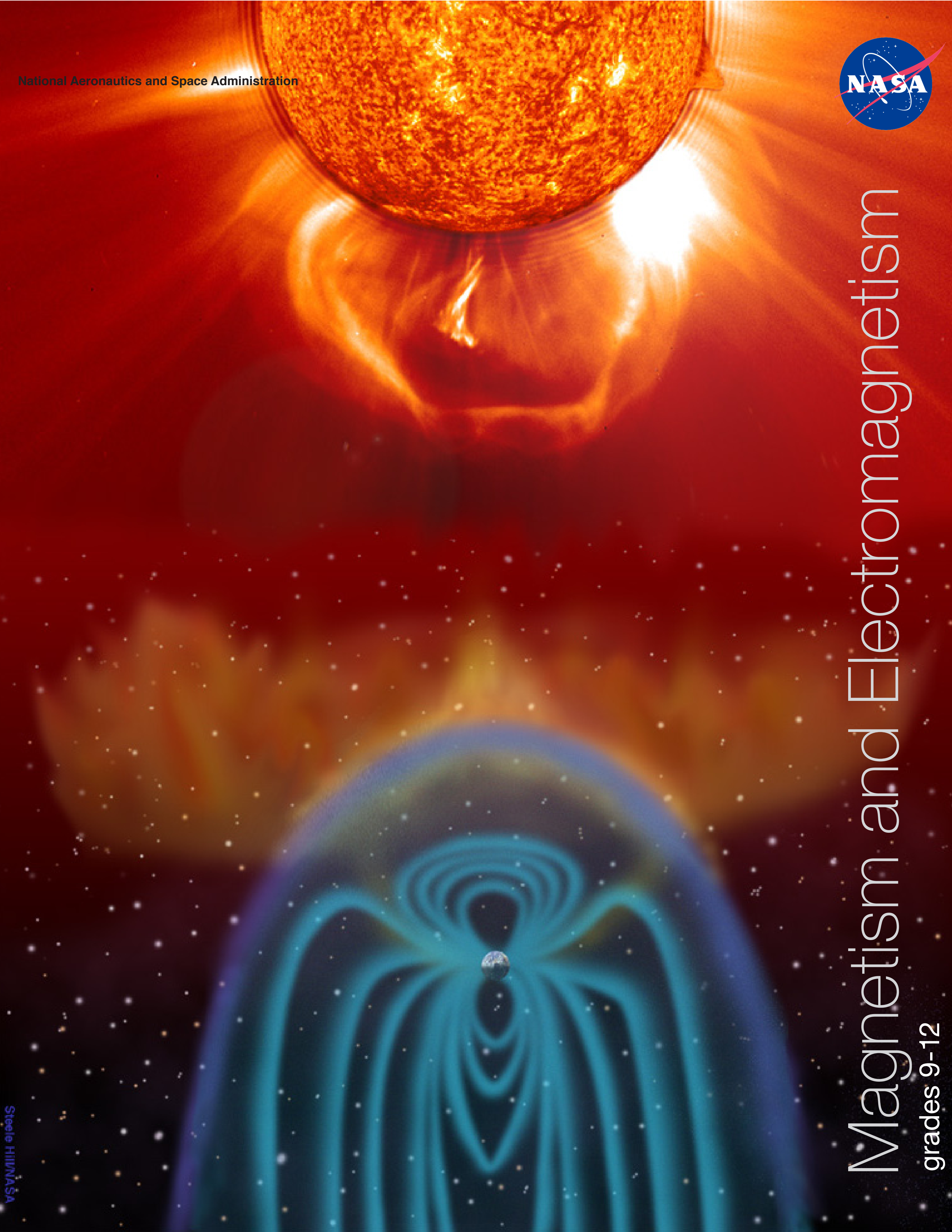
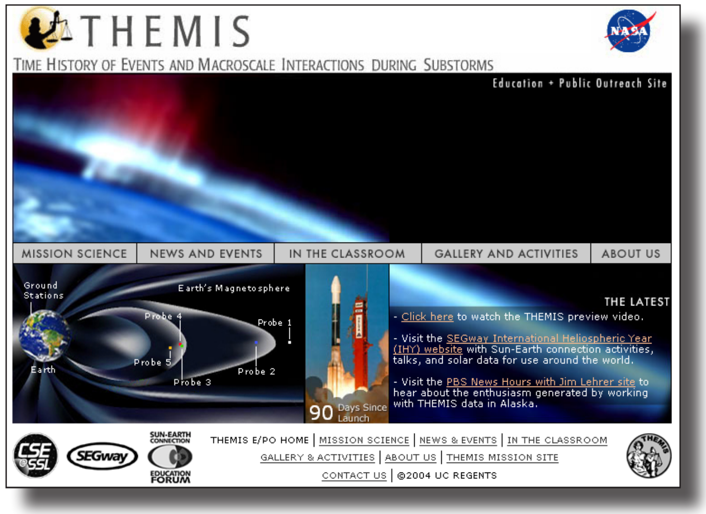
National Aeronautics and Space Administration

Magnetism and Electromagnetism

grades 9-12





This teacher's guide is designed to support a multi-year investigation of Earth's magnetic field using the magnetometer network and resources of NASA's THEMIS (Time History of Events and Macroscale Interactions during Substorms) satellite mission education program. The education program's website can be found at http://ds9.ssl.berkeley.edu/themis/. One particular THEMIS education program, the Geomagnetic Event Observation Network by Students (GEONS), aims to bring magnetometer data to high school classrooms. These guides support that effort.

The activities were designed in partnership with the IMAGE (Imager for Magnetopause-to-Aurora Global Exploration) satellite's education program (http://image.gsfc.nasa.gov/poetry) and the many activities developed for that mission in the exploration of the magnetosphere. The FAST (Fast Auroral Snapshot) education program also contributed to this effort (http://cse.ssl.berkeley.edu/fast_epo).

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Contents

National Science Education Standards

Standards Key

M - major emphasis
m - minor emphasis
i - indirect; i.e., not directly tied to standard, but important background information.

The letters A-G represent various areas in the National Science Education Standards, as follows:

A - Science as Inquiry
B - Physical Science: Motion and Forces
C - Life Science
D - Earth and Space Science
E - Science and Technology
F - Science in Personal and Social Perspectives
G - History and Nature of Science

Activity	A	B	C	D	E	F	G	Emphasis
1 - Perm Bar Magnets	M	M		i			m	A: [Students] formulate and revise scientific explanations and models using logic and evidence. B: Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces, and moving magnets produce electric forces. G: Scientific explanations must meet certain criteria. First and foremost, they must be consistent with experimental and observational evidence about nature, and must make accurate predictions, when appropriate, about systems being studied.
2 - Electro-Magnets	M	M		i			m	A: [Students] formulate and revise scientific explanations and models using logic and evidence. B: Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces, and moving magnets produce electric forces. G: Scientific explanations must meet certain criteria. First and foremost, they must be consistent with experimental and observational evidence about nature, and must make accurate predictions, when appropriate, about systems being studied.
3 - Jump Rope Generator	M	M		i			m	A: [Students] formulate and revise scientific explanations and models using logic and evidence B: Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces, and moving magnets produce electric forces. G: Scientific explanations must meet certain criteria. First and foremost, they must be consistent with experimental and observational evidence about nature, and must make accurate predictions, when appropriate, about systems being studied.
4 - Induction in an Aluminum Can	M	m M					m	A: [Students] formulate and revise scientific explanations and models using logic and evidence. B: (minor emphasis - Motion & Forces) Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces, and moving magnets produce electric forces. B: (major emphasis - Interactions of Energy & Matter) In some materials, such as metals, electrons flow easily, whereas in insulating materials such as glass, they can hardly flow at all. G: Scientific explanations must meet certain criteria. First and foremost, they must be consistent with experimental and observational evidence about nature, and must make accurate predictions, when appropriate, about systems being studied.

National Math Standards

NM-ALG.9-12.4: (Algebra). Analyze change in various contexts.

NM-MEA.9-12.1: (Measurement). Understand measurable attributes of objects and the units, systems, and processes of measurement.

NM-MEA.9-12.2: (Measurement). Apply appropriate techniques, tools, and formulas to determine measurements.

Standards Key

M - major emphasis
m - minor emphasis
i - indirect; i.e., not directly tied to standard, but important background information.

Activity	NM-ALG.9-12.4	NM-MEA.9-12.1	NM-MEA.9-12.2	Emphasis
1 - Perm. Bar Magnets				N/A
2 - Electromagnets				N/A
3 - Jump Rope Generator	m	M	M	NM-ALG.9-12.4: [Analyze change in various contexts. NM-MEA.9-12.1: Understand measurable attributes of objects and the units, systems, and processes of measurement . NM-MEA.9-12.2: Apply appropriate techniques, tools, and formulas to determine measurements
4 - Induction in an Aluminum Can				N/A

Introduction to the THEMIS Magnetism Series

This is one of four magnetism activity guides—plus a background guide for teachers—that provide students with the opportunity to build on science concepts related to Earth's magnetism and its changes. If your students engage in the activities in these four guides, they will have the skills, language and conceptual understandings of magnetism— one-half of the four fundamental forces of nature (the whole force is known as electromagnetism).

All of these guides have been:

- Classroom tested
- Checked for science accuracy by NASA and THEMIS scientists
- Designed to utilize math and writing

The goal of these guides is to give students an appreciation of the major role magnetism plays on Earth and in space, and ultimately enable them to use NASA data as "scientists" researching our magnetic connection to the Sun. We achieve this goal through sequential activities in the four teachers' guides, from basic explorations with magnets, compasses and galvanometers to scientific discoveries using data from instruments called magnetometers. These magnetometers are located in schools across the U.S, as part of the THEMIS education project.

The four activity guides have been used in different types of classes, from physical science and physics classes, to geology and astronomy classes. The excitement of actually participating in the THEMIS project helps motivate the students to learn challenging physical science concepts.

1. **Magnetism and Electromagnetism** is a review of basic magnetism, similar to what is encountered in most grade-level physical science texts. Students map field lines around bar magnets to visualize the magnetic dipole field, and create their own electromagnet using copper wire, battery and a pencil to learn that electric currents create magnetic fields. Two activities introduce generators and Lenz's law, in one case using Earth's magnetic field and a large conducting wire. These materials can be used by teachers presenting Earth and Physical Science courses in grades 6-9, and would fit well into a lab at the end of a high school physics class. These activities are a classroom-ready prerequisite to understanding magnetism on Earth and in space.

2. **Exploring Magnetism on Earth** is intended to help students explore Earth's magnetic field through a variety of math-based activities. This guide contains problems focusing on Earth's changing magnetic field in time and space. Students use compasses to discover how these changes can impact navigation on Earth's surface. They use basic math skills to interpret graphical information showing polar wander and magnetic changes, and answer questions about quantitative aspects of these changes. These lessons can be used in geology and astronomy classes.

3. **Magnetic Mysteries of the Aurora** is a prerequisite to using magnetometer data as students will in the next guide, **Earth's Magnetic Personality**. **Magnetic Mysteries of the Aurora** introduces students to Earth's magnetic field and Northern and Southern Lights (aurora) within the context of the

Sun and space weather. Using worksheets, globes, and a single light source, students review time-keeping on Earth—time zones and Universal Time. Students then go through a series of activities to discover the causes of the aurora and their relation to Earth's magnetosphere and solar storms. Students classify images of aurora by shape and color, create a model of Earth's magnetosphere, forecast magnetic storms using geomagnetic indices, and engage in a presentation about space weather. These lessons have been used in physics and astronomy classes as well.

4. **Earth's Magnetic Personality** is the culmination of all the previous guides. It was developed with the goal that students can now work directly with the THEMIS magnetometer data. Students review vectors through calculations, learn to interpret x-y-z magnetometer plots, predict auroral activity using the x-y-z magnetometer data, calculate the total magnetic field strength and observe it over months, and discover that waves in Earth's magnetic field are excited by large magnetic storms by comparing spectrograms with magnetic indices.

5. The background guide for teachers, the **THEMIS GEONS Users Guide,** describes the important role that terrestrial magnetism plays in shaping a number of important Earth systems. It also explains the basic operating principles behind magnetometers—particularly the system you are now in the process of using to investigate magnetic storms at your school.

Activity 1 - Permanent Bar Magnets

TEACHER'S GUIDE

Although magnets are familiar household items, students may need to be reminded of the basic properties of magnets and magnetism. This hands-on activity allows students to re-acquaint themselves with magnets, magnetic fields and the concept of polarity, which form the basic ingredients of a study of Earth's magnetic field and the technology of magnetometers.

GOALS

1. Students will learn the basic properties of magnets and magnetic forces.
2. Students will learn about polarity, attraction, repulsion, and magnetic field strength, which are the basic terms and concepts we will be using throughout the THEMIS program.

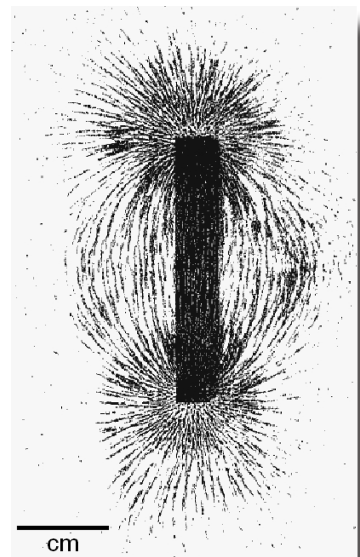


Figure A – The magnetic lines of force surrounding a bar magnet revealed by iron filings.

MATERIALS

- A set of bar magnets, two per student. If there aren't enough magnets to go around, divide the class into small groups, with one magnet per group.
- 10 paper clips per student.

PROCEDURE

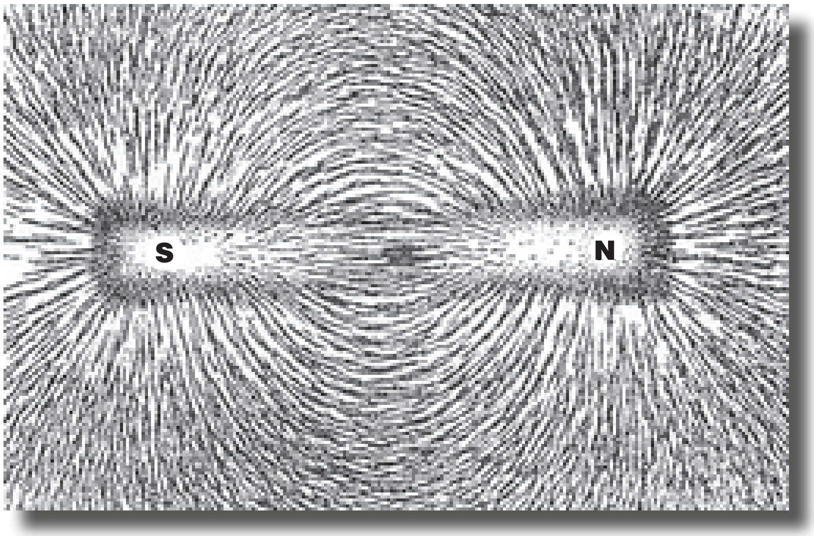
There are many different versions of this activity available on the Internet and you can find some locations provided at the end of this teacher guide. Please consult these sites for suggestions on detailed set-up and specific tasks the students can perform. Below is a shortened strategy that will quickly demonstrate the basic phenomena with which we will be working in THEMIS.

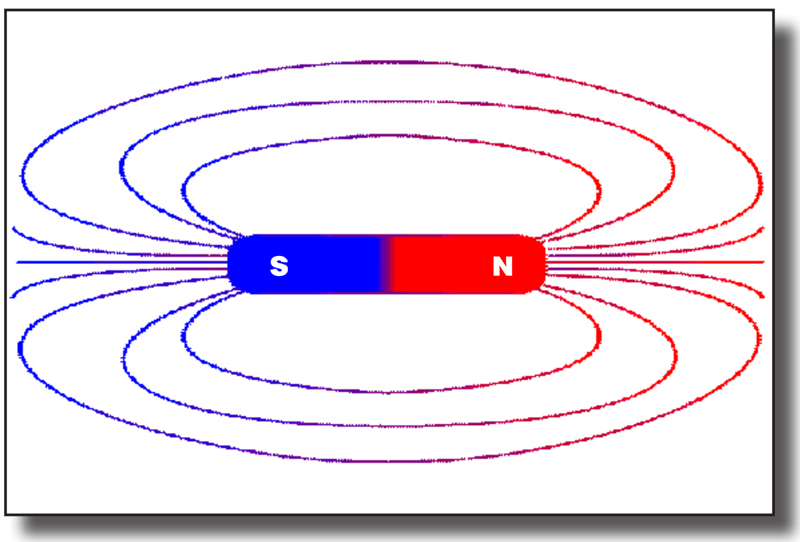
1. Distribute the magnets to the students.

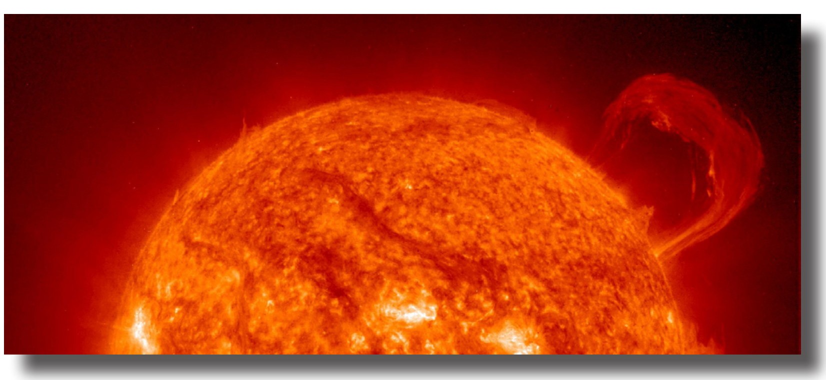
2. Have them experience, tactilely, the repulsive and attractive natures of magnetic forces. Also, have them experience, through magnet manipulation and working with paper clips, the idea that magnetic forces vary in intensity throughout space, becoming weaker as distances increase.

3. Ask one student in the classroom to mark the letter 'N' on one end of a bar magnet. Use this arbitrarily-defined 'North polarity' to determine the N and S polarities of all other magnets in the classroom using the 'likes repel' and 'opposites attract' rule for magnetic polarity.

Magnetic field surrounding a bar magnet







What structural similarities do you see between the magnetic field lines surrounding the bar magnets, and those seen on the Sun?

Vocabulary Words

Polarity – A property of magnets or electrically-charged objects in which there are two possible conditions (north and south for magnets, positive and negative for electrical charges) that describe an important characteristic of the forces that they experience. **Note to teachers: A common misconception is that magnetic poles are "positive" and "negative." This is the wrong terminology and often confuses students into thinking that electrical charges and magnetic charges are the same things.**

Attraction – A condition where objects move or are pulled together under the influence of a force.

Repulsion – A condition where objects move or are pulled apart under the influence of a force.

Field – An influence (such as a force) that some forms of matter produce, which extends throughout the space that surrounds them.

Related Web Activities

1 – Exploring Magnetism guide

http://cse.ssl.berkeley.edu/exploringmagnetism

2 – Student Observation Network magnetism activity

http://son.nasa.gov/tass/pdf/Mapping_Magnetic_Influence.pdf

3 – IMAGE Playing With Magnetism activity

http://image.gsfc.nasa.gov/poetry/activity/l1.htm

4 – Exploring Magnetic Fields (IMAGE)

http://image.gsfc.nasa.gov/poetry/activity/l2.html

Activity 2 - Electromagnets

Teacher's Guide

This activity is commonly performed in science classes, starting in 5th grade and extending through college! It relies on the amazing fact, discovered over 100 years ago by Hans Oerstead, that if you let an electric current flow through a copper wire, it will generate a magnetic field strong enough to deflect a compass needle or pick up bits of iron.

Knowing about the properties of electromagnets is a crucial underpinning for understanding how magnetic fields are generated in nature, in the surface of the Sun, and in the interior of Earth. In preparation for this activity, or as a follow-up, please review with your students the relevant topics in your Earth Science or Physical Science textbook.

Goals

1) Students will see that, when the electrical current is "turned on," the needle of the compass placed close to the wire will suddenly point parallel to the pencil.
2) Students will see that the more loops of wire they wind around the pencil, the more paper clips they can pick up.
3) The more batteries they place "in series," the more current will flow through the wire, and again, the stronger will be the magnetic field.

Materials

- Thin insulated wire
- pencil
- battery
- compass
- paper clips

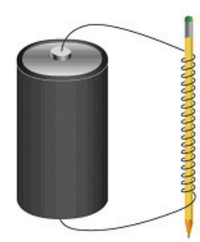


Figure B – Electromagnet made by using a battery, a pencil and thin, insulated wire.

This activity is quite straightforward and considered a "classic" experiment in electromagnetism, and one which students have usally performed at least once by eighth grade. Consult your Physical Science or Earth Science textbook for detailed plans on how to set up the experiment. **Note: We use a pencil rather than a nail because a nail isn't relevant to the electromagnetism phenomenon. You will need to wrap more turns of wire around a pencil, however, in order to achieve a useable magnetic field.**

For THEMIS, we want students to understand, through this hands-on experiment, that magnetic fields can be produced by flowing currents or charged particles (electricity!). We also want them to understand that magnetic fields can be manipulated in strength in one of two easy ways:

1. They can control how much current flows in the wire by using several batteries in series to increase the current flowing in the wire around the pencil.
2. They can increase the magnetic field of the electromagnet by increasing the number of loops of wire wrapped around the pencil.

They can measure the strength of the electro-magnet by counting the number of paper clips the nail can pick up.

PROCEDURE

1. Have the students control how much current flows in the wire by trying different numbers of batteries, in series, to change the current flowing in the wire around the pencil. Have the students keep a lab book and record how many paper clips the electromagnet can pick up with each battery configuration.
2 Next have students change the magnetic field of the pencil by changing the number of loops of wire wrapped around the pencil. Again have the students record their observations in their lab book. The number of paper clips the pencil with coils can pick up indicates the strength of the electromagnet.
3. In Part A we defined the polarity of one of the bar magnets as "N." Using this same bar magnet, explore the magnetic field of the electromagnet and determine which end is "N"" and which end is "S." Then reverse the current direction and repeat this experiment. Ask the students to describe what happens and why. They should note that the polarity depends on the direction of the current flow!

VOCABULARY

Current – A flow of charged particles through a conducting material or through space. These charged particles can be electrons, protons or ions.

Magnetic field – A condition in the space surrounding some objects that causes charged or metallic bodies brought close by to experience the force of magnetism.

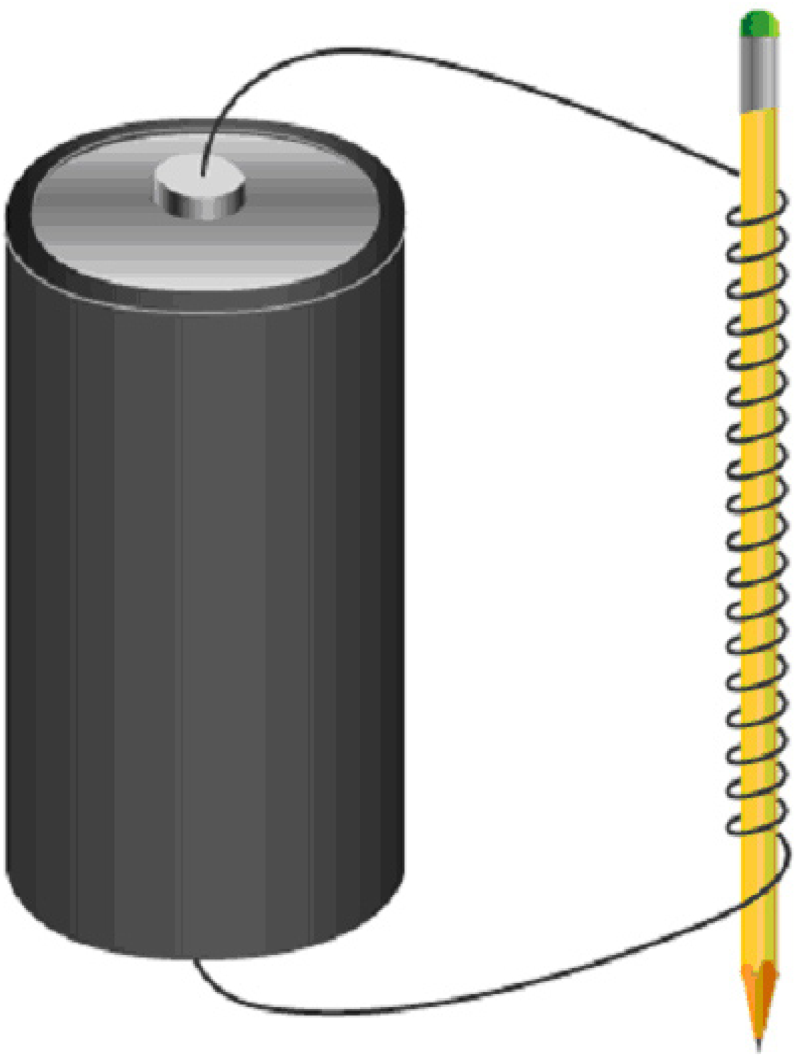
RELATED WEB ACTIVITIES

1. Exploring Magnetism – Activity 2

   http://cse.ssl.berkeley.edu/exploringmagnetism/
2. Electricity and Magnetism (IMAGE)

   http://image.gsfc.nasa.gov/poetry/activity/l4.htm

A Simple Electromagnet



Activity 3 – Jump Rope Generator

Teacher's Guide

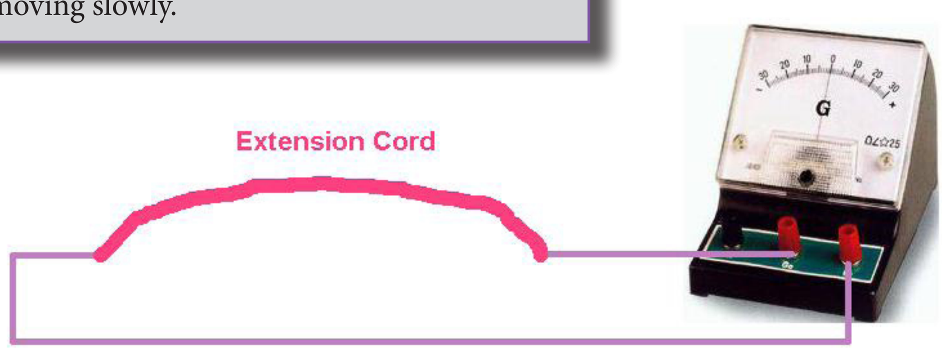
Your class will demonstrate the generator effect, which is due to electromagnetic induction when a conductor (a long metal wire) moves through a magnetic field. In this activity, the magnetic field your students work with is Earth's magnetic field and the long wire is an extension cord. The cord is part of a loop of wire that closes through a galvanometer. This loop is important since electrical current must flow in a loop. When the wire is aligned east to west and rotated clockwise or counter-clockwise, it moves across Earth's magnetic field (which points north and downward) allowing the maximum current to flow. (See the photograph of the teachers on page 8). This current can be detected using the galvanometer. This occurs because when a magnetic field is changed in a loop of wire, a voltage, and hence a current, is induced in the loop. This is what happens when the armature of a generator is rotated, when an iron car drives over a loop of wire imbedded in the roadway to activate a traffic light, or when a piece of wire is twirled like a jump rope in Earth's magnetic field. When the wire is aligned north to south, it is aligned with Earth's magnetic field and moves across Earth's magnetic field only slightly up and down. Moving the wire almost parallel to Earth's magnetic field means that only a small amount of electrical current will flow through the wire.

Goals

1) Students will know that Earth has a magnetic field.
2) Students will observe the deflection of a galvanometer needle when an electrical cord crosses Earth's magnetic field.
3) Students will record how much the galvanometer needle is deflected when the electrical cord is rotated when aligned east to west versus north to south, and also when the cord is rotated while moving quickly versus moving slowly.

Materials

- 100-foot extension cord with ground prong
- Current or voltage galvanometer (micro-Ammeter if using a current galvanometer)
- Two lead wires with alligator clips on at least one end
- One compass



galvanometer

Understanding that Earth has a magnetic field is important to many of NASA's science missions, including THEMIS.

PROCEDURE

1. Attach the alligator clip at the end of one wire to the ground prong of the extension cord. Attach this wire's other end to the galvanometer. Take the second wire, and keeping its alligator clip closed, push the clip into the ground receptacle on the other end of the extension cord. Attach the other end of this second wire to the other contact on the galvanometer.
2. Use a compass to align the extension cord in the east-west direction. Leave both ends of the extension cord on the ground. It helps to have two students stand on the cords, near the end, to make sure the galvanometer stays connected to the cord. Have two additional students pick up the middle half of the cord and twirl it like a jump rope. (See the picture below.) It doesn't matter whether it rotates clockwise or counterclockwise. Have the students observe the galvanometer and record their observations on the worksheet.
3. Have the students twirl the cord faster and observe the galvanometer and record their observations.
4. Repeat step 2, but align the extension cord in the north-west direction again, using a compass. Have the students observe the galvanometer and record their observations.

TEACHER ANSWER KEY

1) higher speed means a larger deflection; 2) The maximum voltage (or current) should occur east-west and fast; 3) The minimum voltage (or current) should occur north-south and slow; 4) the explanation is given above. We recommend you use Question 4 to determine how much more discussion or explanation you need to provide the class before moving to another topic.

Student Name ______________________________ ***Date*** ________

Jump Rope Generator: Observations

Fill out the table with your measurements of greatest deflection on the galvanometer in each of the four cases. Then answer the questions below the table.

	Cord aligned east-west	Cord aligned north-south
Slow		
Fast		

1. What effect does the rotational speed of the cord have on the deflection of the galvanometer?

2. Describe the conditions in which you had the maximum voltage (or current) through the galvanometer.

3. Describe the conditions in which you had the minimum voltage (or current) through the galvanometer.

4. Explain why the galvanometer needle moves when you play jump-rope with the extension cord.

5. Explain why the the orientation of the jump rope to Earth's magnetic field effects the galvanometer reading.

Activity 4 – Induction in an Aluminum Can

Teacher's Guide

In this activity, Lenz's Law is demonstrated. Lenz's Law states that an induced electromotive force generates a current that induces a counter magnetic field that opposes the magnetic field generating the current. In this activity, an empty aluminum can floats on water in a tray, such as a Petri dish. Students spin a magnet just inside the can without touching the can. The can begins to spin. Understanding what happens can be explained in steps:

- First, the twirling magnet creates an alternating magnetic field. Students can use a nearby compass to observe that the magnetic field is really changing.
- Second, the changing magnetic field permeates most things around it, including the aluminum can itself. A changing magnetic field will cause an electric current to flow when there is a closed loop of an electrically conducting material. Even though the aluminum can is not magnetic, it is metal and will conduct electricity. So the twirling magnet causes an electrical current to flow in the aluminum can. This is called an "induced current."
- Third, all electric currents create magnetic fields. So, in essence, the induced electrical current running through the can creates its very own magnetic field, making the aluminum can magnetic. Now the aluminum can's induced alternating magnetic field interacts with the twirling magnet's alternating magnetic field. This interaction spins the can since the magnetic forces are opposed, as Lenz's law states. Because the can sits on top of water, the friction between the can and the surface is very small, and only the magnetic forces act on the can while the students twirl the magnet .

Acknowledgment for this activity goes to Dindorf, W. —"Lenz's Law in the Kitchen." *The Physics Teacher*. Vol. 37, May, 1999.

Goals

1) Students will know that electric current can be induced in non-magnetic metals through changing magnetic fields.
2) Students will know that the formation of an electrical current causes a magnetic field.
3) Students will know that magnetic fields interact with one another.
4) Students will know Lenz's Law: *"An induced electromotive force generates a current that induces a counter magnetic field that opposes the magnetic field generating the current."*

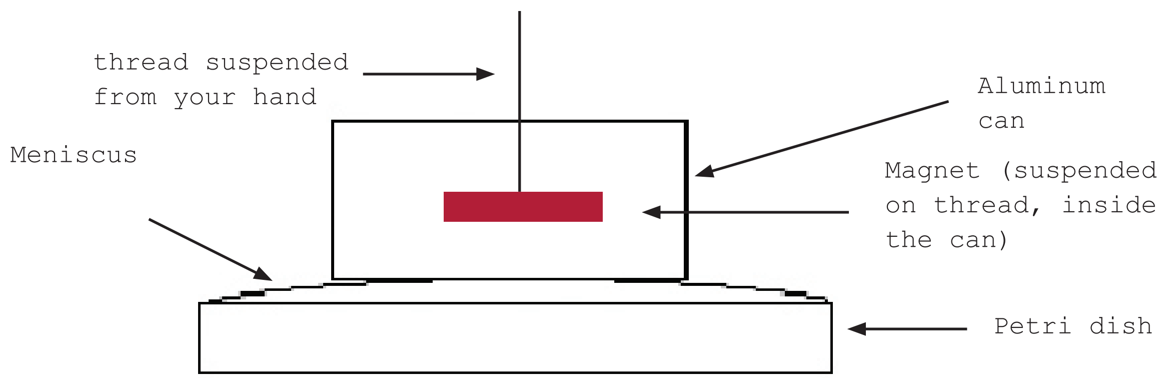
Materials

- Small aluminum can
- Container (in which to float aluminum can)
- Spill tray
- Small cylindrical magnet (neodymium works best)
- Thread
- Tap water

PROCEDURE

1. Have enough materials on hand for student groups of two. Cat food cans work well. Just be sure they are made of aluminum. Soft drink cans do not work well. Their walls are too thin and sharp edges on cut cans poses a safety risk. Petri dishes make good float containers, and Styrofoam meat trays will do as spill trays.

2. Have students fill the container in which they will float the aluminum can as full as they can with water. They should form a meniscus at the top of the container so that the aluminum can floats above the top of the container.



3. The length of thread should be tied to the center of the magnet so that it hangs straight. When you dangle the magnet into the can, the magnet should also be at least one inch shorter than the diameter of the can so that it does not bang into the sides of the can while students attempt to spin it.

4. As you dangle the magnet from your hand, when you twist the thread between your fingers, the magnet should spin. Students may need to practice this so that they can successfully do it for the activity.

5. When the spinning magnet is lowered into the can, an electrical current is induced in the aluminum – which is a conductor. This electrical current itself creates a magnetic field in the metal of the can that opposes the magnetic field of the spinning magnet. These opposing fields cause the can to spin.

6. This is a demonstration of an electromagnetic effect known as Lenz's Law. Explicitly state Lenz's law (found on previous page) to the class.

TEACHER ANSWER KEY

1) No. Aluminum is not a magnetic metal; 2) The compass needle moves and/or the can is spinning; 3) The can slowly spins; 4) The answer to how this experiment works can be found above. **We recommend this question be used to determine if further discussions or explanations are needed with the class.**

Student Name ______________________________ ***Date*** ________

Induction in an Aluminum Can

Please answer the following question related to this activity:

1. Does the aluminum can seem to be magnetic when the magnet is not rotating? Explain your answer.

2. How can you tell there is a changing magnetic field near the can?

3. Describe how the aluminum can moves when it is sitting on the water in the Petrie dish with a rotating magnet inside.

4. Use your own words and drawings to describe why the magnet causes the can to move.

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