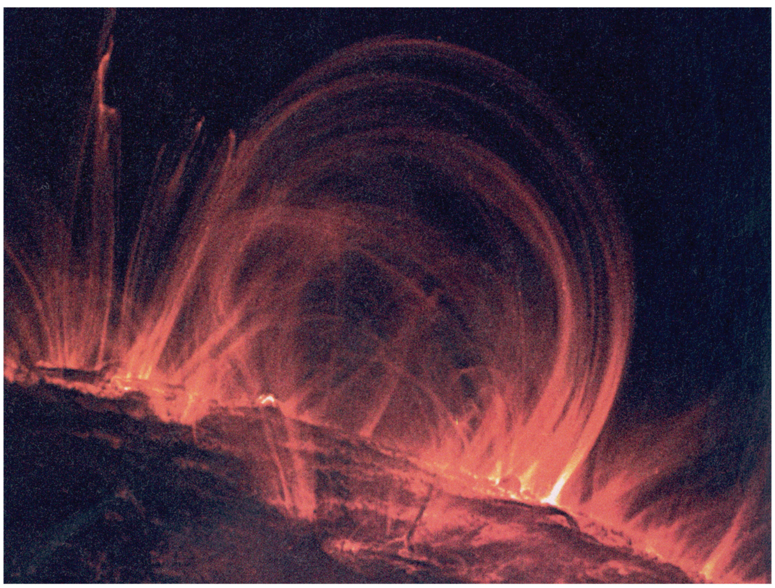
National Aeronautics and
Space Administration

Educational Product	
Educators & Students	Grades 6 - 9

A Teacher's Magnetism Activity Guide

Exploring Magnetism



The Center for Science Education at the
Space Sciences Laboratory
University of California at Berkeley

Table of Contents

Acknowledgments

Doctors Bryan Méndez, Laura Peticolas, Nahide Craig, Janet Luhmann, and Michelle Larson developed and produced these lessons using funding from the Education and Public Outreach program of the NASA STEREO-IMPACT Mission while at the Center for Science Education at the Space Sciences Laboratory (CSE@SSL) at the University of California in Berkeley. Several people at CSE@SSL helped with testing, editing, and producing the lessons and the guide. We thank them heartily: Darlene Park, Igor Ruderman, Karin Hauck, and Todd McGill. The teacher feedback we received regarding these activities was invaluable and we are especially grateful for their comments: Tom Shefler, Libby Dalcamo, Lonny Villalobos, and the many teachers who took part in our workshops at national conferences and CSE@SSL. We also thank Dr. George Craig and the NASA reviewers for giving us their comments on this teacher's guide. And last, but certainly not least, we would like to thank those involved in creating the Lawrence Hall of Science Great Exploration in Math and Science (GEMS) Teacher's Guides for Grades 6-8, because this teacher's guide was inspired by the GEMS guides.

Introduction

A Summary of the Teacher's Guide

In the sessions of this teacher's magnetism activity guide, "Exploring Magnetism," your students will act as scientists discovering magnetic fields and electromagnetism through inquiry and measurement.

Included at the beginning of each session is a summary of the session, a list of national education standards that the session covers, and a list of materials required for the session. Each session is broken into several activities, with each activity outlined for the teacher. In the Background Material section, you can find science background for the lessons. A glossary can be found after the background section, and at the very end we recommend different resources finding materials to purchase and for learning more about magnetism.

The activities in this guide are meant as primers for supplementary guides that allow students to learn about the importance of magnetic fields in space science, which are studied by NASA scientists. For example, in *Exploring Magnetism in the Solar Wind*, students learn about the stream of charged particles emanating from the Sun—called the Solar Wind— and how NASA scientists are designing a mission called STEREO to study it and its magnetic field. The other guides, *Exploring Magnetism in Solar Flares* and *Exploring Magnetism in the Aurorae*, allow students to learn about magnetism in the Sun-Earth System with more hands-on lessons.

The Science

Around 1000 A.D., the magnetic compass was discovered in China. But not until 1600 A.D. did William Gilbert publish "De Magnete," declaring that Earth is a giant magnet. More recently, scientists have found magnetic fields associated with planets and the Sun. It is now well known that the Sun's magnetic field reaches out past the planets. Charged particles spiral around this magnetic field as they move out past the planets with the magnetic field. The charged particles make up the ***solar wind***. This wind, together with the Sun's magnetic field, interacts with Earth's magnetic field. This complex interaction causes electric currents to flow through Earth's upper atmosphere/ionosphere, causing the Northern and Southern Lights (***aurorae***) to glow green and red. These currents can induce strong currents in power grids, occasionally blowing fuses and shutting down large sections of cities at high latitudes.

The Sun sometimes stores so much energy in its magnetic field that when localized parts of the field rapidly change their shape, enormous amounts of energy are released. These rapid changes in the solar magnetic field cause ***Solar Flares*** and can also accelerate solar wind particles to nearly the speed of light. This tremendous release of energy is sometimes associated with large pressure pulses of solar wind that interact with Earth's magnetic field, accelerating particles to extremely high energies in the radiation belts, i.e. ***Van Allen Belts***, in Earth's magnetic field. The solar wind particles moving at near the speed of light can harm astronauts not protected by their spacecraft. The energetic particles in the Van Allen Belts can damage or destroy human-made satellites. In order to understand and predict these phenomena, we need to understand what magnetic fields are.

Using the Teacher's Guide

The education programs of NASA's STEREO-IMPACT, RHESSI, THEMIS, and FAST missions provide these sessions and activities on magnetism to inspire your students to learn how electricity and magnetism are connected, and how to apply this knowledge. The goal is for your students to develop a deeper understanding of electromagnetism. The first session in the guide is designed to teach students that magnets have an invisible force field known as the magnetic field, and that this field has an effect that can be measured around the magnet using a compass. There are two activities in this section. Activity 1 explores magnetism and uses compasses to map magnetic field lines and their directions. Activity 2 uses iron filings to visualize the magnetic field lines in two and three dimensions.

The second session is designed to teach students that electricity flowing in wires creates an invisible magnetic field that can also be measured using a compass, that the larger the current the stronger the magnetic field, and that moving magnets across wires creates an electric current. This session has five activities. Activity 1 is a free exploration activity looking for magnetic fields around a room with compasses. Activity 2 is an activity to discover that electric currents can be the cause of the magnetic fields seen around electronic devices. In Activity 3 students use compasses to trace out the magnetic field surrounding a coil, in the same way as around a bar magnet in Session 1, Activity 1. In Activity 4 students investigate the strength of the magnetic field produced by coils of wire with current traveling through the wire. And Activity 5 demonstrates that moving magnets across a closed wire loop will generate current as measured by a galvanometer.

All of the activities are inquiry-based. One benefit of such inquiry learning is to teach the students how a scientist performs research by asking questions, testing their ideas, and collaborating with others. Another benefit of inquiry-based activities is to engage the students in the process of learning science.

These sessions can be used as a unit on magnetism in an Earth or Space Science course, a Physical Science course, or as a supplement to existing science curriculum. The activities can be used together or separately, depending on the time available to the teacher. We estimate that teaching all of the activities in each session in the guide would take two weeks (ten days) in an 8th grade classroom with 50-minute class periods, i.e. a total of 8.3 hours. The entire guide could be done in five days with 50 minute class periods, if some activities were cut or demonstrated. These activities may also be used in science museum center offerings and in teacher professional development short courses.

Session 1: Magnetism

"Science is built up with facts, as a house is with stones. But a collection of facts is no more a science than a heap of stones is a house." - Jules Henri Poincare

Session Summary

Students will learn about the magnetic field of a bar magnet. By the end of this activity, the students will know that bar magnets have two "poles," and that similar poles repel and different poles attract. They will know that magnetic fields are invisible, but they can be measured and they have a direction. They will know that a compass is made up of a tiny bar magnet that aligns itself with strong magnetic fields.

Student Objectives

1. Students will know that magnets have an invisible force field known as a magnetic field.
2. Students will be able to detect and draw a magnetic field using compasses.
3. Students will know that a compass is made up of a tiny bar magnet that aligns itself with a large magnetic field.
4. Students will know that bar magnets have two poles and that similar poles repel each other and differing poles attract each other.

National Science Education Content Standards

- Unifying Concepts and Processes: Evidence, models, and explanation; Change, constancy, and measurement
- Science as Inquiry: Abilities necessary to do scientific inquiry; Understandings about scientific inquiry
- Physical Science: Properties and changes of properties in matter; Motions and Forces

Materials Needed (per group of students)

- 1 magnetic compass per student
- 2 Alnico bar magnets
- 6 sheets of white paper
- 4-5 paper clips, a wooden or plastic ruler, and a pencil
- (optional) 1 salt shaker of iron filings
- copper or aluminum wire

Additional Materials (for demonstration or per group)

- 1 cow magnet
- 1 small/medium sized bottle (clear plastic or glass)
- 2 tablespoons of iron filings
- 1 manila envelope
- 1 roll of scotch tape (duct tape would be fine too)
- 1 piece paper or tissue paper

Hints

- **Caution:** Chrome-Steele and ceramic bar magnets
  Chrome bar magnets quickly lose their magnetic fields when dropped and we recommend that you do not use them. Ceramic bar magnets are usually very strong but brittle and hard to work with. However, there are some ceramic bar magnets that are coated with plastic that will last longer than the non-coated ceramic bar magnets.
- **Recommendation:** Alnico and cow magnets
  We recommend that you use Alnico bar magnets or cow magnets. See the Resources Section for some companies that sell these types of magnets on-line, and the text below for more information on cow magnets.
- **Recommendation:** Compasses with transparent (glass or plastic) faces
  These types of compasses can be used on overhead transparencies to demonstrate how to do the magnetic field mapping or together with iron filings to include the direction of the magnetic field. The Resources Section lists some companies that sell these types of compasses on-line.
- **Caution:** Compasses can easily change polarity using magnets
  It is fun to use the bar magnet to make a compass needle rotate around. However, if while doing this the needle does not move, the polarity (north and south locations) can be reversed. To make the needle point in the correct direction, the polarity of the needle must be such that the arrow points toward Earth's geographic north when standing outside away from electricity and other magnets. In order to reverse the polarity of the compass needle in a controlled fashion, hold the compass so the needle is horizontal. Then take the bar magnet and move one pole of the magnet length-wise across the compass needle, making sure the needle does not move.
- **Caution:** Naming conventions with magnetic poles
  By convention in the United States today, the compass arrow points in approximately the direction of the North Geographic Pole. And by convention (unrelated to the first convention), the compass arrow is a magnetic north pole, which is attracted to (points to) the magnetic south pole of a bar magnet, often marked with an "S" or with blue color. Using the fact that opposite poles attract, this means that the compass arrow must be attracted to a magnetic south pole in the Northern Hemisphere on Earth. See the Background Material section for more information on the convention of Geographic North and Magnetic North Poles.

- **Caution:** Safely working with iron filings
  To avoid students accidentally getting iron filings in their eyes during this session, students should wear safety goggles when working with iron filings.

Activity 1: Mapping Magnetic Field Lines

!! WARNING !! Do not bring bar magnets near computers, computer monitors, audio tapes, or other such magnetic devices. Strong magnets can destroy materials with magnetic properties.

1. Begin this lesson with an introductory discussion with the students about magnetism. Ask your students about their experiences with magnetism and their knowledge and ideas about what it is and what causes it. Ask questions about whether or not Earth is magnetic, how they know if it is or not, and if there are any other astronomical bodies that are magnetic (like the Sun). You might also ask if they know what a magnetic compass is and what it does.

   One key goal of this discussion is to draw out any misconceptions that may be in students' minds about magnetism. One such misconception is that magnetism needs to be transmitted through a medium. It does not, it can be transmitted through a complete vacuum.

2. Hand out "Worksheet 1.1" and two Alnico bar magnets to groups of 2-4 students. Allow students some time to freely experiment with the magnets and materials around them, such as paper clips, rulers, copper or aluminum wire, and pencils. You may make some suggestions about trying to get the magnets to attract or repel each other and attract or repel the other objects. Have the students take notes about their discoveries on worksheet 1.1.

   The goal here is for the students to discover that magnets attract metals containing iron, nickel, and/or cobalt but not most other materials. You may want to direct them toward discovering the fact that when some metals are touching a magnet they becomes magnetic themselves: i.e. if you touch one end of a paperclip to a magnet, the other end will attract other paper clips. You may wish to provide non-magnetic metals, such as copper or aluminum to demonstrate that these metals are not magnetic.

3. Now give each student a magnetic compass. Discuss with the students what they know about compasses. Teach the students how a compass works by having each student hold the compass so that the disc of the compass is horizontal and the N-S markings are facing up. Next have the students align the line marked "N" (for North) on the glass/plastic top with the arrow inside the compass. Talk about how compasses are used in the wilderness.

4. Let the students experiment with bringing the compass near their bar magnets, first with one bar magnet and then with pairs of bar magnets in random configurations. Have them take notes and make sketches about what they discover on worksheet 1.1.

5. Eventually, have the students arrange their compasses around one of the bar magnets as shown in Figure 1.1

6. Ask the students: "How do compasses work?" Eventuallly bring out the fact (after ample discussion) that the compass needle is a tiny magnet suspended on a pivot (so that it will turn with minimal friction if a magnetic force is applied to it).

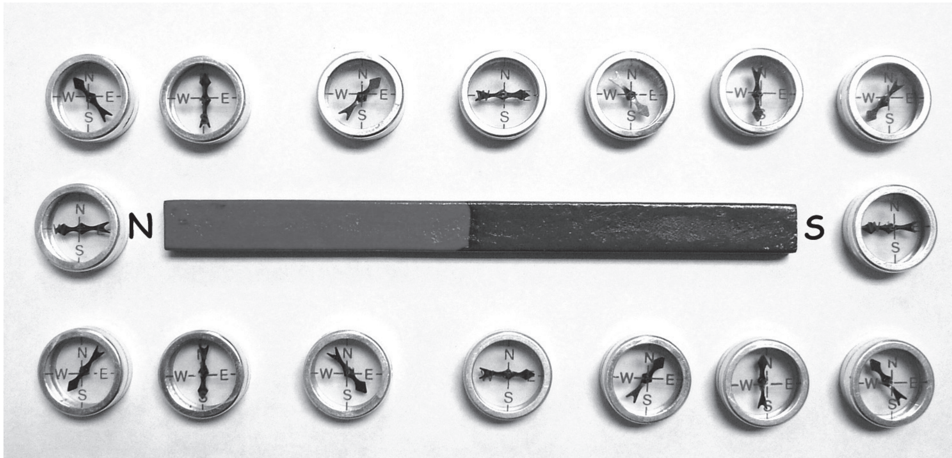


Figure 1.1: Bar Magnet with magnetic compasses placed around it. Note how the heads of the compass needles point toward the magnetic south pole and away from the magnetic north pole of the Bar Magnet.

7. Next, hand out Worksheet 1.2. Have the students tape some white paper together and place the bar magnets on top and in the middle of the taped paper. Tell the students that they will now trace the magnetic force field shape around the bar magnet. Ask them to hypothesize what they think the magnetic force field will look like and to draw it on Worksheet 1.2.

To make the tracings, have the students do the following:

a. Draw a dot somewhere near the magnet and place the center of a compass over the dot.
b. Draw a dot at the location of the arrow head (or tail) of the compass needle.
c. Move the compass center to this new dot, and again draw a dot at the location of the compass needle head (or tail).
d. Remove the compass from the paper and draw lines connecting the dots with arrows indicating the direction that the compass points.
e. Continue steps b-d until the line meets the magnet or the edge of the paper.
f. Pick another spot near the magnet and repeat the process (steps a-e).

Have the students continue until they have lines surrounding the magnet as shown in Figure 1.2: a ***dipole*** pattern of force field. Introduce the term *dipole* (two-pole) *magnetic field*.

8. If time permits, have them place two magnets side-by-side and do the same magnetic field tracing procedure again. Be sure to ask the students to draw their predictions of what the field of force will look like on Worksheet 1.2 before they determine its configuration with the compass and paper.

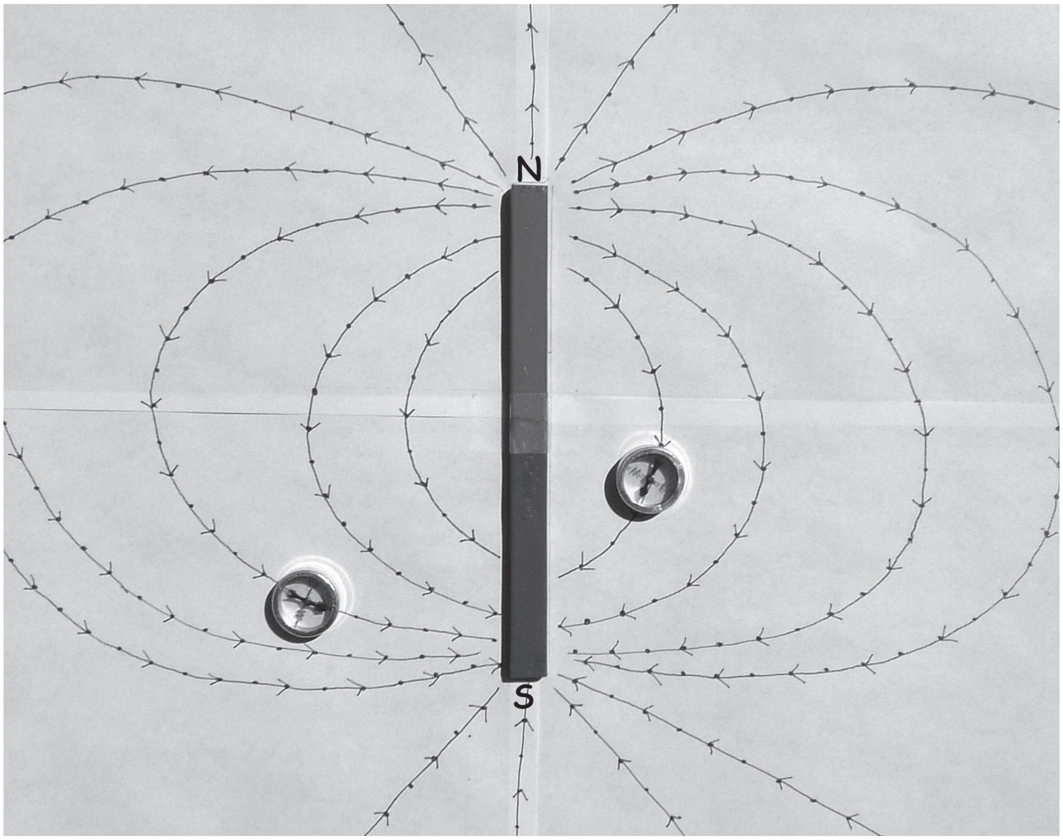


Figure 1.2: Magnetic Field line tracing of a bar magnet with a dipole magnetic field using compasses.

Activity 2: Iron Filings and (2-3D) Magnetic Field Lines

[These activities are optional or they can be demonstrated in front of the class by the teacher instead of done by the students. If done as a demonstration, the iron filings should be sprinkled on a transparency that lays on top of the magnet(s) on an overhead projector.]

!! WARNING !! Iron filings are messy and will stick to magnets. It is important to have paper or transparencies between the filings and the magnets.

9. Give groups of 2-4 students iron filings and several thin sheets of paper. Have the students place the paper on top of one of their bar magnets, trace the outline of the bar magnet and mark which end is North and which is South. Lightly sprinkle the iron filings uniformly over the paper and then give the paper some gentle taps to make the filings align with the magnetic field, as shown in the photographs in Figure 1.3.

10. Have the students record their observations on Worksheet 1.3. Ask some probing questions to get the students to think about what they are seeing. Can they explain what is happening? Have them form some ideas (hypotheses) about what could be the explanation for what they observe. Do they see the

same shape as they did with their compass tracings on paper around the bar magnets? The students should write down their answers to the questions on Worksheet 1.3. If you haven't already discussed how the filings act like tiny magnets, maybe now some students will be able to deduce this fact.

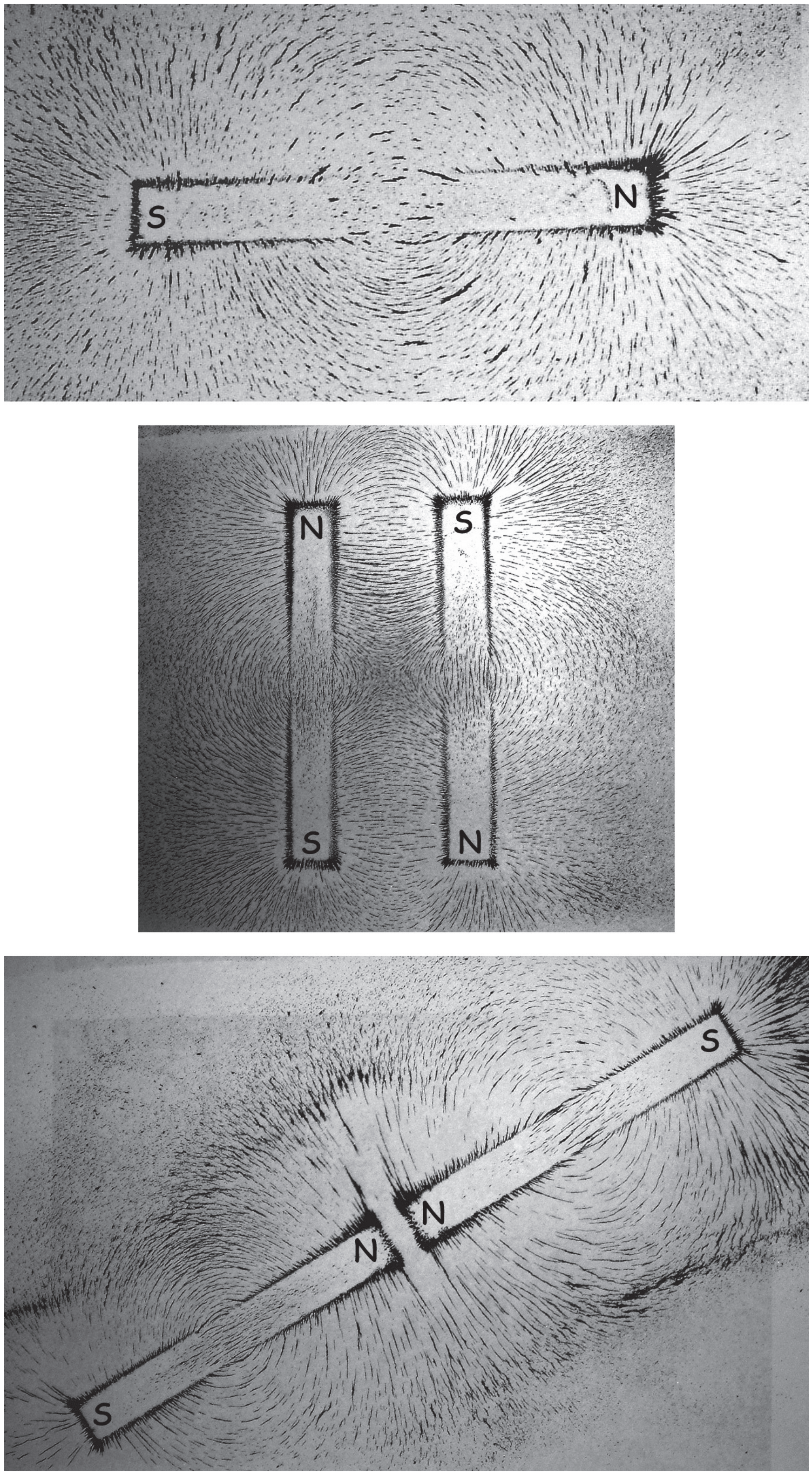


Figure 1.3: Iron filings on thin sheets of paper over bar magnets.

11. Lift up the paper carefully so as to not spill any of the filings, and funnel them back into your filings jar. Have the students place two magnets in some configuration of their choosing. On Worksheet 1.3, have students record a drawing of what they hypothesize the magnetic field will look like, then place the paper on top of the magnets and sprinkle some iron filings over it, tapping gently the paper to get the filings to align with the magnetic field. Now what do they see? Make sure they record their observations carefully by making drawings of their results and compare them to their predictions.

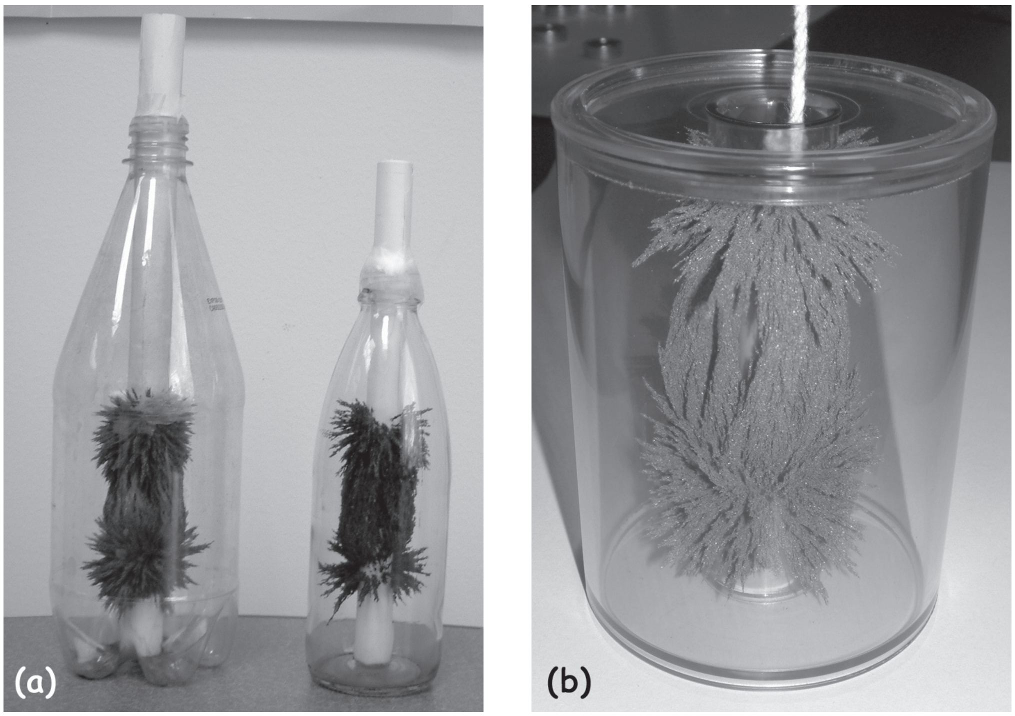


Figure 1.4: Visualizing the 3D magnetic field around a cow magnet using a 3D magnetic field visualizer made with simple materials (a), and purchased commercially (b).

12. For this step the teacher may simply do a demonstration for the class, or if you have enough materials, each group could build a 3-Dimensional (3-D) magnetic field visualizer. As the name suggests, you will construct (or buy if you have the funds) a device to visualize the 3-D structure of a magnetic field around a cow magnet.

    To construct your visualizer obtain a clear plastic or glass bottle, small/medium sized (i.e. a 20 oz. soda or water bottle). Clear away any labels on the bottle.

    - Cut a manila folder so that you can roll it up tightly into a tube about the diameter of your cow magnet and a length slightly longer than your bottle. Tape the tube to keep it rolled up.
    - Seal one end of the tube with tape and stuff some paper into that end from the open end so that when you insert the cow magnet into the tube it will not go all the way to the bottom of the tube.

- Pour some iron filings into the bottle; enough to coat the bottom with a layer $\frac{1}{4}$ inch thick should be fine.
- Insert the tube into the bottle and use paper and tape to seal up the bottle opening around the tube.

Now, drop your cow magnet into the tube. Use a pencil to hold it in place and then shake the bottle. The iron filings will then stick to the outside of the tube and take the form of the magnetic field surrounding the magnet. Have students hypothesize the shape of the field before you actually do this.

You can remove the cow magnet by turning the bottle over and shaking it out (it will resist as the magnetic force of the filings will act to hold it in). Or you can fish it out of the tube by tying a string to a large paper clip and dropping it down into the tube and then pulling the magnet out. It's a neat effect to watch the filings be dragged up the tube until the magnet disappears and the filings drop away like dust.
You can also purchase a pre-made, sealed tube with iron filings inside and a cow magnet for about $13 at most science classroom supply stores online (see resource list). For examples of the home-made tubes, see Figure 1.4a), and of a manufactured tube, see Figure 1.4b).

An optional method of viewing the 3-D field of force surrounding a magnet is to fill a bottle with mineral oil and a couple of table spoons of iron filings. Seal the bottle and shake it up. As the filings begin settling place a magnet (the stronger the better, and cow magnets are stronger than bar magnets of the same size generally) against the side of the bottle. Hold the bottle up to the light and you will see the filings moving along the magnetic lines of force. You should be able to see full loops of force from one pole to the other. If you have a horseshoe magnet (a bar magnet that has been bent into the shape of a horseshoe such that both poles are near each other) it can yield the most dramatic demonstration of the magnetic loops.

13. After completing the preceding activities the teacher should discuss with the students some of their observations, and have them explain their ideas and conclusions. Make sure to bring out the idea of like poles repelling and opposite poles attracting and that the magnetic force field has a direction. Also make note that the magnet would attract metals but not other kinds of materials. Perhaps bring out the idea that the iron filings were like tiny bar magnets that were aligning their poles with the attraction of opposite poles and repelling of like poles. Worksheets 1.1, 1.2, and 1.3 can be used as are appropriate and you can develop your own question and answers.

Worksheet 1.1

Name: ______________________________

Date: ______________________________

1. What do you notice about the interaction of the bar magnets you were given?

2. What materials interact with the magnets and how do they interact?

   Interacts with magnets:

   Does not interact with magnets:

What do all the materials that interact with the magnets have in common?

3. What happens when you bring a compass near a magnet? How does it depend on where you place the compass? (Use the back of this sheet if you need more space)

Worksheet 1.2

Name: ______________________________

Date: ______________________________

1. Draw what you hypothesize the magnetic field will look like around a single bar magnet. Include arrows that point in the direction the compass points north (red by convention).

2. Draw how it looks from your measurements with the compass.

3. Draw what you hypothesize the magnetic field will look like around two bar magnets in a configuration (or configurations) of your choice.

4. Draw how it looks from your measurements with the compass:

Worksheet 1.3

Name: ______________________________

Date: ______________________________

1. What did you observe when you sprinkled the iron filings over the paper covering the bar magnet? Draw what you observed.

2. Can you explain why the iron filings behaved that way?

3. Do you see the same patterns as you did with the compass tracings?

4. Draw what you expect to see when you sprinkle iron filings over two bar magnets in a new configuration.

5. Draw what you did, in fact, see with your two magnets in the new configuration. How were your expectations the same or different?

Additive Assessment Rubric: Session 1 - Magnetism

With an additive rubric, students have to learn more content in greater depth to achieve higher levels. Teachers should introduce the rubric before the activities begin and encourage students to achieve to their highest potential.

	1	+2	+3	+4	+5
Science Content: Student understands the concept of magnetism.	*Level 2 tasks attempted but not completed or mastered.	*Student understands how a compass operates and that some metals contain a property known as magnetism. *Student knows that a compass is made up of a tiny magnet that aligns itself with a larger magnetic field.	*Student recognizes changes in the compass when brought near a metal with magnetic properties. *Student, through successful completion of activity 1, is able to detect and draw a magnetic field using the compass.	*Student predicts what the magnetic field of both a single and double bar magnet would be. *Student knows that a magnet has an invisible force field and that bar magnets have two poles. *Student, through successful completion of activity 2, discovers that similar poles will repel each other and opposite poles will attract each other.	*Student predicts what will happen as iron shavings come in contact with a metal containing magnetic properties. *Student successfully completes activity 3 by correctly identifying the reaction of iron shavings to metals with magnetic properties. *Student makes the connection between these invisible forces measured by their compass and the concept of magnetism. *Student fully demonstrates comprehension of magnetic fields through successful exploration of activities and 90% and above correctness in activity worksheets.
Collaborative Worker	Participates but does not successfully complete one or more requirements of Level 2.	Arrives on time with materials. Shows respect for others; cares for equipment and resources.	Stays focused on assigned task and helps others do the same. Shares work equally.	Facilitates the participation of all in group. Tutors and/or supports other students.	Takes all group roles with equal skill. Assists others as they learn to do the same.

Session 2: Electromagnetism

"We now realize that the phenomena of chemical interactions and, ultimately life itself are to be understood in terms of electromagnetism." - Richard Feynman

Session Summary

Students will learn about the generation of magnetic fields from currents in wires and they will learn how to measure the magnetic field directions. By the end of this session, the students should know specifically that currents in wires create magnetic fields. Students will use magnetic compasses to explore magnetic fields in their environment where they will discover that electronic equipment also produces magnetic fields. Students will also learn that moving magnetic fields can create currents and thus that the magnetic and electric forces are interrelated.

Student Objectives

1. Students will know that the Earth has a magnetic field and it acts almost like a bar magnet.
2. Students will know that electricity flowing in wires creates an invisible magnetic field.
3. Students will be able to use magnetic compasses to explore the magnetic fields in their world.
4. Students will understand the relationship between magnetic and electrical fields known as electromagnetism.

National Science Education Content Standards

- Unifying Concepts and Processes: Evidence, models, and explanation; Change, constancy, and measurement
- Science as Inquiry: Abilities necessary to do scientific inquiry; Understandings about scientific inquiry
- Physical Science: Properties and changes of properties in matter; Motions and Forces

Previous Knowledge Required

For this session, students should already understand electricity, circuits, and the concepts of electrical charge and force . Students should also understand that:

- electricity is moving charges that create a current,
- metals more readily conduct electricity,
- in electrical circuits charges will flow through conducting material when an electrical force is applied across it, and
- when a battery is connected to a circuit it provides such a force and that negative charges will flow away from the negative terminal toward the positive terminal.
- How to set up a simple electrical circuit with batteries in series, a switch, and a coil.

The teacher should provide a lesson or review of these topics prior to teaching about electromagnetism. See the "Resources" section for good electricity and circuit lessons.

Materials Needed (per group of students)

- 1 magnetic compass per student
- 1 "boombox" stereo with audio speakers (optional)
- several pieces of blank Paper
- 1 pair of wire cutters (in most cases scissors will do the trick)
- A spool of copper wire (covered with an insulating enamel)
- Small patch of sand paper for removing wire enamel at connection points
- 3 insulated wires with alligator clips
- 3 Batteries (D-cells, 9-volt, etc.) with optional battery holders.
- 1 AC to DC adapter with variable voltage
- 1 knife switch
- 1 Ammeter or Galvanometer
- 1 bar magnet and/or cow magnet
- 1 or 2 paper clips
- Scotch tape
- Pencils and paper

Hints

- **Recommendation:** Checking that current is flowing in a circuit
  You can check to see if current is flowing in a circuit by attaching an ammeter or galvanometer in series. These should read off the amount of current flowing. Another way is to add a small light bulb in series to the circuit. However, a light bulb will add resistance to the circuit which will decrease the current. This weakens the magnetic field significantly. It is not recommended that you leave the light bulb in the circuit while doing the activities.

- **Caution:** Using alligator clips
  The alligators clips used in these experiments are often made of metals that are magnetic. The copper wire leads to and from the coils used in the experiment should be long enough that the alligator clips are kept a reasonable distance away from the coils. Otherwise, the alligator clips will magnetically interact with the magnets, compasses, and electrified coils.

Activity 1: Exploring Magnetic Fields in Your Environment

1. If possible, take the class outside, far away from buildings, power lines, or anything electrical or metal. Have them bring a compass and a lab notebook. Have students spread out and walk around a bit. Ask them to point in the direction their compass is pointing when the face of the compass is horizontal. Make sure that they move slowly and allow the compass needle to stop its oscillations (caused by moving it around) before they point. They should all

be pointing in the same direction toward North. [Note: they will be pointing toward the magnetic pole which is offset from the geographic pole.]

2. Discuss with students that Earth has a magnetic field and it acts almost like a bar magnet.

3. Hand out Worksheet 2.1 to your students. Have students draw what they think Earth's magnetic field looks like.

4. Next, have students use the compasses to probe whether there are any sources of magnetic fields (large and small) around the school and in their classroom. They should be sure to take careful notes on the kinds of objects and places they explore and what kinds of magnetic fields they encounter. They can fill out Worksheet 2.1 to guide their note-taking. Near the end of their explorations about the school, the teacher should bring out a boombox stereo and have them explore the magnetic field around it while it is operating, paying special attention to the speakers (which work using a modulating magnetic field) and the CD player which uses an electromagnetic motor to spin the disc.

5. Have a discussion about the students' observations by asking questions such as:
    a. Where did they detect magnetic fields?
    b. Were they complex, as with several magnets, or simple, like one magnet?
    c. Were they constant in time?

   In general, they should find magnetic fields around operating electronic equipment, and possibly metals.

<u>Activity 2</u>: Compass Needles Around a Simple Circuit

!! WARNING !! AC currents and voltages from household electrical outlets are potentially lethal and students should be instructed explicitly not to experiment with them. However, the batteries and circuits that students will investigate in this lesson are not dangerous. The voltage provided by even many batteries in series can produce enough current to make the wires very hot, but there is no danger of life-threatening shocks.

During this activity, groups of students will set up simple electrical circuits (See Figure 2.1) to demonstrate that electric currents can be the cause of the magnetic fields seen around electronic devices (some are caused by magnets in the electronics themselves, like the boombox stereo speakers).

6. To set up the simplest electric circuit connect the positive and negative terminals of a battery using the **insulated** alligator clip wires to a switch (pictures in Figure 2.1). Have students set up the apparatus and make sure they understand that electricity will be flowing through the wire when the switch is closed (turned on). Allow students to explore the wire with a magnetic

compass *before* closing the switch. Then have students close the switch and explore the wire again with the compass. Suggest that the students pick up the wire and measure the magnetic field direction all around the wire. Have them record all observations. They should observe that when current is flowing in the wires there is a magnetic field present around the wire. Be sure that they observe the direction of the magnetic field with the compass. Students may be surprised that the magnetic field does not point along the wire but rather perpendicular to it. Discuss with the students what they observed.

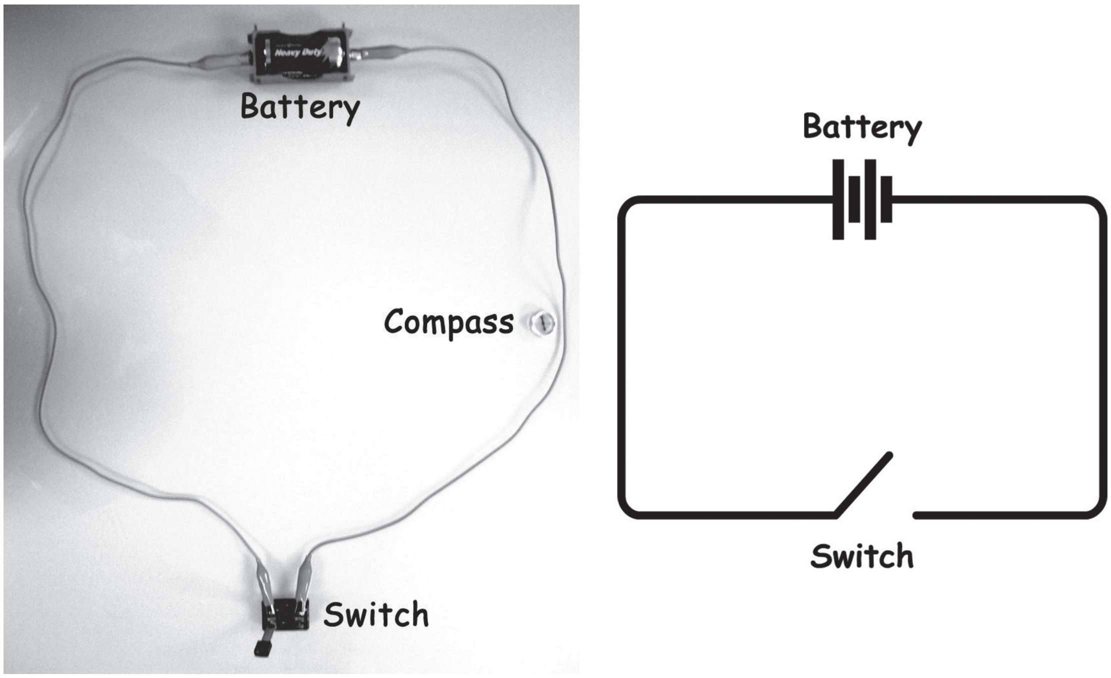


Figure 2.1: A simple electrical circuit

7. Emphasize that currents generate magnetic fields. Electronic equipment operates by using electric circuits. Therefore electronic equipment generates magnetic fields. Depending on the level of the students, explain (or not) that current is a moving charge—as a charge moves, it creates a changing electric field of force around it. This changing electric field manifests itself as a magnetic field that is found to wrap around the wire. It is important to emphasize this point

8. Next, from a spool of copper wire have students measure out and cut off two lengths of wire, approximately 6-feet and 24-feet long. Have the students wrap the wires into coils. The diameter of the coils should be large enough that the magnets will fit inside length-wise (about an inch or so). They can use scotch tape to hold the coil together. Example coils are pictured in Figure 2.2.

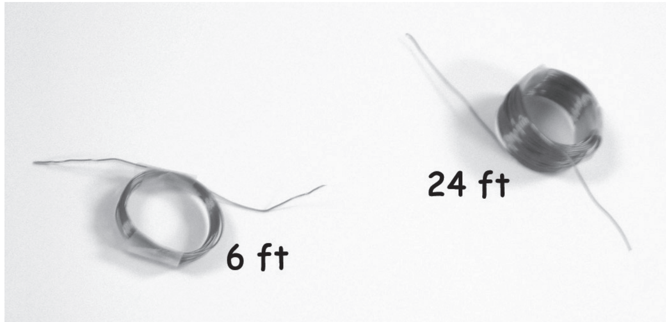


Figure 2.2 : Coils of wire, taped together. On the left is a 6-foot length of wire, on the right is a 24-foot length of wire.

9. Students should first connect the smallest coil to their electrical circuit as pictured in Figure 2.3. Note: they will need to add an additional alligator clip wire to the circuit. Also, since the wire wrapped into coils is likely (and should be) coated in an insulating enamel the students will need to make sure that they scrape the enamel off at the points of contact between the alligator clips and the coil. Sand paper works very well for this. Be sure to lay the coil on its side (as pictured) rather than on an end for these experiments.

10. Before closing the knife switch to complete the circuit and start electricity flowing in it, the students should place several magnetic compasses around the coil. Then, when they close the switch they should note what happens to the compasses. The compass needles should deflect in response to the new magnetic field being generated by the current in the coil.

11. Open the knife switch and next have students place a paper clip just barely inside the coil. Have them throw the switch. Does it move? Can they pick up the paper clip with the coil? [With only 1 D-cell battery the coil will probably not pick up the paper clip. Putting 2 D-cell batteries in series (to produce a total voltage of 3 volts) will cause the paper clip to be sucked into the coil provided that the coil is big enough.]

12. Last, have students hold a cow or bar magnet horizontally and hang the coil on the very edge of one end of the magnet (see Figure 2.7), then close the switch. The coil will either shoot off the magnet or get pulled toward its center. If it gets pulled toward the center, turn the magnet around and the coil will then shoot off.

13. Allow students the time to explore freely with the magnet and the coil with the electricity on and off. Ask them if the copper wire is magnetic with the electricity off, and ask again if it is magnetic with the electricity on.

14. Ask the students: "How are magnets and coils of electrical current alike and different?" and discuss their answers with them. Have the students open the knife switch and leave it open until returning to this set-up in Activity 4.

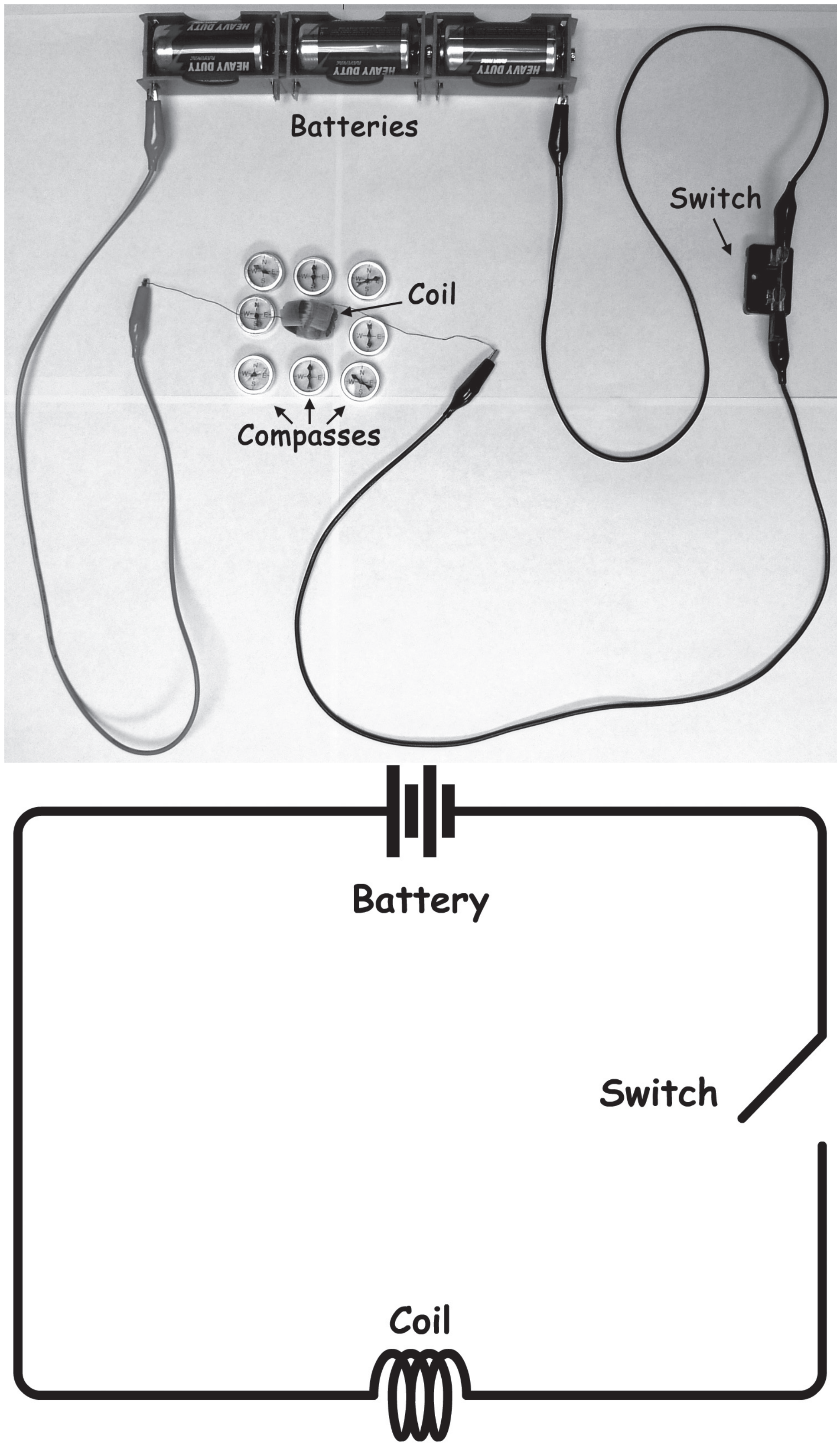
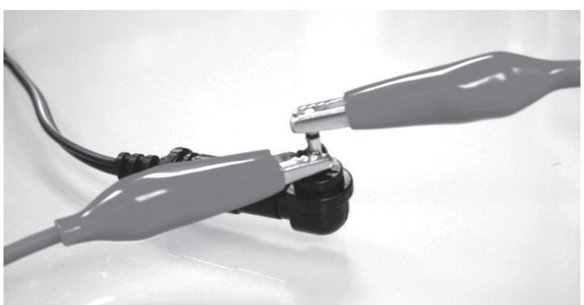


Figure 2.3: An electrical circuit with a coil of wire included. Compasses placed around the coil will detect any magnetic fields produced by the electrical current.

Activity 3: Mapping Magnetic Field Lines

!! WARNING !! AC currents and voltages from household electrical outlets are potentially lethal, and students should be instructed explicitly not to experiment with them. However, the batteries and circuits that students will investigate in this lesson are not dangerous. The voltage provided by even many batteries in series can produce enough current to make the wires very hot, but there is no danger of life-threatening shocks.

In this activity, students will use compasses to trace out the magnetic field surrounding a coil, just as they did with a bar magnet in Session 1. To get a large enough magnetic field that can be easily traced, you will need to have a very large coil of wire with a moderate-to-large voltage. If you have enough spools of wire, each group should use an entire spool as their coil (See Figure 2.5). Also, you may need a more steady voltage source than chemical batteries can provide. Over the time that it will takes students to do the tracings the batteries' voltages will fluctuate, which could make doing the tracing very difficult as the shape of the magnetic field will also fluctuate. One possibility is for you to connect the electrical circuit to an AC to DC adaptor which will then be plugged into an AC electrical outlet in your classroom. Voltages produced by such adapters typically range from around 3 volts to 12 volts. See Figure 2.4 on how to configure the circuit with an AC to DC adapter as the power source.



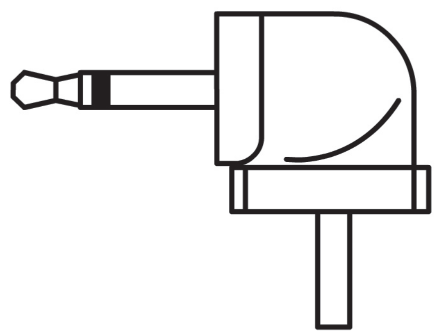


Figure 2.4 : Configurations for using an AC to DC adapter as a power source in the electrical circuit. Configurations will vary depending on the type of adapter plug. For the adapter shown, positive and negative terminals are on the outside of the plug separated by a plastic insulator.

If you are concerned about using the electrical outlets in your room for this experiment then use at least 3 D-Cell batteries connected in series for the voltage source. Chemical batteries may not put out a consistent voltage for long periods of time, but if the students conduct the field tracing quickly they may not experience too much of a problem.

Also, note that the higher the voltage used, the quicker the coil of wire will become hot to the touch. If you are using a full spool for each group, instruct the students to avoid touching the spool. After about 10 minutes instruct the students to open the switch and let the coil cool. If the students need more time for tracing they should take care not to move the coil or any of the set-up until they close the switch again and continue with the tracing.

For the tracing it is useful to get the connection wires away from the table surface. Pictured in Figure 2.5 is one possible way to accomplish this (using plastic cups and rulers). The coil should also be taped down to the paper on the table. Taping the paper together and then down to the table is also suggested.

[**Hint:** If you are short on supplies or unable to have each group of students have access to an electrical outlet, this activity and the next two in the session could be done as stations. Students can then rotate from one station to the next.]

15. Have students use a ruler, books, tape, a coil of wire, and alligator clipped wire, and paper to construct the mapping area, as shown in Figure 2.5.

16. Have the students map the magnetic field as was done in Session 1. See in particular action 7 to review how to do the tracings.

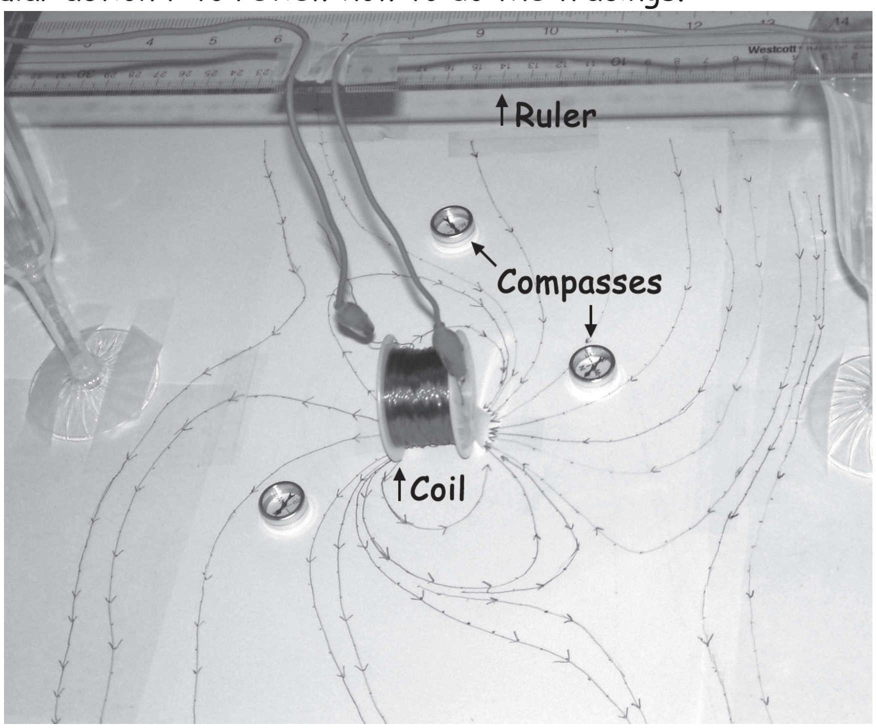


Figure 2.5: Here the entire spool of wire is used as a coil in an electrical circuit. The glasses and ruler are used to hold the wires off the table so that a tracing of the magnetic field around the coil can be drawn on the paper beneath it.

17. Discuss the mappings with the students. How do they compare with the bar magnet mappings in Session 1? [Students may find that not all the loops they started end up closing back on the coil. Some lines may just go off in one direction parallel to one another. This is Earth's magnetic field. The magnetic field of Earth and the field of the coil add together and subtract from each other depending on the directions of the fields. Closer to the coil the dipole field of the coil dominates and farther from the coil Earth's magnetic field dominates.]

Activity 4: Jumping Coils

!! WARNING !! AC currents and voltages from household electrical outlets are potentially lethal, and students should be instructed explicitly not to experiment with them. However, the batteries and circuits that students will investigate in this lesson are not dangerous. The voltage provided by even many batteries in series can produce enough current to make the wires very hot, but there is no danger of life-threatening shocks.

In this Activity students will investigate the strength of the magnetic field produced by coils of wire with current traveling through the wire.

18. Have the students return to their coil circuit as discussed in Activity 2 of Session 2 and Figure 2.3. Students will use worksheet 2.3 and the set-up of Activity 2. Students will set up 6 different configurations of their circuit and coils. For both the 6-foot coil and 24-ft coil the circuit will include either 1, 2, or 3 batteries in series. For each configuration, students will conduct two experiments:
    (1) Have them line up three compasses spaced about half a centimeter apart along one side of the axis of the coil and also place a bar magnet perpendicular to the coil axis several inches away (see Figure 2.6). When the switch is closed they will qualitatively measure how much each compass needle deflected. (e.g.: not at all, slightly, moderately, a lot). The bar magnet is there to insure that the compass needles are not initially lined up with the coil axis, but be sure it is not too close, otherwise it will dominate over the magnetic field of the coil.
    (2) Have them hold a cow or bar magnet horizontally and hang the coils on the very edge of one end of the magnet. When the switch is closed, they will measure how far the coil was thrown (see Figure 2.7). They can do this by marking the starting and ending position on a piece of paper placed on the table-top. Make sure there is enough wire connected between the coil and the switch and batteries so that it will not interfere with the jumping distance.

    [**Hint**: For this step a cow magnet works great and is recommended. However, a regular bar magnet will work too.]

    In the end, they should conclude from their data that a coil with more loops of wire produces a stronger magnetic field, and that a larger voltage from more batteries in series (and hence a larger current) also produces a stronger magnetic field. They should also note that the strength of the field gets weaker with distance, as is true of all magnets.

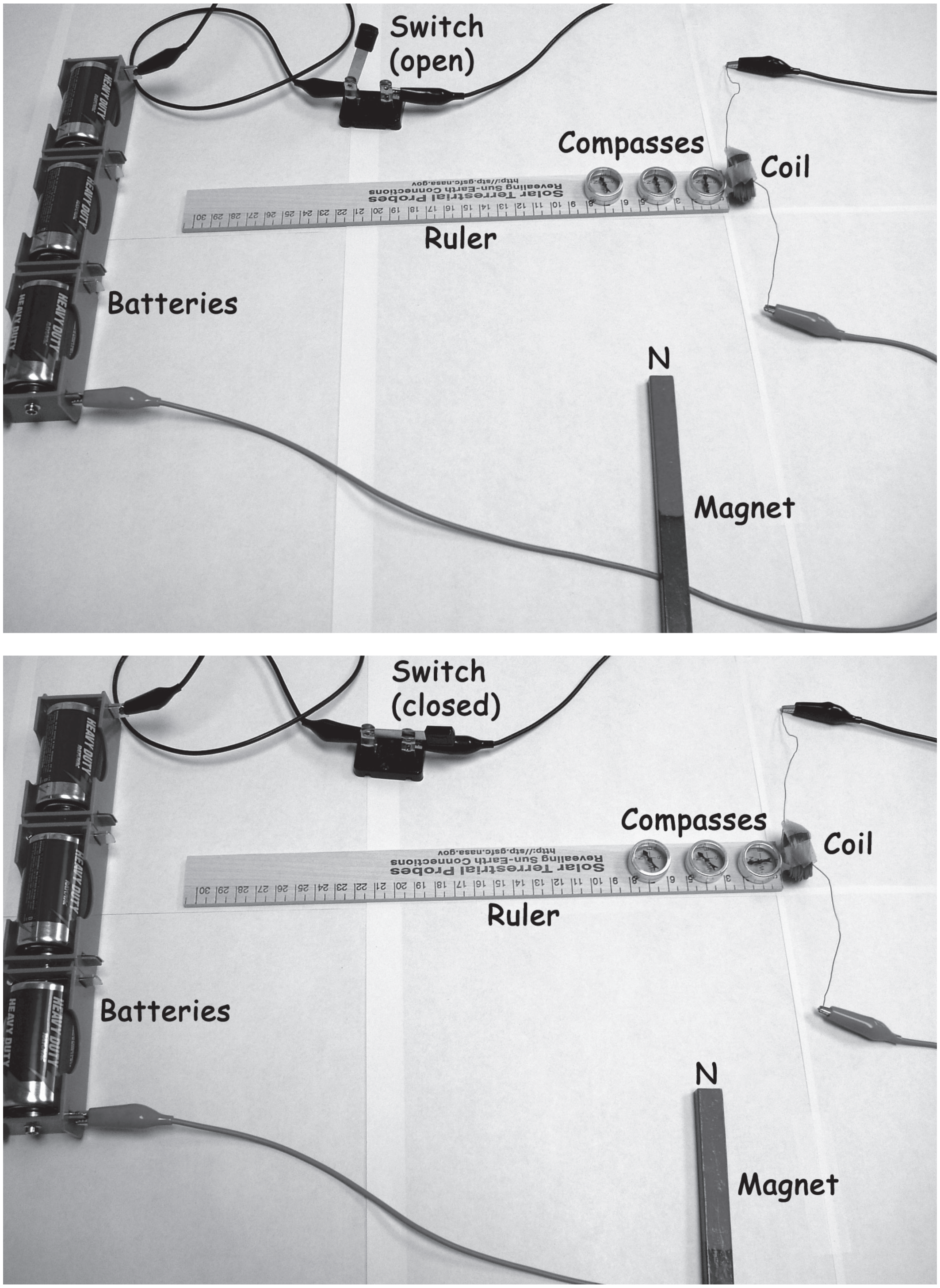


Figure 2.6: Set-up for the experiment with compasses aligned along the axis of a coil of wire.

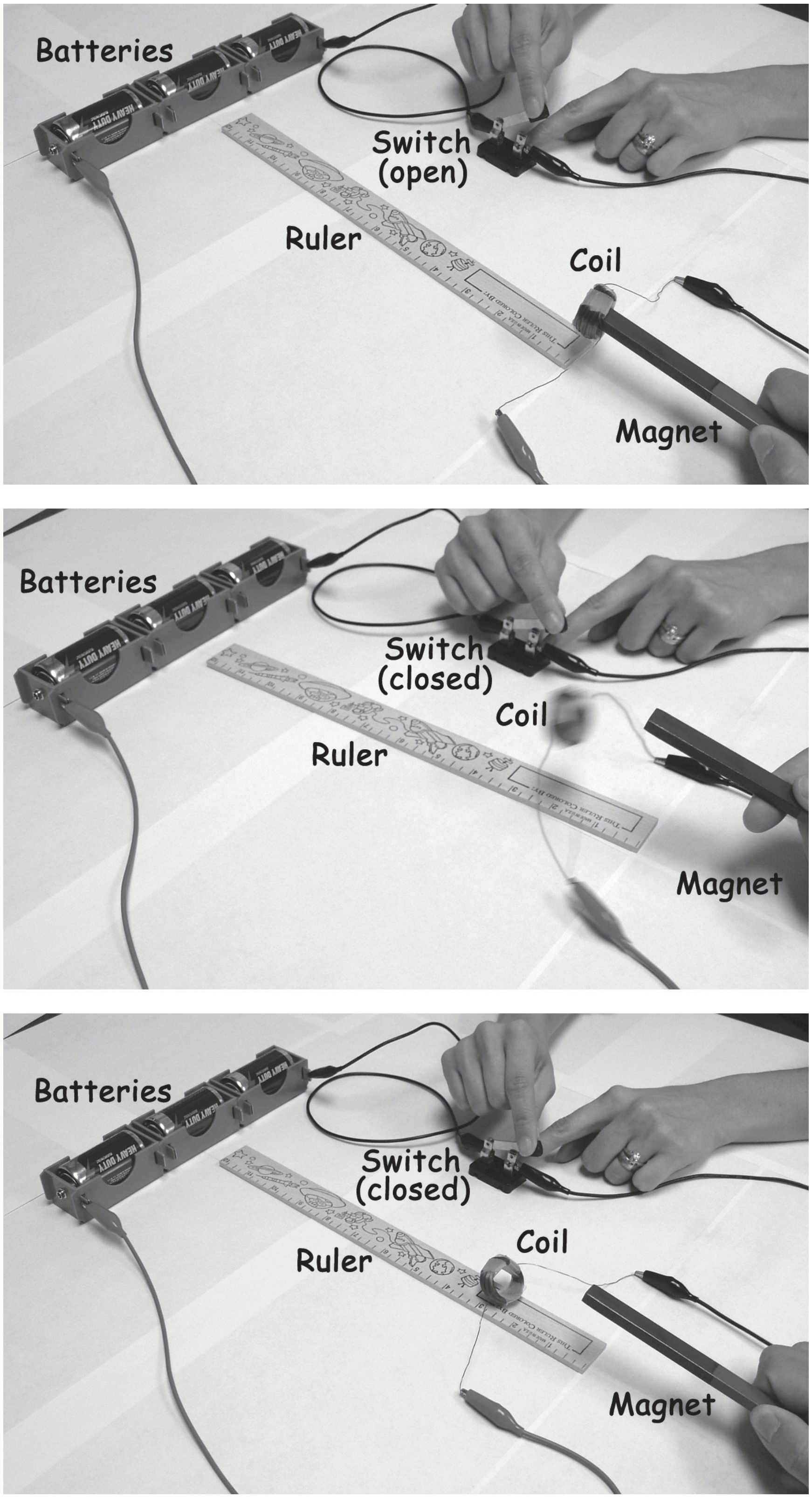
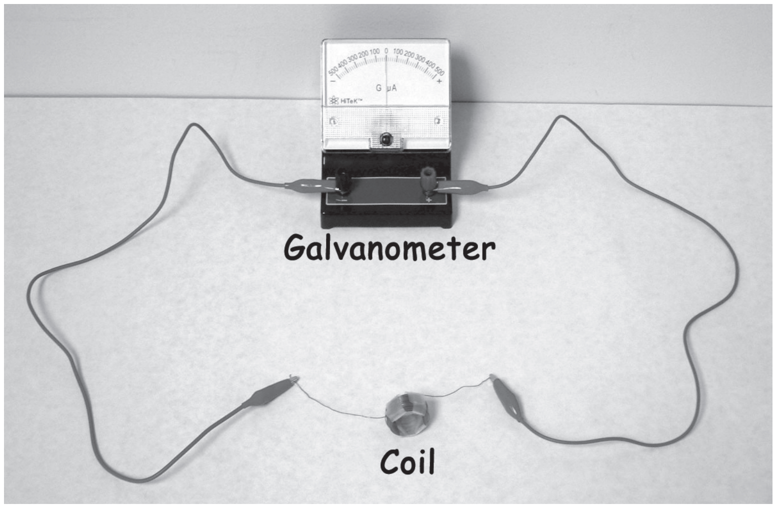


Figure 2.7: Set-up for the Jumping Coils Experiment

Activity 5: Electric Current Generated with a Moving Magnet

[This last Activity of Session 2 is an appropriate continuation of the lesson for high school students. The aim of these steps is to allow students to discover what the source of magnetism is. National Science Education Standards suggest that using the particulate nature of matter to explain electrical and magnetic phenomena is inappropriate for younger middle school students, as they may not be developmentally ready for that concept.]



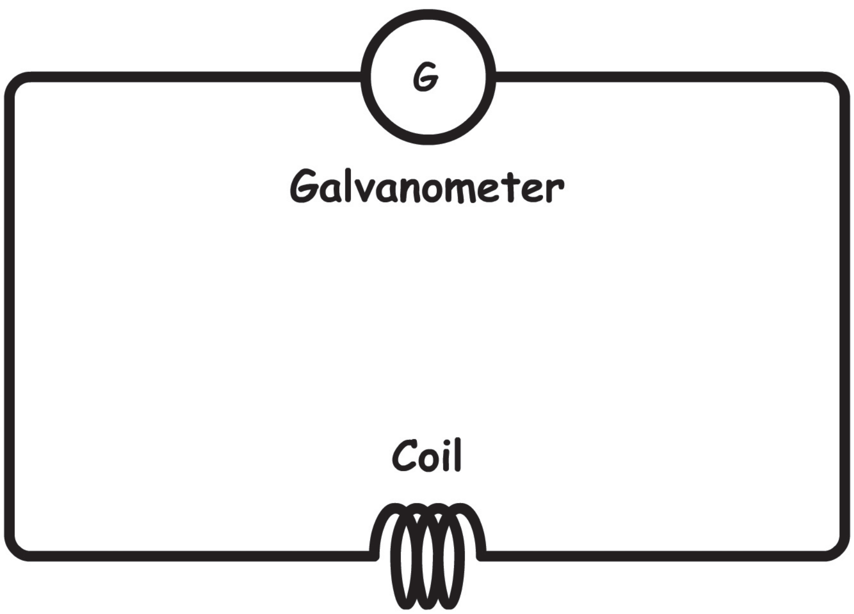


Figure 2.8 : Coil of wire in an electrical circuit with a galvanometer

This activity demonstrates that moving magnets across a closed wire loop will generate current. Before you start with the students, set up a different apparatus in the electrical circuit. Take a coil of wire and connect it to an ammeter or galvanometer (See Figure 2.8).

19. Hand out Worksheet 2.4 to your students and have them answer the questions as they explore with the galvanometer circuit.

20. Instruct the students to try and make the galvanometer needle move using the coil and the magnet. Let them explore in their groups to discover that they need to *move* the magnet through the coil.

21. Have students take the bar magnets or cow magnets and move them through the coil and record what they observe. They should see that the moving magnet produces a current in the wire (Figure 2.9). Students should experiment with the different coils and the different magnets. Which configurations create more current?

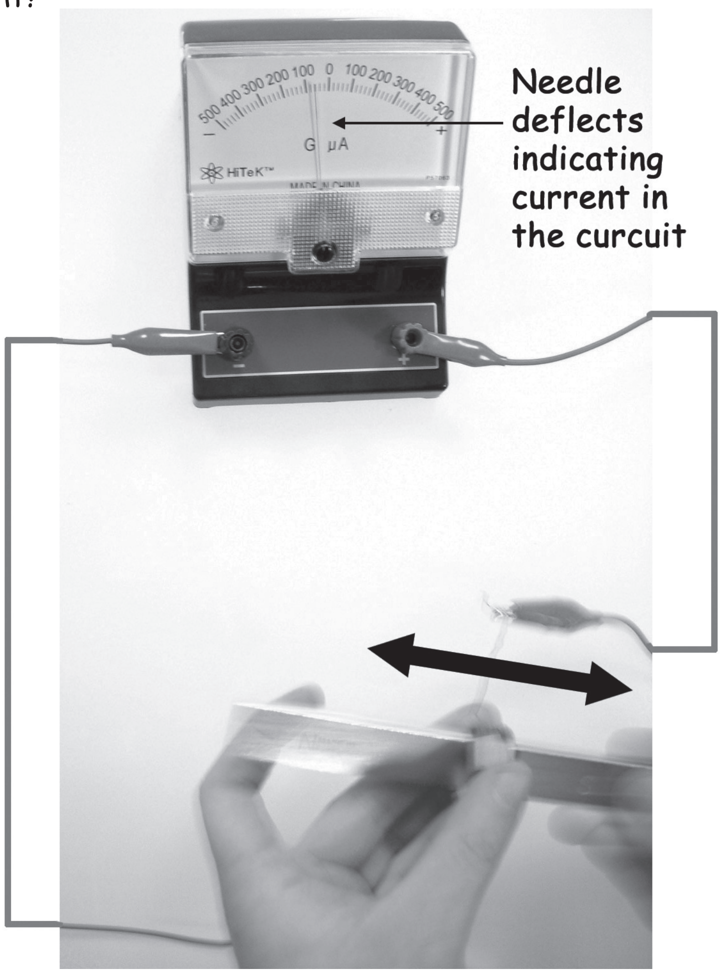


Figure 2.9 : Moving a magnet through the coil of wire produces a current. Blurry elements in the figure are an effect of this mothion being photographed.

22. Discuss with the students what they are observing. [A moving magnet pushes charge. How? Charge can only be pushed by an electric field so the changing magnetic field must create an electric field, just as the changing electric field of the moving charges created a magnetic field in the previous steps. In the 19th century, it was realized that the electric and magnetic forces were really two manifestations of the same force, called the electromagnetic force.]

23. To conclude this activity, have a discussion about the production of magnetic fields in nature. Have students brainstorm about where in nature they have experienced or heard of magnetic fields existing. Examples: Aurora, Lightning,

Loadstones, Earth, Planets, the Sun, the Solar Wind, the Interstellar Medium, the Galaxy. The teacher could begin talking about how waves in the electric field would be expected to produce waves of magnetic fields, which would in turn induce more waving electric fields, resulting in electromagnetic waves which could travel through a vacuum (as well as through conducting media) at a speed of 300,000 km/s (186,000 miles/sec) which is the speed of light. This realization lead James Clark Maxwell to theorize that light was in fact a form of electromagnetic radiation, which was later proved to be the case. Other forms of electromagnetic radiation are Radio Waves, Microwaves, Infrared light, Ultraviolet light, X-rays, and Gamma Rays.

24. Hand out Worksheet 2.2 to assess your students' understanding of their observations.

Worksheet 2.1

Name: ______________________________

Date: ______________________________

1. Draw what you think Earth's magnetic field looks like.

2. In your explorations of your school and classroom, where did you find magnetic fields?

3. What were the shapes of the magnetic fields like? How could you tell?

4. Were the magnetic fields constant in time?

5. What had the strongest magnetic fields? How did you determine which had the strongest magnetic fields?

Worksheet 2.2

Name: ______________________________

Date: ______________________________

1. Describe your observations of the compass near the electric circuit before and after there was current flowing in it.

2. What happens to the compass needles placed around the coil of wire when the switch was thrown starting current flowing in the circuit? Draw what you see.

3. Does the coil of wire attract paper clips like a magnet does?

4. What happens when the coil is placed on a magnet and then the electricity is turned on?

5. How are magnets and coils of electrical current alike and different?

Worksheet 2.3

Name: ______________________________

Date: ______________________________

In the table below, record your observations for the 6 different configurations of your electrical circuit in Step 6 of Activity 2; for example, the short coil with 2 batteries in series. Be as qualitative as you like in the compass deflections. You could simply state that the closest compass (compass 1) deflected strongly, weakly, or not at all for a given configuration. Use a ruler, if you can, to measure the horizontal distance that the coil shoots.

	Low Voltage (1 Battery)	**Medium Voltage (2 Batteries)**	**High Voltage (3 Batteries)**
Short Coil	Compass Deflection: 1. 2. 3. Coil Distance:	Compass Deflection: 1. 2. 3. Coil Distance:	Compass Deflection: 1. 2. 3. Coil Distance:
Long Coil	Compass Deflection: 1. 2. 3. Coil Distance:	Compass Deflection: 1. 2. 3. Coil Distance:	Compass Deflection: 1. 2. 3. Coil Distance:

What configuration produces the strongest magnetic field?

What factors affect the strength of the magnetic field produced by a coil? Does distances from the coil make any difference?

Worksheet 2.4

Name: ______________________________

Date: ______________________________

1. What did you have to do to make the needle move on the galvanometer/ammeter, indicating that current was flowing?

2. If you observed a current, how strong was that current?

3. Did the different magnets produce different sizes in current? If so, how were the magnets different?

4. Did different coils produce more or less current? How were the coils different?

5. What factors do you think affect the size of the current induced in the circuit, and in what ways?

Additive Assessment Rubric: Session 2 - Electromagnetism

With an additive rubric, students have to learn more content in greater depth to achieve higher levels. Teachers should introduce the rubric before the activities begin and encourage students to achieve to their highest potential.

	1	+2	+3	+4	+5
Science Content: Student understands the concept of electromagnetism	*Level 2 tasks attempted but not completed or mastered.	*Student, through successful completion of activity 1, discovers magnetic fields around their school or classroom using the compass. *Student demonstrates that they know Earth has a magnetic field and it acts almost like a bar magnet. *Student knows that their compass can detect the magnetism of Earth as well as smaller magnetic fields.	*Student, through successful completion of activity 2, recognizes changes in the compass when near an electric current (electricity). *Student demonstrates, through successful completion of activity 3, that they understand how magnets and coils of electrical currents are alike and different.	*Student, using the compass and through successful completion of activity 4, recognizes the greatest magnetic field between two differing coils and voltages. *Student knows that electricity flowing in wires creates an invisible magnetic field. *Student knows that their compass is detecting the magnetic field coming from sources of electricity.	*Student, through successful completion of activity 5, recognizes changes in the galvanometer/ ammeter when different sized magnets are passed through differing coils. *Student identifies the factors that affect the size of currents induced in the circuit. *Student fully demonstrates comprehension of electromagnetism through successful exploration of activities and 90% and above correctness in activity worksheets.
Collaborative Worker	Participates but does not successfully complete one or more requirements of Level 2.	Arrives on time with materials. Shows respect for others; cares for equipment and resources.	Stays focused on assigned task and helps others do the same. Shares work equally.	Facilitates the participation of all in group. Tutors and/or supports other students.	Takes all group roles with equal skill. Assists others as they learn to do the same.

Background Material

Important Questions about Magnetism:

1) What is Magnetism?
Magnetism is a force of nature, like *gravity*. But it is quite different from gravity in many respects. Gravity is a force of attraction between all objects with *mass*. Matter can be defined as objects in the universe that have mass. Therefore, all matter attracts other matter to it through gravity. Much of the fundamental matter in the Universe also has *charge*. Whereas there is only one kind of mass, there are two kinds of charge: positive or negative. Objects may contain equal numbers of positive and negative charges and therefore have no net charge overall. Objects with different charges will attract one another very much like how mass attracts mass through gravity. But objects with the same charge will repel one another. This force of attraction or repulsion due to charge is called the *electric* force. But what about magnetism, is there a fundamental property of some matter that makes things magnetic? The answer is: "sort of." *Electric current* is the source of magnetism. Electric current is charge in motion. Anywhere there is an electric current there is a magnetic force field present, just as anywhere there is charge there is an electric force field present, and anywhere there is mass there is a gravitational force field present. If an object has no net electric current flowing through it, there will be no magnetic field overall.

2) Why are some objects magnetic and others are not?
All atoms are magnetic; they have charges moving around within them. For a macroscopic object made of atoms to be a magnet, the atoms' magnetic fields in it have to align with each other. This will create a large scale magnetic field around the object. In order for the atoms' magnetic fields to line up within the material, they have to be able to move freely. In many materials the atoms are held too rigidly in place to be able to line up with any external magnetic field. If the magnetic fields of all those atoms are randomly oriented then they would cancel each other out and the material would have no net magnetic field.

For example, a bar magnet's atoms are lined up so that their north and south magnetic poles align with one another, as shown in Figure B.1. This gives an overall very large magnetic field. However, a pencil's atoms are arranged in such a way that their north and south magnetic poles are lined up randomly, also shown in Figure B.1.

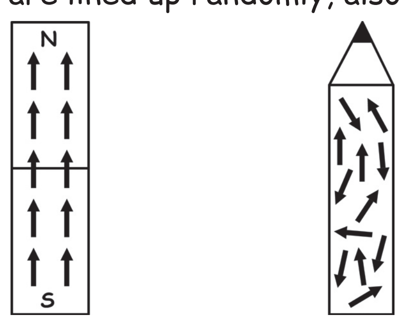


Figure B.1: Cartoon of atom's magnetic dipole fields in a bar magnet and in a pencil.

3) What's the deal with the whole compass pointing North thing?

The needle of a compass points North, and the part of the compass pointing North is a north magnetic pole. But like magnetic poles repel and opposite magnetic poles attract. What's the deal?

The deal is that the magnetic pole located in the Northern Hemisphere is actually a south magnetic pole. Likewise the magnetic north pole is located in the Southern Hemisphere. So why do we call it North if that's where a south magnetic pole is located?

It's really just an accident of history, which we are stuck with. But it turns out not to be so bad. Nowadays, scientists define North by using what they call a "right-hand rule." If you take your right hand and curl your fingers in the direction that Earth spins while keeping your thumb extended, then your thumbs points North. Likewise, magnetic north is defined the same way. If you take your right hand and curl your fingers in the direction that positive current flows (i.e. the direction that positive charges are moving — or opposite the direction that negative charges are moving) then again your thumb points north. You can verify this for yourself in Session 2, Activity 3 of this guide. Check which direction the positive current flows through the coil of wire and which direction is north for the magnetic field that is mapped out around the coil. Even though it is confusing, it all turns out to be consistent.

Glossary[1]

Atmosphere: The mixture of gases that surround an object in space, such as a planet, moon or star, held near it by gravity.

Atom: A basic unit of matter. Every atom has a positively charged center called a nucleus that is surround by a number of negatively charged electrons.

Attract: To draw to or toward itself.

Aurora: (plural = **aurorae**) Light radiated by ions and atoms in Earth's upper atmosphere, in the region of Earth's poles. Aurora can be an extremely impressive spectacle. The *Aurora australis*, or "Southern Lights" occur near the South Pole while the *Aurora borealis*, or "Northern Lights" occur near the North Pole.

Boom: A part of a spacecraft that is long and cylindrical to hold instruments far from the satellite bus when it is in space.

Cause: Something that produces an effect.

Compass: A device that determines the presence of a magnetic field and its direction.

Corona: The outer part of the Sun's "atmosphere." In the outer region of the corona, particles travel away from the Sun and stretch far out into space. The corona can only be seen during total solar eclipses, appearing as a halo around the moon.

Coronal Mass Ejections (CMEs): Huge bursts of solar wind rising above the Sun's corona. These are one of the biggest explosions in the Solar System.

---

[1] *This Glossary was adopted from the Helios glossary (http://helios.gsfc.nasa.gov/gloss_ab.html). Underlined words represent words that are defined in this Glossary.*

Dipole: Two electric charges or magnetic poles that have the same strength but are opposite in sign or polarity (North versus South) and are separated by a small distance.

Earth: The third planet from the Sun on which we all live.

Eclipse: The blocking of some or all of the light from one object by another.

Effect: Something brought about by a cause; a result.

Electric charge: A physical state based on the amount and location of electrons and protons in matter. Matter with more electrons than protons is negatively charged. Matter that attracts free electrons is positively charged.

Electric circuit: A system that connects electrical components so that they will operate.

Electric current: A flow of electric charge.

Electron: The negatively charged part of an atom and one of the smallest particles in the universe. It orbits the atom's nucleus. Electrons are very light compared to protons and neutrons.

Element: A material consisting of atoms, all with the same atomic number. Approximately 90 different elements are known to exist in nature and several others have been created in nuclear reactions. For more information about the elements, see the Periodic Table of the Elements.

Experiment: A test under controlled conditions that is made to determine how something in nature works.

Gas: A low number of atoms or molecules in a relatively large volume of space so that their interaction is small.

Geographic North Pole: The northern point on Earth around which Earth rotates.

Gravity: A physical force that attracts objects to one another. This force is very weak and only objects made of a lot of protons and electrons will have enough gravity to affect other objects. For example Earth has enough atoms that its gravity holds us on this planet. But a teacher does not have enough atoms to attract a coffee mug with gravity.

Hydrogen: The most common element in the universe. Each atom of hydrogen contains one proton and one electron.

Interplanetary: Between the planets in our solar system.

Instrument: An electrical and/or mechanical device that collects data as part of an experiment.

Ion: An atom that carries a positive or negative electric charge as a result of having lost or gained one or more electrons.

Iron: An element that has an un-paired electron making it able to align with a nearby magnetic field.

Magnet, solenoid: A solenoid magnet is a coil of insulated wire, usually cylindrical in shape and with a length greater than its diameter. An electric current passing through the solenoid produces a magnetic field similar to that of a bar magnet.

Magnetic field: A region of space near a magnetized body or electrical current where magnetic forces can be detected.

Magnetic field lines: These lines are a way to show the structure of a magnetic field. A compass needle will always point along a field line. The lines are close together where the magnetic force is strong, and spread out where it is weak.

Magnetism (Electromagnetism): A physical property of an object that shows attraction for iron, as in a magnet. Electromagnetism acts between particles with an electric charge, such as electrons, protons, and ions. It is associated with moving electricity, and it creates fields of force.

Magnetometer: An instrument that measures the magnitude (strength) and direction of a magnetic field.

Magnetosphere: The region surrounding a planet where the planet's magnetic field dominates.

Molecule: Two or more atoms bound together. As an example, a molecule of water consists of two atoms of hydrogen and one of oxygen.

Neutron: The part of an atom that has no charge. It is often part of the nucleus.

Nucleus: (plural=nuclei) The small, massive center of an atom containing its protons and neutrons bound together by nuclear force, the strongest force known in nature.

Orbit: The path a body takes around another object or point in space under the influence of various physical forces, including gravity.

Physics: The science dealing with matter and energy and their interaction.

Planet: A body that orbits a star such as the Sun.

Proton: The positively charged part of an atom.

Satellite: An object that revolves around a larger object. Planetary moons are natural satellites.

Satellite bus: The body of a man-made satellite that the control functions of the satellite and most of the scientific instruments.

Solar: Having to do with the Sun.

Solar wind: Ions and electrons that come out of the Sun in all directions at very fast speeds.

Solar system: The Sun and its associated planets and their moons, and all other objects that are held by the Sun's gravity and orbit around it.

Space: The area between all of the bodies in the universe. It is not empty! It contains magnetic fields, electromagnetic radiation (i.e. light), gases, dust and other particles.

Sun: The star at the center of our solar system. It is made mostly of hydrogen and helium with a very small amount of heavier elements.

Resources

Online Vendors with Classroom Supplies

Arbor Scientific: http://www.arborsci.com

Edmund Scientifics: http://www.scientificsonline.com

Educational Innovations: http://www.teachersource.com

Ward's Natural Scientific: http://wardsci.com

Science Kit & Boreal Laboratories: http://www.sciencekit.com

1 on 1 School Supplies: http://www.1on1schoolsupplies.com/index.html

Home Training Tools: http://www.hometrainingtools.com/index.php

The PhysLink eStore: http://www.physlink.com/estore

Cow Magnets can be purchased cheapest from pet/farm supply stores:

http://www.petvetsupply.com
http://www.valleyvet.com
http://www.americanlivestock.com

Slaughter houses may also give away recovered magnets.

AC Adapters can be found in most hardware and electronics stores. Make sure they have variable voltage outputs and a connection plug with both terminals on the outside separated by a plastic insulator (submini plug see below).

http://store.yahoo.com/abccables-store/900-032.html
http://www.maxiaids.com/store
http://www.voltageconverters.com
http://www.accessorytown.com/detail.asp?Product_id=F3A114-W#
http://www.acehardware.com

Related Curriculum Materials

Electric Circuits Teacher's Guide, National Science Resources Center, Carolina Biological Supply Company, Burlington, NC, 2002.

Magnets and Motors, National Science Resources Center, Carolina Biological Supply Company, Burlington, NC, 2002.

Electric Circuits Teacher's Guide and *Magnets and Motors* are available at:

Carolina Biological Supply Company
2700 York Road
Burlington NC 27215

Phone: (800) 334-5551, Fax: (800) 222-7112
E-mail: customer_service@carolina.com
Web: http://www.carolina.com

Electric Circuits: Inventive Physical Science Activities, Great Explorations in Math and Science (GEMS), Lawrence Hall of Science, University of California at Berkeley, CA, 2004, grades 3-6.

Electric Circuite: Inventive Physical Science Activities is available at:

University of California, Berkeley
Great Explorations in Math and Science
Lawrence Hall of Science #5200
Berkeley, CA 94720-5200

Phone: (510) 642-7771, Fax: (510) 643-0309
E-mail: gems@berkeley.edu
Web: http://www.lhsgems.org

Stop Faking It! Electricity & Magnetism, William Robertson, Science Teachers Association, Arlington, VA, 2004

Stop Faking It! Electricity & Magnetism is available at:

NSTA
1840 Wilson Boulevard
Arlington VA 22201-3000 USA

Phone: (703) 243-7100
Web: http://store.nsta.org

Web Pages

http://www.nasa.gov : NASA's web page with links to information on NASA missions and educational materials.

http://www-spof.gsfc.nasa.gov/Education/Intro.html : David Stern's overview of space physics with good links to other educational web sites.

http://www.spaceweather.com/glossary/imf.html : Spaceweather.com's page on the Interplanetary Magnetic Field (IMF).

http://www.agu.org/sci_soc/cowley.html : A guide to Earth's Magnetosphere.

http://www.windows.ucar.edu/tour/link=/teacher_resources/magnetometer_edu.html&edu=high : K-12 lesson to make a magnetometer

http://my.execpc.com/~rhoadley/magindex.htm : Rick Hoadley's very extensive web page on magnetism with experiments you can do and many explanations.

Exploring Magnetism Supplemental Guides

-Available Now-
Exploring Magnetism in the Solar Wind, Center for Science Education, Space Sciences Laboratory, University of California at Berkeley, Berkeley, CA 2004.

-Still in development as of November 2004-

Exploring Magnetism in Solar Flares

Exploring Magnetism in the Aurorae

Center for Science Education at Space Sciences Laboratory
University of California, Berkeley
7 Gauss Way, MC 7450
Berkeley, CA 94720-7450
Phone: (510) 643-3936, Fax: (510) 643-5660
E-mail: outreach@berkeley.edu