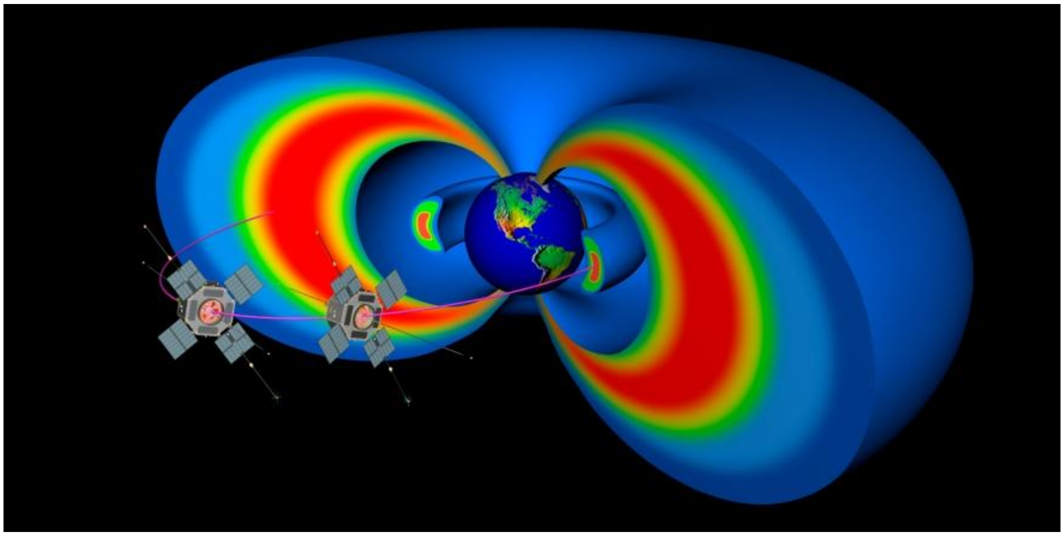
RBSPICE In The Classroom:

Changing Magnetic Fields and Electrical Current

A hands-on exercise exploring the relationship between changing magnetic fields and the generation of electrical circuits.



Overview:

The Radiation Belts Storm Probes (RBSP) with its Ion Composition Experiment (ICE) are designed to explore the Earth's inner and outer trapped radiation. This region of space, also known as the Van Allen Belts in honor of their discoverer James Van Allen, are very sensitive to changes in the solar wind resulting from solar flares and coronal mass ejections (CMEs). Solar storms impacting our planet's magnetic field can generate electrical currents and accelerate charged particles in the trapped radiation belts. This activity is designed to allow students to explore the relationship between electrical currents and magnetic fields, how currents create magnetic fields, and how changing magnetic fields can generate electrical currents. By building a simple laser galvanometer for themselves, students will gain confidence and experience in crafting and engineering their own experimental apparatus, setting the groundwork for them to create new experiments in the future.

Learning Outcomes:

1. Demonstrate how electrical currents generate magnetic fields.
2. Determine how the direction of the produced magnetic field is related to the direction of the current in a wire loop using a compass.
3. Describe what a galvanometer is, and how it functions.
4. Explain how the rate of change of a magnetic field and its direction near a wire loop effect the strength and direction of current in the wire.
5. Extrapolate the observations made of the wire loops and galvanometer readings to the Earth's magnetosphere and trapped radiation belts.

National Science Standards Addressed:

(Grades 8 – 12)
Standard 1: SCIENCE AS INQUIRY – The student will develop the abilities necessary to do scientific inquiry and develop an understanding of scientific inquiry.

Benchmark 1: The student will demonstrate the abilities necessary to do scientific inquiry.

Standard 2B: PHYSICS – The student will develop an understanding of the structure of atoms, compounds, chemical reactions, and the interactions of energy and matter.

Benchmark 3: The student will understand the nature of the fundamental interactions of matter and energy.

Standard 4: EARTH AND SPACE SCIENCE – The student will develop an understanding of energy in the earth system, geochemical cycles, the formation and organization of the earth system, the dynamics of the earth/moon/sun system, and the organization and development of the universe.

Benchmark 3: The student will develop an understanding of dynamics of our solar system.
Benchmark 4: The student will develop an understanding of the organization of the universe, and its development.

Standard 5: SCIENCE AND TECHNOLOGY – The student will develop understandings about the relationship between science and technology.

Benchmark 1: The student will develop an understanding that technology is applied science.

Standard 7: HISTORY AND NATURE OF SCIENCE – The student will develop understanding of science as a human endeavor, the nature of scientific knowledge, and historical perspectives.

Benchmark 1: The student will develop an understanding that science is a human endeavor that uses models to describe and explain the physical universe.
Benchmark 2: The student will develop an understanding of the nature of scientific knowledge.

Equipment:

- 20 ft. of enameled magnet wire
- Two strong rare-earth button-shaped magnets
- 6 ft. of fishing line
- One laser pointer
- Two 3-inch lengths of cardboard tubing
- Four iron washers approximately two inches in diameter
- Double-sided tape
- One small mirror
- One whiteboard or sheet of white poster board (as a background)

Introduction:

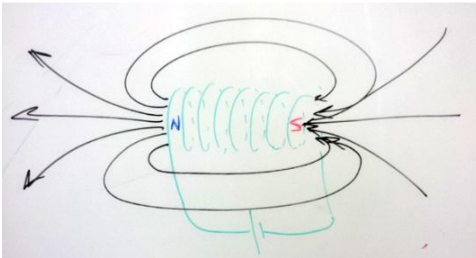


Figure 1: Diagram showing the magnetic field produced by a current-carrying wire loop. The end from which the magnetic field lines emanate is defined as a north magnetic pole, and where the field lines enter the wire loop is defined as a south magnetic pole.

For a very long time, electricity and magnetism were seen as two separate phenomena. The first hints that they were related came when in April of 1820 Hans Christian Ørsted discovered that electrical currents can produce magnetic fields when during one of his lectures while demonstrating the behavior of electrical currents, he noticed that a compass was deflected when a current was ran through a nearby wire. In September of that same year, André-Marie Ampère shared Ørsted's discovery with the French Academy of Sciences using a simple compass to show that a nearby electrical current would deflect its needle, and then took the idea further and derived a quantitative relationship between the intensity of the current and the strength of the magnetic field it produced.

We now understand that all magnetic fields are produced by electrical currents. The simplest example of this is the basic electromagnet. Take some wire, wrap it around a large nail or bolt, and connect the wire to a 9V battery. Voila! You have an electromagnet! The current in the wire produces a magnetic field made stronger by the iron in the nail. Even a permanent bar magnet's field is produced by current. In the case of a bar magnet, the current is produced by the orbiting electrons on the very outer edge of the iron atoms inside the magnet. The field from each atom alone is very weak, but when they all line up, all the individual fields from each atom add up to one large field that we can easily detect.


Figure 2: A photographic portrait of Michael Faraday from 1867.

Just as electric charges come in two flavors, positive and negative charge, magnets can be described as having two sides, or poles, as well. The end of a compass needle that points northward is called a north magnetic pole, and the side that points south is called a south magnetic pole. Creative names, right? In trying to explain how electric and magnetic fields could reach out through space and affect one another, Michael Faraday came up with the idea of drawing arrowed lines to represent the strength and direction of these fields. The end of a magnet from which the field lines are emanating is the north pole, and the end of the magnet where the field lines converge and enter is the south pole. Another similarity to positive and negative electric charges is that opposite magnetic poles attract, and like magnetic poles repel. Try it out for yourself using a couple of small button magnets. You'll see that oriented one way, the two magnets will snap together, but when you flip one magnet around the two magnets will repel each other.

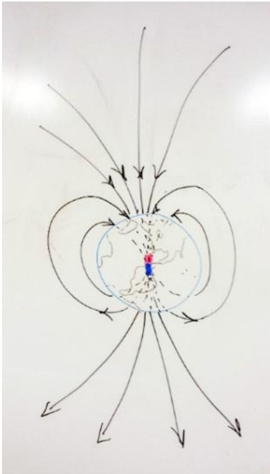


Figure 3: Earth's magnetic field has a south magnetic pole in the Arctic and a north magnetic pole in the Antarctic.

Our Earth has a magnetic field, which is why a compass needle orients itself the way that it does. What does that imply about the interior of our planet? Deep inside, in the molten iron and nickel outer core, there is a large electrical current produced by the combination of the Earth's rotation and the convection happening in the outer core. This electrical current creates a large magnetic field that extends well out into space, creating a region called the magnetosphere. When we think about the orientation of our planet's magnetic field, we realize that near the geographic North Pole is actually a south magnetic pole! Remember that opposite magnetic poles attract each other, so that if the north pole of a compass needle points north, it must be attracted to a south magnetic pole.

In addition to giving us a clever way of visualizing electric and magnetic fields, Michael Faraday also discovered that a changing magnetic field can create an electric field and therefore a current. Faraday constructed a simple device, two coils of wire wrapped around opposite ends of an iron ring. One wire loop was attached to a battery, and the other to a galvanometer, a device for measuring very small amounts of current. When the connection to the battery was made, the galvanometer showed a momentary surge of current, even though the two coils weren't physically connected to each other. When the current was stable and steady in the first coil, the galvanometer showed no current in the second coil. When the battery was disconnected, however, the galvanometer jumped once again. It wasn't the existence of a current in the first coil that created a current in the second coil, but a CHANGE in the current. Recall that currents create magnetic fields. Therefore, a changing current will create a changing magnetic field. What Faraday really demonstrated was that a changing magnetic field creates an electric field that can drive a current, and the strength of the electric field produced is directly proportional to the rate of change of the magnetic field. This is now known as Faraday's Law.

> *Faraday's Law: The strength of an induced voltage in a closed loop is directly proportional to the time rate of change in the magnetic flux through the loop.*

The Sun has ability to release huge clouds of very hot plasma in eruptions called coronal mass ejections (CMEs). The electrically charged particles in this plasma, mainly electrons and protons, move outward as quickly as 1000 km/s or faster! When this solar storm cloud hits our Earth's magnetic field, it compresses it and causes its strength to fluctuate. Remember Faraday's Law: Changing magnetic fields create electric fields. When our magnetic field compresses and relaxes during these solar storms, there is an electric field that is produced, driving the charged particles in the Van Allen belts, belts of trapped radiation in our Earth's magnetosphere, to move in such a way as to produce a current. This current in the trapped radiation belts is called the ring current. The role of RBSP and specifically of RBSPICE is to learn more about this ring current and how its strength and direction are related to the strength and nature of these solar storms.

Learn more about RBSP at http://rbsp.jhuapl.edu/ and RBSPICE at http://rbspice.ftecs.com/.

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Pre-Exercise Questions:

Name: Class:

1. Current is...
   a. the flow of electrical charge.
   b. the change in amount of electric charge.
   c. the strength of a magnetic field.

2. Electrical current can be produced by...
   a. strong magnetic fields.
   b. changing magnetic fields.
   c. strong gravitational fields.

3. Magnetic fields are produced by...
   a. high voltages.
   b. electrical currents.
   c. strong gravitational fields.

4. The Magnetosphere is...
   a. the region of space dominated by Earth's magnetic field.
   b. the region of space dominated by the solar wind.
   c. the region of space dominated by the Earth's gravitational field.

5. The Earth's magnetosphere is...
   a. not affected by the Sun at all.
   b. affected by the Sun's and Moon's gravitational field.
   c. is affected by the Sun's solar wind and solar storms.

Procedures:

- Use a piece of double-sided tape to adhere one end of a three-foot length of fishing line to one of the button magnets.

- Suspend the magnet in the air and observe the orientation of the magnet. What direction does it point? What happens if you try to change the magnet's orientation?

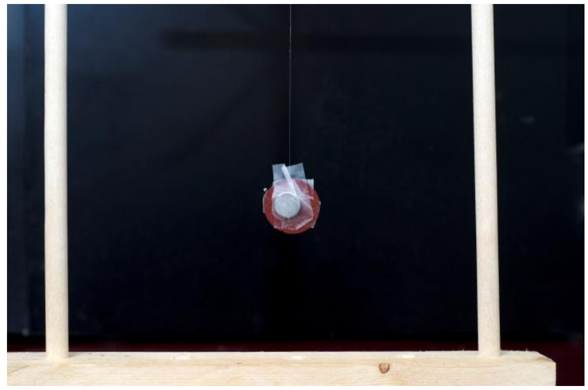

Figure 4: Rare-earth button magnet shown adhered to the back of a small mirror and suspended using a length of fishing line.

- Move the other magnet around, but not too close, to the suspended magnet. Observe what happens. What does this say about your earlier observations when the second magnet wasn't close? Does the Earth have a magnetic field?

DISCUSSION BREAK: Discuss with your teacher the shape of our planet's magnetic field.

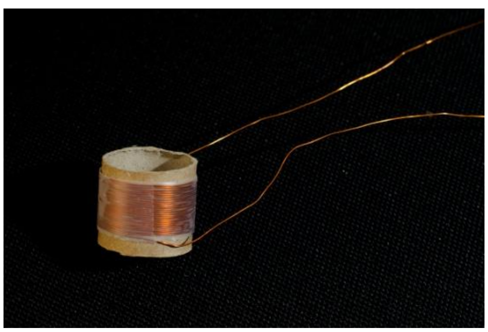

Figure 5: Wire loop made with 26-gauge magnet wire using a cardboard tube as a form. The wire is held in place with a length of transparent tape wrapped around its circumference.

- Make a wire loop by wrapping about 10 feet of magnet wire around a section of cardboard tube. Be sure to leave about a foot of wire at each end to make electrical connections later.

- Hold the wire loop near the suspended magnet. Observe any changes. Does the wire loop produce a magnetic field?

- Now connect a small battery to the two loose ends of the wire loop. Hold the wire loop now connected to the battery near the suspended magnet. Observe any changes. Does the wire loop produce a magnetic field?

DISCUSSION BREAK: Discuss with your teacher the origins of our planet's magnetic field.

- Make a second wire loop (see above).

- Stack four metal washers inside the wire loop, and connect trailing wires of the two loops together to make a circuit. Be sure to sand off the lacquer coating from the wires before connecting them in order to expose the bare copper. You won't get an electrical connection if you don't sand off this coating.

- Take a second button-magnet and move it toward the coil with the washers. What happens to the suspended magnet? What happens when you move the magnet away from the coil? Try moving the magnet toward and away from the coil at various speeds. Record your observations and make a statement about what you think is happening between the two wire loops.

- To make the observations easier, use double-sided tape to adhere a small mirror to the suspended magnet. Point a laser pointer at the mirror so that the laser reflects off the mirror and onto the whiteboard (or use a piece of poster board).

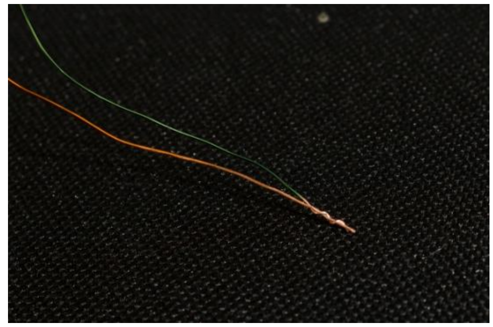

Figure 6: When twisting the two ends of the wire loops together, be sure to remove the lacquer coating to ensure a solid electrical connection between the two wire loops.

- With the second magnet far from the wire loop and suspended magnet, mark the position of the laser beam reflection on the background. Now move the second magnet toward and away from the wire loop with the washers. Observe what happens to the laser beam. As the suspended magnet turns, so does the mirror, causing the laser beam reflection to move.

- The device you just built is called a galvanometer and it is capable of measuring very tiny amounts of electrical current and the magnetic fields they produce. What applications can you think of for such a device?

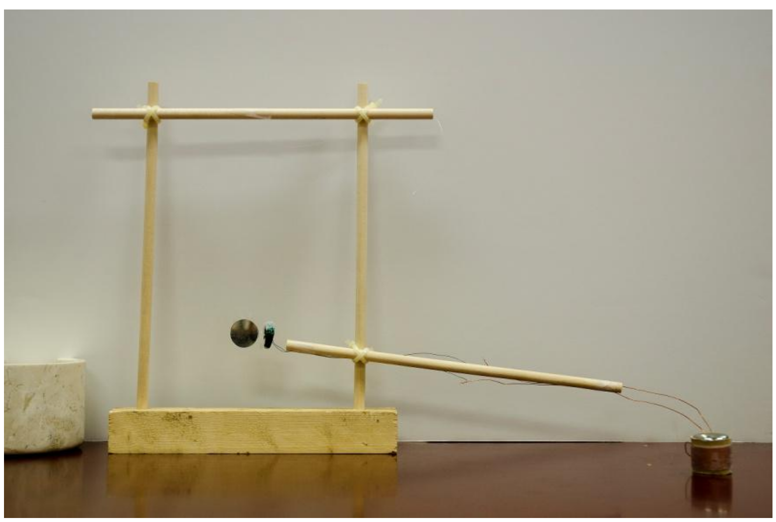

Figure 7: A completed galvanometer.

DISCUSSION BREAK: Discuss with your teacher how solar storms affect the region of space dominated by our planet's magnetic field, the magnetosphere. How do your observations of the behavior of magnetic fields and electrical currents on the small scale relate to what happens on a large scale during solar storms?

Observations:

Galvanometer with no current

Galvanometer with 9V battery

Galvanometer with wire loop: No magnet near the wire loop

Galvanometer with wire loop: Magnet moving toward the wire loop

Galvanometer with wire loop: Magnet near the wire loop but not moving

Galvanometer with wire loop: Magnet moving away from the wire loop

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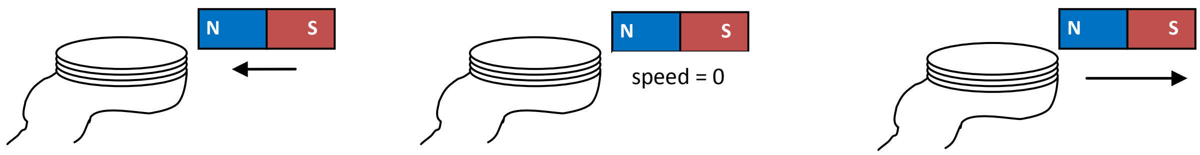
Post-Exercise Questions:

Name: Class:

1. For the figures shown below, determine whether or not there will be a current produced in the wire loop.



2. What generates the Earth's magnetic field?

3. Why is the Earth's magnetic field shaped the way it is?

4. Explain how solar storms affect our magnetosphere and the consequences those storms can have on our infrastructure.