SECTION 2

Electromagnets

Section Overview

Students investigate electromagnets and the variables that affect the strength of the magnetic field they produce. They construct a solenoid and map out the magnetic field it produces using a magnetic compass, which they then compare to the fields they mapped out for bar magnets. The experiments conclude that the strength of the magnetic field produced by a solenoid depends on the current, number of turns, and the type of material in its core. Discussions of magnetic domains, permanent magnets, and electromagnets follow, using students' observations as supporting evidence. Applying their knowledge of these concepts, students solve various problems.

Background Information

The physics phenomenon involved in *Section 2* is the magnetic field of a solenoid.

A wire wound into the shape of a solenoid as shown in the *Investigate,* when carrying a direct current, behaves similarly to a bar magnet with the ends having north and south poles. The field lines shown are backward. It might also be useful to add a large N where the field lines come out of the end of the solenoid and a large S where the field lines go into the end of the solenoid. Considering short segments of the wire of the solenoid as straight pieces of wire, the direction of the magnetic field of each segment can be found using the left-hand rule introduced in *Section 1*. The combined effect of the magnetic fields of segments summed over the entire solenoid results in a magnetic field for the solenoid as shown in the first diagram in the *Physics Talk* in the student text.

A convenient rule for determining the magnetic polarity of a solenoid in relation to the direction of the current in the solenoid is to use the left hand to grasp the solenoid with the fingers pointing in the direction in which the current circles the windings. The extended left thumb points to the north pole of the solenoid. This is known as the left-hand rule for the polarity of a solenoid.

The strength near the center of a solenoid (inside) varies directly with the number of turns and current flowing in the wire, and inversely with the length of the solenoid. The mathematical expression is $B = \mu_0 NI/L$, where B is the magnetic field strength in Tesla, μ_0 is the permeability of air or vacuum (if the core is air or vacuum) in newtons/amp^2, N is the number of windings, I is the current in amps, and L is the length of the solenoid in meters. Note that if other factors are equal, a shorter solenoid has a stronger field. Also note that if a ferromagnetic material such as iron (a material having a high tendency to become magnetized) is used as the core of a solenoid, the magnetism of the core greatly adds to the strength of the solenoid's magnetic field. In such a case, the constant μ_0 in the above equation is replaced by the magnetic permeability, μ, of the core material, which commonly increases the magnetic effect by a factor of thousands. Iron can be treated so that when used as a core material for a solenoid, its magnetism "turns on and off" in concert with the electric current in the solenoid. Notice, in the diagram of the solenoid's field (the first diagram in the *Physics Talk* in this section of the student text), the field lines inside the core of the solenoid are close together and point toward the right; outside above and below the solenoid, the field lines are farther apart and point toward the left. If a current-carrying wire were used as a probe to sample the magnetic field strength, it would show that the field is stronger inside the solenoid than outside. This allows development of an alternate model for expressing the strength of a magnetic field in terms of the number of field lines which penetrate a unit of area oriented perpendicular to the direction of the field; the greater the "density" of lines penetrating a unit of area, the greater the magnetic field strength.

As stated in the previous *Background Information*, magnetism arises due to the properties of spin and charge of fundamental particles. For common permanent magnets, the outermost electrons of these atoms have their spins aligned. This sets up a magnetic dipole (north and south pole) of the atom. When a group of these atoms are together, they may not all align; rather, they may form small domains where they do align. Overall, the material does not exhibit magnetic properties unless a predominance of the domains aligns to give a net magnetic field. To make a permanent magnet, these materials are heated to high temperatures and then placed in a strong magnetic field as they cool. Magnets can lose their macroscopic magnetic properties if they are heated, vibrated, or dropped, causing the domains to lose alignment.

Note that students often believe that the larger the magnet the stronger it is. However, this is not the case. Different materials have different magnetic properties and densities. Some materials that have magnetic properties are iron (Fe), nickel (Ni), cobalt (Co), and some rare Earth metals in the lanthanide elements. Loadstone (a natural magnet) is composed of magnetite, which has iron oxide in it (Fe_3O_4).

A moving charge induces a magnetic field; hence, a current in a wire induces a magnetic field. Similarly, a changing magnetic field pushes or pulls a charge causing it to move. When a magnetic field is induced by a charge in motion, it is called an electromagnet. Magnetic fields interact with each other, either attracting or repelling each other, depending on the direction of the fields. The northern and southern lights are caused by charged particles moving through Earth's magnetic field.

NOTES

Crucial Physics

- A current-carrying coil of wire (solenoid) produces a magnetic field similar to a bar magnet.
- The strength of the magnetic field a current-carrying solenoid produces is directly proportional to the number of coils of wire the solenoid contains and the amount of current in those coils. Placing materials in the core of the solenoid can also affect the strength of the magnetic field; for example, placing iron inside will greatly magnify the magnetic field strength of the solenoid.
- Iron is made of magnetic domains, which are small regions of magnetism within the iron made up of a number of iron atoms. These domains are usually randomly oriented, resulting in no net macroscopic magnetic properties. When the magnetic domains are aligned with the external field, it gives the iron macroscopic magnetic properties.
- Permanent magnets have aligned magnetic domains that resist randomization and produce a magnetic field. Electromagnets are magnetic fields created by a current-carrying wire.

Learning Outcomes	Location in the Section	Evidence of Understanding
Describe the magnetic field of a current-carrying solenoid.	***Investigate*** Step 2.a) ***Physics Talk*** ***Physics to Go*** Questions 3, 5	Students record their observations of how a current-carrying solenoid affects a magnetic compass for various locations of the compass. The class discusses the field produced by a solenoid.
Compare the magnetic field of a solenoid to the magnetic field of a bar magnet.	***Investigate*** Steps 2.b)-c) ***Physics Talk*** ***Physics to Go*** Questions 2, 4	Students compare their observations of the current-carrying solenoid with a bar magnet. The class discusses the contributions of each coil and the similarities it has to the field of a bar magnet. Students consider how they could determine if a bar magnet or a solenoid of equal strength were placed in a black box.
Identify the variables that make an electromagnet strong or weak and explain the effects of each variable.	***Investigate*** Step 5 ***Physics Talk*** ***What Do You Think Now?*** ***Physics Essential Questions*** ***Physics to Go*** Question 6 ***Inquiring Further*** Question 1	Students design investigations to determine the relationship between the magnetic field strength and each of the following: the number of turns of wire, the amount of current through the wire, and the type of core within the solenoid. The class discusses the variables and students reflect on these variables. Students construct instructions they would give a child to make a strong enough electromagnet for a toy. Students design experiments to investigate other variables they think might affect the strength of an electromagnet.

NOTES

Section 2 Materials, Preparation, and Safety

Materials and Equipment

PLAN A		
Materials and Equipment	**Group (4 students)**	**Class**
Compass	1 per group	
Scissors	1 per group	
DC hand-operated generator	1 per group	
Nail, 12d	1 per group	
Paper clips, pkg 100		1 per class
Spool of thread		1 per class
Sandpaper, 60 grit	1 per group	
Battery, D-cell, alkaline	1 per group	
Tape, masking		6 per class
Wire, #24, magnet, 60-ft roll		1 per class
Straw, drinking, transparent, pkg 100		1 per class

Time Requirement

- Allow 30 minutes for students to complete the *Investigate* portion of this section.

Teacher Preparation

- Cut the wires to be used to wrap the solenoids to the appropriate length, and strip or sand the ends to ensure good electric contact.
- Try this investigation prior to allowing students to complete it. Determine if the field strength generated by the equipment students will use is strong enough to attract the staple or the paper clip.
- Be prepared to demonstrate the magnetic field of a bar magnet and a solenoid, noting similarities. Apparatus for demonstrating the fields on an overhead projector are available from several science supply houses, and employ iron filings, or transparent compasses to visualize the fields.

Safety Requirements

- Remind students they are working with electricity, and caution must be taken. Anytime there is electricity running through a resistor, there can be a buildup of heat if the current is on for extended periods of time. Using a generator will help because students will not want to crank it for long periods of time.
- If you are using a power supply to send current through the solenoid, make sure that students turn it off after use, and not leave it on for long periods of time.

Materials and Equipment

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Compass	1 per group	
Scissors	1 per group	
DC hand-operated generator	1 per group	
Nail, 12d	1 per group	
Paper clips, pkg 100		1 per class
Spool of thread		1 per class
Sandpaper, 60 grit	1 per group	
Battery, D-cell, alkaline		1 per class
Tape, masking		6 per class
Wire, #24, magnet, 60-ft roll		1 per class
Straw, drinking, transparent, pkg 100		1 per class

Time Requirement

- Allow one class period or 45 minutes to complete the *Investigate* portion of this section as a whole-class demonstration, as well as the *Physics Talk* and other parts of the section in the *Pacing Guide*.

Teacher Preparation

- Prior to class, set up and test the equipment in a place easily visible for students.
- Prepare a transparency prior to class to show students the data taken on the effect of current, number of turns, and core material on the field strength of a solenoid.
- Be prepared to demonstrate the magnetic field of a bar magnet and a solenoid, noting similarities. Apparatus for demonstrating the fields on an overhead projector are available from several science supply houses, and employ iron filings, or transparent compasses to visualize the fields.

Safety Requirements

- If you are using a power supply to send current through the solenoid, make sure to turn it off after use, and not leave it on for long periods of time.

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Writing a procedure	***Investigate*** Step 5	**Augmentation** • Many students struggle to break tasks into smaller steps and to write clear and concise sentences. For these students, it is very difficult to write their own procedures for an investigation. • Provide opportunities to practice writing procedures for tasks students are more familiar with, such as brushing teeth or making a peanut butter and jelly sandwich. Then ask students to compile a list of tips for writing good procedures. The list should include numbering and ordering steps, using transition words, being clear, naming materials, and so on. Taking the extra time to practice writing a procedure will help students to be more successful with the *Chapter Challenge*. • Remind students that a well-written procedure should tell students what kind of data to collect and how to collect the data. • Provide a graphic organizer that includes transition words, numbered lines, and helpful hints for writing procedures. **Accommodation** • For students with more significant writing struggles, type a step-by-step procedure to investigate one of the variables and then cut the steps apart into strips. Ask students to put the steps in order and write or tape that procedure into their logs. • Ask students to draw a procedure using pictures if they struggle with spelling and writing sentences.
Understanding essential concepts	***Physics Essential Questions***	**Augmentation** • The main objective of this section is for students to understand the variables that make an electromagnet strong or weak. Because students only investigate one of the variables, it is important that they share their results with each other. Develop a class chart that lists all of the variables that were tested and the effects of changing that variable. Students can refer to this chart to answer the *Physics to Go* questions and to develop the toy and instructions for the *Chapter Challenge*. • Developing a chart is also a good method for students to summarize the information they read in the *Physics Talk* or to compare and contrast electromagnets and bar magnets. **Accommodation** • Concrete learners may need to see a demonstration of the effect of changing each variable in order to help them commit the concepts to their long-term memories. • Diagrams may also help these students remember the effects of changing the variables. For example, draw a solenoid with a few loops and write the word “weak” next to it. Then, draw a solenoid with many loops and write the word “strong” next to it.

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Strategies for Students with Limited English-Language Proficiency

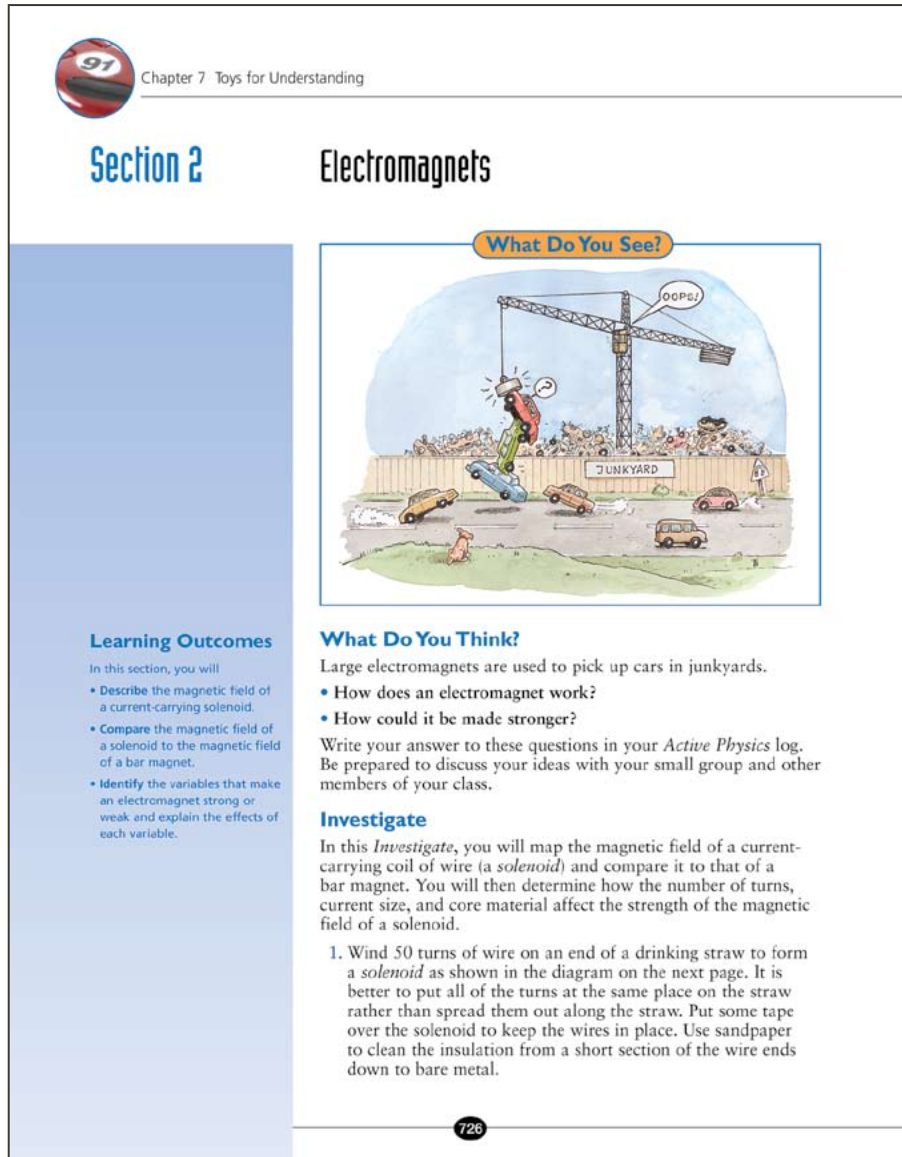
Learning Issue	Reference	Augmentation
Higher-order thinking	***Investigate*** Step 3	Making predictions is an important part of scientific investigation. When students make their predictions in *Step 3*, give them opportunities to verbalize their ideas. After they have tested their predictions, allow them adequate time to consider why their predictions were or were not accurate, and then hold a class discussion to share those thoughts.
Vocabulary comprehension/ fluency	***Investigate*** Step 5 ***Physics Talk***	If time does not allow all students to investigate several variables affecting the behavior of an electromagnet, have groups develop language skills by presenting their results to the class. Students may have difficulty with terms that are similar but do not have identical meanings. To develop fluency with descriptive language, ask volunteers to describe lab setups using the terms "coil," "solenoid," "cylinder," and "loop." Correct any misuses of words to help students distinguish the meanings.
Vocabulary comprehension Understanding concepts	***Physics Talk***	Magnetic domains can be difficult to understand, but they need not be. Emphasize that in everyday language, a domain means "region," or "area of control." When soft iron is used as the solenoid core, the domains within the iron can be controlled to reinforce the magnetic field.
Research skills/ fluency	***Inquiring Further***	Research skills are tremendously important in science. In the *Inquiring Further*, assign students one of two topics to research (such as use of permanent magnets and electromagnets, or magnetic levitation), or allow students to choose. You may wish to have students work in pairs, and may wish to pair ELL students with native English speakers. Once the research is complete and the reports are prepared, have students give an oral report to the class. Encourage ELL students to perform as much of the presentation as possible, as ELL students benefit greatly from speaking in English. At the end of the prepared presentation, encourage questions from the class. ELL students will also benefit from the opportunity to improve their listening skills and will be challenged to speak extemporaneously to answer the questions. Be sure they include appropriate use of science vocabulary as well as topic-specific vocabulary in their responses.

SECTION 2

Teaching Suggestions and Sample Answers

What Do You See?

Elicit students' initial impressions of what they see in the illustration and ask them how they think the vehicle is being lifted in the illustration. When magnets are brought up, ask what type of magnet is being used. After discussing the details of the illustration, ask students what they think the illustration has to do with this section. Point out that once they have formed an initial impression of this illustration they will be returning to this section at a later stage after a detailed investigation of physics concepts. Consider using the overhead of the illustration as a focal point for discussion.



Chapter 7 Toys for Understanding

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.

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Students' Prior Conceptions

Students may not have had the opportunity to inquire into the nature of the electric force qualitatively or quantitatively, so they believe that the electrical force is the same as the gravitational force. They may then apply this erroneous reasoning to the magnetic field as well. This section provides the opportunity for students to recognize the different effects of these fields and to identify why and how electromagnets work.

1. **The electrical force, and by extension the magnetic one, is the same as the gravitational force.** The main way that you can intervene in this thought process is to lead students to understand that only the gravitational force is an attractive force, whereas electrical and magnetic forces may be either attractive or repulsive.
2. **Electromagnetic and magnetic forces need a medium through which to work**. During discussions, you should extend student ideas to include magnetism, so that they recognize that a number of variables can change the strength of an electromagnet and its subsequent field. The magnetic field of a solenoid does not require a medium for its transmission and may be communicated through space or through a complete vacuum. Students should care about magnetic and electromagnetic fields because they also affect astronomical objects such as the Sun and Earth.

What Do You Think?

Let students know that electromagnets are used to lift and move vehicles and other scrap metal in junkyards. Then have students consider the questions. After they discuss their ideas with their group members, focus on the responses that provide an opportunity for your class to become engaged in the physics concepts presented in this section. Emphasize that there are no "right" answers, and that all answers are acceptable. The purpose of the question is to elicit students' prior knowledge and address misconceptions as they arise during a study of this section. Ask them to refer to their answers while they are being introduced to new physics concepts. Point out that when they are aware of what they think, they will be better able to increase what they know.

Investigate

Teaching Tip

Overlapping the turns will produce a stronger field than the one that is produced when the coils are spread out.

1.

Students should wind the turns around the straw in a small area. 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 to ensure proper electrical contact when it is connected in a circuit.

What Do You Think?

A Physicist's Response

Electromagnets are the result of an electrical current in a wire surrounding a soft iron core. The greater the current flowing through the wire or the greater the number of coils around the the core, the greater will be the magnetic force. To increase the strength of an electromagnet, you can increase the current by increasing the number of coils around the wire. You can also place a substance with magnetic properties (such as iron) inside the coils of wire and increase the strength of the magnetic field induced by the moving charge (current).

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NOTES

NOTES

Teaching Tip

It may be necessary to lay the straw/solenoid right on top of the compass to see results. Bring the solenoid in from a perpendicular direction to make the deflection more obvious.

2.a)

When the generator is cranked and the end of the solenoid is brought very close to the compass, the needle will deflect. The degree of deflection will depend upon how fast the generator is cranked, and how close to the pole of the compass the solenoid is brought.

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2.b)

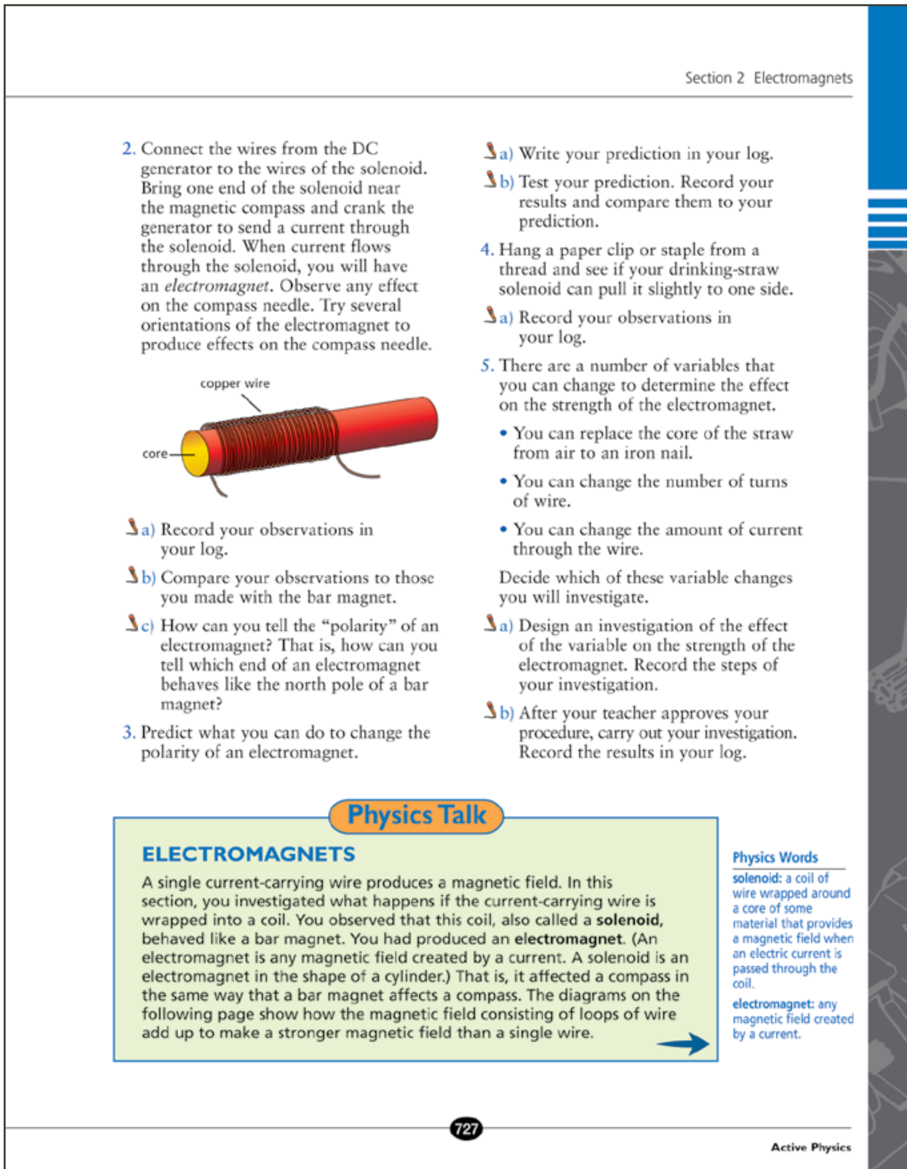
Students should note that the needle does not deflect as much as when the bar magnet was brought nearby, and that the needle only deflected when the generator was providing current to the solenoid.

2.c)

The "polarity" refers to which pole of the compass the solenoid attracts. The pole of the solenoid is opposite to the compass pole that is attracted to it.

3.a)

Predictions should include that reversing the current will reverse the solenoid's poles.



Section 2 Electromagnets

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.

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Active Physics

Teaching Tip

Using the iron core with a compass is not a valid test of the solenoid field strength. Because the compass itself is a small magnet, it will attract the iron core and rotate into position to maximize the attraction with or without a current in the solenoid. It is simply a test to see if iron is ferromagnetic.

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5.a)

After choosing one of the three suggested variables, students should run a series of trials, changing only the variable they are investigating, but keeping the others constant. For example, if students choose to change the amount of current through the wire, keep the number of turns constant and always use an air core while changing the generator speed to change the current. (Using an air core is suggested to prevent any magnetism of the iron core.)

5.b)

Students should carry out the investigation and discover that increasing the turns and the current increase the deflection of the staple. Adding an iron core greatly increases the strength of the solenoid.

3.b)

Students test their prediction and record the results.

Teaching Tip

A long thread supporting the staple is better than a short thread because less force is necessary to move the staple through a visible angle.

4.a)

A staple will work better than a paper clip because it has less mass. In general, the magnetic field of an air core solenoid is quite weak, so only a small deflection will be seen.

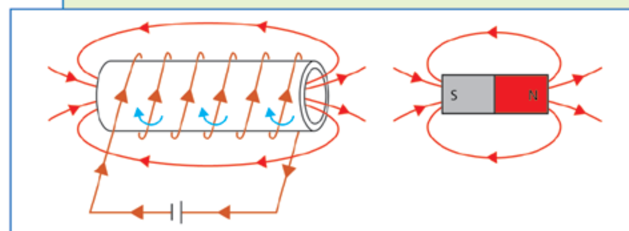
Physics Talk

This *Physics Talk* provides students with a description of electromagnets, comparisons between the field produced by a solenoid and that of a bar magnet, variables that affect the magnetic strength of a current-carrying solenoid, and why some materials placed within a current-carrying solenoid increase its magnetic strength. Magnetic domains are introduced with a brief discussion on permanent magnets.

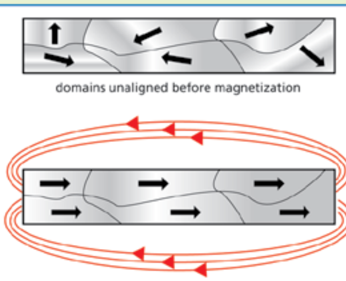
Ask the class what an electromagnet is, and then define it, making it clear that any magnetic field created by a current is an electromagnet. Then define and describe a solenoid. Ask what variables affect the magnetic field induced by a solenoid and have students support their claims with their observations from the *Investigate*.

Transition the discussion of variables that affect magnetic strength to magnetic domains using the variable of the iron core. Describe how some atoms have intrinsic magnetic properties, such as iron atoms, and that these atoms often combine to form small domains that act as a tiny magnet. In a large piece of iron, these domains are randomly oriented so the net magnetic field is zero; however, when the iron is placed in an external magnetic field, such as the field that a solenoid produces, its domains begin to align themselves. This effectively increases the magnetic field of the solenoid by adding to it the net magnetic field of the aligned domains in the iron core. Describe the iron used in the core as soft iron, which means that

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.


domains unaligned before magnetization

domains aligned after magnetization

"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.

the iron has not been hardened by heat treatments or added ingredients. Emphasize that it does not take a strong magnetic field to line up most of the domains of soft iron.

Consider describing how permanent magnets are made. Atoms with inherent magnetic properties (such as iron, cobalt, nickel, or the rare earth neodymium) are heated to a high temperature so they are in a liquid state. Then they are cooled in a strong magnetic field. While the atoms are in the liquid state, it is easier for them to rotate and align themselves with the strong magnetic field. As they cool and go into the solid state, most of the atoms are aligned forming one magnetic domain. Often other metals are added to the mixture to harden the metal, so that it is more difficult for the atoms to change their position and re-orient their magnetic field.

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?

Checking Up

1.

The magnetic field of a solenoid most closely resembles the magnetic field of a bar magnet.

2.

Soft iron does not make the best magnetic material even though it has magnetic properties because its magnetic domains are randomly oriented so that the net magnetic field produced by the iron is zero. However, the ease at which these domains can change direction also makes them useful in constructing powerful electromagnets.

3.

Adding an iron nail to a solenoid increases its strength because it is similar to adding another, combining the strength of the solenoid's magnetic field with another magnetic field. When the nail (usually soft iron) is placed in the core, its magnetic domains become more aligned, causing the iron nail to have a net magnetic field that adds to the solenoid's field.

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Remind students that they will be designing a toy with a motor and/or generator in it. Let them know that all motors and generators contain magnets as one of their fundamental parts, and that this magnet could be a permanent magnet or an electromagnet. Ask students what motors and generators do and explain that motors convert electrical energy to motion (kinetic) energy and generators convert kinetic energy into electrical energy.

7-2b Blackline Master

Active Physics Plus

This *Active Physics Plus* provides an opportunity for students to increase the depth of their understanding about Earth's magnetic field.

1.

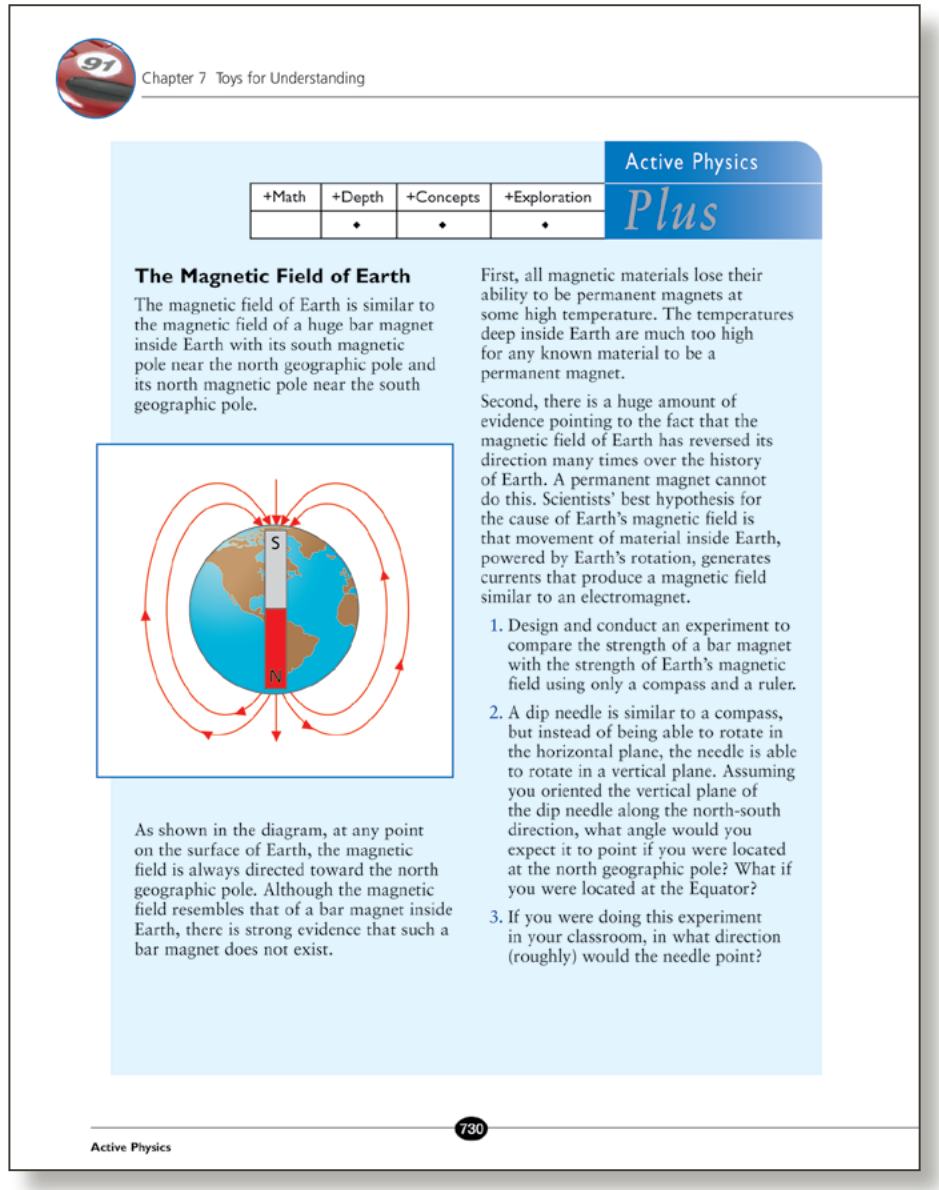
Students' experiments should be a fair test. Students might measure the deflection of the compass needle as the distance is increased from a bar magnet, and likewise use the distance the compass is from Earth and its deflection as a comparison.

2.

If you were located at the geographic North Pole, the dip needle would align its magnetic north pole straight downward toward Earth's magnetic south pole (which is located at the geographic North Pole). (Actually, Earth's magnetic south pole is currently located about 1000 km from the geographic North Pole.) If you were standing at the Equator, it would point sideways (or at 90˚ from the vertical). Dip needles often were constructed so that they could rotate to the horizontal plane and be used as a standard compass.

3.

Students' responses should indicate the approximate angle of your geographic location from the geographic North Pole, or the latitude. This is not truly the magnetic dip angle as Earth's magnetic pole moves and is usually not located at exactly the geographic North Pole. The field is also affected by local effects and does not simply follow field lines similar to a bar magnet's magnetic field.



Active Physics Plus

+Math	+Depth	+Concepts	+Exploration
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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?

Ask students to review their previous answers to the *What Do You Think?* questions. Ask them how they would answer these questions now and point out that scientists often change their ideas as they gather more information. Consider discussing the information in *A Physicist's Response*. Consider having different groups explain the relationship between a variable of a solenoid and its magnetic-field strength based on their observations in the *Investigate*. Students should now show you answers that demonstrate their understanding of electromagnets.

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.

Encourage students to think through their written responses and carefully edit their previous misconceptions before they submit them to you for a final check.

Reflecting on the Section and the Challenge

Ask students to summarize what they have learned in this section. Let students know that an electromagnet is often the basic moving part of an electric motor. Emphasize that knowledge of electromagnets will help them in designing their toy, and will affect how they change the speed and strength at which the motor in their toy rotates.

Physics Essential Questions

What does it mean?

An electromagnet is a magnet created by an electric current.

How do you know?

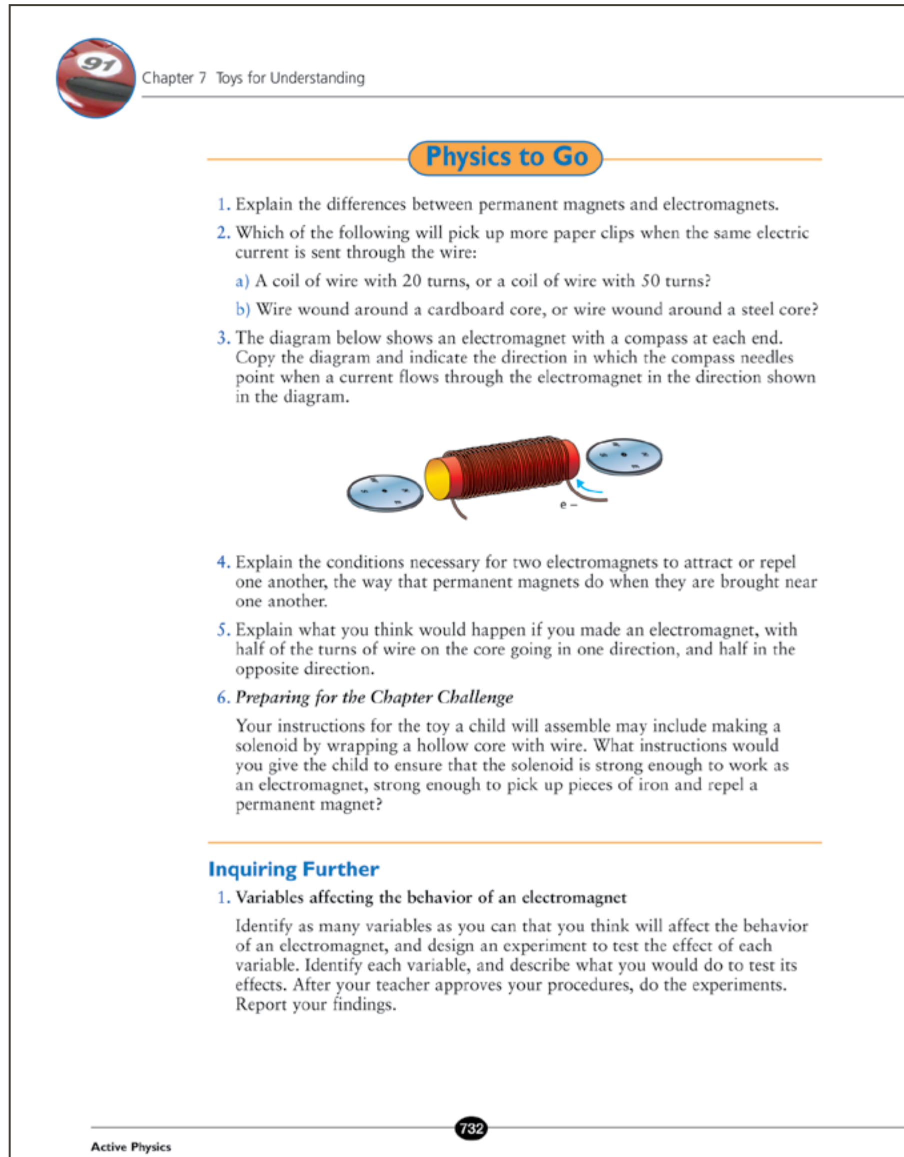
The field strength of the electromagnet can be increased by increasing the number of coils, the amount of current through the coils, or by adding a piece of iron within the coil.

Why do you believe?

Without being able to change the current in the solenoid, the magnetic fields would be identical in shape and you could not distinguish the bar magnet from the electromagnet.

Why should you care?

You can increase the current, increase the number of coils, and insert a piece of iron in the core.


Chapter 7 Toys for Understanding

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.

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Active Physics

Physics to Go

1.

A permanent magnet maintains its magnetic field with or without a current. An electromagnet arises any time there is a moving charge or current. When a charge moves, it induces a magnetic field.

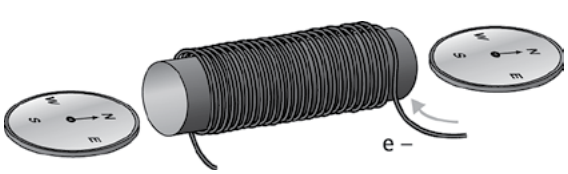
2.a)

An electric current sent through a coil of wire with 50 turns will pick up more paper clips than one with 20 coils because it will produce a stronger magnetic field.

2.b)

An electric current through wire wound around a steel core will produce a stronger magnetic field than that around cardboard and hence, will pick up more paper clips.

3.



4.

For two electromagnets to attract one another, their induced magnetic fields must be such that the opposite poles are facing each other, just as with two bar magnets. This means that two identical electromagnets, facing each other head-on or sitting on a straight line one after the other, would attract each other if they had the same current flow. However, two identical electromagnets sitting side-by-side, with opposing current directions would be attracted to each other, as their poles would be opposite and would attract each other, just as in the illustration in the student text of the bar magnets in *Section 1* of this chapter in *Active Physics Plus*. Two electromagnets side-by-side would repel each other if their currents were in the same direction, inducing like poles on the same ends.

5.

If an electromagnet were constructed with half of its turns going in one direction and the other half going in the other direction, it would not produce an overall field as a bar magnet. The first half of coils would induce a magnetic field that repelled the magnetic field induced by the second set of turns. If the turns were side-by-side, then the two halves of coils would repel each other in the middle where they would create like poles. The net field would be reduced or canceled depending on location.

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.

a) What possibilities do "maglev" trains, cars, or other transportation devices have for the future?

b) What advantages would such devices have?

c) What problems need to be solved? Prepare a brief report on your research.

6.

Preparing for the Chapter Challenge

Students should write instructions for making a solenoid that include working as an electromagnet, being strong enough to pick up pieces of iron, and to repel a permanent magnet. Their instructions should include "checks" that it fulfills these criteria. Consider asking students to also include explanations on why and how the electromagnet works.

Inquiring Further

Variables affecting the behavior of an electromagnet

1.

Students' experiments should be fair tests in which all variables are held constant except for the one they are manipulating and possibly the magnetic field strength. Students should conduct the experiment after you have approved it.

Use of permanent magnets and electromagnets

2.

Students should research and report on different uses of permanent magnets and electromagnets in junkyard lifting devices, buzzers, electrical relays, and/or microphones and speakers. Consider having students present their reports to the class.

Magnetic levitation

3.

Students should research and report on magnetic levitation, including super-conducting electromagnets and maglev trains.

a)

Students should provide their ideas for possibilities of maglev trains, vehicles, and other transportation devices using magnetic levitation for the future.

b)

These devices reduce friction and thereby increase fuel efficiency.

c)

Students should report on current problems involved.

SECTION 2 QUIZ

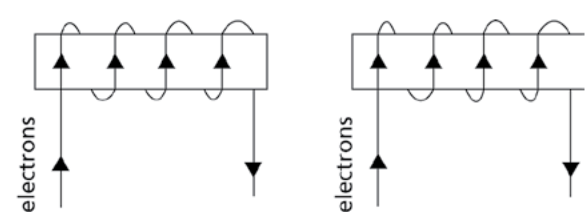
7-2c **Blackline Master**

1. The magnetic field of a bar magnet is most like the magnetic field of
   a) a current-carrying wire.
   b) a solenoid.
   c) a horseshoe magnet.
   d) Earth.

2. Which of the following would increase the magnetic field strength of a solenoid?
   a) Decreasing the current in the coils.
   b) Increasing the insulation around the wires.
   c) Increasing the number of turns of wire.
   d) Adding an aluminum core.

3. Soft iron makes a good core material for an electromagnet because
   a) It has many magnetic domains.
   b) Its magnetic domains are impossible to reverse after they are lined up.
   c) Its magnetic domains line up with Earth's magnetic field.
   d) Its domains are easily lined up to strengthen the electromagnet's field.

4. The diagram at right shows two solenoids with current flowing in the directions indicated. The two solenoids would



   a) attract due to their magnetic fields.
   b) repel due to their magnetic fields.
   c) attract due to their electric fields.
   d) repel due to their electric fields.

5. The north pole of a magnet brought near a steel ball attracts the ball. The magnet is then reversed and the south pole is brought near the steel ball. As a result, the steel ball will be
   a) repelled by the south pole.
   b) attracted to the south pole.
   c) will be neither attracted nor repelled.
   d) will be attracted at first and then repelled by the south pole.

SECTION 2 QUIZ ANSWERS

1. b) a solenoid. A bar magnet and a current-carrying solenoid have similar magnetic fields. Consider discussing the comparison students made in the *Investigate* and the discussion in the *Physics Talk*.

2. c) Increasing the number of turns of wire. Decreasing the current would decrease the magnetic field. Increasing the insulation of the wire would not affect the magnetic field produced. Putting an aluminum core in the solenoid would increase the magnetic field, but not by much. However, increasing the number of turns of the wire in the same direction would increase the strength of the solenoid.

3. d) Its domains are easily lined up to strengthen the electromagnet's field. The number of domains may be many, but this is not what makes it a useful core for the electromagnet. The fact that the domains are easily lined up in an existing magnetic field is why soft iron makes a good core for an electromagnet.

4. a) attract due to their magnetic fields. Both solenoids set up a south magnetic pole on their left side and a north magnetic pole on their right side. Therefore, the solenoids will attract because the left solenoid's north pole is next to the right solenoid's south pole.

5. b) attracted to the south pole. The steel ball, like paper clips, easily realigns its magnetic domains so that it is attracted to both the north and south pole of the magnet.