbs may break when being inserted into some sockets if they are not correctly aligned, or overtightened. Dispose of broken bulbs immediately so they do not shatter and cause a broken glass hazard.
- If any glass breaks, clean up the pieces immediately and avoid handling broken pieces when possible.
- Caution students not to bring the magnets near any items that have magnetic strips that code information (for example, a credit card) or other magnetic media.

CHAPTER 7

Materials and Equipment

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Magnet, large bar	2 per group	
Compass	1 per group	
Scissors		1 per class
DC hand-operated generator		1 per class
Alligator clip leads (singles)		2 per class
Base for mini-light bulbs		1 per class
Paper clips, pkg 100		1 per class
Sandpaper, 60 grit		1 per class
Mini-light bulb		1 per class
Tape, masking		6 per class
Wire, #24, magnet, 60-ft roll		1 per class
Piece of paper*	1 per student	
Pencil*	1 per student	

*Additional items needed not supplied

Time Requirement

- Allow one class period or 45 minutes to complete *Part B* of the *Investigate* portion of this section plus the *Physics Talk* and other portions of the section from the *Pacing Guide*.

Teacher Preparation

- Have the generator, light bulb and compass circuit pre-assembled and tested in a position where students can clearly see the demonstration portion of the investigation.
- Prepare a transparency of *Part A, Step 4.c)* to insure that students understand how to plot a magnetic field with a compass.
- Check all the compasses and magnets to insure the correct end of the compass points north, and that the magnets have the correct number of poles in the correct positions. (Magnets that are stored incorrectly may develop multiple poles or reversed poles.)
- Be aware not to crank the hand generators very fast. The gears inside usually are nylon, and can be stripped.

Safety Requirements

- Light bulbs may break when being inserted into some sockets if they are not correctly aligned, or over tightened. Dispose of broken bulbs immediately so they do not shatter and cause a broken glass hazard.
- If any glass breaks, clean up the pieces immediately and avoid handling broken pieces when possible.
- Caution students not to bring the magnets near any items that have magnetic strips that code information (for example, a credit card) or other magnetic media.

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Learning content vocabulary	***Chapter Challenge*** Physics Corner	**Augmentation** • Students with language-based learning disabilities and memory difficulties struggle to read, remember, and use content area vocabulary. One strategy that helps students with vocabulary is to learn how to read the words before they begin learning the concepts. Post the list of vocabulary words from the *Physics Corner* in a prominent spot in the classroom. Read all of the words aloud, then ask students to do the same. If they recognize the words, they can more easily access and comprehend the new content. Also, students are more likely to use vocabulary when answering questions if the words are visible because they do not have to worry about making spelling errors or pronunciation errors when they are asked to share their answers with the class. **Accommodation** • Some students may need to learn a few words at a time and practice reading those words aloud and then add a few more until all vocabulary can be recognized and read.
Understanding gravitational and magnetic fields	***Investigate*** Part B: Steps 6-7 ***Physics Talk*** ***Checking Up*** Question 3	**Augmentation** • Students who are concrete learners may struggle to understand the abstract concept of a magnetic or gravitational field because they are unable to see the forces and can only feel the effects of the forces. • Make an explicit connection between the diagram drawn in *Investigate, Part A: Step 4* and the idea that this diagram represents what the field would look like if it were visible. Then show students images that represent Earth's gravitational field and ask them to identify similarities and differences with the magnetic-field diagram they have drawn.
Understanding which direction electric current flows	***Physics Talk***	**Augmentation** • Students cannot see the electric current flowing and may not remember everything they learned about electric current in *Chapter 6*. Review the concept that electric current flows from the negative terminal of a battery to the positive terminal by giving students batteries to look at and asking them to draw the battery, label the positive and negative terminals, and draw arrows to represent the direction of the current. • Some students may also confuse the direction of the current with the direction of the magnetic field. Ask them to draw the direction of the current with one color and the direction of the magnetic field with another color. Discuss the direction of electron flow and the direction of current, which are conventionally in opposite directions.
Using the features of nonfiction text	***Physics to Go***	**Augmentation** • Students know that they are supposed to use the words in a textbook to help them understand new concepts, but they are often not aware of the value of using the graphical features including photos, diagrams, and graphs. Provide direct instruction to teach students ways to use these graphical features to help them answer questions. For example, use the diagram in the *Physics Talk* to answer *Question 1* in the *Physics to Go*. **Accommodation** • Provide page numbers for students to reference when they are answering each *Physics to Go* question.

Strategies for Students with Limited English-Language Proficiency

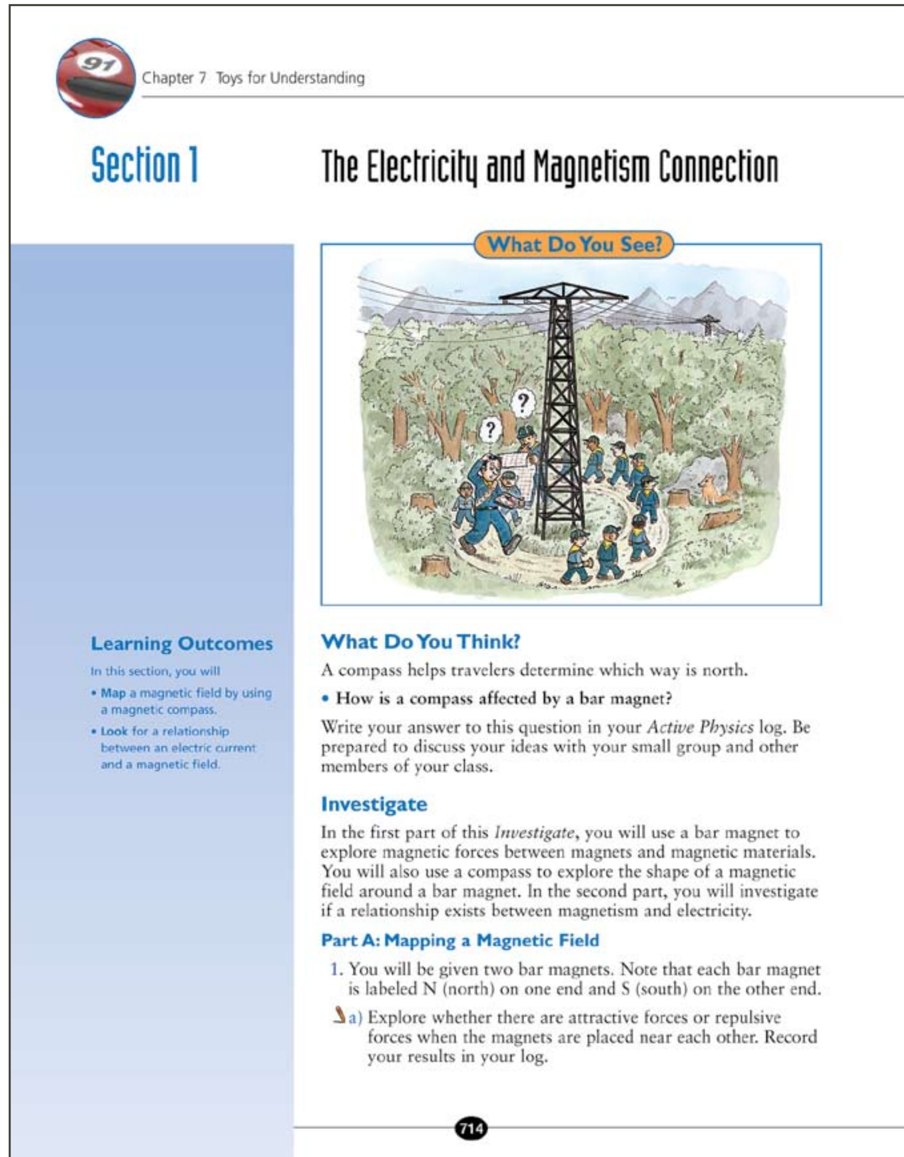
Learning Issue	Reference	Augmentation
Vocabulary comprehension	***Investigate*** Part A: Step 1.a)	Students may have difficulty with the terms "attractive" and "repulsive." Tell them that forces that "attract" move toward each other. Forces that "repulse" retreat or move away from each other.
Comprehension	***Investigate*** Part A: Steps 2 and 4	When you get to *Step 2*, hold a class discussion about the term "magnetic field." Have students discuss what they think the term means. Then have the discussion again once students have finished *Step 4*. Clear up misunderstandings, if necessary.
Vocabulary comprehension	***Investigate*** Part A: Steps 2 and 3.b)–c)	Clarify that "dependable" in this context means to produce the same result in repeated trials. A compass is dependable because it usually is not placed near a strong magnetic field.
Comprehension	***Investigate*** Part A: Step 4	ELL students may associate the term "pole" with rotation; for example, Earth rotating on an imaginary axis passing through the poles. However, because there is no obvious association of rotation with magnets, students may be confused by the term "pole." Reinforce the association by explaining that the term "pole" is used because one end, or pole, of a compass needle points toward Earth's magnetic north pole in the absence of any other magnetic field.
Comprehension	***Investigate*** Part B: Steps 5-6	For students to fully recognize that the compass and the wire do not need to be in contact, you may wish to have students repeat the series circuit from *Part B: Step 2*, without the wire touching the compass. Instruct them to set up the circuit, place the compass near the wire, and watch the needle as they turn the generator handle. Ask an ELL volunteer to explain the term "action at a distance." Then give students time to address *Steps 5.a)*, *6.a)*, and *6.b)* in their *Active Physics* logs. Hold a class discussion to check students' understanding of parallels between magnetism and gravity, and between "magnetic field" and "gravitational field."
Comprehension	***Physics Talk***	Have students demonstrate the left-hand rule to test their understanding. You may wish to have them trace the direction of the magnetic field with the fingers of their right hands. This exercise will be helpful to kinesthetic learners as well as to ELL students.
Comprehension	***Active Physics Plus*** Is There an Equation for the Strength of a Magnetic Field?	The magnetic field strength equation involves numbers that can be difficult to work with. Collaborate with students' math teachers to determine student proficiency with negative exponents. You may wish to work through a sample equation on the board, with help from volunteers, before having students work through calculations on their own.

SECTION 1

Teaching Suggestions and Sample Answers

What Do You See?

Elicit students' initial impressions of what they see in the illustration. Using the overhead of the illustration as a focal point, have a class discussion on the illustration. Students might describe how the group of hikers is going around in a circle—and perhaps the nearby power lines are affecting the compasses. Record students' ideas and revisit them later as you reach the end of this section. The *What Do You See*? illustration is meant to engage students' curiosity by using a visual technique and prepares them for them for the question in the *What Do You Think?* section.



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Section 1 The Electricity and Magnetism Connection

What Do You See?

Learning Outcomes

In this section, you will

- **Map** a magnetic field by using a magnetic compass.
- **Look** for a relationship between an electric current and a magnetic field.

What Do You Think?

A compass helps travelers determine which way is north.

- **How is a compass affected by a bar magnet?**

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 the first part of this *Investigate*, you will use a bar magnet to explore magnetic forces between magnets and magnetic materials. You will also use a compass to explore the shape of a magnetic field around a bar magnet. In the second part, you will investigate if a relationship exists between magnetism and electricity.

Part A: Mapping a Magnetic Field

1. You will be given two bar magnets. Note that each bar magnet is labeled N (north) on one end and S (south) on the other end.

a) Explore whether there are attractive forces or repulsive forces when the magnets are placed near each other. Record your results in your log.

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Students' Prior Conceptions

As students work with magnets and map magnetic fields to observe what happens between a magnetic field and electric current, it is important for you to encourage students to describe the nature of charge in their own words, and the effects on a compass by a charged field.

1. **Students may believe that a charged object has only one kind of charge. Concomitant with this belief is that there is only one kind of charge and that it is negative; positive charge, deficit of negative charge, has no charge at all.** In discussing charged and uncharged objects, you may review the neutrality of atoms and the fact that atoms, and subsequently all materials, consist of both positively charged areas, the dense, central nucleus, and negatively charged areas, the electron cloud surrounding the nucleus. Hence, a charged body must consist of two types of charges that are unbalanced. Remind students that only electrons move within and among atoms of materials to create charged objects. In comparison, magnetic poles only come in pairs (called a dipole), but do not carry any net electric charge. No single magnetic pole has ever been discovered. Hence, the magnetism of a north magnetic pole is not due to the absence of south poles but refers to the direction of the field. Likewise, when an object is magnetized, there is no transfer of magnetic pole from one object to another as it occurs with charges.
2. **The iconic symbols for charge, either the symbol "+" or the symbol "–," are absolute designations.** This also relates to the terms "south" and "north" for the poles of a bar

What Do You Think?

Ask students to use their own experiences and the illustration to help them answer the question. Then have a class discussion, eliciting and recording students' ideas. Show them one of the magnetic compasses they will be using during the *Investigate*. Ask them what physics concepts they think are used to explain whether there is or is not an effect between a compass and a bar magnet. Encourage them to ask questions of each other during the discussion and remind them to record their ideas in their log.

What Do You Think?

A Physicist's Response

Magnets interact with other magnets. They can either attract each other (a pull on each magnet from the other) or repel each other (a push on each magnet from the other). A simple magnetic compass used to show direction is made of a tiny bar magnet that aligns itself with Earth's magnetic field when no other magnetic field is nearby. This small magnet is free to pivot and align itself with the net magnetic field. When a bar magnet is nearby, the compass will be affected by the bar magnet. The north magnetic pole of the compass magnet will be attracted to the south magnetic pole of the bar magnet, and the south magnetic pole of the compass magnet will be attracted to the north magnetic pole of the bar magnet. This will cause the compass needle (magnet) to rotate so that it aligns itself with the magnetic field of the bar magnet. Students will observe this during the *Investigate*.

An electric current produces a magnetic field, so a magnetic compass also interacts with currents. A single straight current-carrying wire will produce a circular magnetic field around it, which will affect a compass. Note, however, in the *What Do You See?* illustration that the power tower is designed to hold the current-carrying wires from the power plants above the ground. However, the illustration is a little misleading. The transmission lines may very well be affecting the compasses, but the magnetic field they develop would not be in the direction that the hikers are traveling. For the magnetic field to be circular around the power tower, a current would need to flow down the power tower to the ground to cause the compasses to always point in the circular direction that the hikers are walking in. To learn more about the transmission of electricity, consider doing an Internet search on "power lines."

Investigate

Part A: Mapping a Magnetic Field

1.a)

Students' record attractive forces when opposite poles are brought together and repulsive forces when like poles are near one another. Some students may investigate what occurs when a pole is brought near the center of a bar magnet.

magnet. Student misconceptions arise from erroneous presentations of these symbols in textbooks. You should emphasize that these terms are historical conventions. For a positively charged object, you speak of positive charge as one that has a deficit of electrons. For a magnet, it is the alignment of atoms within the material of the magnet that produces a dipole. Actually, a bar magnet has a myriad microscopic north and south poles, and these poles always occur in pairs. It is the alignment of the individual dipoles that give rise to the macroscopic field, rather than the excess or deficit of one type of pole.

3. **The electrostatic force between two charged objects is independent of the distance between them.** Students perceive that the electric or the magnetic field is static in nature and the distance between a charged object and a field is irrelevant. Assist students in altering this misconception by listening carefully and guiding the analysis of the data obtained by the deflection of the compass as students map the magnetic field. Allowing students to manipulate a pair of magnets will quickly convince them that both the repulsive and attractive forces depend upon distance. Listen to student explanations to ascertain that they recognize the strength of the deflection of the compass or how the force between two magnetic poles changes with the distance between the poles. Students may leap to the conclusion that the strength of a magnetic field is inverse-square as is the field surrounding

1.b)

Students' results will vary greatly with the type of magnet used. Alnico magnets are typically much stronger than the standard steel magnets, and will pick up many more paper clips.

Teaching Tip

Magnets that have been stored improperly may have multiple poles. Check the magnets before issuing them to students and discard those with more than two poles. Caution students not to turn the generator handle too rapidly because it could break the generator.

2.a)

Students should note that the needle does not change direction. They may be confused when the case rotates, thinking that the direction changes because the compass needle points toward different direction marks when the case rotates. Consider discussing how a compass is used.

3.a)

Students should describe the movement of the compass needle when it is brought near the bar magnet. They should record that different poles of the magnets attract different ends of the compass when the magnets are nearby.

3.b)

The compass aligns with the magnetic field of the magnet, rather than Earth's magnetic field. The compass will not point toward north when the bar magnet is nearby, unless the bar magnet happens to be oriented that way.

3.c)

Students should recognize that compasses align with the prevailing magnetic field, and do not just point toward the geographic North and South Poles. If another magnetic field is nearby, and it conflicts with Earth's magnetic field, the compass will point in the direction that is the vector sum of these two fields.

4.a)

Have students outline both the bar magnet and the compass with a pencil to indicate their positions. With the compass near the bar magnet, students should mark the position of the head and the tail of the arrow on the circle that they drew.

Teaching Tip

To illustrate a magnetic field in greater detail than is possible with a compass, you can use a magnet and iron filings. Students can place a sheet of paper over the top of the magnet, and then sprinkle iron filings lightly on top of the paper. To reduce friction and allow the filings to show the magnetic field, students should gently tap the paper to allow the filings to align with the magnetic field. A clear image of the magnetic field will appear. Caution students to be careful and not allow the iron filings to touch the magnet, since removing them is difficult. A 3-dimensional magnetic field can be produced in a similar manner with iron filing. A commercial apparatus to show this is available from science supply stores.

Students' Prior Conceptions *(continued)*

a point charge. Point out that due to the dipole nature of magnetism, the dependence of field upon distance is more complicated.

4. **Students perceive that magnetic fields are two-dimensional**. Students may have seen demonstrations with magnets or even explored magnetic fields with iron filings on a sheet of paper or between two sheets of plastic that portray the resulting field in a flat manner, disregarding the 3-D nature of a field. Address this misconception by extending the *Investigate* to encourage students to move the compass off of the table and explore the nature of the magnetic field above and even below the bar magnet if it is suspended from a string. Commercial devices that show three-dimensional magnetic fields are also available.

5. **Electrical or magnetic fields do not exist unless there is something to detect them**. You can modify this misconception by asking students if the field of the magnet only exists when the compass detects it or is it always there. If the magnetic field is detected, a small piece of iron (say a single staple), ask students: How does the staple know that there is a magnetic field in the region if the field is not present?

b) Determine the strength of one of the bar magnets by measuring how many paper clips the magnet can lift.

2. The needle of a compass is a small bar magnet that is placed on a point so that it can rotate easily. It can be used as a magnetic-field detector. Any magnet or magnetic material will affect the compass. When the compass is not near any magnet or magnetic material, it aligns itself with Earth's *magnetic field* and indicates which direction is north.

Note the direction of the compass needle. Rotate the casing.

a) Did the compass needle change direction?

3. Set the magnetic compass on the table and bring another type of magnet, such as a bar magnet, into the area near the compass needle. But do not get them too close because a strong magnet can ruin a compass needle if it gets too close.

a) Describe your observations.

b) What happens to the dependable north-pointing property of the compass?

c) How dependable is the compass at pointing north when it is placed in a region where there are other magnetic effects, in addition to Earth's magnetic field?

4. You will now make a map of the magnetic field of the rectangular bar magnet. Place the magnet on a piece of paper and trace its position. Label which end of the bar magnet is the N pole and which is the S pole. Keep the compass a centimeter or two away from the magnet to avoid ruining the compass. Place the compass at one location and mark the direction it points. Remove the compass.

Note: If the bar magnet is an extremely strong one, you should keep it close enough to the compass to see the effects, but not close enough to damage the compass.

a) Sketch a small arrow at the location from which you removed the compass to show the way it pointed. Pay attention to which end of the compass needle points to which pole of the magnet.

b) Place the compass at a second location near the tip of the first arrow you sketched. Remove the compass and sketch another small arrow in this location to show the way the compass pointed. See the diagram at the top of the following page.

4.b)

Students should adjust the position of the compass so that when they draw a circle around it, the circle touches the previous circle, and the head of one arrow points to the tail of the other arrow in the adjacent circle. (See the diagram in *Step 4.c)* of the *Student Edition.*)

CHAPTER 7

4.c)

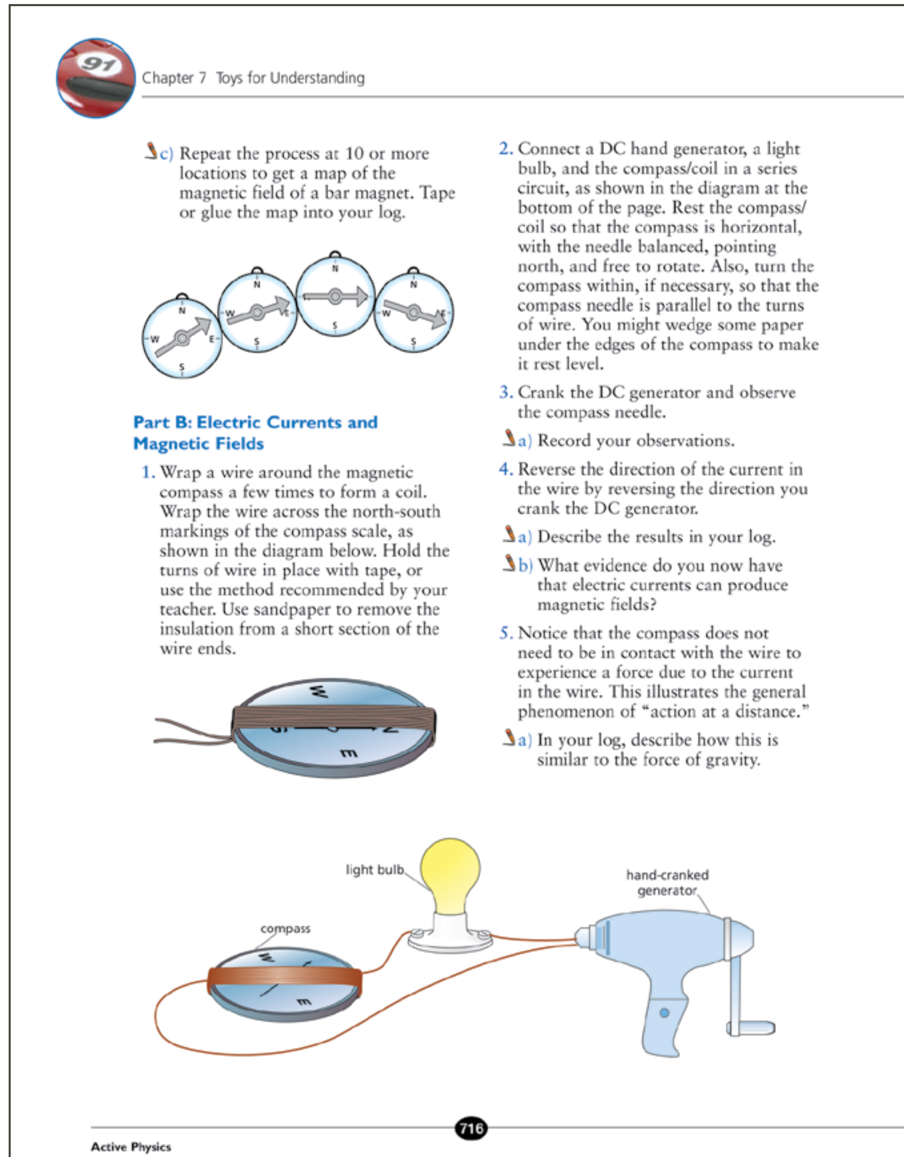
The process listed for *Step 2.b)* should be continued until a complete field line is sketched (or as close as possible). Completing a second field line on the opposite side of the magnet is desirable.

Teaching Tip

If any ferrous metals (iron, steel, etc.) are nearby, they will affect the magnetic field of the magnet, and how the compass responds. For this reason, this investigation should not be performed on the students' desks if they have steel supports beneath their desktops.

To extend and reinforce the magnetic-field-line concept, do the following. Place one of the bar magnets on an overhead projector, and place a transparent sheet of plastic over the magnet. Lightly sprinkle iron filings on the plastic and then gently tap the plastic to loosen filings. The filings will then align with the magnetic field giving a better representation of the field in two dimensions.

If desired, special jars that are filled with iron filings in oil that have a place to insert the magnet are available to show the field in three dimensions.



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c) Repeat the process at 10 or more locations to get a map of the magnetic field of a bar magnet. Tape or glue the map into your log.

Part B: Electric Currents and Magnetic Fields

1. Wrap a wire around the magnetic compass a few times to form a coil. Wrap the wire across the north-south markings of the compass scale, as shown in the diagram below. Hold the turns of wire in place with tape, or use the method recommended by your teacher. Use sandpaper to remove the insulation from a short section of the wire ends.

2. Connect a DC hand generator, a light bulb, and the compass/coil in a series circuit, as shown in the diagram at the bottom of the page. Rest the compass/coil so that the compass is horizontal, with the needle balanced, pointing north, and free to rotate. Also, turn the compass within, if necessary, so that the compass needle is parallel to the turns of wire. You might wedge some paper under the edges of the compass to make it rest level.

3. Crank the DC generator and observe the compass needle.

a) Record your observations.

4. Reverse the direction of the current in the wire by reversing the direction you crank the DC generator.

a) Describe the results in your log.

b) What evidence do you now have that electric currents can produce magnetic fields?

5. Notice that the compass does not need to be in contact with the wire to experience a force due to the current in the wire. This illustrates the general phenomenon of "action at a distance."

a) In your log, describe how this is similar to the force of gravity.

light bulb
compass
hand-cranked generator

716 Active Physics

Part B: Electric Currents and Magnetic Fields

1.

If insulated wire is used, strip the insulation off the ends of the wire. If magnet wire that is covered with a varnish is used, sand the ends of the wire to remove the varnish and ensure a good electrical contact. Have students turn the compass so that the compass needle points parallel to the wire coils around the compass. Taping the coils in place makes the rest of the investigation easier.

2.

Students set up and adjust the compass in a circuit according to directions.

3.a)

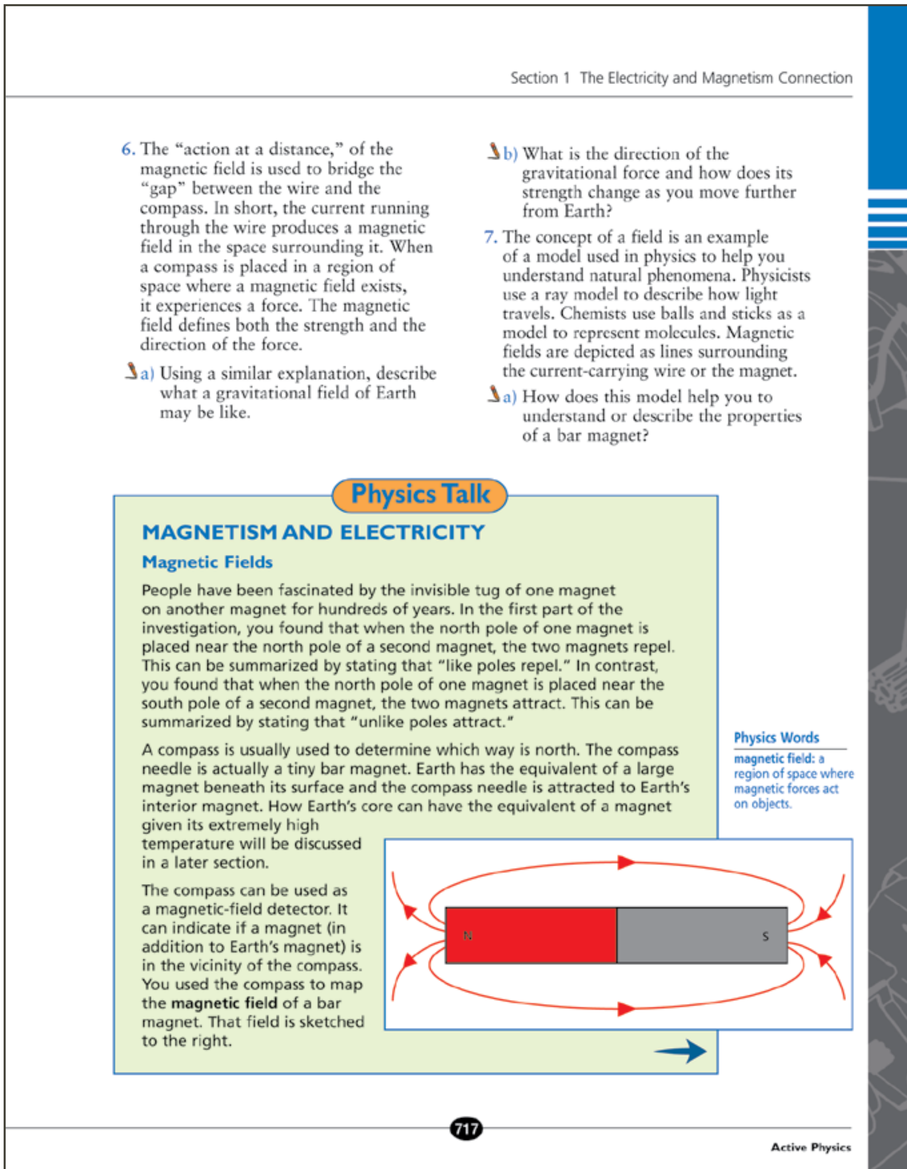
Students should observe the compass needle swing around so that it points approximately perpendicular to the coils. The harder they crank the generator, the more nearly perpendicular to the coils the compass needle comes.

4.a)

Reversing the current reverses the direction of the compass needle, until it is almost perpendicular to the coils again.

4.b)

Students should use their observations to support the idea that a current in a coil of wire sets up a magnetic field that may be stronger than Earth's magnetic field.


Section 1 The Electricity and Magnetism Connection

6. The "action at a distance," of the magnetic field is used to bridge the "gap" between the wire and the compass. In short, the current running through the wire produces a magnetic field in the space surrounding it. When a compass is placed in a region of space where a magnetic field exists, it experiences a force. The magnetic field defines both the strength and the direction of the force.

a) Using a similar explanation, describe what a gravitational field of Earth may be like.

b) What is the direction of the gravitational force and how does its strength change as you move further from Earth?

7. The concept of a field is an example of a model used in physics to help you understand natural phenomena. Physicists use a ray model to describe how light travels. Chemists use balls and sticks as a model to represent molecules. Magnetic fields are depicted as lines surrounding the current-carrying wire or the magnet.

a) How does this model help you to understand or describe the properties of a bar magnet?

Physics Talk

MAGNETISM AND ELECTRICITY

Magnetic Fields

People have been fascinated by the invisible tug of one magnet on another magnet for hundreds of years. In the first part of the investigation, you found that when the north pole of one magnet is placed near the north pole of a second magnet, the two magnets repel. This can be summarized by stating that "like poles repel." In contrast, you found that when the north pole of one magnet is placed near the south pole of a second magnet, the two magnets attract. This can be summarized by stating that "unlike poles attract."

A compass is usually used to determine which way is north. The compass needle is actually a tiny bar magnet. Earth has the equivalent of a large magnet beneath its surface and the compass needle is attracted to Earth's interior magnet. How Earth's core can have the equivalent of a magnet given its extremely high temperature will be discussed in a later section.

The compass can be used as a magnetic-field detector. It can indicate if a magnet (in addition to Earth's magnet) is in the vicinity of the compass. You used the compass to map the **magnetic field** of a bar magnet. That field is sketched to the right.

N S

Physics Words
magnetic field: a region of space where magnetic forces act on objects.

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Teaching Tip

To demonstrate to students that contact is not necessary, make a large coil of wire hooked up in a circuit and place a compass inside the coil without contact with the wires.

5.a)

The force exerted by the magnetic field is similar to that of the gravitational field because direct contact is not necessary for the force to work.

7-1a **Blackline Master**

6.a)

The gravitational field of Earth exerts a force on a mass, the same way that a magnetic field exerts a force on a compass (another small magnet).

6.b)

Earth's gravitational field is directed toward the center of Earth, and gets weaker as you move away from Earth's surface.

7.a)

The field-line model helps students picture the direction and shape of the magnetic field. Point out that field lines are an artificial construct used to help picture the magnetic field, and do not actually exist.

Physics Talk

This *Physics Talk* supports students' observations of how two magnets interact, how an electric current and magnet interact, and how the magnetic fields are mapped out. Students are provided with more in-depth information on magnets and magnetic fields for both a permanent magnet, and those induced by a current (after reading about Oersted's experiment).

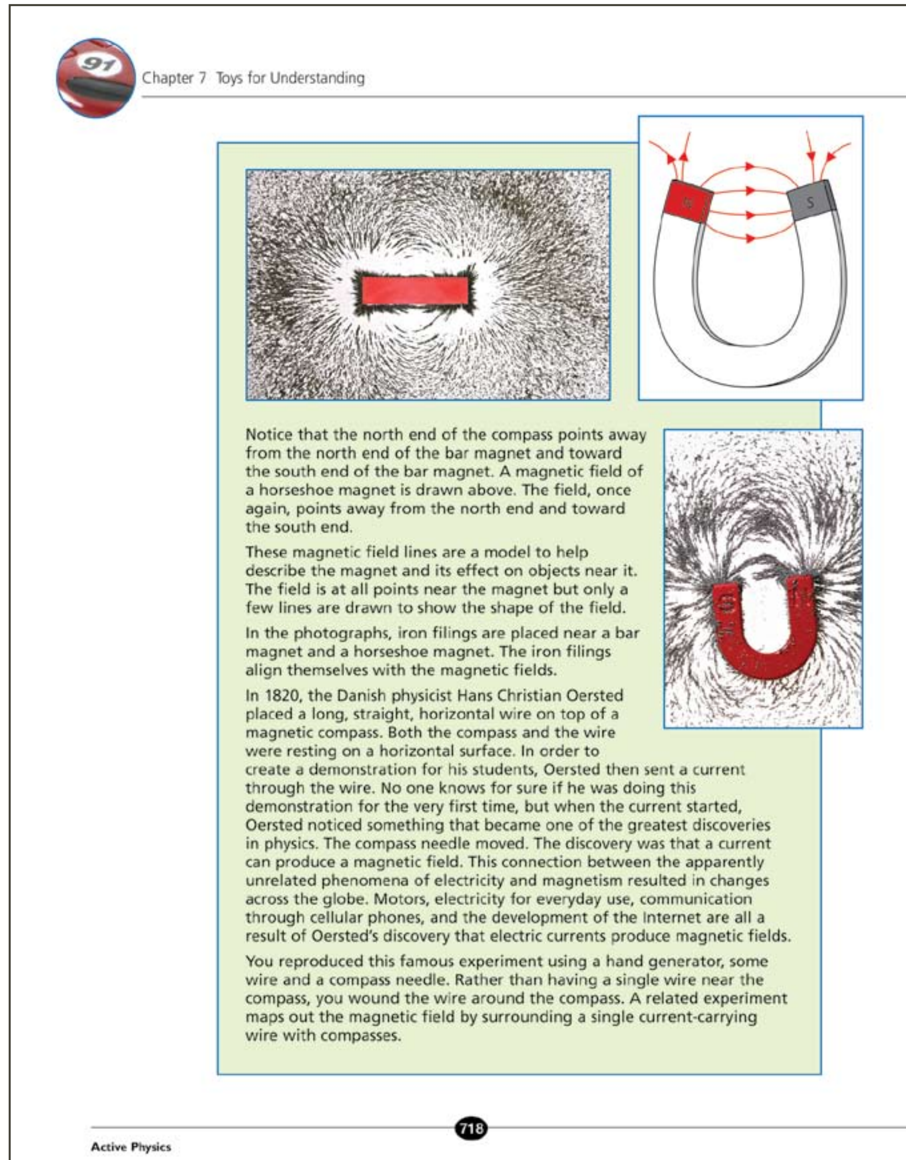
Review the basic properties of magnets: Magnets have two poles, north and south. Like poles repel. Unlike poles attract. Discuss how a compass is just a tiny bar magnet that aligns itself with Earth's magnetic field when no other magnetic fields are nearby. Ask students how the compass behaved when they brought it near the bar magnet.

Discuss how the compass can be used to draw the magnetic field lines of a magnet, as they did in the *Investigate*. Emphasize that the magnetic field lines are always drawn pointing away from the north pole of a magnet toward the south pole of the magnet. Consider mentioning that because the magnetic north pole of a compass points to the geographic North Pole of Earth, the geographic North Pole of Earth is Earth's magnetic south pole.

If possible, demonstrate how iron fillings line up with the magnetic field lines. This can be done using an overhead projector, a magnet, and iron filings placed on a transparency sheet. Consider showing the field in three dimensions using iron filings that have been placed in special fluid-filled jars that have a place to insert the magnet.

Discuss Oersted's experiment (that students reproduced in the *Investigate*) in which he discovered that a current-carrying wire produces a magnetic field. Emphasize the importance of this experiment being the first documented link between electricity and magnetism. This link resulted in many technological developments as described in the student text.

Describe mapping out the magnetic field produced by the current-carrying wire using a compass and using the left-hand rule. Provide students with several examples where they try to determine the direction of the induced magnetic field due to the current.



Chapter 7 Toys for Understanding

Notice that the north end of the compass points away from the north end of the bar magnet and toward the south end of the bar magnet. A magnetic field of a horseshoe magnet is drawn above. The field, once again, points away from the north end and toward the south end.

These magnetic field lines are a model to help describe the magnet and its effect on objects near it. The field is at all points near the magnet but only a few lines are drawn to show the shape of the field.

In the photographs, iron filings are placed near a bar magnet and a horseshoe magnet. The iron filings align themselves with the magnetic fields.

In 1820, the Danish physicist Hans Christian Oersted placed a long, straight, horizontal wire on top of a magnetic compass. Both the compass and the wire were resting on a horizontal surface. In order to create a demonstration for his students, Oersted then sent a current through the wire. No one knows for sure if he was doing this demonstration for the very first time, but when the current started, Oersted noticed something that became one of the greatest discoveries in physics. The compass needle moved. The discovery was that a current can produce a magnetic field. This connection between the apparently unrelated phenomena of electricity and magnetism resulted in changes across the globe. Motors, electricity for everyday use, communication through cellular phones, and the development of the Internet are all a result of Oersted's discovery that electric currents produce magnetic fields.

You reproduced this famous experiment using a hand generator, some wire and a compass needle. Rather than having a single wire near the compass, you wound the wire around the compass. A related experiment maps out the magnetic field by surrounding a single current-carrying wire with compasses.

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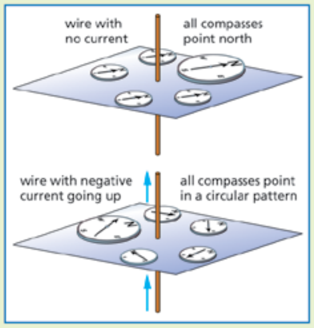
Active Physics

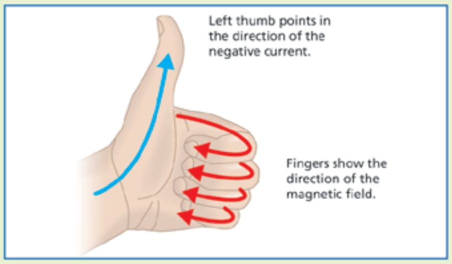
Consider asking students their ideas about fields and then discuss how fields are used in science, as a way to describe what force would occur between an object, such as a bar magnet, and another object (such as a compass) if it were placed near it. Emphasize that the concept of the field is a model that scientists use to explain natural phenomena and interactions between objects. Describe the gravitational field and the magnetic field and consider pointing out their similarities and differences. Mention that phenomena involving electric charge can be described using electric fields.

CHAPTER 7

In the diagram at the right, you can see that when no current is flowing in the wire, all the compass needles point north. When a current is flowing, the compass needles all point in different directions.



The important concept is that the current-carrying wire can produce a magnetic field that can be detected with compasses. The magnetic field is circular about the wire. The direction of the magnetic field can be found experimentally with a compass. This direction can be recalled by using the left-hand rule. Point your left thumb in the direction of the current (the electron current travels from the negative terminal of a battery to the positive terminal). The direction of the curve of your fingers indicates the direction of the circular magnetic field.



Notice that the compass does not need to be in contact with the wire to experience a force due to the current in the wire. This situation illustrates the general phenomenon of "action at a distance." In other words, the current produces a force (an action) without touching (at a distance). In order to better understand how this occurs, the concept of the magnetic field is introduced to describe the empty space between the wire and the compass. The current in the wire produces a magnetic field in the space surrounding it. When a compass is placed in a region of space where a magnetic field exists, it experiences a force.

Checking Up

1.

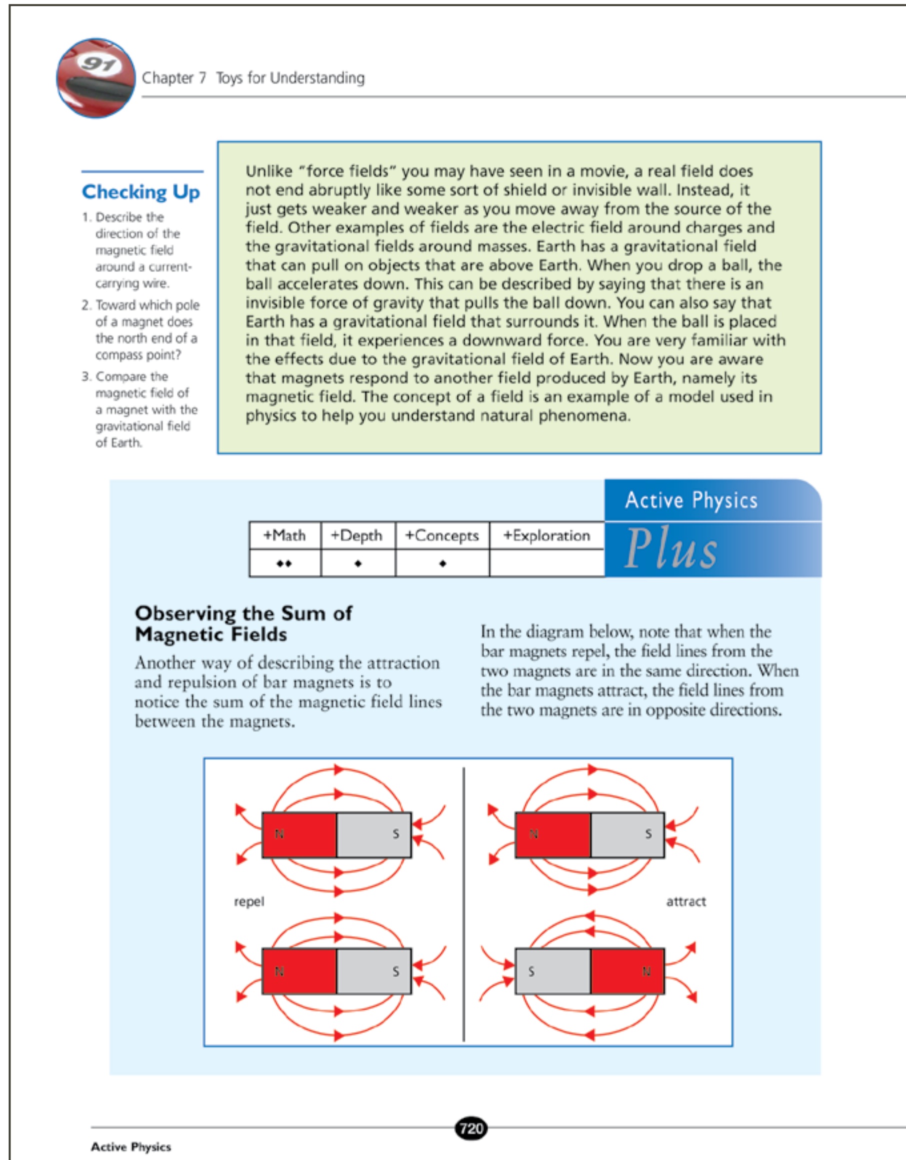
To indicate the direction of the field around a current-carrying wire, point the thumb of your left hand in the direction of the electron flow. The fingers of your left hand will then curl around the wire in the direction the magnetic field is pointing at various positions in space.

2.

The north end of a magnetic compass points toward the south magnetic pole of a magnet. In the case of Earth's magnetic field, it points toward Earth's south magnetic pole, which is located at Earth's geographic North Pole.

3.

The magnetic field of a magnet is similar to the gravitational field of Earth in that both are fields that describe what force would be exerted on an object that interacts with the field. Both are due to forces that act at a distance (do not require direct contact). Differences are that Earth's magnetic field always points toward Earth's center of mass, and only attracts mass, pulling it along its field lines, toward Earth. A magnet's field points toward its north pole and away from its south pole and interacts with other magnetic fields (produced by another magnet or a charge cutting across magnetic field lines).



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Checking Up

1. Describe the direction of the magnetic field around a current-carrying wire.
2. Toward which pole of a magnet does the north end of a compass point?
3. Compare the magnetic field of a magnet with the gravitational field of Earth.

Unlike "force fields" you may have seen in a movie, a real field does not end abruptly like some sort of shield or invisible wall. Instead, it just gets weaker and weaker as you move away from the source of the field. Other examples of fields are the electric field around charges and the gravitational fields around masses. Earth has a gravitational field that can pull on objects that are above Earth. When you drop a ball, the ball accelerates down. This can be described by saying that there is an invisible force of gravity that pulls the ball down. You can also say that Earth has a gravitational field that surrounds it. When the ball is placed in that field, it experiences a downward force. You are very familiar with the effects due to the gravitational field of Earth. Now you are aware that magnets respond to another field produced by Earth, namely its magnetic field. The concept of a field is an example of a model used in physics to help you understand natural phenomena.

Active Physics Plus

+Math	+Depth	+Concepts	+Exploration
••	•	•	

Observing the Sum of Magnetic Fields

Another way of describing the attraction and repulsion of bar magnets is to notice the sum of the magnetic field lines between the magnets.

In the diagram below, note that when the bar magnets repel, the field lines from the two magnets are in the same direction. When the bar magnets attract, the field lines from the two magnets are in opposite directions.

Active Physics 720

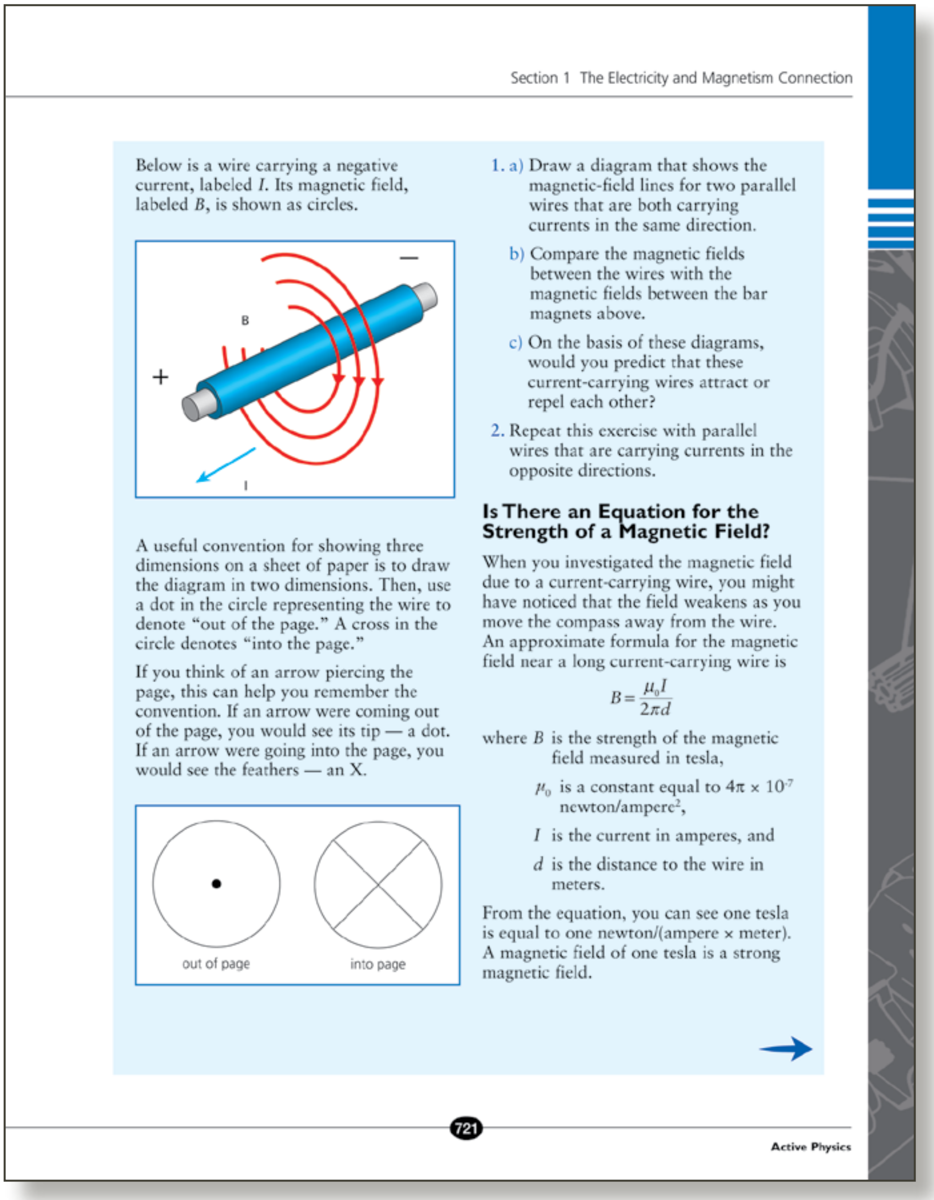
Active Physics Plus

This *Active Physics Plus* is geared toward increasing students' depth of understanding and further introducing the concepts of magnetic fields and engaging students in a more mathematical approach.

Observing the Sum of Magnetic Fields

Discuss the diagrams of the bar magnets. Emphasize that the magnetic field lines always point away from the north pole and toward the south pole of a magnet.

Describe the convention scientists use in diagrams to indicate different directions.



Section 1 The Electricity and Magnetism Connection

Below is a wire carrying a negative current, labeled *I*. Its magnetic field, labeled *B*, is shown as circles.

A useful convention for showing three dimensions on a sheet of paper is to draw the diagram in two dimensions. Then, use a dot in the circle representing the wire to denote "out of the page." A cross in the circle denotes "into the page."

If you think of an arrow piercing the page, this can help you remember the convention. If an arrow were coming out of the page, you would see its tip — a dot. If an arrow were going into the page, you would see the feathers — an X.

1. a) Draw a diagram that shows the magnetic-field lines for two parallel wires that are both carrying currents in the same direction.

   b) Compare the magnetic fields between the wires with the magnetic fields between the bar magnets above.

   c) On the basis of these diagrams, would you predict that these current-carrying wires attract or repel each other?

2. Repeat this exercise with parallel wires that are carrying currents in the opposite directions.

Is There an Equation for the Strength of a Magnetic Field?

When you investigated the magnetic field due to a current-carrying wire, you might have noticed that the field weakens as you move the compass away from the wire. An approximate formula for the magnetic field near a long current-carrying wire is

$$B = \frac{\mu_0 I}{2\pi d}$$

where B is the strength of the magnetic field measured in tesla,

μ_0 is a constant equal to $4\pi \times 10^{-7}$ newton/ampere^2,

I is the current in amperes, and

d is the distance to the wire in meters.

From the equation, you can see one tesla is equal to one newton/(ampere × meter). A magnetic field of one tesla is a strong magnetic field.

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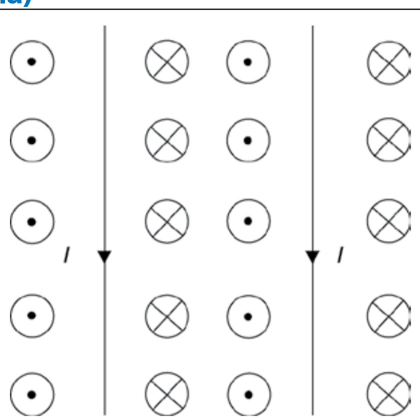
Active Physics

1.a)



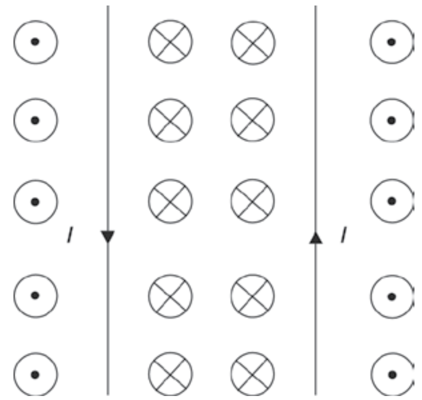
1.b)

The magnetic fields induced by each wire between the wires point in opposite directions. This is similar to the two bar magnets that have their poles pointing in opposite directions and the fields between them point in opposite directions.

1.c)

Students should predict that these parallel current-carrying wires attract since the fields between them are pointing in opposite directions.

2.a)



2.b)

The magnetic fields induced by each wire between the wires point in the same direction. This is similar to the two bar magnets that have their poles pointing in the same direction and the fields between them point in the same direction.

2.c)

Students should predict that these parallel current-carrying wires repel since the fields are pointing in the same direction.

Is There an Equation for the Strength of a Magnetic Field?

Discuss the approximate formula for a magnetic field near a current-carrying wire, and the units used.

1.

For 0.5 cm from a current-carrying wire of 3 A the magnetic field is

$$B = \frac{\mu_0 I}{2\pi d} = \frac{(4\pi \times 10^{-7}\ \text{N/A}^2)(3\ \text{A})}{2\pi(0.005\ \text{m})} = 0.00012\ \text{T} = 1.2 \times 10^{-4}\ \text{T}.$$

For 1.0 cm from a current-carrying wire of 3 A the magnetic field is

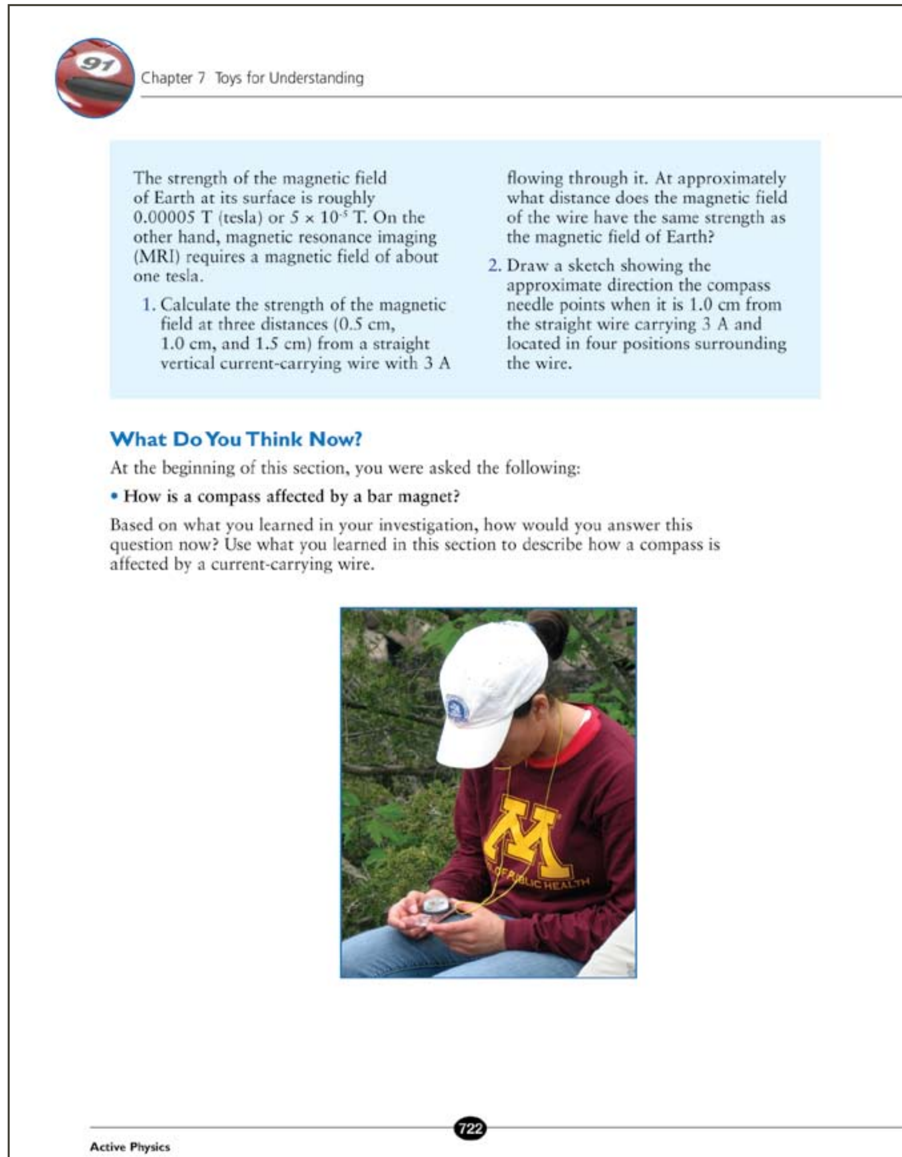
$$B = \frac{\mu_0 I}{2\pi d} = \frac{(4\pi \times 10^{-7}\ \text{N/A}^2)(3\ \text{A})}{2\pi(0.01\ \text{m})} = 0.00006\ \text{T} = 6 \times 10^{-5}\ \text{T}.$$

For 1.5 cm from a current-carrying wire of 3 A the magnetic field is

$$B = \frac{\mu_0 I}{2\pi d} = \frac{(4\pi \times 10^{-7}\ \text{N/A}^2)(3\ \text{A})}{2\pi(0.015\ \text{m})} = 0.00004\ \text{T} = 4 \times 10^{-5}\ \text{T}.$$

2.

The magnetic field produced by this current-carrying wire of 3 A is most similar to Earth's magnetic field between 1.0 and 1.5 cm. Many students will select 1.25 cm (halfway between the two distances). Calculating the field at that distance yields 4.8×10^{-5} T. Students may also try using the value of Earth's magnetic field provided to calculate for distance in the equation. This gives a distance of 1.2 cm.


Chapter 7 Toys for Understanding

The strength of the magnetic field of Earth at its surface is roughly 0.00005 T (tesla) or 5×10^{-5} T. On the other hand, magnetic resonance imaging (MRI) requires a magnetic field of about one tesla.

1. Calculate the strength of the magnetic field at three distances (0.5 cm, 1.0 cm, and 1.5 cm) from a straight vertical current-carrying wire with 3 A flowing through it. At approximately what distance does the magnetic field of the wire have the same strength as the magnetic field of Earth?
2. Draw a sketch showing the approximate direction the compass needle points when it is 1.0 cm from the straight wire carrying 3 A and located in four positions surrounding the wire.

What Do You Think Now?

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

- **How is a compass affected by a bar magnet?**

Based on what you learned in your investigation, how would you answer this question now? Use what you learned in this section to describe how a compass is affected by a current-carrying wire.

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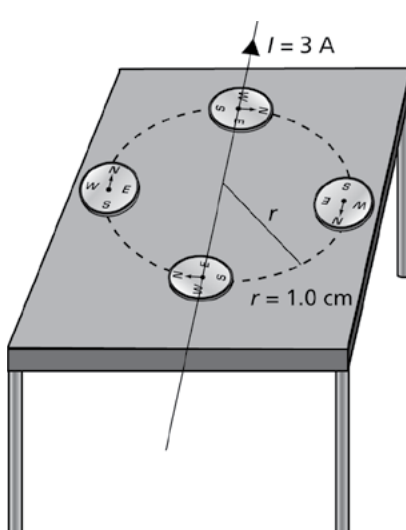
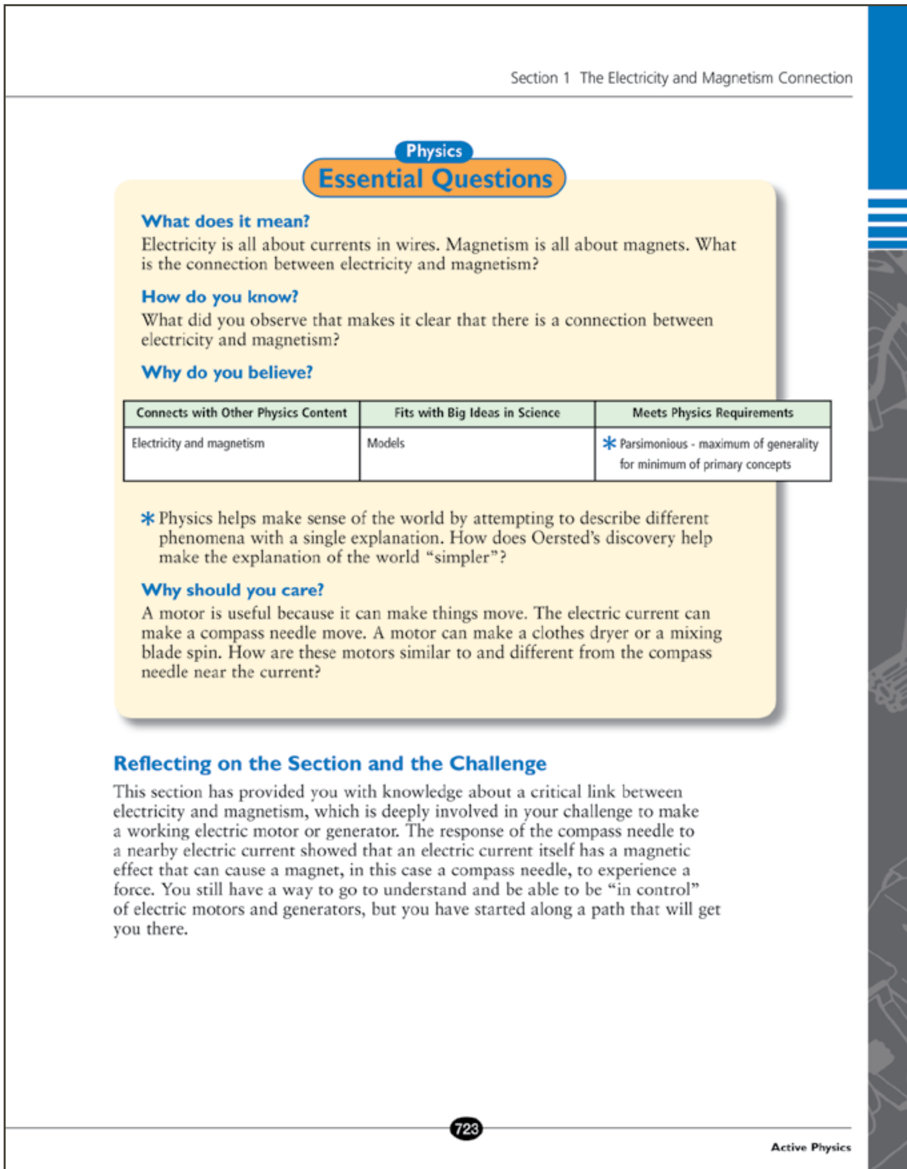


What Do You Think Now?

Have students revisit the *What Do You See?* illustration and ask them to describe what they think about it now. Ask them what other ideas they now have about how a compass is affected by a magnet. Students should apply ideas from the *Investigate* and the *Physics Talk* of this section. Consider sharing the information in *A Physicist's Response* and



Physics

Essential Questions

What does it mean?

Electricity is all about currents in wires. Magnetism is all about magnets. What is the connection between electricity and magnetism?

How do you know?

What did you observe that makes it clear that there is a connection between electricity and magnetism?

Why do you believe?

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

* Physics helps make sense of the world by attempting to describe different phenomena with a single explanation. How does Oersted's discovery help make the explanation of the world "simpler"?

Why should you care?

A motor is useful because it can make things move. The electric current can make a compass needle move. A motor can make a clothes dryer or a mixing blade spin. How are these motors similar to and different from the compass needle near the current?

Reflecting on the Section and the Challenge

This section has provided you with knowledge about a critical link between electricity and magnetism, which is deeply involved in your challenge to make a working electric motor or generator. The response of the compass needle to a nearby electric current showed that an electric current itself has a magnetic effect that can cause a magnet, in this case a compass needle, to experience a force. You still have a way to go to understand and be able to be "in control" of electric motors and generators, but you have started along a path that will get you there.

elicit their opinions. Encourage students to review their *What Do You Think?* answer a few times and discuss it with their class members.

Reflecting on the Section and the Challenge

Have a discussion based on the connection between electricity and magnetism. Emphasize that when students complete the *Chapter Challenge* they will need to explain how and why the toy works in terms of basic principles of physics, and the link between electricity and magnetism should form a part of their explanation. Consider eliciting ideas from students on how and/or why this link is critical.

Physics Essential Questions

What does it mean?

A current creates a magnetic field. The magnetic field is in a circle surrounding a current-carrying wire.

How do you know?

You set up a coil of wire around a compass. When there was no current, the compass needle pointed north. When there was a current, the compass needle rotated to a new position. This is evidence that the current produced a magnetic field, which affected the compass.

Why do you believe?

People were familiar with permanent magnets. People were also familiar with electric currents. Oersted showed that currents can produce magnetic fields. What were once considered to be two independent phenomena are now related to each other. Therefore, the world is a simpler place.

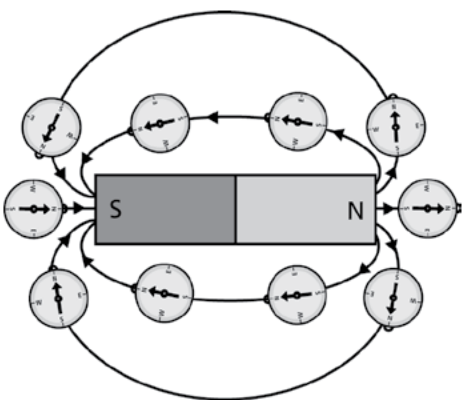
Why should you care?

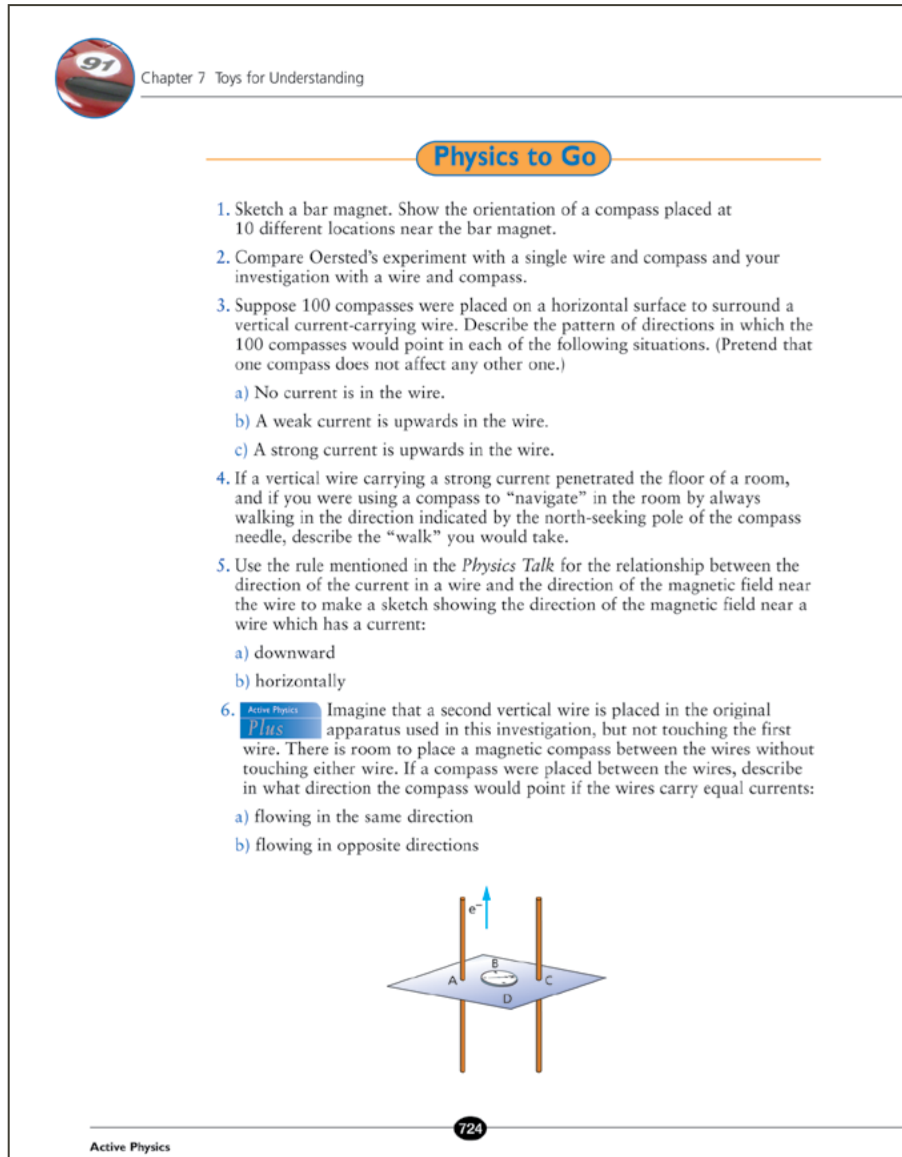
A current can move the compass needle in the same way that the current can move a motor. The current required to move a compass needle is extremely smaller than the current required to move a motor.

Physics to Go

1.

Student sketches should show a bar magnet with the north and south poles indicated and ten compass locations in which the compass's north pole is pointing toward the magnet's south pole, and its south pole is pointing toward the bar magnet's north pole. The compass arrow should follow field lines as shown in the diagram in the beginning of the *Physics Talk*. An example is shown below.




Chapter 7 Toys for Understanding

Physics to Go

1. Sketch a bar magnet. Show the orientation of a compass placed at 10 different locations near the bar magnet.
2. Compare Oersted's experiment with a single wire and compass and your investigation with a wire and compass.
3. Suppose 100 compasses were placed on a horizontal surface to surround a vertical current-carrying wire. Describe the pattern of directions in which the 100 compasses would point in each of the following situations. (Pretend that one compass does not affect any other one.)
   a) No current is in the wire.
   b) A weak current is upwards in the wire.
   c) A strong current is upwards in the wire.
4. If a vertical wire carrying a strong current penetrated the floor of a room, and if you were using a compass to "navigate" in the room by always walking in the direction indicated by the north-seeking pole of the compass needle, describe the "walk" you would take.
5. Use the rule mentioned in the *Physics Talk* for the relationship between the direction of the current in a wire and the direction of the magnetic field near the wire to make a sketch showing the direction of the magnetic field near a wire which has a current:
   a) downward
   b) horizontally
6. Active Physics *Plus* Imagine that a second vertical wire is placed in the original apparatus used in this investigation, but not touching the first wire. There is room to place a magnetic compass between the wires without touching either wire. If a compass were placed between the wires, describe in what direction the compass would point if the wires carry equal currents:
   a) flowing in the same direction
   b) flowing in opposite directions

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Active Physics

2.

Students should describe how both experiments showed that a current-carrying wire interacts with a magnetic compass, deflecting the compass needle. The difference is that Oersted used a straight wire on top of a magnetic compass and in the *Investigate*, students used wire wrapped around a compass.

3.a)

If no current is in the wire, and the compasses do not affect each other, then each compass would align itself to Earth's magnetic field, pointing toward geographic North.

3.b)

If a weak current was pointing upward in the wire, then looking down the wire (current coming at you), the compasses would align themselves such that they formed concentric circles pointing in the clockwise direction. The effect would be much smaller the further you were away from the current-carrying wire. With a weak current, it is likely that the compasses further out from the wire will feel a greater interaction with Earth's magnetic field than the wires. Consider describing the strength of a current-carrying wire of 3 A and how the magnetic field it induces is about as strong as Earth's magnetic field at a distance of 1.2 cm from the wire.

3.c)

If a strong current was in the wire pointing upward in the wire then, looking down at the wire, the

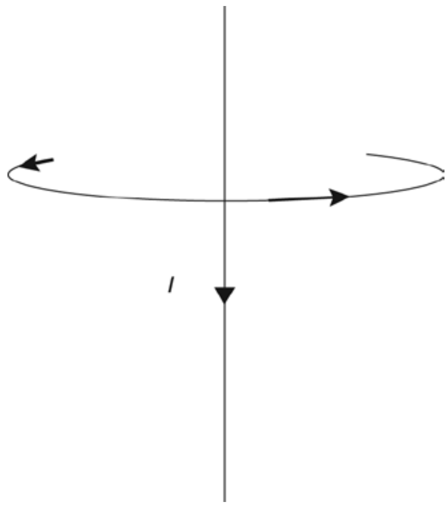
CHAPTER 7

compasses would still be aligned in concentric circles pointing in the clockwise direction. The compasses that interact with the wire will be at a greater radius from the wire than for the weak current. There probably will still be some compasses that interact more with Earth's magnetic field, but these will be less.

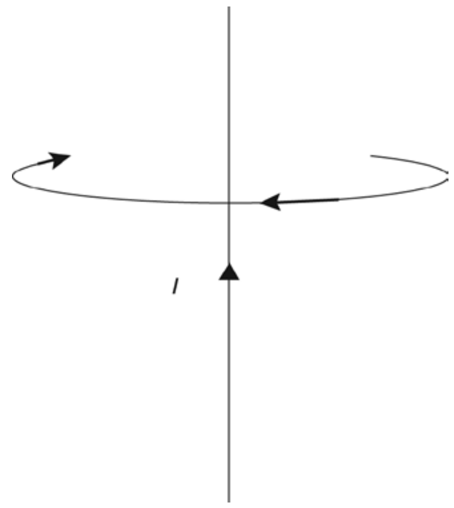
4.

Students should describe walking around in a circle about the wire.

5.a)



5.b)



6.a) Active Physics *Plus*

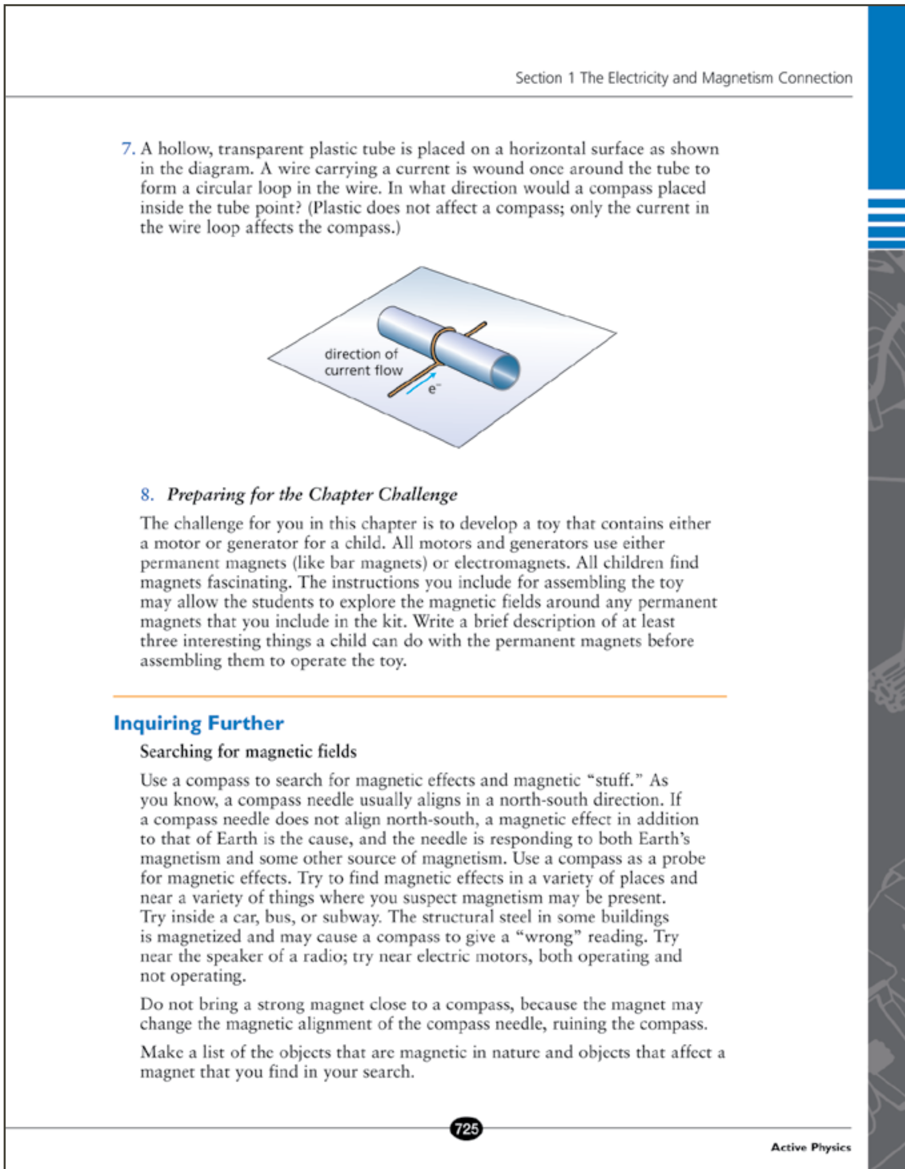
If the negative currents are flowing in the same direction, then the magnetic fields induced by each wire should point in opposite directions between the two wires. The field lines should oppose each other leading to no deflection of the compass if it is in the middle.

6.b) Active Physics *Plus*

If the negative currents are flowing in opposite directions then the field lines induced by each wire should point in the same direction, and the compass should align itself with the field lines. For the image shown in the student text, this would point toward D if the negative current in the wire near C points downward, and toward B if the currents are reversed (the wire near A has a downward negative current and that near C has an upward negative current). Note that this is for the flow of negative charge (negative current).

NOTES

NOTES



7. A hollow, transparent plastic tube is placed on a horizontal surface as shown in the diagram. A wire carrying a current is wound once around the tube to form a circular loop in the wire. In what direction would a compass placed inside the tube point? (Plastic does not affect a compass; only the current in the wire loop affects the compass.)

8. *Preparing for the Chapter Challenge*

The challenge for you in this chapter is to develop a toy that contains either a motor or generator for a child. All motors and generators use either permanent magnets (like bar magnets) or electromagnets. All children find magnets fascinating. The instructions you include for assembling the toy may allow the students to explore the magnetic fields around any permanent magnets that you include in the kit. Write a brief description of at least three interesting things a child can do with the permanent magnets before assembling them to operate the toy.

Inquiring Further

Searching for magnetic fields

Use a compass to search for magnetic effects and magnetic "stuff." As you know, a compass needle usually aligns in a north-south direction. If a compass needle does not align north-south, a magnetic effect in addition to that of Earth is the cause, and the needle is responding to both Earth's magnetism and some other source of magnetism. Use a compass as a probe for magnetic effects. Try to find magnetic effects in a variety of places and near a variety of things where you suspect magnetism may be present. Try inside a car, bus, or subway. The structural steel in some buildings is magnetized and may cause a compass to give a "wrong" reading. Try near the speaker of a radio; try near electric motors, both operating and not operating.

Do not bring a strong magnet close to a compass, because the magnet may change the magnetic alignment of the compass needle, ruining the compass.

Make a list of the objects that are magnetic in nature and objects that affect a magnet that you find in your search.

CHAPTER 7

7.

Follow the direction of negative current flow with your thumb. The induced field from the wire adds up as it is coiled around the cylinder. This will cause the compass needle to deflect so it is aligned along the long axis of the cylinder. The direction along the long axis of the cylinder depends on whether the coil was first looped around the bottom or the top of the cylinder.

8.

Preparing for the Chapter Challenge

Responses will vary, but should include three instructive things for a child to do with a magnet. Examples include exploring how magnets interact with other materials, exploring how magnets interact with other magnets, exploring the strengths of magnets, determining the direction of Earth's magnetic field, and so on. Students may also suggest searching for magnetic fields as described in *Inquiring Further*.

Inquiring Further

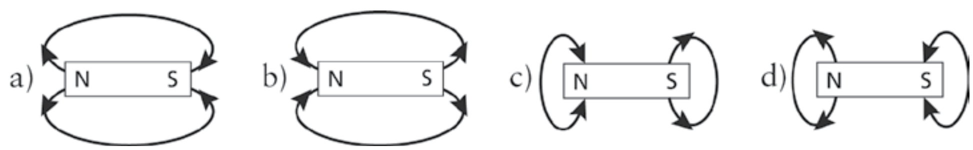
Searching for magnetic fields

Students should describe the magnetic affects they observe and construct a list of objects that are magnetic in nature and objects that affect a magnet.

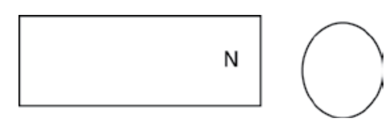
SECTION 1 QUIZ

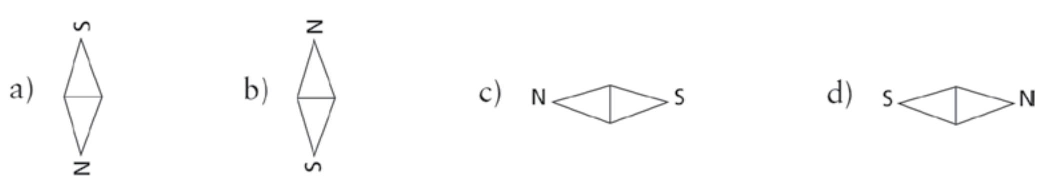
7-1b **Blackline Master**

1. Which diagram below correctly shows the magnetic field surrounding a bar magnet?

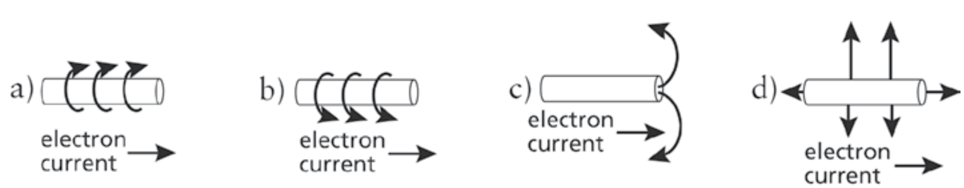


2. The diagram at the right shows a compass placed near the north pole (N) of a magnet. Which diagram below best represents the needle of the compass as it responds to the magnetic field of the magnet?





3. Which diagram below best represents the magnetic field around a straight, current-carrying wire?



4. Which of the following devices could be used to detect a current flowing upward in a wire behind a wall?

a) Another wire.
b) A voltmeter.
c) A compass.
d) A hand generator.

5. A bar magnet is suspended from a string free to rotate away from all magnetic material and other magnets. When the bar magnet comes to rest, the north pole of the magnet will be pointing

a) toward Earth's North Pole.
b) toward Earth's South Pole.
c) toward the center of Earth.
d) directly away from the center of Earth.

SECTION 1 QUIZ ANSWERS

1. a) Magnetic field lines always point away from the north pole and toward the south pole.

2. d) The south magnetic pole of the compass needle is attracted to the north magnetic pole of the bar magnet and the compass's north pole is repelled by the north pole of the bar magnet. This causes the compass needle, which is free to rotate, to align its south pole to the north pole of the bar magnet.

3. a) Using the left-hand rule, students should point the thumb of their left hand in the direction of the negative current (or the direction of the flow of electrons) and their fingers wrap around in the direction of the induced magnetic field.

4. c) Because the wire is behind a wall, it would require cutting into the wall, and a voltmeter is used to measure voltage. The generator hooked up to a wire with current might move, but again it would require cutting into the wall. Another wire, if carrying a current, might detect a current if the two wires induced a magnetic field, but it does not say that this second wire is carrying a current. Therefore, the best answer is the magnetic compass, which may deflect in the presence of a magnetic field created by the current-carrying wire in behind the wall. The deflection may be slight depending on the amount of current the wire carries and how far away it is from the compass.

5. a) toward Earth's North Pole. Earth's magnetic south pole is located near its geographic North Pole.