Investigating the Ring Current

Overview: Students will explore Earth's magnetic field using a dipole magnet and compass, and then build a model of Earth's ring current and use it to observe a magnetic field's response to a fluctuating electric current in this hands-on investigation of electromagnetism.

Target Grade Level: 9-12

Estimated Duration: 90 min.

Learning Goals: Students will…

- develop an operational definition of the shape of Earth's magnetic field using a dipole magnet.
- build models to demonstrate the structure and properties of Earth's magnetic field and ring current.
- demonstrate the effect of an induced current on a magnetic field and relate it to the analogous response of Earth's magnetic field to a change in the Earth's ring current during a solar storm.

Standards Addressed:

Next Generation Science Standards ©

HS-PS2 Motion and Stability: Forces and Interactions

HS-PS2-5: Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.

DCI PS2.B: Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.

HS-PS3 Energy

HS-PS3-5: Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

Contents:

Background Science for the Teacher:

Figure 1. The identical Van Allen Probes follow similar orbits that take them through both the inner and outer radiation belts. Image courtesy: JHU/APL

To help us understand how the Earth responds to changes in the Sun's energy, and how that response affects life and society, NASA launched the twin Van Allen Probes on August 30, 2012. The Van Allen Probes spacecraft are investigating this extreme region of space, searching for answers to critical questions about the behavior of the Van Allen Radiation Belts. The spacecraft chase each other in nearly the same orbit, investigating the storms in the radiation belts caused by our Sun, gathering data to better understand this region and how it affects our modern way of life. The ability to model and predict the behaviors of the radiation belts will enable engineers and space weather forecasters to better protect our astronauts working in this region as well as our satellite investments that we depend upon for communication, defense, shipping, air and ground navigation and much more.

MORE! Learn more about the Van Allen Probes mission, the radiation belts in which they orbit, and the science behind the mission here: http://vanallenprobes.jhuapl.edu/

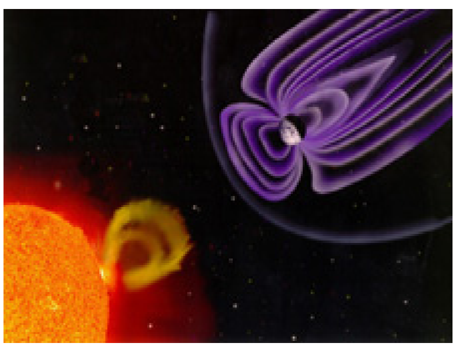


Figure 2. The source of space weather, our dynamic Sun, shown with a coronal mass ejection that will interact with the Earth's magnetosphere producing geomagnetic storms. (Image courtesy: NASA)

What is radiation?

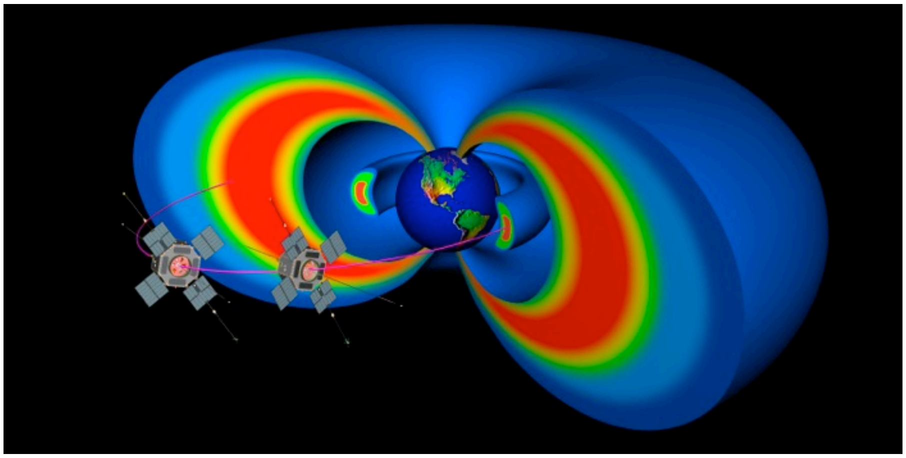
You may have heard the term radiation used in different ways, such as in relation to medicine, to the Sun, or even to heat. Sometimes it refers to electromagnetic waves of energy like x-rays or gamma rays in the electromagnetic spectrum, other times to fast moving particles. When we talk about radiation in the Van Allen belts we are referring to electrically charged particles such as protons and electrons moving very fast. Sometimes these particles move close to the speed of light, about 300,000 km/s (186,000 miles per second). The faster something moves the more energy it has. Even tiny particles like electrons that are moving close to the speed of light have so much energy that they can cause electrical damage or degrade any materials they encounter.

MORE! Learn more about the Earth's magnetosphere and these concepts here: http://www.phy6.org/Education/Intro.html

What are the Van Allen Radiation Belts?

The Van Allen Radiation Belts are two donut-shaped regions encircling Earth, where high-energy (i.e., fast-moving) particles such as protons and electrons are trapped by Earth's magnetic field. While the Sun may look the same every day to us from Earth, in fact the Sun's surface is quite dynamic and so is the steady stream of particles, such as electrons and protons, that is constantly released from the Sun's surface. Sometimes the Sun releases a lot of these particles at once in an event called a Coronal Mass Ejection (CME). The Van Allen belts response to these solar storms is variable. For example, sometimes after a solar storm the number of particles can increase dramatically, and their speeds can become close to the speed of light. Other times, after similar space weather events the particles decrease in number and speed, and sometimes

MORE! Watch a video of these dynamic belts, "Van Allen Probes Reveal A New Radiation Belt Around Earth": http://vanallenprobes.jhuapl.edu/gallery/video.php conditions seem to stay the same. The Van Allen Probes have even recorded the formation of a capricious third belt.



Are the radiation belts brightly colored? No! The colors here are used to represent conditions that are not actually apparent visually; red indicates areas where there are a lot of high-energy particles, yellow areas are a little less intense, and green and blues have the least radiation. In reality, if you were to stand in the middle of the radiation belts, you wouldn't be able to see them at all!

Figure 3. An artist rendering of the twin Van Allen Probe spacecraft orbiting Earth in the Van Allen radiation belts. (Image courtesy: JHU-APL)

Earth as a Giant Magnet

Does the shape of the Van Allen radiation belts look oddly familiar? Many of the charged particles that make up the radiation belts are not traveling through this region encircling Earth in random directions, but are actually moving along Earth's invisible magnetic field lines. Imagine Earth as a giant bar magnet, with the magnet basically aligned with Earth's rotational axis. In Figure 4, notice how the magnetic field lines exit from Earth's South Pole and re-enter near the North Pole, and how similar the shape of the magnetic field lines are to the artist representation of the radiation belts in Figure 3. As is often true in nature, Earth's actual magnetic field is not quite as neat and tidy as the one represented in Figure 4. The steady stream of particles in the solar wind can blow at up to about 2,000,000 miles/hr (roughly 3,000,000 km/hr). When this wind reaches Earth, the charged particles actually push against the magnetic field on the side facing the Sun and stretch it out into a long tail on the opposite side. The region above Earth where the solar wind flows around the magnetic field is called the *magnetosphere*.

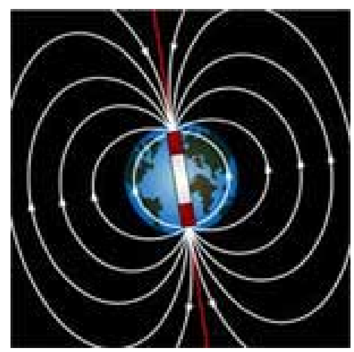


Figure 4. Earth's magnetic field is similar to a bar magnet, with invisible field lines exiting near the South Pole and re-entering near the North Pole. (Image courtesy: NASA)

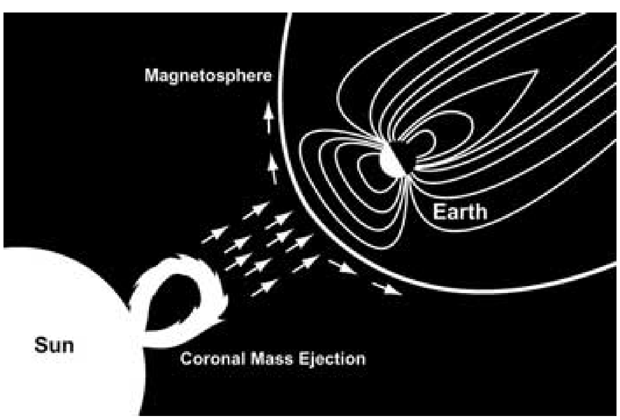


Figure 5. Earth's magnetic field is compressed on the Sun side by the solar wind or the more intense coronal mass ejections. As the stream of particles flows around the Earth's magnetic field it stretches out the long tail on the side opposite the Sun. These processes create the Earth's magnetosphere. (Image courtesy: NASA)

Ring Current

Charged particles trapped in the radiation belts have three different motions, all of which can take place simultaneously. They can bounce from pole to pole along Earth's magnetic field lines. Meanwhile, they are rotating or gyrating around those field lines. In addition, they are drifting from one field line to the next around Earth in the equatorial plane. About 25,000 km (~15,500 mi) above Earth's surface at the equator, positively charged particles (ions) drift clockwise if viewed from the north while negatively charged particles (electrons) drift the other direction. The motion of these charged particles is equivalent to an electric current. What happens when an electric current travels in a circle? A magnetic field is generated!

The ring current particles induce a magnetic field that is in opposition to the Earth's magnetic field. The presence of this opposing field actually reduces the strength of Earth's magnetic field in the equatorial region. The ring current becomes really interesting when there is a space weather event, such as a coronal mass ejection. During such storms the number of charged particles in the region increases and as a result further decreases the strength of Earth's magnetic field at the equator. Such changes in magnetic field strength can be measured here on Earth. We call this phenomenon a *storm-time ring current*. In the graph below (Fig. 6), the *disturbance storm time* index (Dst) is measured over time in units of *nanoteslas* (nT). The Dst is a measure of geomagnetic activity and is recorded hourly at four observatories located around Earth's equator. You can think of it as the strength of Earth's magnetic field at the equator. Notice how, as the storm begins (red arrow), the Dst sharply decreases, almost recovers, and then decreases again. While the details of these graphs change from storm to storm, the dramatic decrease of the Earth's magnetic field strength followed by a recovery phase are signatures of storm-time ring currents.

> ***MORE!*** Learn more about ring currents here: http://www-spof.gsfc.nasa.gov/Education/wtrap1.html

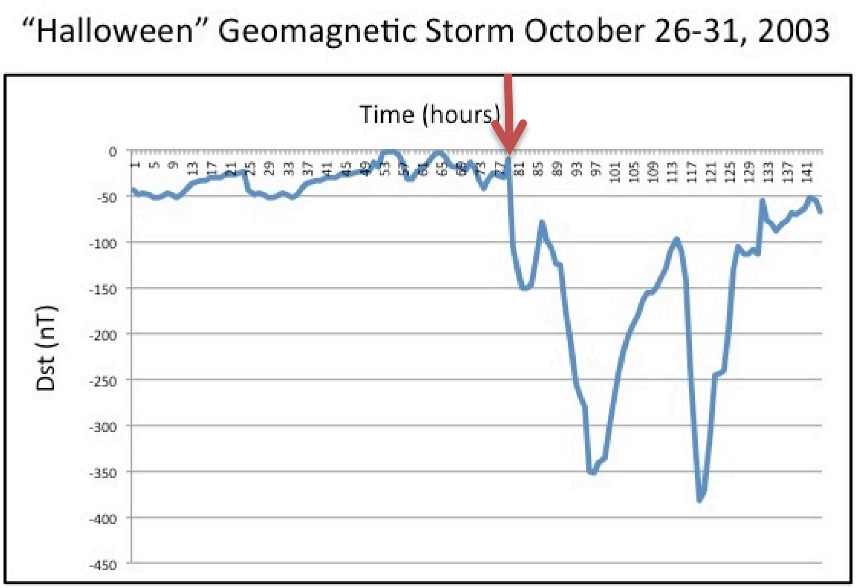


Figure 6. A graph of disturbance storm time index (Dst) versus time (hours) showing how a large geomagnetic storm causes the Dst to decrease and eventually recover. Dst can be thought of as the strength of the Earth's magnetic field at the equator. (Image courtesy: JHU-APL)

In this activity you will first sketch the magnetic field lines for a bar magnet and use that as your operational definition of the Earth's magnetic field without the influence of the solar wind. You will then create a current loop using magnet wire and a 9-volt battery that will induce a magnetic field similar to that of the ring current. You will explore how the electrically charged particles in the ring current model affects the magnetic field of the bar magnet using a compass. Finally, if desired, you can use a smart phone with a magnetometer App to measure the ring current and bar magnet interactions.

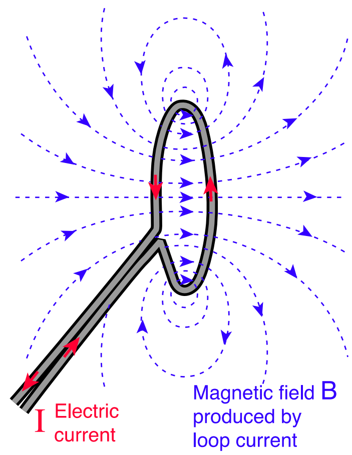


Figure 7. Using wire and a battery you can create a current loop. Earth's ring current is similar to this current loop. A magnetic field is induced by the current loop, as pictured above. (Image courtesy: R. Nave)

Materials:

- 9-volt battery
- Spool of magnet wire (22 gauge, about 18 ft (5.5 m) per group)
- Wire cutters (for teacher use only)
- Scissors or exacto knife (for teacher use only)
- Piece of cardstock (about 8.5 x 11 in, 1 per group)
- Pencil (1 per student)
- Compass (1 or 2 per group)
- Small bar magnet (weaker magnets work better) (1 per group)
- Small box (to support piece of cardstock with wire coil through it) (1 per group)
- Ring Current worksheet (1 per group)
- Earth as a Bar Magnet graphic (projection or copy)
- Earth's Magnetosphere graphic (projection or copy)
- **mobile phone with magnetometer App installed
- **computer with a spreadsheet program such as Microsoft® Excel

These materials are for the **optional technology extension. See the Extensions section for more information.

Procedure:

Generally speaking…

The teacher will prepare a coil of wire for each group, as described in the Advance Preparation section below. Then the teacher will provide a brief introduction to ring currents using information from the Background section. He/she will then divide the class into groups and guide students through a simple magnetic field mapping activity, after which they will discuss how the bar magnet serves as a good model for Earth's magnetic field, but how the actual magnetic field differs from this model (using Earth as a Bar Magnet and Earth's Magnetosphere graphics). For part 2, the teacher will help students cut a slit through their magnetic field drawing on cardstock and provide each group with a Ring Current worksheet, a coil of magnet wire and a battery. The teacher will briefly give instructions and then travel between groups to facilitate the activity. Finally, the teacher will guide a discussion about the Earth's ring current and observations during the activity.

The students will map the magnetic field lines of a bar magnet and engage in discussion about how this is a model for Earth's magnet field, and also how the actual magnetic field differs from this model. After they are given the materials to explore a current loop, they will record how it produces a magnetic field and interacts with the magnetic field of a bar magnet in their Ring Current worksheet. In the closing discussion, they will relate the current loop and bar magnet to Earth's ring current and magnetic field.

<u>**Advance Preparation**</u>

- If unable to project the Earth as a Bar Magnet and Earth's Magnetosphere graphics, make a copy of each for every group
- Make copies of Ring Current worksheet (1 per group)
- Assemble the current loops by wrapping the magnet wire around the base of a coffee mug or something similar that is about 8 cm in diameter (Fig. A), making about 20 loops with

Figure A

10 cm extra on each end (Fig. B). Before removing the loops from the base of the mug wrap a small scrap of wire around the loop where the two 10 cm tails meet to keep it from unwrapping (Fig. B). Assuming you are using an 8 cm diameter mug, you will need about 5.5 m (18 ft) of wire for each current loop (and one current loop for each group). Since magnet wire has a clear coating, you will need to gently scrape off that coating at the ends of the 10 cm tails so that you can make a good contact with the battery terminals. One method to remove the coating is to hold an exacto knife perpendicular to the wire and gently scrape off the clear coating, repeating that as you rotate the wire.

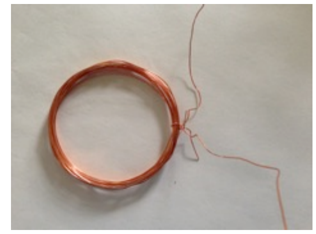


Figure B

In-class Procedure

Part 1: Earth as a Giant Bar Magnet

1. This activity assumes prior knowledge about current and basic magnetic fields. Building from that, tell students they will be exploring Earth's magnetic field and some processes in the radiation belts surrounding Earth. Distribute a Ring Current worksheet, a piece of cardstock, a (weak) bar magnet, and 1 or 2 compasses and pencils to each group. (Using 2 compasses will help students quickly work through Part 1).
2. Ask students to follow the instructions in the Ring Current worksheet and answer questions as they proceed. Walk between groups and make sure their setup is as pictured in Figure C. NOTE: if the field lines are not connecting from the south pole of the magnet to the north, check to see if metal bars in the table or some other metal is interfering. Move their paper if necessary.

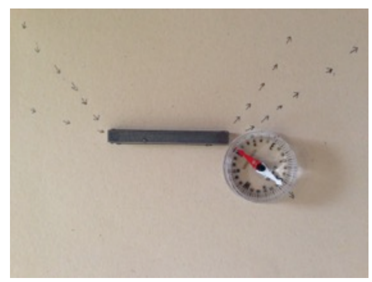


Figure C

3. After students complete Part 1, lead a discussion about Earth's magnetic field and the magnetosphere using the graphics provided. Here are some Q & A to help guide your discussion:
   Q: What do you think you were mapping in Part 1?
   A: The magnetic field of the bar magnet.
   Q: When you look at this picture of the Earth as a Bar Magnet, how does it compare to your drawing?
   A: The bar magnet drawing and the Earth as a Bar Magnet diagram (should) look very similar.
   Q: Now look at the diagram of Earth's Magnetosphere. What is different about this diagram as compared to the Earth as a Bar Magnet diagram?
   A: The magnetic field lines look compressed on one side (closest to the Sun) and then they extend out into a long tail on the other side (furthest from the Sun).
   Q: What do they think might be causing this shape?
   A: The solar wind pressure! The solar wind can blow up to 3,000,000 km/hr (roughly 2,000,000 miles/hr)! Note that this shape persists—the day side (facing the Sun) is always the side that is compressed by the force of the solar wind and the

night side (furthest from the Sun) is always extended into a tail, much like a wind sock's tail always points away from the direction from which the wind is blowing.

Part 2: The Current Loop

4. After discussing Earth's magnetic field and magnetosphere, distribute a wire current loop and a battery to each group (they should keep their compasses). Explain that they will be exploring how current flowing through a current loop interacts with a compass and why that is true.

5. Demonstrate how students can wrap the end of one of the wire tails around the "crown" shaped battery terminal and then **BRIEFLY** touch the other tip of the wire tail to the other battery terminal. **IMPORTANT**: insist that students do not keep the two wire tips touching the battery terminals (current flowing) for more than 2 seconds at a time! The battery and wires will heat up if left connected for too long and could cause burns. Ask students to follow the directions in their Ring Current worksheet and answer the questions for Part 2.

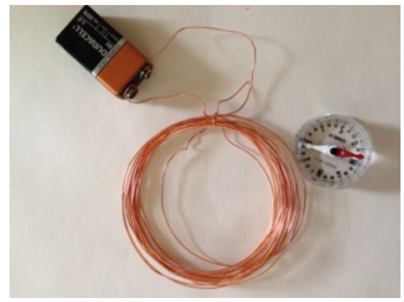


Figure D

6. Walk between groups and make sure they are not connecting the current loop to the battery for too long and their setup is similar to Figure D. Answer questions as necessary.

7. Lead a discussion about what the students observed. Here are some Q & A to help guide your discussion:

   Q: What happened to the compass needle when you "completed the circuit" by connecting both wire ends to the battery terminals?
   A: The compass needle deflected or moved.
   Q: Why did the compass needle move/deflect?
   A: When the circuit is complete, charges are moving within the wires. Moving charges generate a magnetic field. The magnetic field generated by the current loop is stronger at the compass than the Earth's magnetic field, so it causes the compass to detect the generated magnetic field of the current loop rather than Earth's magnetic field.
   Q: What happened when you switched the wires and put them on opposite terminals (while leaving everything else in the same place)?
   A: The compass needle deflected in the opposite direction.
   Q: Why do you think the needle deflected in the opposite direction?
   A: The current was traveling through the loop in the opposite direction, so the direction ("poles") of the generated magnetic field changed, too.

Part 3: The Ring Current

8. Ask groups to bring their cardstock magnetic field drawings from Part 1 to you so that you can cut an 8 cm (or equal to the diameter of your current loop) slit through the cardstock using an exacto knife. The slit should be perpendicular to the bar magnet outline and in the center, as shown in Figure E.

9. Once the slits have been cut, help them assemble their boxes by inserting the current loop into the slit you just created so that half of the current loop is above the cardstock and half is below, as in Figure F. Finally, place the cardstock on top of the box so that half of the current loop is beneath the paper, in the box, and the other half is above the box (Figure G). You want to make sure the magnetic field lines from Part 1 are showing (on the top side of the paper). Have students take their assembled ring current boxes back to their tables (bar magnets and compasses should still remain at their tables).

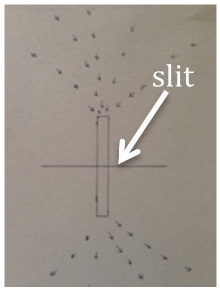


Figure E

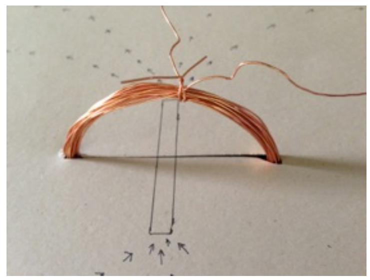


Figure F


Figure G

10. Students should follow the directions in their Ring Current worksheets. Make sure groups are following directions and answer questions as necessary.
11. Lead a discussion about what the students observed. Here are some Q & A to help guide your discussion:

    Q: What happened to the compass needle when you "completed the circuit" by connecting both wire ends to the battery terminals alongside the bar magnet?

    A: Again, the compass needle deflected or moved.

    Q: Why did the compass needle move/deflect?

    A: When the circuit is complete, charges are moving within the wires. Moving charges generate a magnetic field. The magnetic field generated by the current loop is stronger at the compass than the Earth's magnetic field, so it causes the compass to detect the generated magnetic field of the current loop rather than Earth's magnetic field.

    Q: How is this scenario different from the last (without the bar magnet)?

    A: Initially the compass is not detecting the Earth's magnetic field, but rather the magnetic field of the bar magnet. Since the compass is really close to that bar magnet, the field is stronger and so the needle deflects/moves less in response to the current loop generated field in this scenario. (Note: magnetic field strength and distance are basically related by the inverse square law—as the distance increases the field strength decreases rapidly).

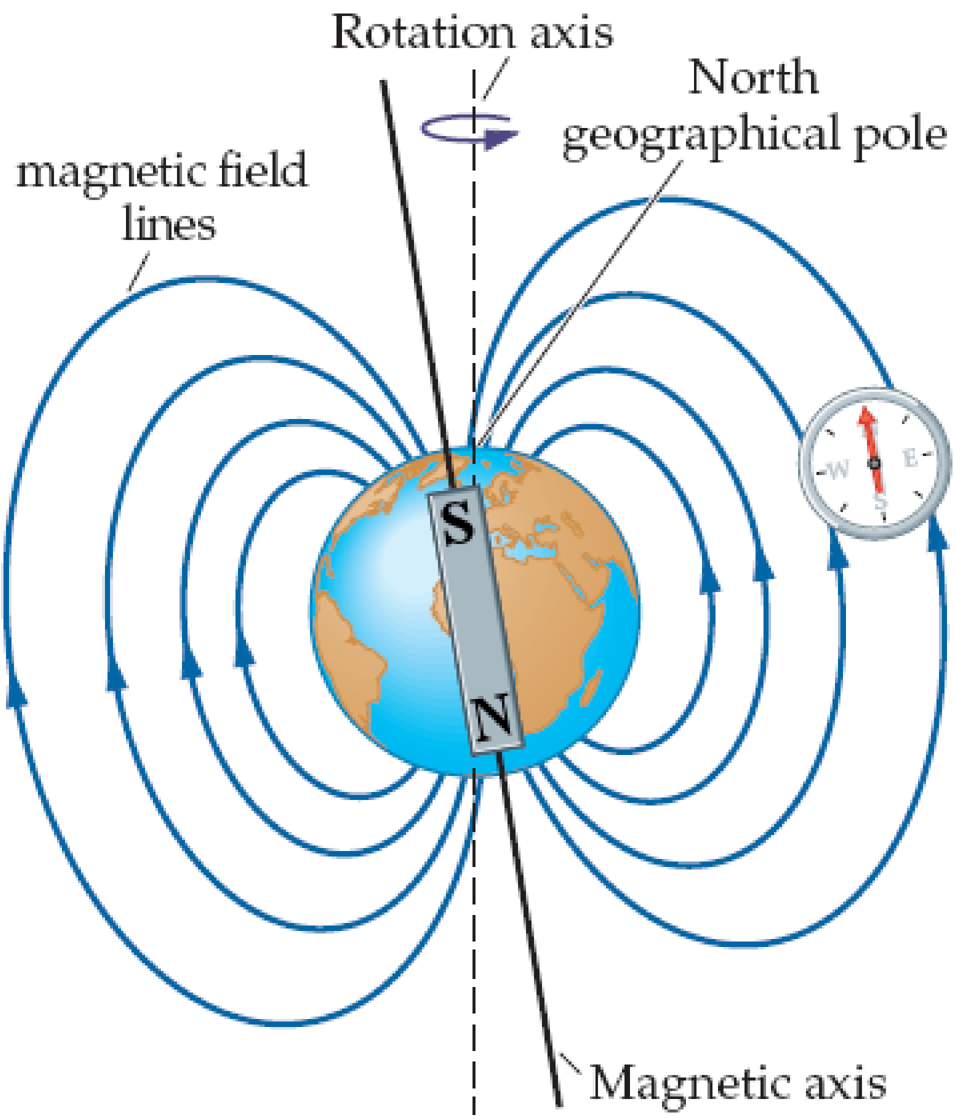
    Q: What would happen if you connected a much more powerful battery?

    A: The magnetic field generated by that battery would be much stronger.

    Q: How do you think this scenario is like Earth?

    A: Earth has a magnetic field that is sort of like a bar magnet and it has a current (positive and negative charges moving in opposite directions) around the equator, which is sort of like the current loop. Earth's magnetic field is influenced by the magnetic field generated by the ring current, and when the ring current increases Earth's magnetic field detects that change.

Earth as a Bar Magnet



The Sun and Earth's Magnetosphere

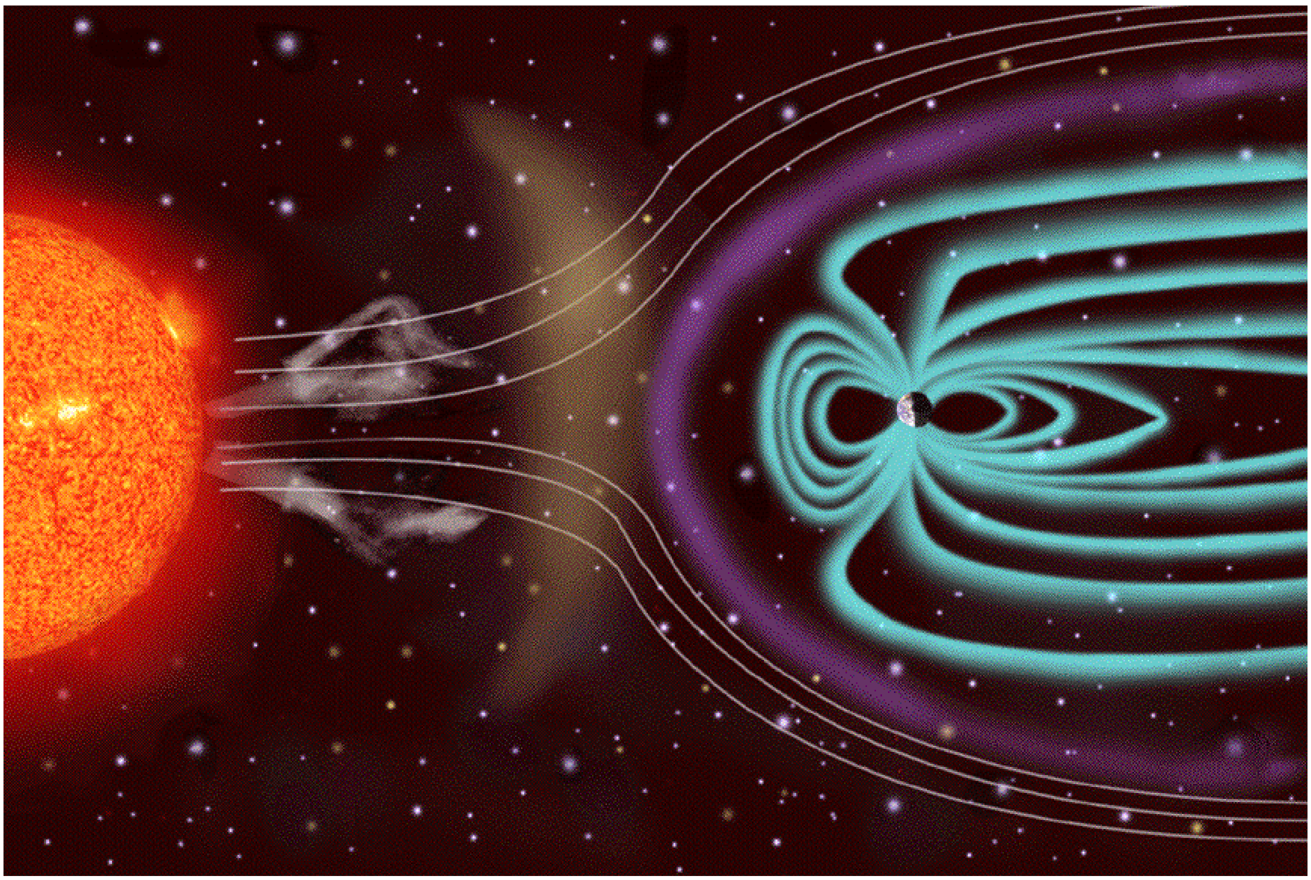


Image not to scale

Names: ____

Ring Current

Part 1. Earth as a Giant Bar Magnet

Directions:

- Place your bar magnet in the middle of your paper (cardstock) and outline it so you can place it back in the same location later.
- With your compass located away from the magnet or any other large metal objects, determine which side of the needle points toward North. That is the side of the needle you will use in this activity.
- Next, place your compass on the paper and using the needle that you determined points north, draw a small arrow pointing in the same direction in front of it on your paper. Move the compass so it is over the top of the arrow you just drew and draw another arrow in the direction the needle is pointing. Continue in this manner until you have reached a pole of the magnet. NOTE: if you have two compasses, both can be mapping the magnetic field in different locations!
- Pick up your compass and place it in a new location on the paper, repeating this process until you have several lines drawn on the paper.

1. What do you think the lines you mapped on your paper represent?

Part 2. The Current Loop

Directions:

- Wrap ONE end of your wire loop to the "crown" shaped battery terminal.
- Place your compass near your wire loop.
- **BRIEFLY** touch the other end of the wire loop to the other terminal on the battery. IMPORTANT: only touch both wires to both terminals BRIEFLY (1-2 seconds). If connected for too long the battery and wire loops will heat up and could cause burns!
- Repeat this several times and watch the compass as you connect the second wire end to the second terminal.

2. What happens to the compass needle when you "complete the circuit" by connecting both wire ends to the two battery terminals?

3. Why do you think the compass needle is doing what it does when the circuit is complete? (Hint: what is controlling the compass needle?)

4. What happens if you keep the compass and the wire loop in the exact same spot, but you switch the wires so they are on opposite terminals? (Again, wrap one wire

around the “crown” battery terminal and then BRIEFLY touch the other wire to the other terminal).

5. Explain what you observed in #4. Why do you think that happened?

Part 3. The Ring Current

Directions:

- Your assembled box should have your magnetic field map from Part 1 with your current loop sticking partly out of it, all atop a box. Remember the outline you drew around the bar magnet in Part 1? Replace your bar magnet in that same spot, just as it was when you created the magnetic field map.
- As before, wrap ONE end of your wire loop to the “crown” shaped battery terminal.
- Place your compass near your wire loop.
- **BRIEFLY** touch the other end of the wire loop to the other terminal on the battery. IMPORTANT: only touch both wires to both terminals BRIEFLY (1-2 seconds). If connected for too long the battery and wire loops will heat up and could cause burns!
- Repeat this several times and watch the compass as you connect the second wire end to the second terminal.

6. What happens to the compass needle when you “complete the circuit” by connecting both wire ends to the two battery terminals?

7. Again, what causes the compass needle to change as observed in #6 when the circuit is completed?

8. Is the compass needle pointing in the same direction (geographic north) before you “complete the circuit” in this scenario? Why or why not?

9. How is the compass different in this scenario when compared to Part 2?

10. As in Part 2, reverse the wires so they are connected to the opposite terminals and record your observations.

11. Explain what you observed in #10.

12. What do you think would happen in this experiment if you could connect a much more powerful battery to the wires?

13. Recall from Part 1 that Earth acts a bit like a giant bar magnet. What happens to the magnetic field of the bar magnet when current is traveling through the current loop?

14. If charged particles (current!) were traveling in a giant loop around the Earth's equator, do you think it would interact with Earth's magnetic field?

15. Imagine a solar storm caused the number of particles to greatly increase in the "ring current" that encircles Earth at the equator. How do you think this would affect Earth's magnetic field?

Ring Current:
Teacher Answer Key

Part 1. Earth as a Giant Bar Magnet

1. What do you think the lines you mapped on your paper represent?
   A: The magnetic field lines of the bar magnet.

Part 2. The Current Loop

2. What happens to the compass needle when you "complete the circuit" by connecting both wire ends to the two battery terminals?
   A: The compass needle deflects or moves.
3. Why do you think the compass needle is doing what it does when the circuit is complete? (Hint: what is controlling the compass needle?)
   A: When the circuit is complete, charges are moving within the wires. Moving charges generate a magnetic field. The magnetic field generated by the current loop is stronger at the compass than the Earth's magnetic field, so it causes the compass to detect the generated magnetic field of the current loop rather than Earth's magnetic field.
4. What happens if you keep the compass and the wire loop in the exact same spot, but you switch the wires so they are on opposite terminals? (Again, wrap one wire around the "crown" battery terminal and then BRIEFLY touch the other wire to the other terminal).
   A: The compass needle deflected in the opposite direction.
5. Explain what you observed in #4. Why do you think that happened?
   A: The current was traveling through the loop in the opposite direction, so the direction ("poles") of the generated magnetic field changed, too.

Part 3. The Ring Current

6. What happens to the compass needle when you "complete the circuit" by connecting both wire ends to the two battery terminals?
   A: The compass needle deflected or moved.
7. Again, what causes the compass needle to change as observed in #6 when the circuit is completed?
   A: When the circuit is complete, charges are moving within the wires. Moving charges generate a magnetic field. The magnetic field generated by the current loop is stronger at the compass than the Earth's magnetic field, so it causes the compass to detect the generated magnetic field of the current loop rather than Earth's magnetic field.
8. Is the compass needle pointing in the same direction (geographic north) before you "complete the circuit" in this scenario? Why or why not?
   A: Initially the compass is not detecting the Earth's magnetic field as it was in the last scenario, but rather the magnetic field of the bar magnet.
9. How is the compass different in this scenario when compared to Part 2?
   Since the compass is really close to that bar magnet, the field is stronger and so the needle deflects/moves less in response to the current loop generated field in this scenario.

10. As in Part 2, reverse the wires so they are connected to the opposite terminals and record your observations.
    A: The magnet deflects/moves in the opposite direction.
11. Explain what you observed in #10.
    A: The current was traveling through the loop in the opposite direction, so the direction ("poles") of the generated magnetic field changed, too.
12. What do you think would happen in this experiment if you could connect a much more powerful battery to the wires?
    A: The magnetic field generated by that battery would be much stronger.
13. Recall from Part 1 that Earth acts a bit like a giant bar magnet. What happens to the magnetic field of the bar magnet when current is traveling through the current loop?
    A: The current loop creates a magnetic field when it is connected to the battery, so the magnetic field of the bar magnet and the magnetic field generated by the current loop interact. If they are opposing, they each become weaker in the region between them, and if they are aligning, they create a stronger overall field.
14. If charged particles (current!) were traveling in a giant loop around the Earth's equator, do you think it would interact with Earth's magnetic field?
    A: Yes! Because Earth has a magnetic field that is similar to a bar magnet and it has a current (positive and negative charges moving in opposite directions) around the equator, which is similar to the current loop. Earth's magnetic field is influenced by the magnetic field generated by the ring current, and when the ring current increases Earth's magnetic field detects that change.
15. Imagine a solar storm caused the number of particles to greatly increase in the "ring current" that encircles Earth at the equator. How do you think this would affect Earth's magnetic field?
    A: If the two fields are in opposition, the Earth's magnetic field will get weaker as the ring current generated field gets stronger. If the two fields were aligned, as the ring current generated field got stronger, so too would the Earth's field.

Extensions and Adaptations:

- A great extension to this activity would be to actually measure the changes in the fields in Parts 2 and 3 using a magnetometer App on a smartphone. There are many available and you can download the data into a spreadsheet format. Since all Apps differ slightly and we don't endorse a single developer, we encourage you to see what is available for your phone and explore!
- If it is cost prohibitive or inconvenient to purchase enough magnet wire for each group to have their own current loop, you can demonstrate Parts 2 and 3 in front of the class or to small groups as they complete Part 1. The same discussions will ensue.
- This activity could be extended to compare the magnetic properties of the Sun and Earth with 3-D magnetic fields: http://www.nasa.gov/pdf/626531main_Solar_System_Magnetism.pdf
- As a class you could extend this activity by building a simple magnetometer so you could see real time changes in Earth's magnetic field. Here are two resources:
    - A more complicated version: http://hackaday.com/2012/01/21/pvc-magnetometer-to-measure-magnetic-storms/
    - A simple "low tech" version: http://lasp.colorado.edu/home/wp-content/uploads/2011/08/magnetometer.pdf
- This activity could be extended to quantify the relationship between field strength and distance using this interactive simulation (link below), which shows the interaction between a compass and a bar magnet with the options to measure the field with a field meter and vary the magnet's strength: http://phet.colorado.edu/en/simulation/magnet-and-compass
    - This activity could be used along with the interactive simulation: http://phet.colorado.edu/en/contributions/view/4041

Resources:

- Van Allen Probes Mission website: http://vanallenprobes.jhuapl.edu
- Supplemental background information for radiation trapped by Earth's magnetic field: http://www-spof.gsfc.nasa.gov/Education/wtrap1.html
- Supplemental background information about Earth's radiation belts: http://www-spof.gsfc.nasa.gov/Education/Iradbelt.html
- Magnet wire should be available from most science supply stores, such as Fisher Scientific: https://www.fishersci.com/shop/products/enameled-magnet-wire-22-awg/s4828a
- PhET interactive simulation showing the interaction between a compass and a bar magnet with the options to measure the field with a field meter and vary the magnet's strength: http://phet.colorado.edu/en/simulation/magnet-and-compass
    - This activity could be used along with the interactive simulation: http://phet.colorado.edu/en/contributions/view/4041