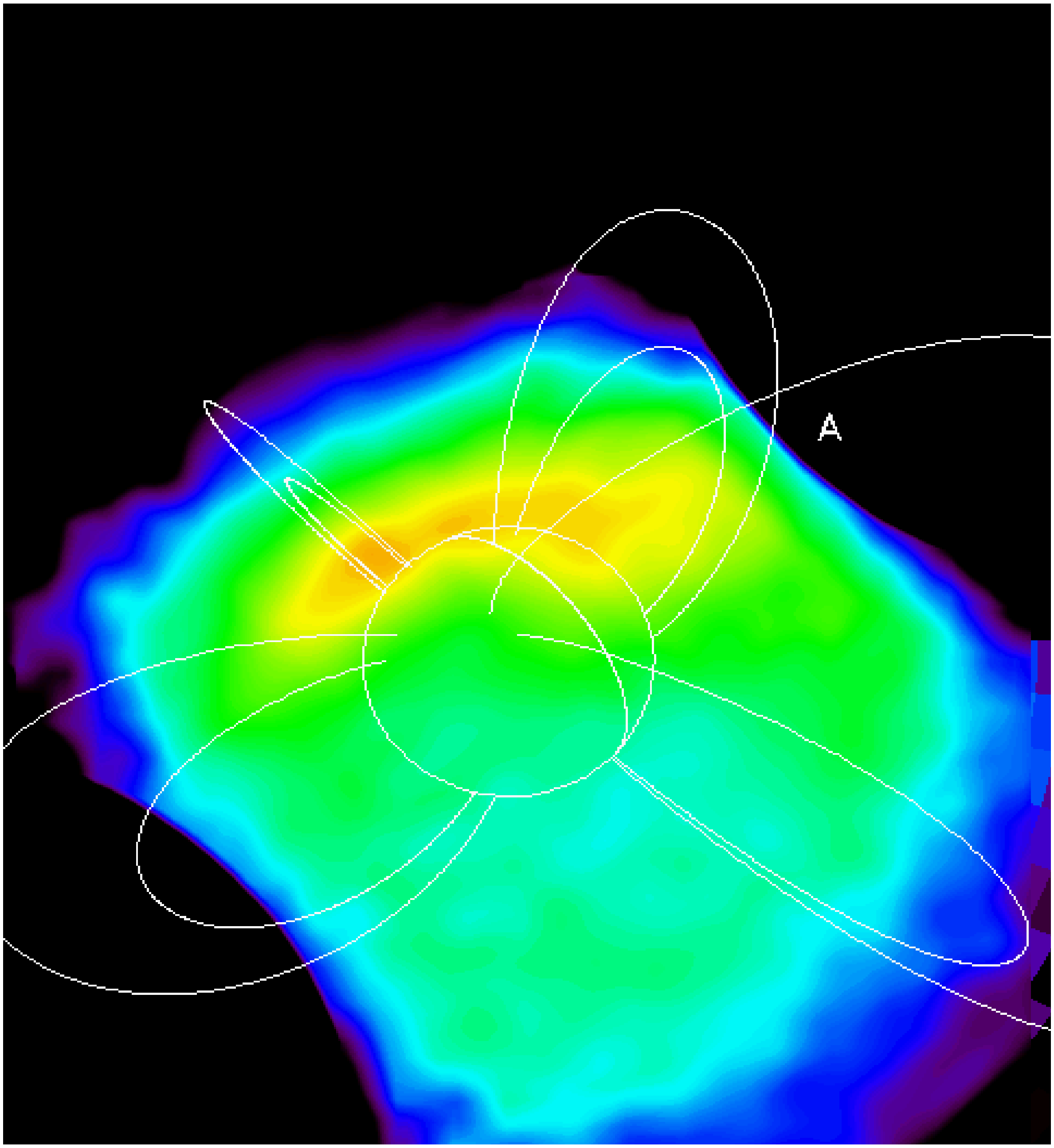
Exploring the Earth's Magnetic Field

An IMAGE Satellite Guide to the Magnetosphere



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<u>*Cover Artwork:*</u>

Image of the Earth's ring current observed by the IMAGE, HENA instrument. Some representative magnetic field lines are shown in white.

This resource was developed by the NASA Imager for Magnetopause-to-Auroral Global Exploration (IMAGE)

Information about the IMAGE Mission is available at:

http://image.gsfc.nasa.gov
http://pluto.space.swri.edu/IMAGE

Resources for teachers and students are available at:

http://image.gsfc.nasa.gov/poetry

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Coordination with Science Standards

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Motion			X							X	X	X							X	X		X	
Forces	X	X	X	X					X	X	X	X	X	X		X	X	X	X	X	X	X	
Light																					X		
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Magnetism	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	
Energy			X					X									X	X	X	X	X	X	
Astronomy		X	X		X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
Earth	X	X		X	X	X	X	X		X	X	X	X		X	X	X	X	X	X	X	X	X
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Science					X	X	X	X															
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What is a Magnet? | **Investigating the Earth's Magnetism** | **Magnetic Storms, Aurora and Space Weather**

This book was designed to provide teachers with activities that allow students to explore topics related to the Sun-Earth Connection.

We have provided a full range of activities for the grades 3-12 community so that teachers may see how the single topic of magnetism can evolve in sophistication as the student matures. Teachers are invited to use the activities as-is, or to modify them as needed to suit their particular objectives.

The units are designed for use in conjunction with your current curriculum as individual lessons or as a unit. The chart above is designed to assist teachers in integrating the activities contained with existing curricula and National Science Standards.

Throughout the lessons you will find activities that require the students to make observations, and record their findings. Observations can be recorded in science learning logs, journals or by organization into charts or graphs.

Introduction

"Students should be actively engaged in learning to view the world scientifically. They should be encouraged to ask questions about nature and to seek answer, collect things, count and measure things, make qualitative observations, organize collections and observations and discuss findings."
(American Association for the Advancement of Science; Benchmarks for Science)

Scientists and students share an active curiosity about the world. A true scientist maintains that inquisitive quality and continues to question, explore and investigate.

In developing this book, we have attempted to stimulate an active curiosity about the Sun-Earth Connection, and specifically how Earth and its magnetic field react to solar influences. The activities in this book combine hands-on experimentation with the use of satellite data resources on the internet, to provide students with a well-rounded perspective into basic issues in contemporary Sun-Earth research.

"When students observe differences in the way things behave or get different results in repeated investigations, they should suspect that something differs from trial to trial, and try to find out what." (AAAS 'Benchmarks for Science Literacy, 1999)

Each lesson focuses upon a particular aspect of studying the Sun and the Earth as a system, and how scientists make the observations. Included in the procedure sections are questions that will further encourage scientific inquiry.

Each lesson begins with a description of the activities in which the students will participate, and provides general background information. The objectives sections highlight the science process skills the students will develop while completing the activities. The procedures sections are general, and can be adapted to meet the knowledge and developmental levels of the students.

Many lessons have extension activities designed to have the students apply the new knowledge in grade appropriate activities.

Although the lessons may be used with only the information provided, we include where appropriate the addresses of web pages on the Internet, and on the IMAGE '*Space Weather*' CDROM, so that further material can be incorporated into the lesson. For further information, please visit the IMAGE satellite's Education and Public Outreach web site at:

The scientific study of Earth's magnetic field is a complex subject that has evolved tremendously since William Gilbert's book 'De Magnete' was published in 1600. The 1800's were a period of understanding how magnetic forces operated in great mathematical detail by physicists such as Oersted, Faraday, and Gauss, culminating with the electromagnetic theory by James Clerk Maxwell. The relationship of laboratory magnets to terrestrial magnetism became a dynamic scientific discipline once physicists realized that aurora were related to disturbed magnetic conditions; a discovery made by Alexander von Humbolt in the 1820's. During the 20th century, sophisticated physics models were developed to explain how Earth's magnetic field changes, especially due to solar storms and the outpouring of matter and electromagnetic energy.

Satellite observations since the 1980's have helped scientists explore the detailed interactions between the various plasmas and fields that surround Earth within the magnetosphere: the region of space around Earth where its magnetic influences control the behavior of charged particles. In the 21st century, satellites such as the NASA, Imager for Magnetospause-to-Auroral Global Exploration (IMAGE) will investigate the detailed motions of the various particles that flow within in the magnetosphere. In the years to come, NASA will launch constellations of satellites to map the entire magnetosphere on a day-to-day basis so that scientists can greatly improve their ability to forecast when conditions may turn hostile for our astronauts and our billions of dollars of satellite resources.

For more information about Earth's magnetic field, and why space weather issues are becoming increasingly important, visit the following web resources:

IMAGE Education Web page	http://image.gsfc.nasa.gov/poetry
Exploration of the Magnetosphere	http://www-istp.gsfc.nasa.gov/Education/Intro.html
NASA, Sun-Earth Forum	http://sunearth.gsfc.nasa.gov
NASA,OSS Resource Directory	http://teachspacescience.stsci.edu/
Space Weather Illustrated Primer	http://sunearth.gsfc.nasa.gov/sechtml/tut.html
Today's Space Weather	http://www.sec.noaa.gov/SWN
A recent book about human impacts	http://www.theastronomycafe.net/

Although it is not required in order to use this teacher's guide, the IMAGE, 'Space Weather' CDROM has many resources that are relevant to the activities in this workbook. Here is a short index of the resources assuming that your computer listed the CDROM device as 'Drive I':

Supplementary activity workbooks for K-12 students:
file:///I|/poetry/activities.html

Articles about the IMAGE mission, space weather, and human impacts:
file:///I|/poetry/resources.html

Case histories of several major storms including representative data:
file:///I|/poetry/today/IMAGESEE.html

Images and movies from the IMAGE satellite:
file:///I|/poetry/multimedia.html

How to build a magnetometer and join 'MagNet':
file:///I|/poetry/workbook/magnet.html

FAQs about astronomy and space physics:
file:///I|/poetry/ask/askmag.html

The latest news from IMAGE:
file:///I|/poetry/news/newnews.html

Space Weather Primer:
file:///I|/poetry/tutorial/tut.html

Live data from space:
file:///I|/poetry/today/intro.html

What is Space Weather?
file:///I|/poetry/skytel.htm

Introducing the IMAGE satellite:
file:///I|/poetry/swri/index.html

I...Playing with Magnetism

Introduction:

What is magnetism? We have all had the experience of using simple magnets to hold notes on surfaces such as refrigerator doors. Magnetism is the force produced by magnets which does all of the "holding". Magnetism is also a very important force in nature which can move hot gases in stars, and in the space around Earth. The students will investigate magnetism and magnetic forces. The students will explore the attracting and repelling properties of magnets through hands on experiences.

Objectives:

- Students will identify items that are attracted to magnets.
- Sudents will experiment with an invisible force.
- Students will learn about polarity.

Materials:

Magnets

Paper clips

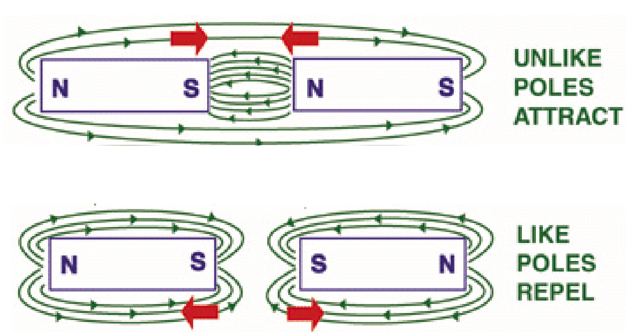
String

Books

Ruler

Various metal samples to test.

Note: Provide enough of the above resources so that each student has enough to do the activity.

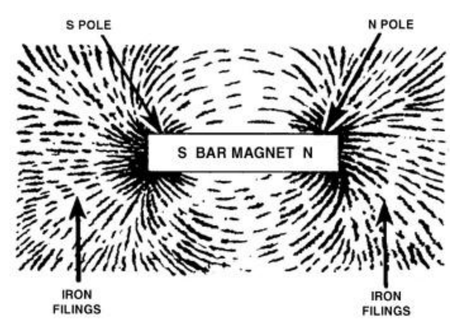


Key Terms:

<u>Magnet</u> - a metal that can attract certain other metals.

<u>Magnetic Properties</u> - refers to an item which can attract or repel items as a magnet does.

<u>Poles</u> - refers to the two areas of a magnet where the magnetic effects are the strongest. The poles are generally termed the north and south poles. Poles that are alike (both north or both south) will repel from each other, while poles that are different (one north, one south) will attract to each other.



Procedure:

- Give each student a magnet. Have the students explore the metallic samples attracted to the magnet. The students should look at the samples and find common characteristics. Have them fill in the table below and add their own samples. The students should record their findings in a learning log.
- Tape one end of a piece of string to a desk; tie the other end onto a paper clip. Take a second piece of string and suspend the magnet from a ruler anchored with books. Adjust the level of books so that the distance between the magnet and the paper clip allows the clip to stand up without touching the magnet. The students should see that a magnetic force could be invisible. You can place pieces of paper or cloth between the clip and the magnet to show the strength of the magnetic force. Can the students find materials that block magnetic forces?
- With the string still attached, have the students try to raise the paper clip from the desk with a magnet. They should try to accomplish this without letting the magnet and paper clip touch. The students should keep a log of how they were able to accomplish this; what methods and strategies were used.
- Give each student two magnets. Allow the students time to explore the attracting and repelling properties of magnets. They should be able to demonstrate that a magnet has two ends or poles that will attract or repel from other poles. Have the students observe what happens when two magnets are repelling from each other. The students should find a partner and discuss what they have seen and whether their classmate was able to discover the same properties.

Conclusions:

The students will learn the characteristics of magnetism. The students will demonstrate the attracting and repelling properties of magnets.

ITEM	Attracted to Magnet	Not Attracted to Magnet
paper clip nickel penny paper Aluminum foil		

II...Exploring Magnetic Fields

Introduction:

What are magnetic fields? In physical science, a "field of force " is a region or space in which an object can cause a push or pull. This field extends infinitely in all directions but gets weaker as you get farther from the source of the field. Magnetic lines of force show the strength and direction of this field. The students will explore the lines of force of magnets and compare them to the lines of force on the Sun and Earth**.**

When the students are using the iron filings to define the magnetic lines of force, it is important to stress that the procedure must be done slowly and carefully to have the best effects.

Safety goggles should be used.

Objectives:

- The students will describe the magnetic field lines of a magnet.
- The students will draw the magnetic field lines between two attracting and two repelling magnetic poles.
- The students will describe the magnetic properties of the Earth and the Sun.

Materials:

Strong Magnets- enough for class or small groups

Plastic wrap

Iron filings

Plastic teaspoon

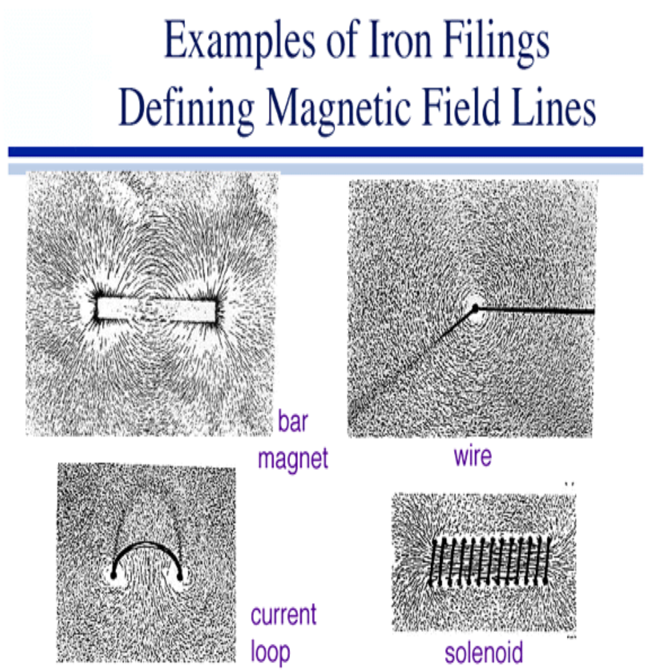
Paper or overhead transparency

Plastic tray

Compass

Photograph of sunspot/magnetic loops on the sun

Also available through the TRACE satellite site at http://vestige.lmsal.com/TRACE/



Procedures:

****Caution the students that the iron filings should not be eaten or blown into eyes. *****

- Cover the magnets with plastic wrap to keep the iron filings off them. Place the covered magnet in the plastic tray and place the paper on top. The students should carefully use the spoon to sprinkle a small amount of the iron filings on the paper. The iron filings will stay in a pattern that indicates the lines of force of that magnet. The students should draw their observations in their learning logs. After the students have completed their observations, the iron filings can be poured off the paper and the tray back into the container.

- Give each group of students a pair of covered magnets. Place the covered magnets about an inch apart in the plastic tray and place the paper on top. The students should carefully sprinkle a small amount of the iron filings on the paper. The iron filings will stay in a pattern that indicates the lines of force between the magnets. The students should look at the lines of force and determine whether the magnetic poles are alike or different. Have the students record their observations in their learning logs.

- Have the students repeat the activity of finding lines of force, but this time one of the magnets must be reversed so that its opposite pole is about an inch away from the other magnet. The students should look at the lines of force and determine whether the magnetic poles are alike or different. The students should record their observations in their learning logs.

- Display the photograph on page 14, or the TRACE website of magnetic loops on the Sun's surface without informing the students of the source. Question the students about what they observe in the photograph. The image should resemble the magnetic lines of force the students saw in the previous activity. The students, as scientists, should understand that they are seeing magnetic properties on the Sun. How does the pattern compare to the iron filings near a bar magnet? Answer: They should display a definite North and South polarity as well as loops. Scientists have in fact confirmed this using other observations.

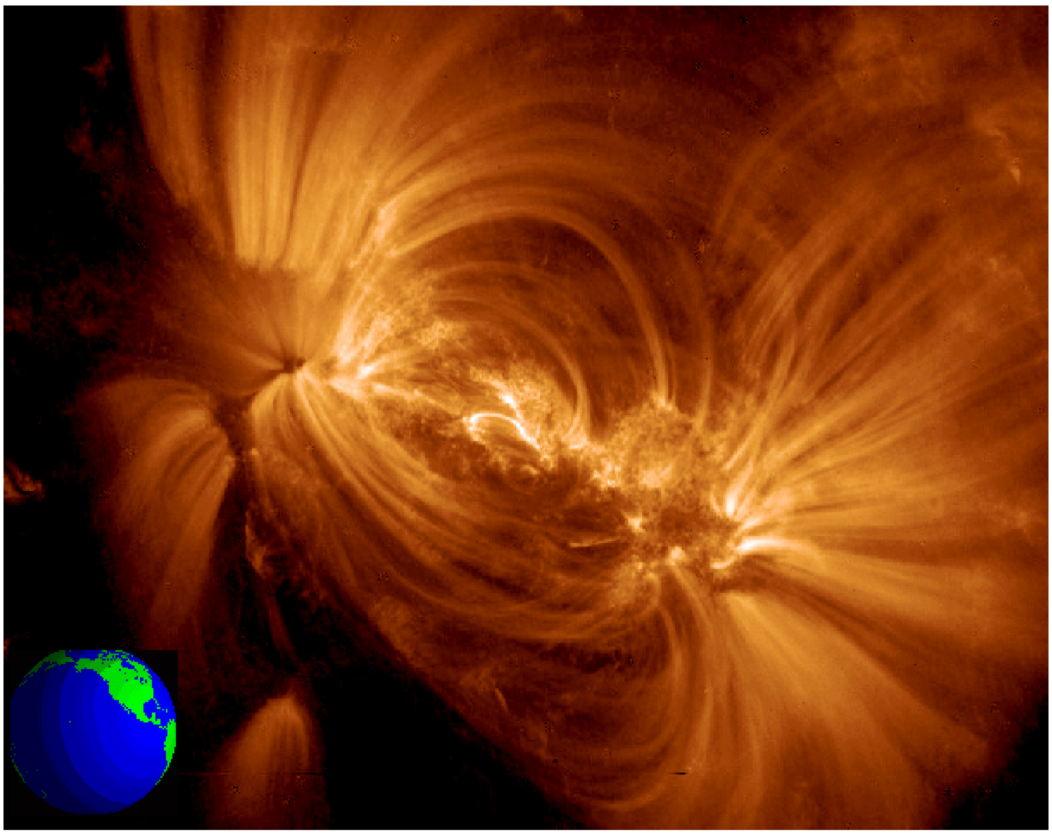
- Discuss the student's observations which were noted in their log books.

- Display a compass to the students. Explain that in the Northern Hemisphere the needle of the compass will point to the magnetic north because it is magnetized. When a compass is held on Earth, the Earth's magnetic field exerts a force on the needle. This should help the students understand that Earth also has magnetic properties. If the "north" part of a compass is attracted to the magnetic north pole of Earth, what is the polarity of the Earth's north magnetic pole? Answer - South!

Conclusions:

The students will gain an understanding of the presence of magnetic fields around magnets, the Sun and Earth. The students will learn that the magnetic poles attract when they are different and repel when they are the same.

Sunspots also have magnetic fields, and they look a lot like the kind you see with a bar magnet. This view (note the earth for scale) is provided by the NASA, TRACE satellite shows million-degree gases flowing along the lines of magnetism and illuminating them.



III...The Earth as a Magnet

Introduction:

What is the Earth's magnetosphere? Scientists call the region surrounding Earth where its magnetic field is located, the Magnetosphere. When the solar wind sends streams of hot gases (plasma) towards Earth, the magnetosphere deflects most of this gas. Students will use hands-on experiences to learn about the magnetosphere (the magnetic field surrounding Earth). They will learn how the solar wind (the stream of electrically conducting plasma emitted by the Sun) interacts with the magnetosphere. There is a wonderful animated graphic available for this in the Blackout! Video (information available through the IMAGE/POETRY site at http://image.gsfc.nasa.gov/poetry/

or at the Windows on the Universe site at www.windows.umich.edu/spaceweather/

Objectives:

- The students will use models to learn how Earth's magnetic field protects us from solar storms.
- Students will describe the shape of the Earth's magnetic field in space and learn its correct name.

Key Terms:

Magnetosphere – magnetic cavity carved out of the solar wind by virtue of the magnetic field surrounding Earth.

Materials:

Magnets– strong polarity bar magnet (enough for groups if possible)

Plastic wrap - 3" square

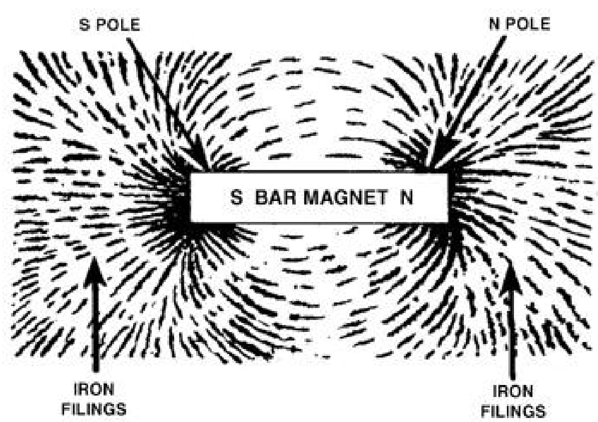
Iron filings...1 oz. per student

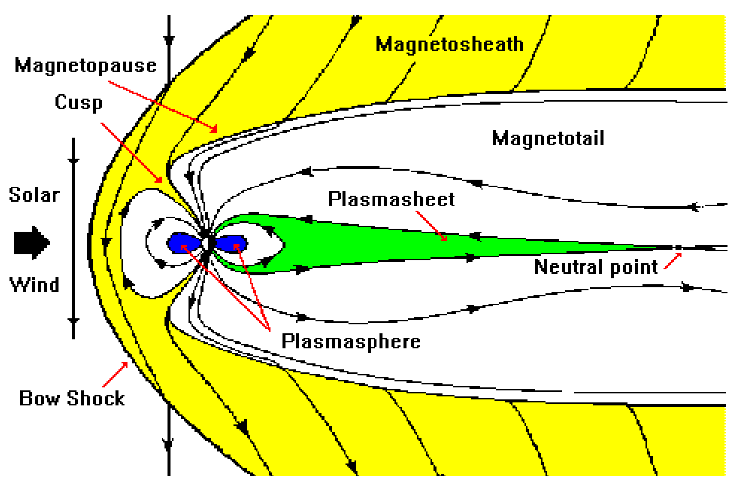
Plastic salad tray or aluminum tray

Straws - 1 per student

Safety goggles - 1 per student

Note: Teacher may elect to perform the experiment using an overhead projector if it is deemed that students blowing iron filings with a straw presents a significant safety hazard.





Procedure:

What protects the Earth?

- Earth has a protective cover called the magnetosphere. It works as skin does on your body to keep out harmful things. Students can observe a model of the magnetosphere using magnets and iron filings. To keep your bar magnet clean, wrap it in plastic wrap with tape around it, or put contact paper around it. Place a bar magnet under a plastic salad tray or aluminum tray. Sprinkle some iron filings onto the tray from a distance of about 10 inches. Observe the pattern made by the iron filings held in place by the forces between the opposite poles of the magnets. The earth's magnetosphere can be modeled by blowing softly through a straw towards the magnetic field lines. A squishing of the field lines on one side of the model shows how Earth's magnetosphere looks. Have the students draw the model of Earth's magnetosphere in their learning logs.

What happens when the solar wind approaches the earth's magnetosphere?

- Students can observe the way water flows around a stone as a pattern of the solar wind as it flows around the Earth.
- Place the bar magnet under a plastic tray or aluminum tray. Place a small button directly above the center of the magnet to model the Earth. Sprinkle the iron filings along the edge of one side of the tray covering the magnet. Softly blow the filings toward the button through a straw. Caution the students to blow carefully so that no iron filings get into eyes or mouth! Depending on the force used in blowing, the filings will be trapped in the magnetic lines of force. Compare this to the trapping of the solar particles by Earth's magnetosphere. Have the students draw the model of the effects of the solar wind on Earth's magnetosphere.

Conclusions:

The students will gain an understanding of Earth's protective region, called the magnetosphere. The students will gain an understanding of how Earth's magnetosphere interacts with the charged plasma sent from the sun in solar wind and in solar storm events called Coronal Mass Ejections (CMEs).

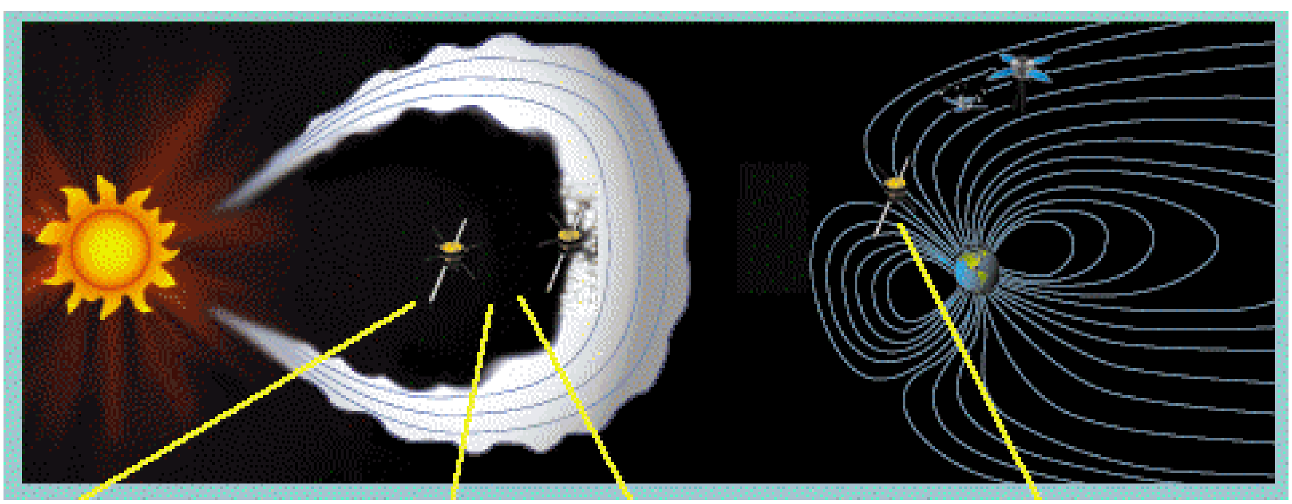
Culminating Activity :

Grades 3-5

The students will work as a class or in groups with an adult to write the story of a charged particle in the sun as it makes its way to Earth. The story could be written on chart paper or made into a book with student illustrations. Story events should include, gases coming from activity on the Sun's surface, being organized with other particles in the magnetic fields of the Sun, and the type of phenomena that took the particle away from the Sun.

Grades 6-8

The students will work as a class, individually, or in-groups to write a story or rap song about a charged particle in the plasma of the Sun. Story events should include; coming from activity on the Sun's surface, being organized with other particles in the magnetic fields of the Sun, the type of phenomenon that took the particle away from the Sun and what occurred when the plasma approached Earth's magnetosphere.



IV...Electricity and Magnetism

Introduction:

Moving magnets can induce electric currents, and electric currents can cause magnetism. Based on this statement, there is obviously a close relationship between electricity and magnetism. Electric current flowing in a wire creates a magnetic field around it. This magnetic force is evidence of the phenomena known as electromagnetism.

Purpose:

The following activities (Part 1 and Part 2) will show the relationship between electricity and magnetism. They will show how the changes in Earth's magnetic field can affect the flow, and sometimes interupt the flow, of electricity from power company to consumer.

Materials:

1. Dry cell battery. Use a 6-volt lantern battery for best results
2. Large nail or metal rod (about 10 cm long)
3. Two meters of bell wire (insulated)
4. Paper clips or small metal washers
5. Galvanometer
6. Bar magnet

Teacher Notes:

1. The use of 10 loops vs 20 loops will work if your metal rod is too short to fit the full, 40 loops in the second part of the activity.

2. Remind the students to put the loops close together when they do their wrapping.

3. For best results, a 6-12 volt battery is recommended.

4. Have students take an average of the number of clips magnets can hold at 20 and 40 loops.

CAUTION

Connect the battery to the wire for short periods of time only. The wire will get hot.

Do NOT use a car battery or a motorcycle battery to produce a stronger magnetic field. These batteries will explode if shorted, or cause the wire to spark and melt.

Part 1. How strong are Electromagnets?

Procedure:

1...Carefully wrap the nail with the insulated wire making 20 loops. Connect the bare ends of the wire to the battery (for short periods of time only)

2...Using a Data Sheet, students record the number of paper clips held by the magnet and the number of turns of wire used. Determine the number of paper clips your magnet is able to hold. Now increase the number of loops to 40, and determine how many paper clips your magnet can hold.

Sample Questions:

1.How many paper clips did the magnet hold with 20 loops? How many with 40 loops?
2.What does this show about the strength of magnetic fields?
3.When you disconnect the battery, does the magnet still work?
4.Can you describe a relationship between the flow of electricity and

Part 2. Making currents flow in a wire by magnetic induction.

In the last activity you were able to create a magnet using the flow of electricity through a wire. This is called an **electromagnet**. In this activity you will induce the flow of electricity in a wire using a permanent 'bar' magnet. The flow of electricity will be small so you will need to use the galvanometer to measure the flow.

Note: A **galvanometer** is a piece of common high school laboratory equipment that can be bought through school lab equipment suppliers. It is a meter that measures the current flow in a wire. They are also called 'Am meters' because they measure current flow in units called Amperes. These can also be bought at electrical supply stores such as Radio Shack.

Using the same wire, make a coil big enough to allow the bar magnet to pass through. Hook the bare ends of the wire to the galvanometer. Pass the bar magnet through the coils in a back and forth motion, slowly then quickly. The movement of the needle on the galvanometer is caused by the induced flow of electricity.

Teacher Notes:

1. A stronger bar magnet will yield better results.
2. Students may need to vary the number of coils to get good results, they may also need to alter the speed at which they pass the bar magnet between the wire coils.
3. Students should observe that a current will only flow if the magnet is in motion.

Questions:

1. Does the speed at which you move the magnet through the wire coils have any affect on the needle's movement? What happens?

2. What do you think would happen if the power company was operating at 'full' capacity (such as during a heat wave or extreme cold spell) and a magnetic storm happened? Magnetic storms cause rapid changes in the magnetic field of Earth near ground level.

Chapter 2: Investigating the Earth's Magnetism

For hundreds of years, sailors have relied on magnetic compasses to navigate the oceans. These sailors knew that Earth's magnetic north pole was not in the same place as the geographic North Pole, and they were able to make the necessary corrections to be able to determine where they were (and, more important, how to get home!). In modern times, we have found that the magnetic North Pole does not even stay in the same place, but moves around a significant amount. Small corrections are needed in order to use the magnetic pole for navigation purposes.

Earth has a magnetic field that has a shape similar to that of a large bar magnet . To the north is the magnetic north pole, which is really the south pole of Earth's bar magnet. (It has to be this way since this pole attracts the north pole of the compass magnet!) The Sun also has a magnetic field that is more complicated than, but similar to, that of Earth. The Sun, through its solar wind, has a large impact on the shape of Earth's magnetic field.

Figure 1: The magnetic field of Earth is generated by currents flowing in the liquid outer core region. Like all magnetic fields, it has a north and south polarity. The Earth's field extends over one million miles into space in some directions.

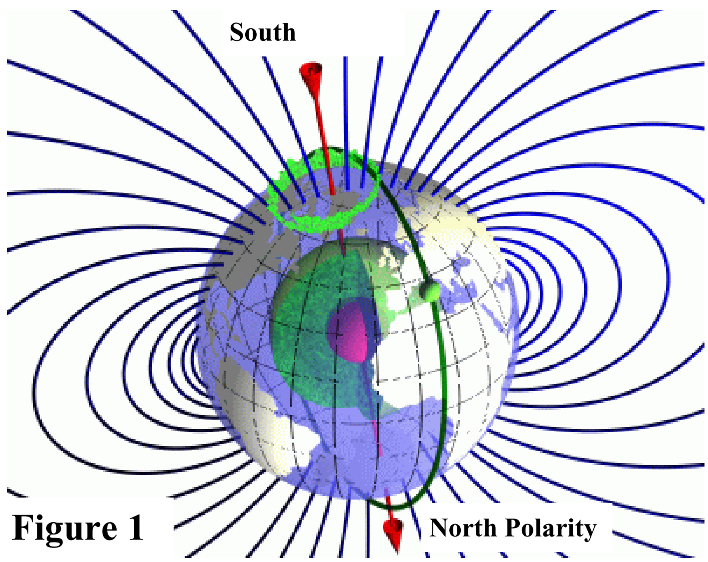


Figure 1

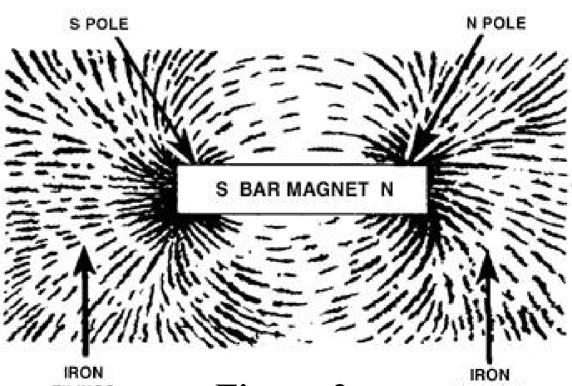


Figure 2

Figure 2: This is the magnetic field of a bar magnet. Notice the symmetry and direction of the field lines. Remember, the <u>magnetic</u> North Pole is not located in the same place as the geographic North Pole.

As the solar wind flows outward from the Sun and encounters Earth's magnetic field, it pushes the Earth's field in on the side toward the sun and stretches it out on the side away from the sun. The result is a magnetic field shape that is not symmetric in the same way as the field of a bar magnet. It is also unlike a magnetic field in a pure vacuum which has an infinite extent in space. The solar wind confines Earth's magnetic field to a limited region in space within the solar system. Severe solar storms, called Coronal Mass Ejections (CME) can produce major distrubances in Earth's ,magnetic field which last for many days at a time and cause Aurora, as well as occasionally satellite outages and electrical blackouts.

The region around Earth where Earth's magnetic field is located is called the **magnetosphere** (Figure 3). Outside this region, in the region called **the Interplanetary Magnetic Field (IMF)**, the solar magnetic field is strongest. The boundary line between the magnetosphere and the IMF is called the **magnetopause**. The part of the magnetosphere that extends from Earth away from the sun is called the **magnetotail**.

On the Sun side, the magnetosphere extends to a distance of about 10 Earth radii (10 **Re**) under normal solar conditions. By the way, space scientists use this unit of measurement (1 Re = 6378 kilometers) much the same way that astronomers use the light-year or parsec. On the side away from the Sun, the magnetosphere is stretched by the solar wind so it extends a great distance. (For comparison, the moon orbits at a distance of about 60 Re .)

Conditions on the Sun, and the related solar wind, are not constant over time. When the sun is at the active stage of the approximately 11-year solar cycle, solar flares and Coronal Mass Ejections are more common. This increased activity can result in large-scale disturbances of the magnetosphere called magnetic storms. The most common effect of a magnetic storm is an increase in the **Aurora Borealis**, or Northern Lights. In the Southern Hemisphere, they are called the **Aurora Australis** or the 'Southern Lights'.

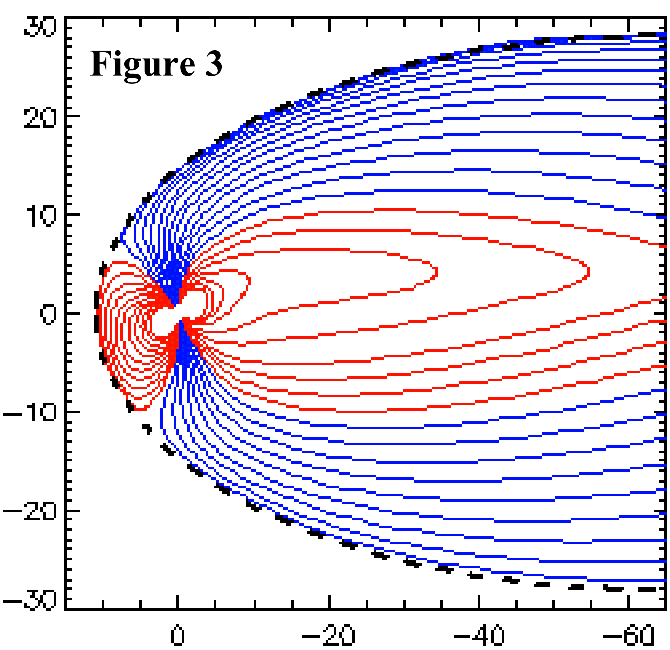


Figure 3. Earth's **magnetosphere**. The curved lines show the magnetic lines of force within this cavity. Note that they do not extend beyond the dashes curve. This is because of the influence of the solar wind which enters the diagram from the left and is blowing to the right. The Sun is located far to the left at a distance of 22,900 **Re.** Earth is located at (0,0). The dashed line is the magnetopause.The unit of distance in the diagram is the Earth radius (Re) and equals 6378 kilometers.

Other effects are also observed and some of them are dangerous and can cause serious damage. These effects include:

1. Induced currents in power company transformers that can cause overload conditions and damage equipment. It is thought that a magnetic storm that resulted from a CME caused the blackout in the northeastern United States and eastern Canada in 1989.
2. Induced currents in pipelines can cause an increase in corrosion and can lead to leaks and breaks. The Alaskan oil pipeline was designed to minimize this effect.
3. Astronauts in space can be exposed to dangerous levels of charged particles. For this reason, astronauts working outside the space shuttle would have to go inside if a solar storm were predicted or observed.
4. Heating of the atmosphere by solar particles causes the atmosphere to expand. The increased friction causes satellites to lose energy and descend into the atmosphere. This is the process that, over time, is thought to have caused the decay of the orbit of Skylab in the 1970's.
5. Satellites in high orbits are subjected to energetic charged particles that can cause damage to electronic components. Failure of some communication satellites, which are in geosynchronous orbits, have been attributed to the impact of severe solar storms.

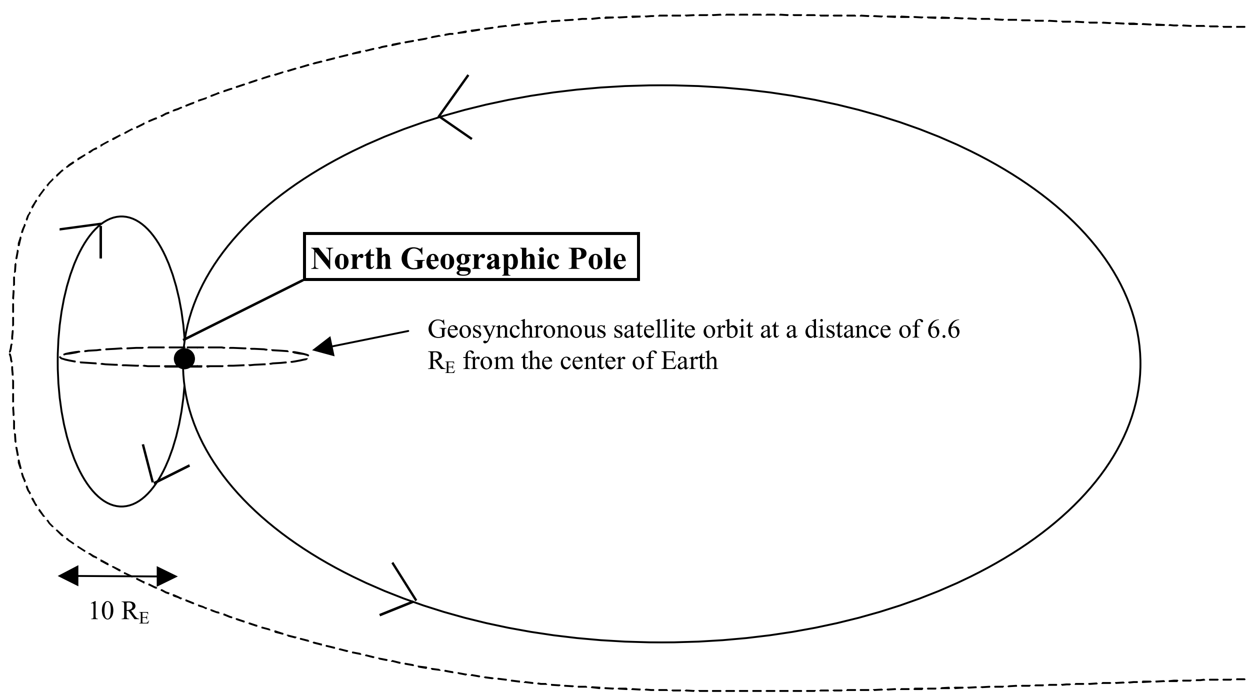


Figure 4. The magnetosphere under quiet solar conditions. The dashed line is the magnetopause which was also shown in Figure 3. The arrows show the polarity of the field. For example, converging arrows indicate a south-type polarity (over the North Geographic Pole)

The two main effects on the magnetosphere of magnetic storms are:

1. The magnetopause in the sunward direction is pushed in from its normal distance of 10 Re .
2. The magnetotail is pinched inward.

The added pressure on the sunward side increases the number of particles that are forced into the magnetosphere. During severe solar storms, this boundary can pass inside the orbits of geosynchronous satellites and subject them to the direct effects of the solar storm.

'Geosync' satellites orbit the Earth at a distance of 6.6 Re. Because their periods are 24 hours, they remain positioned over the same geographic spot. Most communications satellites are located on geosync orbits above Earth's equatorial regions.

In the magnetotail, charged particles are following the magnetic field lines down the tail away from Earth. When the magnetotail gets pinched in, a phenomenon called **magnetic reconnection** can occur. This happens when magnetic field lines within the magnetotail are forced together in such a way that they try to cross (which is not allowed for magnetic field lines) and, instead, reconnect forming a shorter, closed magnetic field line in place of the extremely long field lines extending down the magnetotail. Figures 5, 6 and 7 show the reconnection process.

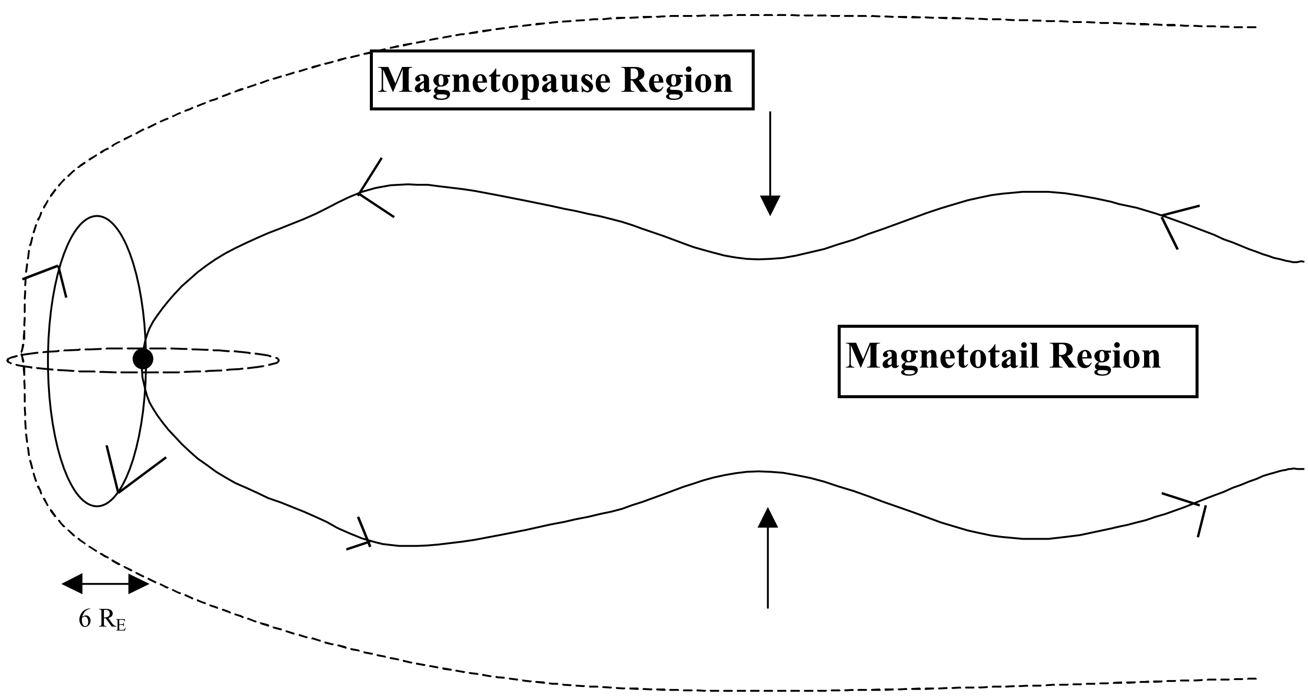


Figure 5. The magnetosphere under active solar conditions after a CME. The sunward magnetopause has been pushed in to 6 Re and the magnetotail has been pinched in (filled arrows). Note that the geosynchronous orbit now extends outside of the magnetopause.

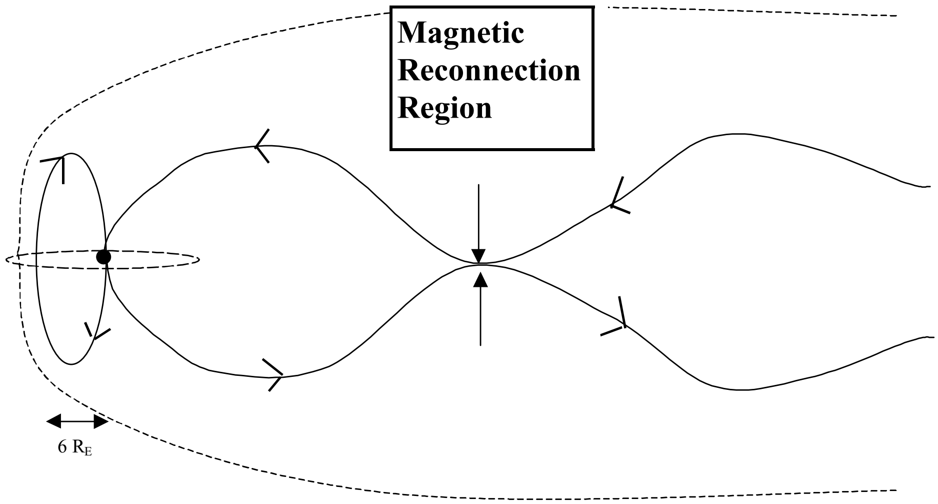


Figure 6. The arrows indicate the point of magnetic reconnection.

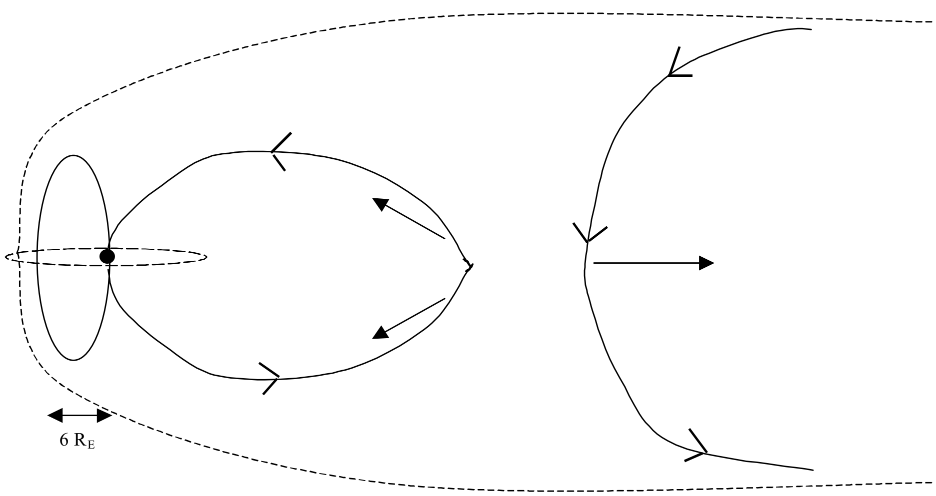
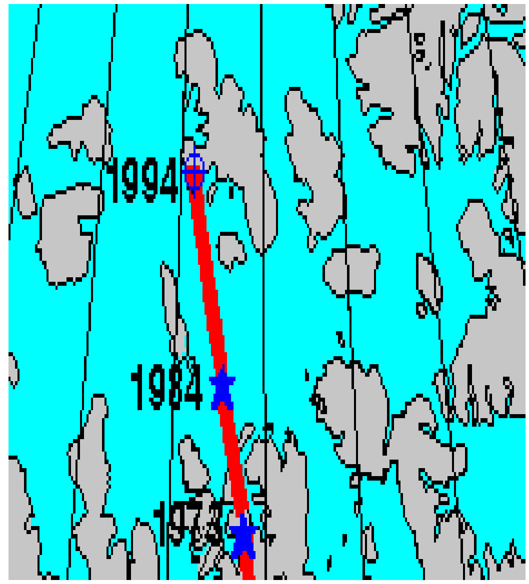


Figure 7. The magnetic field lines just after reconnection. The filled arrows indicate the direction of movement of the magnetic field lines which carry with them all of the charged particles moving along them at the time of reconnection. Also note how the polarity of each field line remains the same, i.e the arrows point in the same direction along each line before and after reconnection.

The process of reconnection results in large numbers of particles moving with high energy both toward and away from Earth. It is thought that the process that carries particles away from Earth is similar to, but on a smaller scale than, the process on the Sun that results in a CME. Of interest here, though, are the particles that are brought back toward Earth as the reconnected field line rebounds into position nearer Earth. Some of these charged particles find an easy path north and south into the auroral zones and some of them are captured near Earth and held there by magnetic field lines forming the radiation belts. As these particles move along magnetic field lines north and south, they rebound back along the field line from the polar regions. As they bounce back and forth, the charges migrate slowly around Earth in the region from about 2 Re to about 7 Re. This movement of charge is known as the **ring current**.

IMAGE will measure the location of the magnetopause, the brightness and location of the aurora and the composition, energy and location of the ring current.

V...The Wandering Magnetic Pole



Before igneous rocks cool and harden, the liquid magma is acted on by the magnetic field of Earth. When the rock hardens, these iron atoms are locked in position "pointing" toward the magnetic north pole. When scientists analyzed rocks formed at different times in the past, they found that the magnetic pointers did not point to the same location on Earth. They interpreted this to mean that the position of the magnetic North Pole had moved over time.

Objective:

Students will plot the position of the Magnetic North Pole from 1994 - 2001 and see that the magnetic pole moves.

Procedure:

1) Make transparencies of any desired materials from the student activity pages in Activities VI, VII and VIII..

2) Copy and distribute the student activity pages.

3) Introduce the material in a manner suited to the class level:
   A) Ninth grade students may need some introduction to some (or each) separate activity.
   B) Twelfth grade students should be able to work all activities with no intervention by the teacher. Provide background knowledge as needed.

4) Go over some (or all) of the responses using a transparency key done by the teacher. Discuss the precision available in the data and maps in light of the variations in responses from students that may be considered equivalent.

Extension and Homework Assignments:

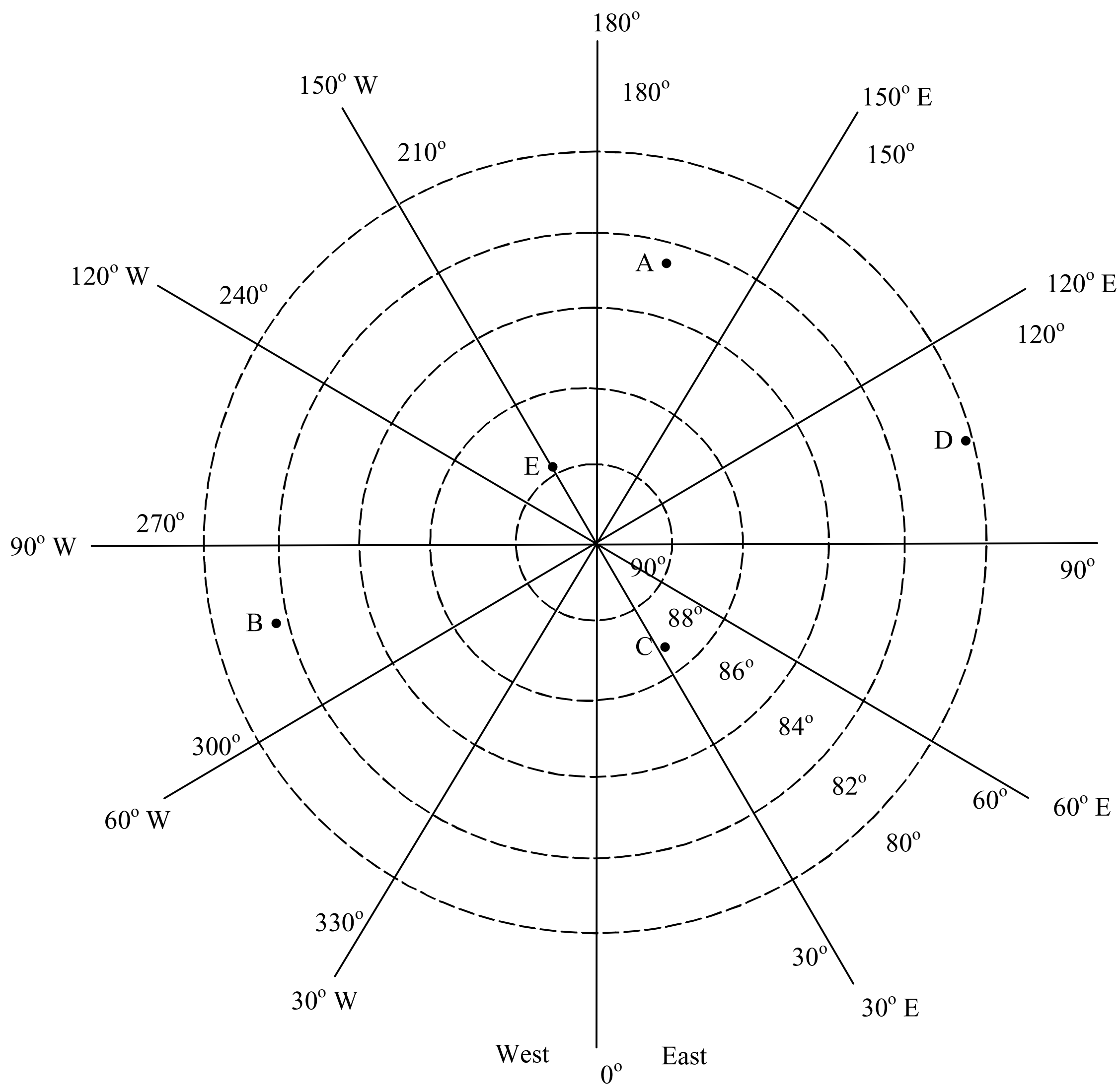
Blank map grids are provided for the teacher to create custom assignments similar to activities VI, VII and VIII.

Activity VIII can be used as a homework assignment by selecting a different pair of dates (for example 1500 – 1600) and having the students answer questions 1 to 4 in Activity VIII.

VI... Plotting Positions in Polar Coordinates

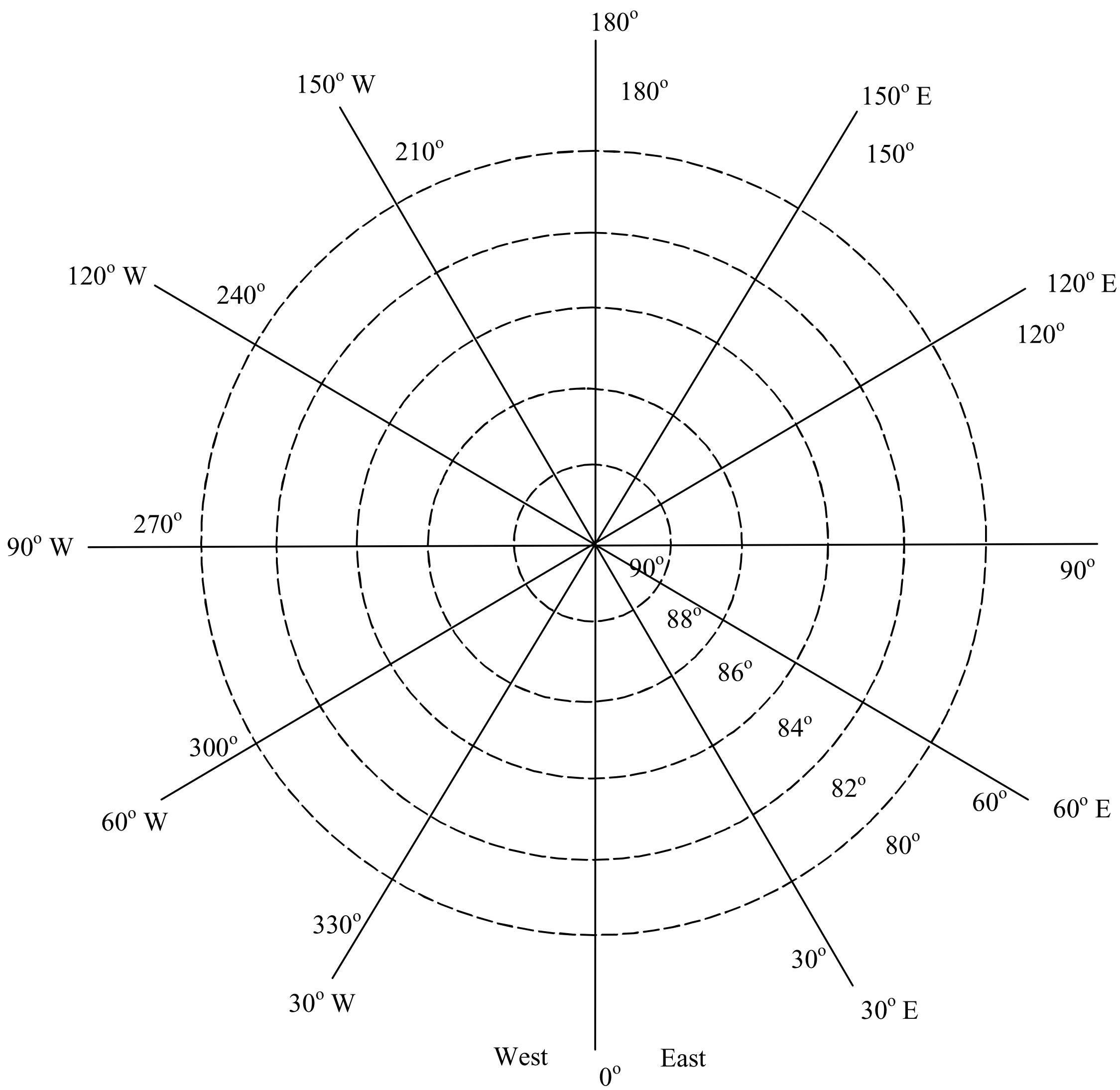
Using the map shown, give the positions of the lettered locations. The first answer is given. Notice that you have to estimate the latitude values since the concentric circles represent 2 degree increments. Longitude values must also be estimated since the longitude lines shown are 30 degrees apart. (Because of the estimating required, you should only expect your answer to be within a degree of the given answer for latitude and within about 5 degrees for longitude.)

Point	Latitude	Longitude
A	82.7°	167°
B		
C		
D		
E		



On the map shown below, plot the points given. Remember to estimate between the latitude circles and the longitude lines. Watch the labels carefully as you find the correct positions. The first example is shown on the map.

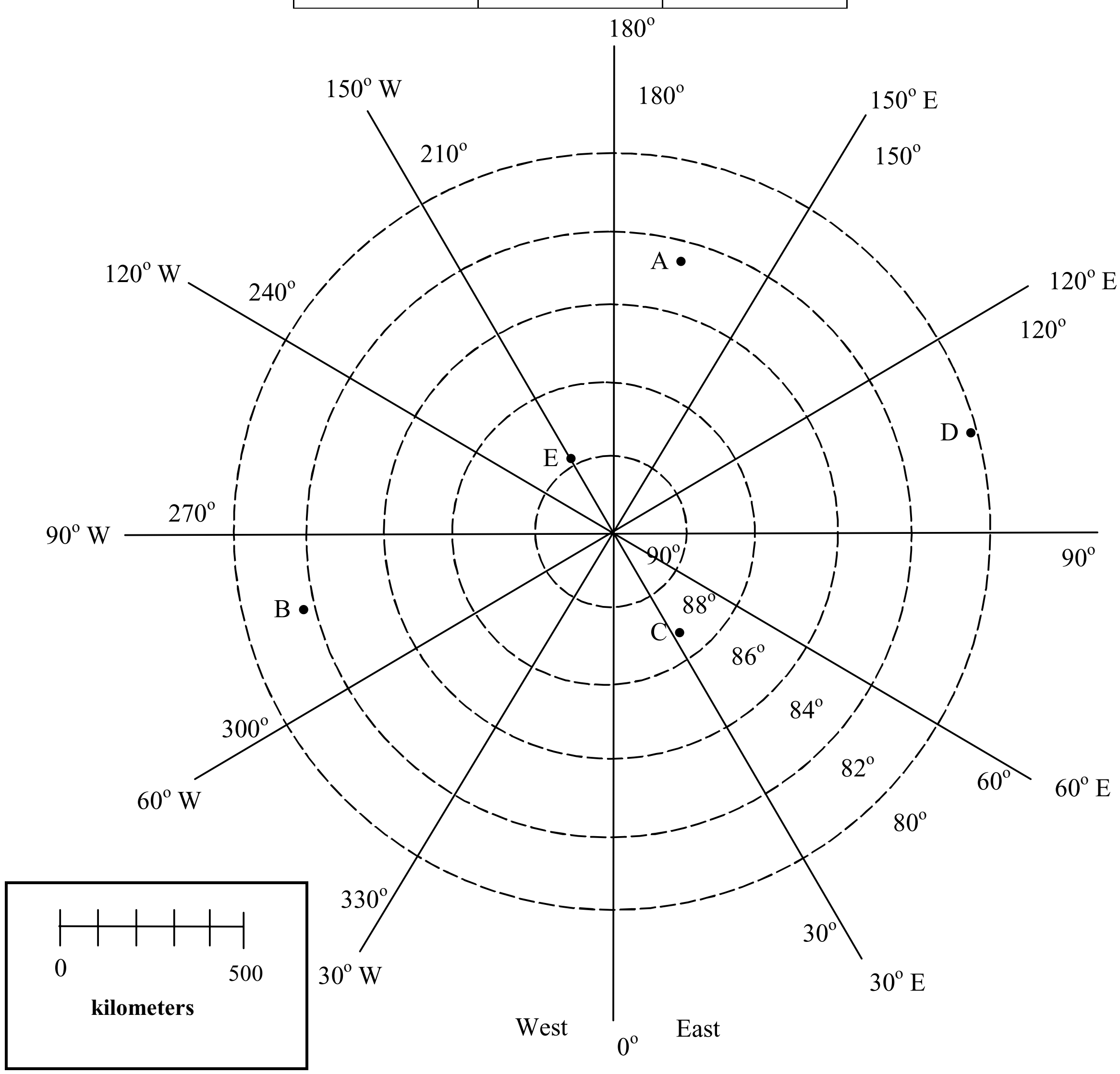
Point	Latitude	Longitude
A	88°	310°
B	82°	60°
C	85°	195°
D	81.7°	260°
E	83.9°	121°



VII... Measuring Distance on the Polar Map

Using the distance scale given, make a scale on a separate paper that will allow you to measure distances up to 2000 kilometers. Using the map below, measure the distances indicated in the table. The first example is worked for you.

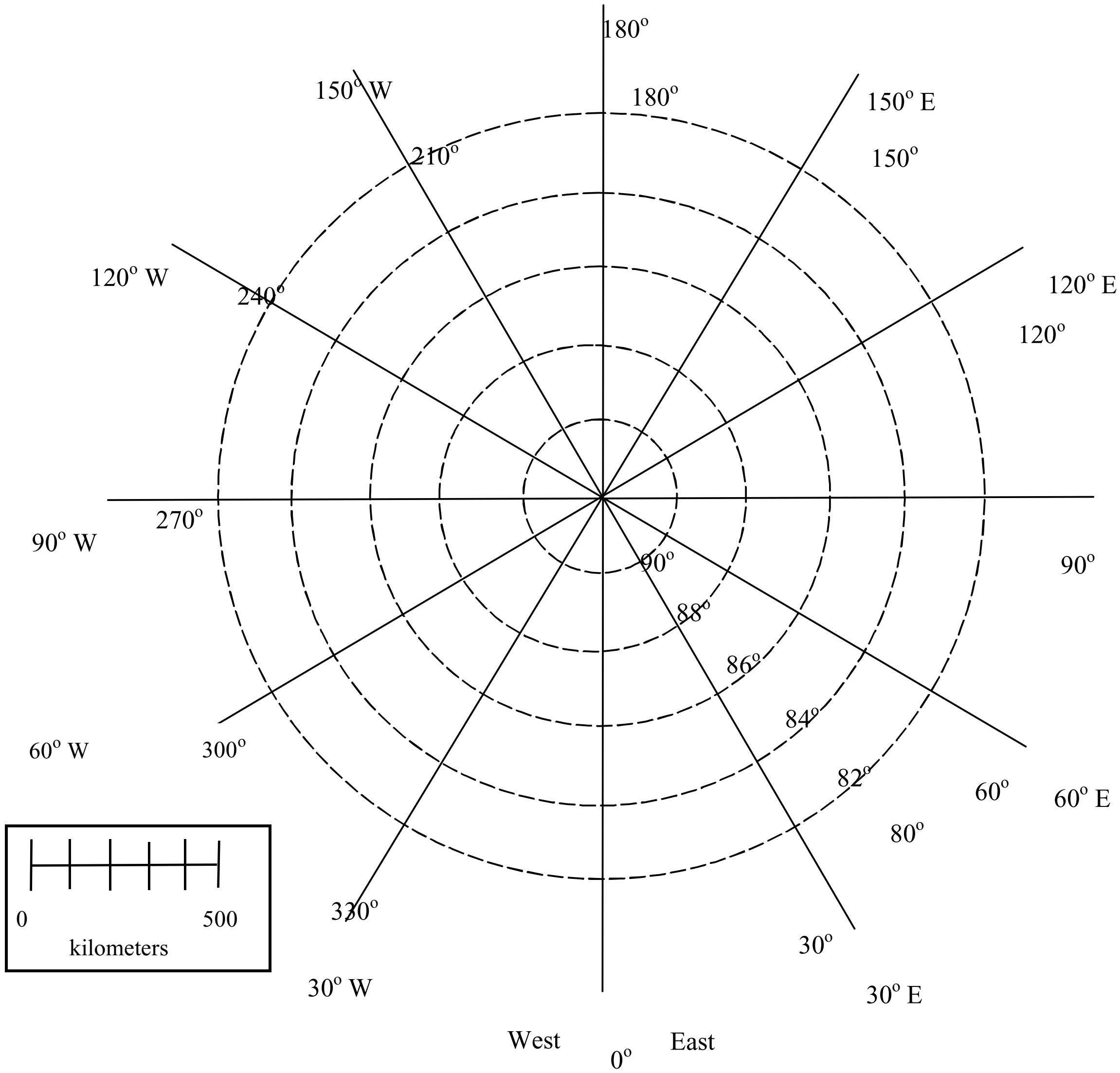
From Point	To Point	distance
A	B	1400 km
B	C	
C	D	
D	E	
E	A	
B	D	
C	A	
E	B	



VIII... Wandering Poles in the Last 2000 Years

The following table shows the estimated position of the magnetic North Pole over the past 2000 years. (This table is taken from The Earth's Magnetic Field by Ronald Merrill and Michael McElhinny, published in 1983 by Academic Press, page 100.) Plot the following positions on the map provided.

Year (AD)	Latitude	Longitude
1	86.4	121.4
100	87.7	143.9
200	87.7	160.3
300	88.9	131.9
400	86.0	316.3
500	86.1	343.5
600	85.6	6.6
700	84.1	33.4
800	81.8	28.0
900	80.2	38.0
1000	81.3	76.0
1100	85.3	110.0
1200	84.3	135.2
1300	83.2	189.1
1400	84.8	228.3
1500	86.3	301.5
1600	85.6	316.7
1700	81.1	307.1
1800	81.1	297.1
1900	82.3	288.2
1980	82.1	284.1



Look at the locations of the pole at 1000 AD and 1100 AD.

1. How far did the pole move? _________
2. How far did the pole move (in km) in one year? _________
3. How far did the pole move in meters in one year? _________
4. Approximately how far did the pole move per day? _________
5. Estimate when the magnetic North Pole was at the same location as the Geographic North Pole (Latitude = 90 °). _________
6. What assumptions must be made to answer Question 5?

IX... The Magnetosphere and Us

Introduction:

The magnetic field of Earth extends far out into space. Disturbances in this field, though invisible, can cause many complex phenomena on Earth including the Northern Lights (Aurora) as well as blackouts and satellite malfunctions. This field has a known size and shape, and scientists keep track of its parts by using specific names for them.

Objectives:

Students will label and describe the parts of the magnetosphere.

Students will determine how big the parts of this field are from a scale drawing, and convert the scaled units into kilometers using the size of the Earth as a guide in the figure.

Materials:

A diagram of the magnetosphere

Data needed to complete activity:

1) Speed of light..........................300,000 km/sec
2) Earth radius (Re)....................6,378 km (Equatorial average)
3) Solar Wind (plasma)..............450 km/sec (an average value)
4) Distance to Sun..................... 150,000,000 km (average)
5) Magnetosphere size:
   Daytime side........... 6 to 12 Earth radii
   Nightime side............. 1,000 Earth radii,or greater.

Questions:

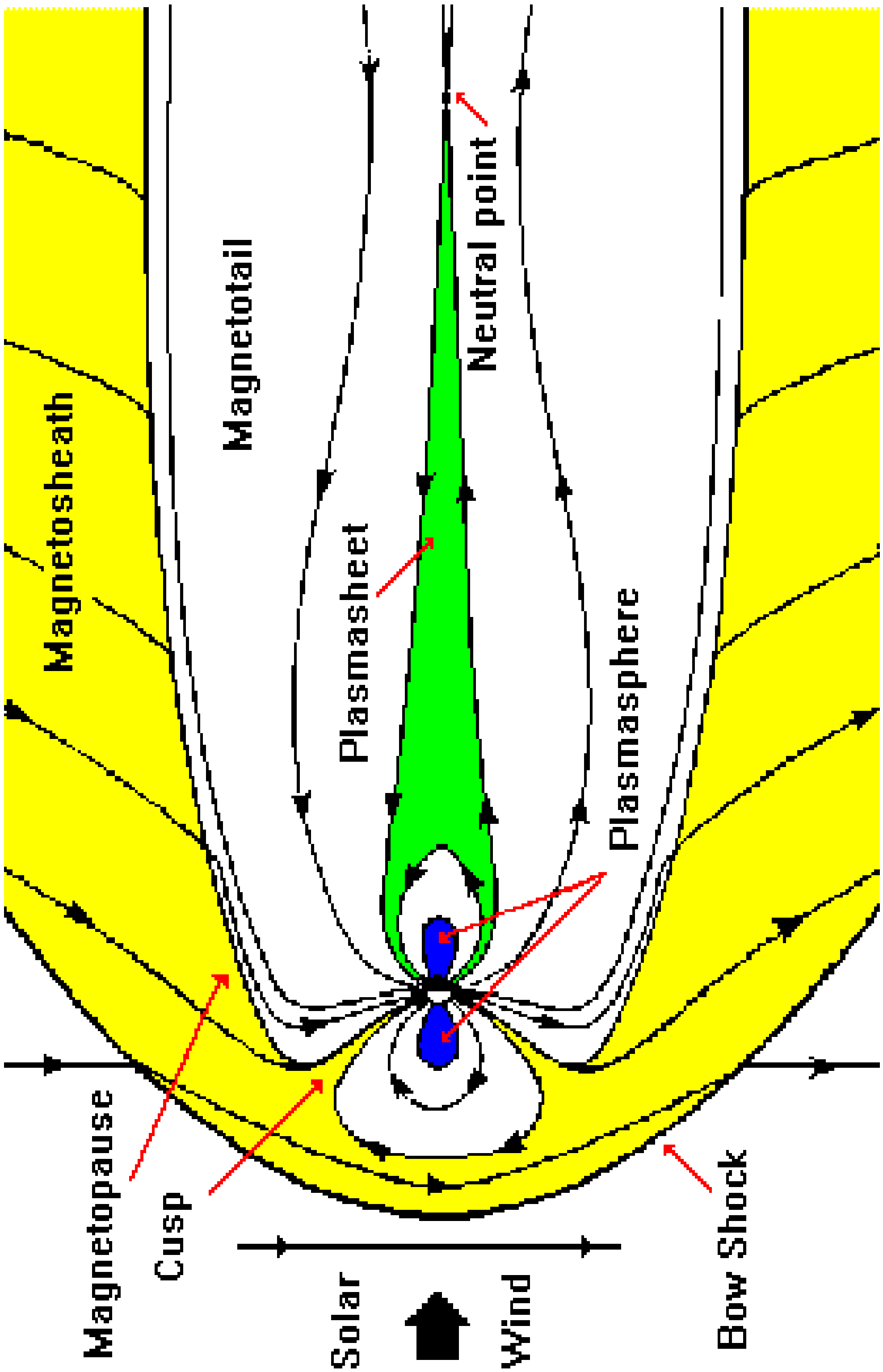
1. How long will it take electromagnetic radiation, including visible light, to reach the earth's surface ?

2.A solar flare has just been detected by a ground-based telescope. How long will it be before the plasma ejected into space could reach the earth and cause a possibe power outage or some other disturbance?

Teacher Notes:

1. Students should compare the diagram of the magnetosphere to the diagram of magnetic lines of force they obtained by using the iron filing method in Activity III. The reason the magnetic lines of Earth do not look the same is because distortions in their shapes are caused by the magnetic interaction with the solar wind.

Diagram of the Magnetosphere for Activity IX



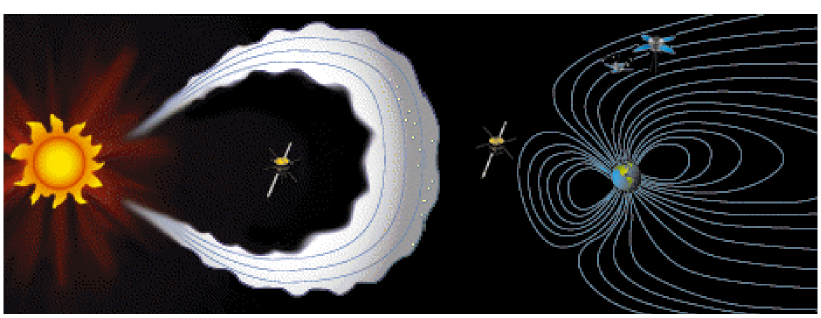
Chapter 3: Magnetic Storms, Aurora and Space Weather

Anyone can tell you that a compass points 'north' because Earth has a magnetic field, but until the advent of the Space Age, no one really understood what this field really looked like or was capable of doing. Since Gilbert proposed in the 17th century that Earth was a giant magnet, scientists have wondered just how this field is shaped, and how it has changed with time. The **geomagnetic field** which gives us our familiar compass bearings, also extends thousands of kilometers out into space in a region called the **magnetosphere**. On the Sun-side, it forms a protective boundary called the **bow shock**.

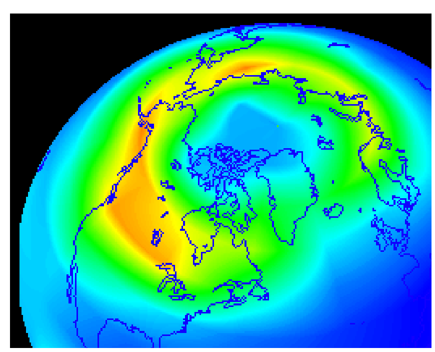
Stretching millions of miles in the opposite direction behind Earth is the **magnetotail**. The solar wind blows upon the magnetosphere and gives it a wind-swept shape, but when solar storms and solar wind streams reach Earth, the magnetosphere reacts violently. On the side nearest the impact, the magnetosphere compresses like a balloon, leaving communications satellites exposed. On the opposite side, it is stretched out, past the orbit of the Moon, or Mars and even Jupiter! The geomagnetic field is remarkably stiff, and so most of the solar wind is deflected or just slips by without notice. But some of the matter leaks in and takes up residence in donut-shaped clouds of trapped particles, or can penetrate to the atmosphere to produce the Northern Lights.

The Aurora Borealis (near the North Pole), and the Aurora Australis (near the South Pole) as they are more formally called, are seen most often in a band located at a latitude of 65 degrees, and about 10 - 15 degrees wide in latitude. From space, the auroral zone looks like a ghostly, glowing donut of light hovering over the north and south poles. This auroral oval can easily be seen in satellite images, and its brightness and size changes with the level of solar activity. Aurora come in many shapes and colors depending on what is happening to the geomagnetic field and the flows of charged particles and plasmas trapped in this field. Magnetic storms happen when the geomagnetic field is suddenly changed. Typically, magnetic storms last only a few hours. The most violent of these cause the aurora to shine brightly at the poles.

They begin in the evening as arcs of colored light which slowly change into rayed-arcs and the familiar folded ribbons or bands. Expanding over the whole sky, the folded bands are colorful, with green rays and red lower borders which change from minute to minute and move rapidly across the sky like some



A Coronal Mass Ejection heads for Earth!



A magnetic storm causes Northern Lighs to glow in a circular halo over the pole.

X...A Simple Magnetometer

Introduction

Solar storms can affect Earth's magnetic field causing small changes in its direction at the surface which are called 'magnetic storms'. A magnetometer operates like a sensitive compass and senses these slight changes. The soda bottle magnetometer is a simple device that can be built for under $5.00 which will let students monitor these changes in the magnetic field that occur inside the classroom. When magnetic storms occur, you will see the direction that the magnet points change by several degrees within a few hours, and then return to its normal orientation pointing towards the magnetic north pole.

Objective:

The students will create a magnetometer to monitor changes in Earth's magnetic field for signs of

Materials

One clean 2 liter soda bottle
2 pounds of sand
2 feet of sewing thread
A 1 inch piece of soda straw
Super glue (be careful!)
2 inch clear packing tape
A meter stick
A 3x5 index card

A small bar magnet
Get this from the Magnet Source. They offer a Red Ceramic Bar Magnet with 'N' and 'S' marked. It is 1.5" long. $0.48 each. Catalog Number DMCPB. Call 1-800-525-3536 or 1-888-293-9190 for ordering and details.

A mirrored dress sequin, or small craft mirror.
Darice, Inc. 1/2-inch round mirror, item No. 1613-41, $0.99 for 10. Order from Darice Inc 1-800-321-1494. mail: 13000 Darice Parkway, Park 82, Strongsville, Ohio, 44136-6699. Available at Crafts Stores under trademark 'Darice Craft Designer'

Teacher Notes:

1) Do not use common ‘refrigerator’ plastic/rubber magnets because they are not properly polarized. Use only a true N-S bar magnet.

2) Superglue is useful for mounting the magnet on the card in a hurry, but be careful not to glue the card to the table underneath as the glue has a habit of leaking through the paper if too much is used.

3) In the January 1999 issue of Scientific American, there is a design for a magnetometer that uses a torsion wire and laser pointer developed by amateur scientist Roger Baker. You can visit the Scientific American pages online to get more information on these other designs.

Light Sources:

A goose neck high-intensity lamp with a clear bulb.

Alternative light source:

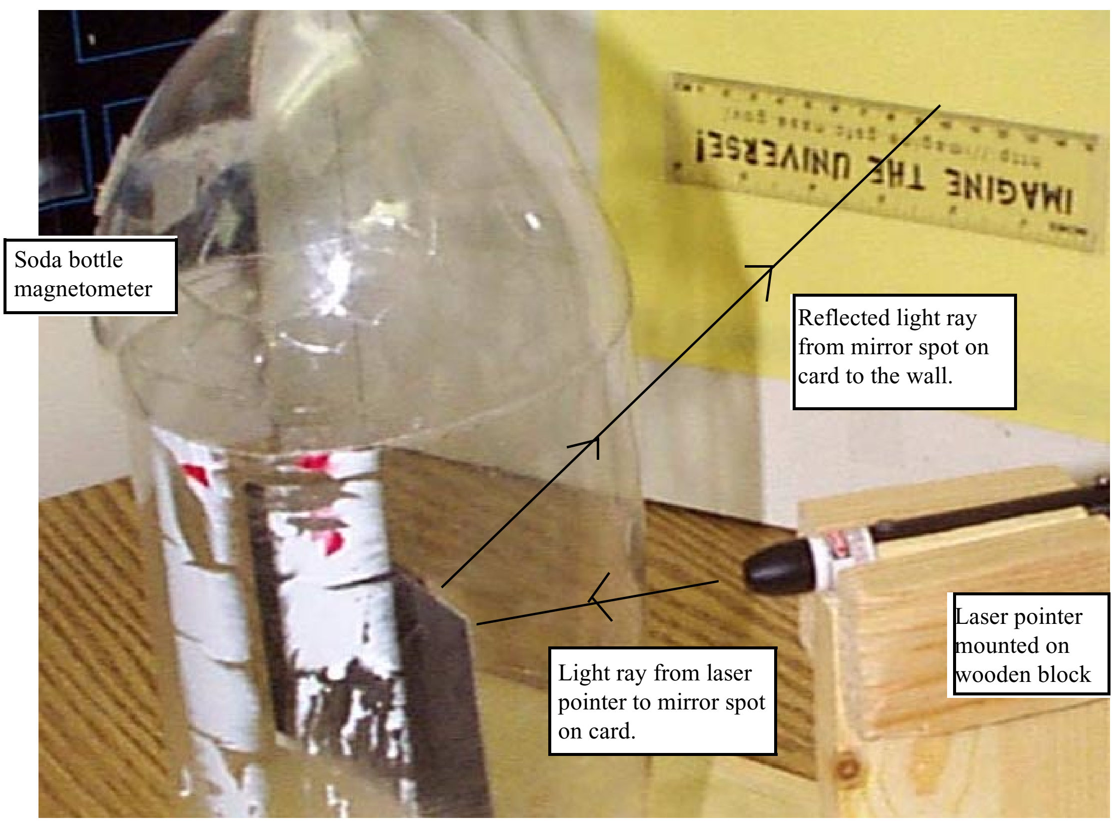
A laser pointer. You will need a test tube ring stand and a clamp to hold it securely.

Safety Concern: To avoid eye damage, students muct be told NOT to look directly into laser beam.

Procedure

1. Clean the soda bottle thoroughly and remove labeling.
2. Slice the bottle 1/3 of the way down from the top of the bottle.
3. Pierce a small hole in the center of the cap.
4. Fill the bottom section with sand. About 2-3 cups to serve as a suitable weight.
5. Cut the index card so that it fits inside the bottle (See Figure 1).
6. Glue the magnet to the center of the top edge of the card.
7. Glue a 1 inch piece of soda straw to the top of the magnet.
8. Glue the mirror spot to the front of the magnet.
9. Thread the thread through the soda straw and tie it into a small triangle with 2 inch sides.
10. Tie a 6 inch thread to the top of the triangle in #9 and thread it through the hole in the cap.
11. Put the bottle top and bottom together so that the 'sensor card' is free to swing with the mirror spot above the seam.
12. Tape the bottle together and glue the thread through the cap in place.
13. Place the bottle on a level surface and point the lamp so that a reflected spot shows on a nearby wall about one or two meters away. Measure the changes in this spot position to detect magnetic storm events.

Safety and Time Concern: Steps #2 and #3 may be completed by teacher prior to class.



Soda Bottle showing laser pointer and path of light ray from mirror to wall.

Tips

It is important that when you adjust the location of the sensor card inside the bottle that its edges do not touch the inside of the bottle. Be sure that the mirror spot is above the seam and the taping region of this seam, so that it is unobstructed and free to spin around the suspension thread.

The magnetometer must be placed in an undisturbed location of the classroom where you can also set up the high intensity lamp so that a reflected spot can be cast on a wall within 1 meter of the center of the bottle. This allows a 1 centimeter change in the light spot position to equal 1/4 degree in angular shift of the magnetic North Pole. At half this distance, 1 centimeter will equal 1/2 a degree. Because magnetic storms produce shifts up to 5 or more degrees for some geographic locations, you will not need to measure angular shifts smaller than 1/4 degrees. Typically, these magnetic storms last a few hours or less.

To begin a measuring session which could last for several months, note the location of the spot on the wall by a small pencil mark. Measure the magnetic activity from day to day by measuring the distance between this reference spot and the current spot whose position you will mark, and note the date and the time of day. Measure the distance to the reference mark and the new
spot in centimeters. Convert this into degrees of deflection for a 1 meter distance by multiplying by 1/4 degrees for each centimeter of displacement.

You can check that this magnetometer is working by comparing the card's pointing direction with an ordinary compass needle, which should point parallel to the magnet in the soda bottle. You can also note this direction by marking the position of the light spot on the wall.

If you must move the soda bottle, you will have to note a new reference mark for the light spot and the resume measuring the new deflections from the new reference mark as before.

Most of the time there will be few detectable changes in the spot's location, so you will have to exercise some patience. However, as we begin to move away from sunspot maximum between after 2001, there should still be several good storms every few months. Large magnetic storms are accompanied by major aurora displays, so you may want to use your magnetometer in the day time to predict if you will see a good aurora display after sunset. Note: Professional photographers use a similar device to get ready for photographing aurora in Alaska and Canada.

This magnetometer is sensitive enough to detect cars moving on a street outside your room. With a 1-meter distance between the mirror and the screen, a car moving 30-50 feet away produces a sudden deviation by up to 1 inch from its refeence position. The oscillation frequency of the magnet on the card is about 4 seconds and after a car passes, the amplitude of the spot motion will decrease for 5-10 cycles before returning to its rest position. You can even determine the direction of the car's motion by seeing if the spot initially moves east or west! Also, by moving a large mass of metal...say 30 lbs of iron nails...at distances of 1 meter to 5 meters from the magnet, you can measure the amount of deflection you get on the spot, and by plotting this, you may attempt to recover the 'inverse-cube' law for magnetism. This would be an advanced project for middle-school students, but they would see that magnetism falls-off with distance, which is the main point of the plotting exercise.

Setting up to take data:

The following information is a step-by-step guide for setting up the magnetometer at home, and making and recording the measurements.

1) During each of the participating school periods, ask for a volunteer from each of the groups to bring the magnetometer home.

2) Have the student pick up the magnetometer after school to minimize damaging the system.

3) Once the magnetometer arrives at home, the student will need to find a room where the instrument will remain undisturbed for the next three days. The student will have to inspect the instrument for damage during transport from school, and make the necessary repairs so that the sensor card hangs freely inside the bottle and does not scrape the inside of the bottle as it moves.

4) Obtain a high-intensity lamp, or a desk lamp with a CLEAR bulb. Do not use a bulb with a frosted lamp because you will not be able to see a glint off of the mirror with such a bulb. The glint/spot you are looking for is actually the image of the filament of the lamp.

5) With the magnetometer positioned 1 meter (39 inches) from a wall on a table, position the lamp so that the center of the bulb shines at a 45-degree angle to the mirror. Search for a glint or spot of light from the mirror on the wall. Make sure the table is stable and not rickety because any vibration of the table will make reading the spot location very difficult. You may also have to relocate the magnetometer several times until you find a convenient location in your house where the spot falls on a wall 1-meter from the magnetometer.

6) Once again, make certain that the sensor card is free to rotate horizontally inside the bottle after you have finished this set-up process.

7) On an 8 1/2 x 11 inch piece of white paper, draw a horizontal line along the center of the long direction of the paper so that you have a line that divides the paper into two parts 4 1/4 x 11 inches in size.

8) With a centimeter ruler, draw tic marks every 1 centimeter on this line starting from the left-hand end of the line. Label the first mark on the left end '0', and then below the line, label the odd-numbered marks with their centimeter numbers. '0, 1, 3, 5, ...' If you label every tic mark, the scale will be too cluttered to easily read from a 1-meter distance.

9) With the lamp turned on and properly positioned, find the spot on the wall, and position the paper with the centimeter scale, horizontally on the wall. Before securing to the wall, make sure that as the spot moves from side to side on the wall, that it travels along the centimeter scale in a parallel fashion. It is convenient to have the spot moving in a parallel line offset about 1 inch above the centimeter scale.

10) At the start of your 3-day observing sequence, you will need to shift the

Making the measurements:

1) For three days of recording, you will be able to fit Day 1 and Day 2 on the front side of a sheet of ruled paper, and Day 3 on the back side. For each day, leave a blank for the date, followed by 4 columns which you will label from left to right 'Time' 'Position' 'Amplitude' 'Comments'.

2) In the 'Time' column, write down the following times in a vertical list:

5:00 PM
5:30
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00

3) The first reading you will make on the first day will always be '15.0' because that is where you set-up the scale on the spot in Step 10 in the instructions above. For the subsequent measurements, you will record the actual spot location on your scale. Do NOT reposition the spot every day. You just need to do this one time at the start of your 2, 3, 5 ...day measurement series.

4) When making a measurement, turn on and off the lamp from the wall plug only. This will avoid accidental vibration or lamp motion if you were to try using the switch on the lamp. You want to avoid disturbing the lamp, magnetometer and centimeter scale during the three-day session.

5) If you know, for a fact, that the set up was disturbed, recenter the centimeter scale on the current spot position at the '15 centimeter' point. Make a note that you did this on the data table at the appropriate time, you can then resume taking normal data at the next assigned time in the data table. Warning, do not assume that just because a big change in the readings occurred, that the instrument was disturbed. You could have detected a magnetic storm!! Only recenter the scale if you physically saw the instrument disturbed, or someone told you that they accidentally touched it.

6) It is important that you make your measurements within 5 minutes of the times listed in the data table. If you are unable to do this for any entry, leave it blank and do not attempt to 'fudge' or estimate what the value could have been. Chances are very good that another student in the network will have made the missing' measurement.

7) The spot on the wall will probably be irregular in shape. Make yourself familiar with what the spot looks like as it moves, and find a portion of the spot that has a good, sharp edge, or some other easily recognized feature. You can also estimate by eye where the center of the spot is if the spot has a simple...round..shape. Try to make all of your measurements in a consistent way each time, and to estimate the spot location to the nearest 0.5 centimeter. Record this number in Column 2 in your data sheet.

8) You may notice several 'behaviors' of the spot. It will either just sit at one location, or it may oscillate from side to side. At a 1-meter distance from the magnetometer, if the spot swings back and forth horizontally by an amount LESS than 0.5 centimeters, consider the spot 'Stationary' and write 'S' in Column 3 after your measurement. If it is obvious that the spot is oscillating back and forth, write 'O' in Column 3 and in Column 4 write down the range of the swing in centimeters along the scale. Example, if it moves from 13.0 centimeters to 17.0 centimeters, write the average position of '15.0' centimeters in Column 2, and then write '13.0 - 17.0' in Column 4.

9) The last thing you would want to note in your data log is local weather conditions IF there is a lightning storm going on. Note the time that the lightning began and ended as a 'Note' on the data page, but don't write this in the data table itself. You also want to mention if the street outside your house is busy with traffic or not. An estimate of how often a car passes would be good to note.

10) When your assigned time is finished, bring the data table and magnetometer back to school.

Sample Data. Case 1.

This data (below) was taken at the Goddard Space Flight Center, in an office, using a magnetometer with a 1-meter distance to the wall. The times are in Eastern Standard Time. The second column gives the spot location on the meter stick, in centimeters.

3-15-99		**3-16-99**		**3-17-99**	
11:05	9.5 cm	9:25	8.0 cm	9:45	6.5 cm
11:35	8.5 cm	10:20	6.5 cm	10:40	6.5 cm
13:25	9.0 cm	13:20	5.0 cm	11:05	6.0 cm
14:00	9.0 cm	14:25	4.5 cm	11:40	4.0 cm
14:20	9.0 cm	15:00	4.5 cm	12:15	4.5 cm
15:25	9.0 cm	15:20	4.0 cm	13:00	6.0 cm
16:00	8.0 cm	16:10	4.5 cm	13:30	7.0 cm
17:00	7.5 cm	16:50	4.5 cm	15:35	1.5 cm
17:25	8.0 cm			16:10	2.5 cm

Visit
http://www.sec.noaa.gov/SWN
To see if any storms may be brewing before you begin taking measurements! Most days are usually very calm.

The magnetometer shows some minor activity. Plot this data on a graph to see them.

Note that at this location, the measurements steadily decline (drift westward) between the morning and evening measurements. Different geographic locations for the magnetometer produce different ‘typical’ patterns of changes.

There were no major magnetic storms in progress during this time, so the measurement changes we are seeing probably have more to do with local environmental effects.

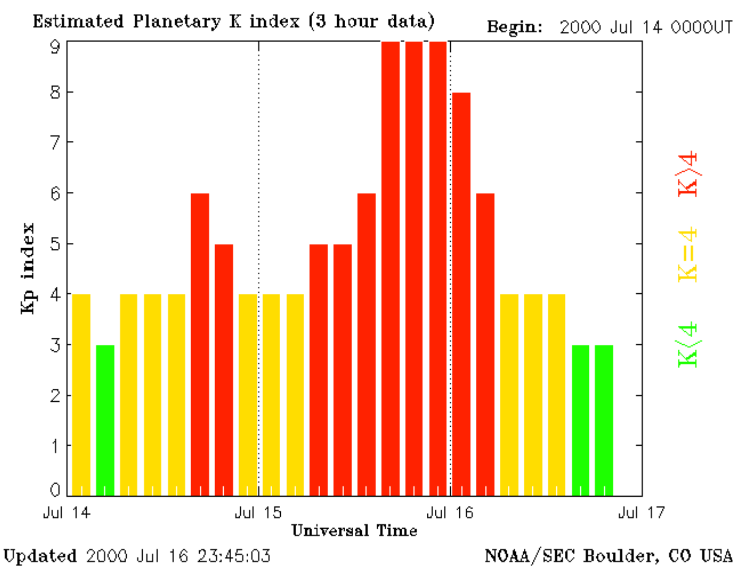
Sample Data: Case 2. A major geomagnetic storm.

The magnetometer trace, below, was taken during Saturday, July 15 between 6AM and 8PM EDT when no aurora could be seen in the daytime. Observers in Virginia and New England did report auroral activity Saturday night, long after the worst of the magnetic storm had passed.

The magnetic activity index (Kp) for the July 15th event was rated at 9.0 so it was one of the typically 2-3 strongest geomagnetic storms seen during any solar cycle. The most common storms have Kp from 6-8 and will be somewhat less easy to see.

To the right is the geomagnetic Kp index plot for the 'Bastille Day' storm. Scientists measure the magnetic changes at 12 observatories worldwide, then assign an index from 1 to 9 based on the number of disturbances they see in each 3-hour interval durin the day to get the Kp index.

For the Bastill Day Storm, a Kp index of 9 was determined for 9 hours straight which is very unusual.

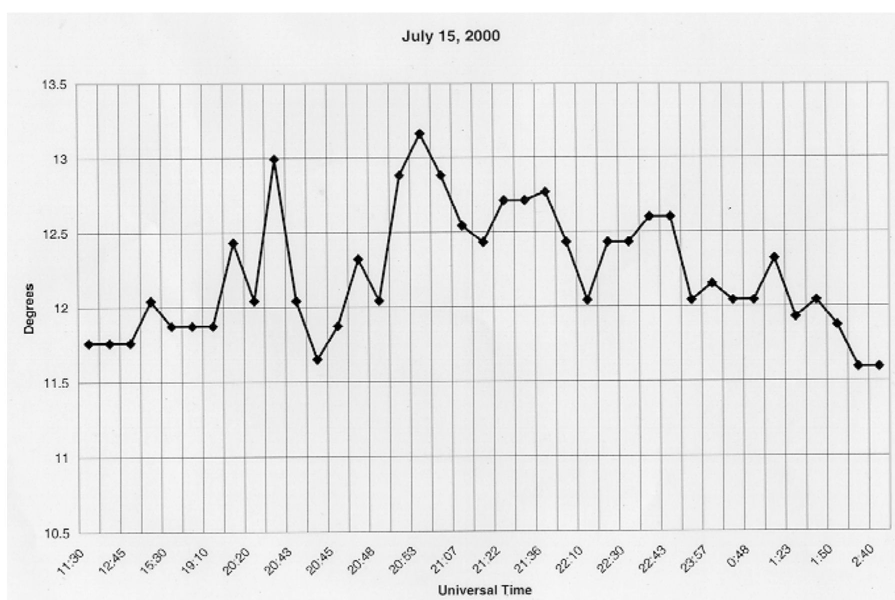


This is a plot of the deflections recorded using a 5-meter distance between the wall and the magnetometer, in the basement of my home in suburban Maryland.

Note, a 1-meter distance would have only recorded changes that were 1/5 what were seen here.

The biggest change of (13.2 - 11.6) = 1.6 degrees corresponded to a linear deflection of 28.5 centimeters for the spot on the wall.

With a 1-meter distance, this would have produced a 5.7 centimeter change. The most common geomagnetic storms are much less violent at geographic latitudes near 40^0, so patience is an asset.



XI...A Bit of Geometry

How does the distance between the mirror and the wall determine the sentitivity?

As a supplementary activity in applied geometry, you may want to show that the angular deflection you will see on the wall will equal TWICE the actual angular deflection of the magnet and its deviation from magnetic north. Here's how to think about this problem.

First, imagine holding the mirror so that it is parallel to the wall, with the light beam also 'skimming the surface' of the mirror. The point where the glancing beam hits the wall will define 'zero degrees'. Now imagine slowly rotating the mirror so that it is at right angles to the wall. The beam will be reflected directly back to the light source located at '180 degrees'. So, by rotating the mirror (magnet) by 90 degrees, the light beam spot on the wall will scan through 180 degrees. At a mirror tilt angle of 45 degrees, the beam will be reflected at a 90 degree angle and the spot on the wall will be at 90 degrees to the light source. For small deviations about this point, you can use the 'skinny triangle' approximation to convert the spot displacement in centimeters to a spot displacement in degrees. From the geometry, the relevant formula is:

$$\textbf{Angle in degrees} = 57.307 \times \frac{\textbf{deflection in centimeters}}{\textbf{distance in centimeters}}$$

BUT the true deflection angle will be 1/2 of this amount because of the discussion above. For example, if the distance between the mirror and the wall is 1 meter (100 centimeters) and you notice a deflection of 1 centimeter from the spots previous position, then the deflection angle of the magnetic field is just

$$\textbf{Deflection in degrees} = 1/2 \times 57.307 \times \frac{\textbf{1 centimeter}}{\textbf{100 centimeter}}$$

or 0.28 degrees. If you prefer using minutes of arc (there are 60 in a degree) then this equals 60 x 0.28 or 17.2 minutes of arc.

XII...What is an Oscillaton Period?

Introduction:

As you will quickly notice, although the mirror sensor card has no pendular motion, it does oscillate from side to side in the horizontal plane. This motion can be studied by the students to learn about oscillations in the horizontal plane, as opposed to the pendular oscillation in the vertical plane. Note also that perpendicular forces do not affect each other so although gravity is pulling on the magnet, this force does not disturb the horizontal motion.

Procedure:

There are two components to the motion, its oscillation period and its amplitude.

Oscillation Period:

1) Construct a table with one column giving the swing number and the second column giving the elapsed time since the start of the measurement series.

2) Set the magnet into a smooth oscillation mode in the horizontal plane, but with little vertical pendular motion. This makes the measurement process easier.

3) Have the students measure with a stop watch the time it takes the light spot to return to its maximum left or right point in its swing. One student will call out the elapsed time since the measurements began, and a second student will record the time.

4) From the table, construct a third column that gives the difference in time between the current time and the previous time. This is the period of the oscillation of the current cycle.

5) You may either plot the periods against the cycle number or work with the table directly.

Materials:

1) The Magnetometer
2) Stop watch

Extension Activity:

Change the type of string or thread being used to suspend the magnet in the magnetometer and repeat this experiment for each one.

You might chose nylon thread, a synthetic thread, fine wire, etc.

Questions:

1) How does the period of the oscillation change depending on the kind of substance the string is made from?

2) Can you predict from the other properties of the material how fast or slow the sensor will oscillate?

An Example.

Students can measure the oscillation period in several ways as we will describe below. The idea is to measure the periods for 10-20 oscillation cycles of the magnet to see whether the period changes as the swing is damped.

The hardest part is to do the rapid-fire timing measurements. This can either be done with a stop watch or with a metronome. In each case, you will need three students. Student 1) sets the oscillation going. Student 2 watches the stopwatch or counts the metronome clicks. Student three writes down the times/clicks called out by student 2. The timing is simply a running time. Do not have the students compute the period in 'real time'.

The stopwatch is started at some convenient time before Student 1 starts the oscillation. Let 1 cycle go by before you start the reading.

If you use a metronome, you will need to calculate how many seconds elapse between clicks. Take a 1-minute time period, count the number of clicks that occur, then divide the 60.0 seconds by the number of clicks to find the interval. A setting of 'Alegro' seems to give about 0.3 second intervals which is adequate.

Below is an example of the metronome method, and a result obtained from two separate trials with the same magnetometer used in previous activities in this Lesson.

Cycle	Trial 1 Clicks	Trial 2 Clicks
1	9	9
2	9	9
3	9	9
4	9	8
5	8	9
6	8	9
7	9	9
8	8	8
9	9	8
10	8	9
11	8	8
12	8	8
13	8	8

The metronome produced 173 clicks in 60 seconds, so the interval between clicks was 0.35 seconds.

Trial 1:

Average clicks per swing = (102)/12
= 8.5

The time between swings
= 8.5 x 0.35 seconds
= 3.0 seconds

Trial 2:

Average clicks per swing = (103)/12
= 8.6

The time between swings
= 8.6 x 0.35 seconds
= 3.0 seconds

XIII...What is an Oscillation Amplitude?

Introduction:

As you will quickly notice, although the mirror sensor card has no pendular motion, it does oscillate from side to side. This motion can be studied by the students to learn about torsional oscillation in the horizontal plane, as opposed to the pendular oscillation in the vertical plane.

Procedure:

There are two components to the motion, its oscillation period and its amplitude.

Oscillation Amplitude:

1) Construct a table with one column giving the swing number and the second column giving the maximum distance of the swing.

2) Set the magnet into a smooth oscillation mode in the horizontal plane, but with little vertical pendular motion. This makes the measurement process easier.

3) Have the students measure how far the light spot moves from the 'zero' position at the maximum of each swing. Just record the distance. Don't try to do the differencing in your head to get the actual deflection distance.

4) From the table, construct a third column that gives the difference between the 'zero' location and the location of the spot at its maximum.

5) Plot the amplitudes against the cycle number to show a declining curve.

Materials:

1) The Magnetometer

Extension Activity:

Change the type of string or thread being used to suspend the magnet in the magnetometer and repeat this experiment for each one.

Change the size of the card that the magnet is attached to.

Question:

1) How many oscillations elapse before the mirror stops moving?

Example:

The magnet was set to swing, and a measurement of the spot on the wall was made each time it reached its maximum left-side excursion from the null position. The null position was at 235 centimeters. The distance from the magnetometer to the wall was 5 meters. Two trials were conducted, each consisting of 22 cycles. Because the spot diameter was 5 centimeters, the following numbers were rounded by eye to the nearest 5 centimeter mark. Compute only the absolute value of the amplitude. Its direction (positive or negative with respect to the 'zero' position) is not needed.

Data Table

Cycle	Trial 1	Trial 2
1	145	155
2	150	160
3	165	170
4	170	175
5	180	185
6	185	185
7	190	195
8	195	200
9	200	205
10	200	205
11	210	210
12	210	210
13	215	215
14	215	215
15	220	215
16	220	220
17	220	225
18	225	225
19	225	230
20	225	230
21	230	230
22	230	230

Calculated Amplitudes

Cycle	Trial 1	Trial 2
1	90	80
2	85	75
3	70	65
4	65	60
5	55	50
6	50	50
7	45	45
8	40	35
9	35	30
10	35	30
11	25	25
12	25	25
13	20	20
14	20	20
15	15	20
16	15	15
17	15	10
18	10	10
19	10	5
20	10	5
21	5	5
22	5	5

The results of the two trials in Table 2 can be plotted against the cycle number to measure the amplitude decay, and to show the classic curve of a decaying system.

Because, in the physics of decay, the curve followed is often an exponential one, we can measure its 'half-life' by finding the cycle number where the amplitude was half of its starting amplitude. In Trial 1, this happened in Cycle 7. Since from the previous Lesson we know that each cycle period is 3.0 seconds, the half life for this magnet oscillator is 3.0 x 7 = 21.0 seconds. As with radioactive systems, if we wait another 'half life' to Cycle 14, the amplitude should have fallen by another factor of two. This is very nearly the actual case.

XIV... The Mathematics of the Simple Oscillator

Introduction:

These kind of systems are found nearly everywhere, and in college, many of your students will study these in considerable detail through math and physics. The previous two activirties exposed your students to the two important aspects of a system (amplitude and frequency) that can be easily observed. The amplitude changes in a periodic manner that illustrates how sines and cosines can be important in describing how some systems work. Without any damping, the amplitude plots from each cycle can be plotted on top of each other to show how the motion is periodic just like a sine or cosine curve. In this activity, some of the mathematics will be explored to further describe how these systems work. Suitable for advanced students in Honors Math or Physics.

1) The oscillation of the magnet can be represented by the following differential equation:

$$\mathbf{m}\ \frac{d^2X}{dt^2} = -\mathbf{k}\ \mathbf{X}^2$$

where **m** is the mass of the magnet and card, **X** is the displacement of the light spot, and **k** is the coefficient that represents the springiness of the string (Hook's Constant)

2) If the magnet is not pushed as it begins its swing, a solution to this equation is given by:

$$X(t) = X(0)\ e^{-if\,t}$$

where X(0) is the amplitude of the swing, and f is the natural oscillation frequency and i is the square root of -1.

3) Substitute solution into the differential equation and determine how the quantities X(0) and f are related to the parameters that define this particular system, namely, m and k, as follows:

$$\mathbf{m}\ \frac{d^2[X(0)\ e^{-if\,t}]}{dt^2} = -k\,X(0)\ e^{-if\,t}$$

$$\mathbf{m}\ X(0)\,f^2\ e^{-if\,t} = -k\,X(0)\ e^{-if\,t}$$

4) Note the factors that cancel on both sides, leaving the natural frequency now defined by m and k which are properties of the magnetometer:

$$f = \left[\frac{k}{m}\right]^{\frac{1}{2}}$$

Note: This is actually a measure of the angular frequency in radians/sec. To get the frequency in cycles/ sec divide 'f' by 2π

Plotting Activity:

5) The solution we have found can be translated into the familiar sines and cosines by using the

$$e^{-ift} = \cos(ft) + i \sin(ft)$$

If you start tracking the oscillation when the spot is at its maximum displacement at time t=0, then plot the formula

$$X(t) = X(0) \cos(ft)$$

If you start the measurement when the displacement is at its null 'minimum' position, then use the formula:

$$X(t) = X(0) \sin(ft)$$

6) Students will plot X(t) for the appropriate case using the measured frequency of oscillation, and compare the plotted sin/cosine curve against what they observed for the magnetometer. They will note that although they were able to correctly predict when the amplitude would reach zero at each swing, they will not be able to reproduce the declining amplitude values. That is because we have not allowed for damping in the above physical model.

Including Damping in our Physical Model

7) A damped oscillator operates in the presence of a retarding force, in this case air friction, which physically occurs because of the speed of the movement through the resisting medium. The higher the speed, the more resistance. The lower the speed, the less the resistance. The differential equation, in this case, has a second term on the right-hand side that is proportional to the speed of the motion (what we call in this equation, its first derivitive in time). The equation would look like this:

$$m \frac{d^2X}{dt^2} = -k\,X + R \left[\frac{dX}{dt} \right]$$

8) The first term (-kX) is the restorative tension force in the string, and the damping force has an opposite sign to this. Moreover, air friction can be measured to be proportional to the square of the speed of the object. The quantity, R, is a coefficient of friction that depends on the viscosity of the medium and the geometry (cross sectional area) of the body moving through the medium

9) The solution to this equation is a little more complicated than for the previous undamped system because the amplitude X(0) now depends on time as well. The damping introduces an exponential decay factor:

$$e^{-Dt}$$

10) The formal solution to the above differential equation is probably beyond even your most able student to work out, but we can approximate the solution by 'guessing' that it might look like this:

$$X(t) = X(0)\; e^{-Dt}\; e^{-if\,t}$$

11) This solution has the desired property that it is a periodic function (the second exponential factor) and that it decays in time (the first exponential factor). The quantity 'D' in the exponent determines how rapidly the amplitude will decrease after each swing. A small value, indicating little friction, causes the amplitudes to barely change. A large factor, representing large friction, causes a rapid decrease in the swing amplitude. To estimate a value for D, students can plot the amplitudes of each swing, and then plot the factor $\mathbf{e^{-Dt}}$ to find a value for D that matches the plot. By experimenting with different types of thread or wire suspending the magnet in the bottle, a variety of different values for D will result.

XV...The Inverse-Cube Law of Magnetic Forces

Introduction: A simple experiment with your instrument can be used to show that magnetism follows an inverse-cube law rather than the familiar inverse-square law that radiation and gravity follow.

Objective: Students will measure the deflection of the magnetometer spot and by plotting the data, discover that magnetism follws an inverse-cube law of change.

Materials:

1) The Magnetometer
2) A 6-10 pound container of iron nails or the equivalent

Procedure:

The magnet on the card will sense the iron mass as it is moved closer and closer to the soda bottle. This will cause a deflection of the light spot on the wall. Measure the location of the light spot and plot its deflection from the null position against the distance between the magnet and the iron mass.

Sample Data:

The magnetometer in this high-sensitivity mode was 5 meters from the wall. From the resolution formula, this corresponds to an angular deflection scaling of 0.28/5 = 0.056 degrees per centimeter. The null position was at 225 centimeters. The weight of the iron was 6.2 pounds.

Spot Position	Mass Location	Angular Deflection
225 cm	24 inches	0.00 degrees
230 cm	12 inches	0.28 degrees
240 cm	10 inches	0.84 degrees
260 cm	7 inches	1.96 degrees
290 cm	5 inches	3.64 degrees

Calculation of deflection for the first measurement:

Angle = 0.056 X (230 - 225)

= 0.056 X 5 cm

= **0.28 degrees**

You can use a calculator to verify that the force law is not inverse square, but is closer to inverse-cube to within the measurement accuracy as follows:

The distance is changed from 5 inches to 12 inches, which is a factor of (15/5) = 2.4
The deflection change between these two locations is a factor of (3.64/0.28) = 13.0.

If the force law was Inverse-square, the deflection change would have been a factor of $(2.4)^2$ = 2.4 x 2.4 = 5.76.

If the force law is Inverse-cube, then the deflection change would be closer to a factor of $(2.4)^3$ = 2.4 x 2.4 x 2.4 = 13.8 which is very close to what was actually measured.

Students may combine their measurements by averaging them and reduce the measurement error.

XVI...Magnetic Storms from the Ground

Introduction

Coronal Mass Ejections (CMEs) and other solar storms can buffet the magnetic field of the Earth with clouds of charged particles and magnetic fields. Not only do these interactions affect the large-scale properties of the geomagnetic field, but their effects can also be easily detected on the ground. During the last 100 years, many 'magnetic observatories' have been commissioned around the world to monitor Earth's surface field conditions. These have been, historically, important for navigation by ships at sea. The data from these observatories can also be used to examine what happens when solar storms arrive at Earth.

Objective

Students will plot changes in Earth's magnetism, and identify the regions where magnetic storms are the most intense.

Procedure

1) Plot the location of each magnetic observatory on a map of Canada. Label each station number next to the plotted point.

2) Analyze the magnetic intensity plot for each station and identify the difference between stable activity, and the largest difference in change in activity, either positive or negative, on the plot. The units of magnetic intensity are in micro-Teslas, abbreviated as 'μT'.

3) Find the percentage change for each station. Round the answer to the nearest hundredth of a percent. Write the number below the location of the station on the map. See the Teacher's Answer Key.

4) Discuss and work the following questions and procedures:

—Where are the largest magnetic changes located for this event?

—Draw a circle around the three stations with the largest magnetic changes. Did the largest changes occur at the same time? Explain.

—On the Data Sheet, organize the plots in order from the largest to the smallest change. Do you see any patterns?

—Organize the magnetic intensity plots according to similar shapes. Are there any trends?

Materials

—5-station magnetic field Data Sheet.

—Calculator

—Map of Canada

Example: For Fort Churchill the normal 'stable' level was 59.3 mT and the largest deflection happened near 8:00 Universal Time (UT) at about 59.8 mT,

$$\% = 100 \times \frac{(\text{max - stable})}{\text{stable}}$$

$$\% = 100\times \frac{(59.8-59.3)}{59.3}$$

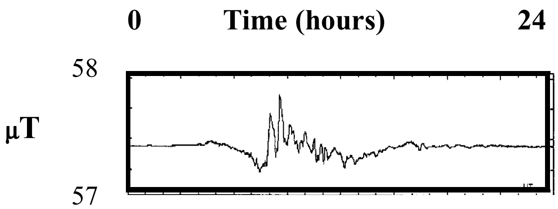
or 0.85 percent.

Conclusion:

Students should have learned that Earth's magnetic field does not remain constant in time, but can change its strength. By investigating and plotting data, students should have revealed the changes in intensity of Earth's magnetic field due to solar storms. From this, students will locate those regions of Earth that are most susceptible to solar storms.

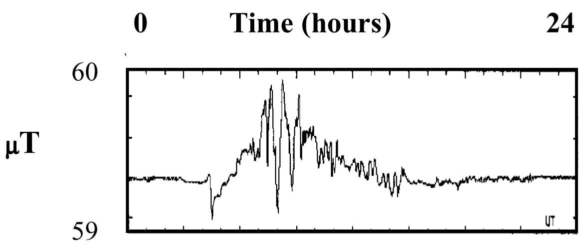
Teacher's Answer Key

Note: Times given to 1/2 hour accuracy are adequate for this exercise. Percentages may vary by 0.1 percent depending on how students measure. Students may average their results for each station to produce a better 'class average' percentage.



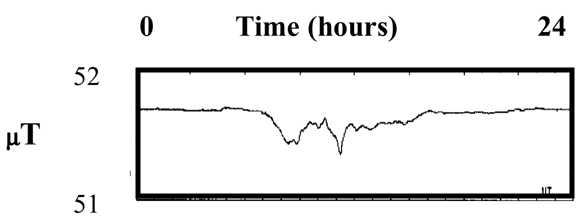
Station 1: **Meanook**
Latitude: **54.6 North** **Longitude:** **113.3 West**

Time: **8:00** **Percent:** **0.70**



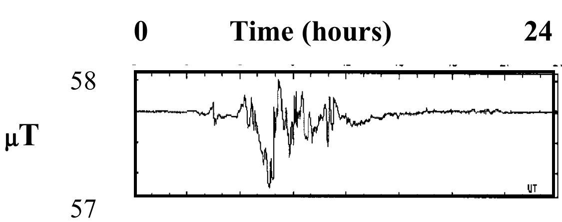
Station 2: **Fort Churchill**
Latitude: **58.8 North** **Longitude:** **94.1 West**

Time: **8:00** **Percent:** **0.85**



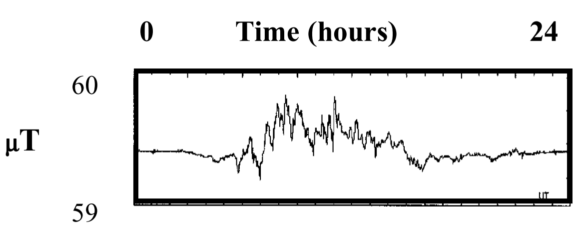
Station 3: **Victoria**
Latitude: **48.5 North** **Longitude:** **123.4 West**

Time: **11:00** **Percent:** **0.58**



Station 4: **Poste-de-la-Baleine**
Latitude: **55.3 North** **Longitude:** **77.8 West**

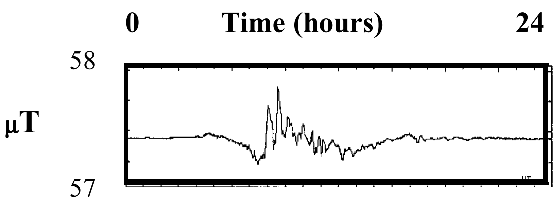
Time: **7:30** **Percent:** **1.05**



Station 5: **Yellowknife**
Latitude: **62.4 North** **Longitude:** **114.5 West**

Time: **8:00** **Percent:** **0.60**

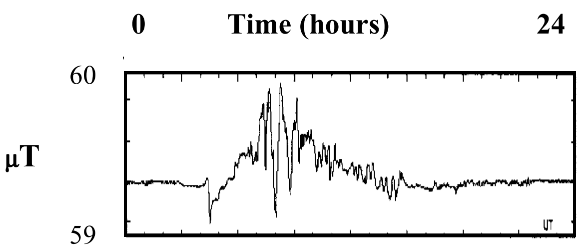
Student Data Sheet



Station 1: Meanook
Latitude: 54.6 North **Longitude:** 113.3 West

Time:

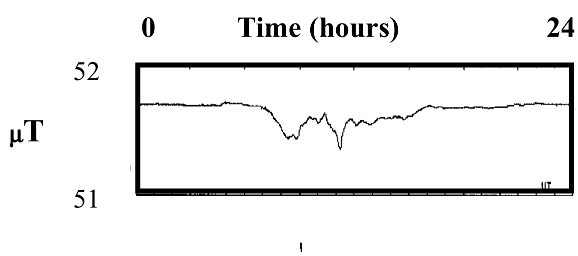
Percent:



Station 2: Fort Churchill
Latitude: 58.8 North **Longitude:** 94.1 West

Time:

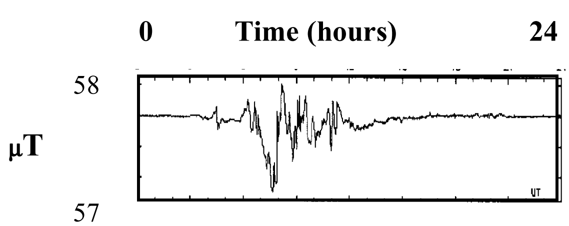
Percent:



Station 3: Victoria
Latitude: 48.5 North **Longitude:** 123.4 West

Time:

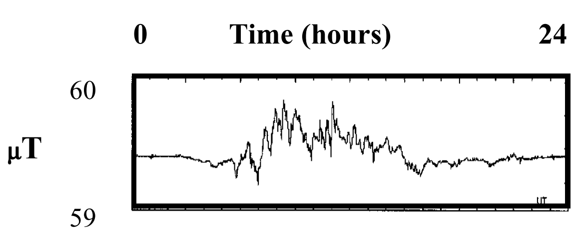
Percent:



Station 4: Poste-de-la-Baleine
Latitude: 55.3 North **Longitude:** 77.8 West

Time:

Percent:

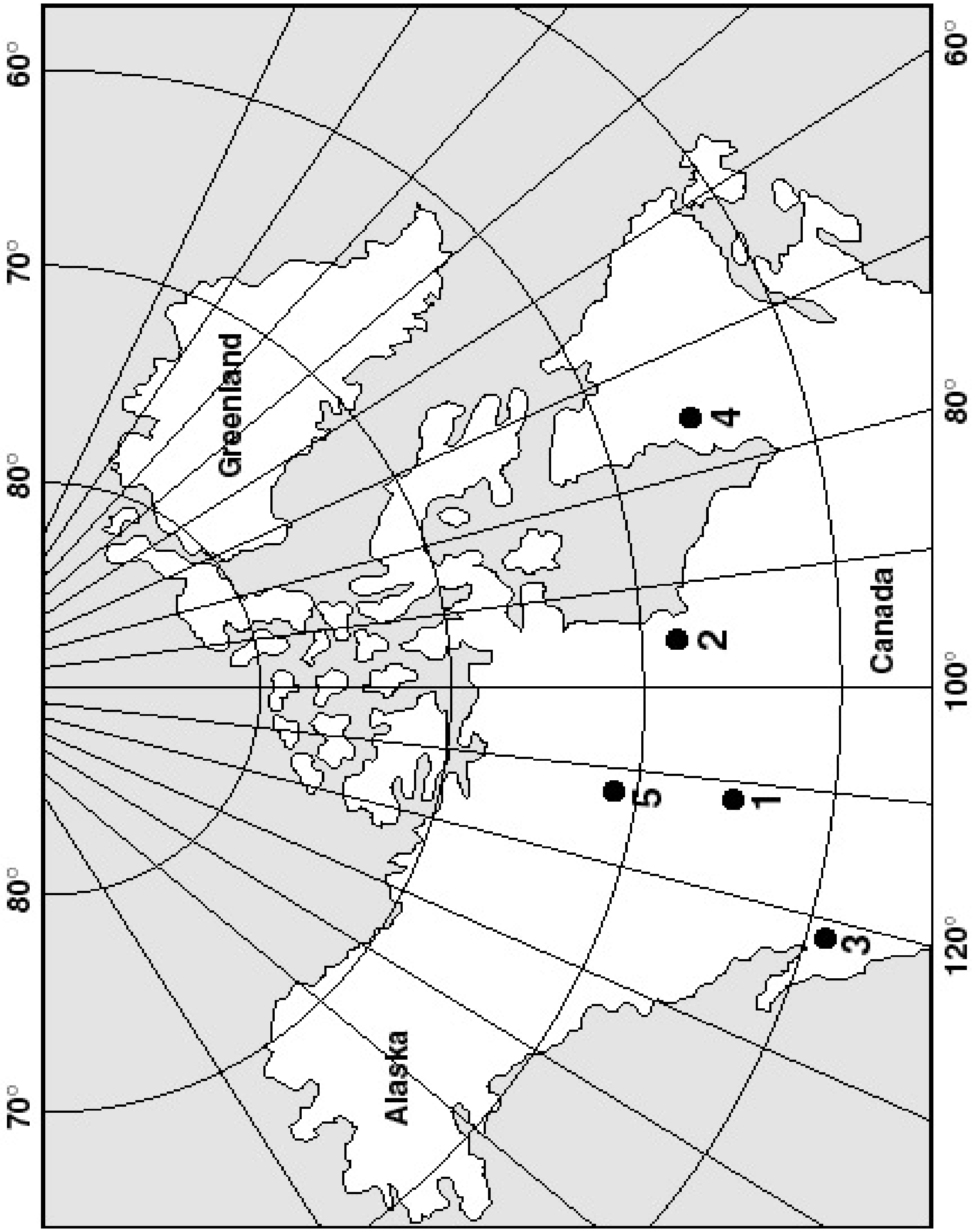


Station 5: Yellowknife
Latitude: 62.4 North **Longitude:** 114.5 West

Time:

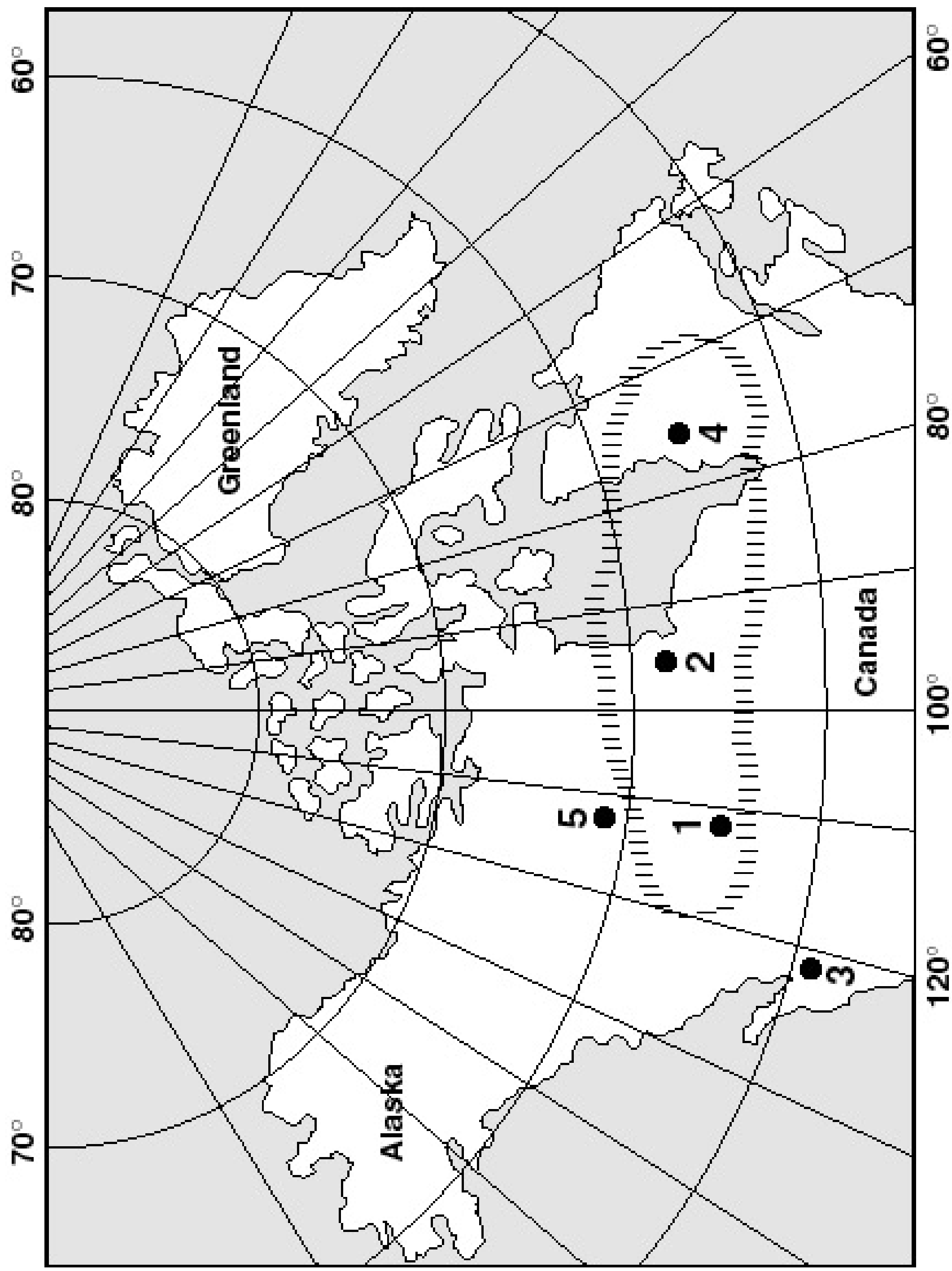
Percent:

Name ______________________ **Date** __________



1...Meanook **3...Victoria** **5...Yellowknife**
2...Fort Churchill **4...Poste de la Baleine**

Teacher’s Answer Key



1...Meanook
2...Fort Churchill
3...Victoria
4...Poste de la Baleine
5...Yellowknife

XVII...Investigating Magnetic Storms

Introduction:

Every three hours throughout the day, magnetic observatories around the world measure the largest magnetic change that their instruments recorded during this time. The result is averaged together with those of the other observatories to produce an index that tells scientists how disturbed Earth's magnetic field was on a 9-point scale. This scale is called the Kp scale. The larger the index (9+) the more magnetically active Earth has been. The smaller the index (1-2) the more quiet it is. Sometimes changes in the Sun's activity can cause big changes in Kp. At other times, large Kp values can indicate sudden rearrangements of Earth's field due to the solar wind. When Kp is above 6 or 7, satellite problems, blackouts or equipment interferrence often

Objective:

Students will identify how frequently magnetic storms of different severities occur during the year, and during the solar sunspot cycle.

Procedure:

1) Visit the archive of the NOAA Kp bar charts for 2000-present at:

http://www.sec.noaa.gov/ftpmenu/plots/kp.html

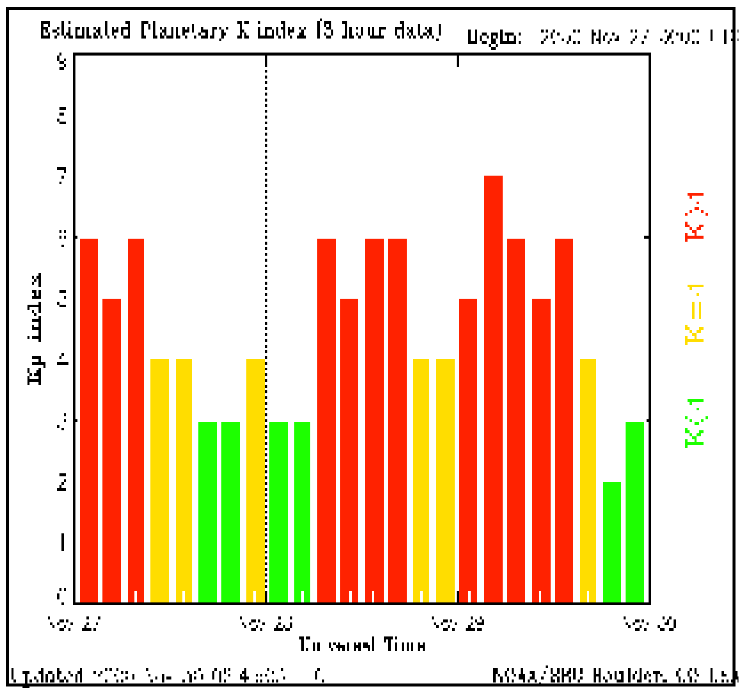
A sample of the 3-day plots is shown in Figure 1 and was listed as file 20001129_kp.gi in their FTP archive.

2) Select a range of data spanning a week, a month, 6 months, or a year.

3) For each of the Kp bar graphs, count the number of times that Kp equaled 4, 5, 6,7, 8 and 9. *The figure, for example, shows 7 times when Kp = 6.*

4) Construct a bar graph that plots the Kp value on the horizontal axis and the number of events on the vertical axis.

5) Answer the accompanying questions.



Questions:

1) What is the most common level of activity for the Earth's magnetic field at ground level?

2)How long would you have to wait, on average, for a very severe storm with Kp > 8?

3) How long would you have to wait, on average, for a moderate storm with Kp = 7.

4) How frequent are magnetic storms with Kp = 8 or stronger compared to storms with Kp = 6?

XVIII...Magnetic Storms and Solar Activity

Procedure:

1) Return to the Kp archive at NOAA and select 6 months during sunspot maximum conditions in the year 2000, and 6 months during sunspot minimum conditions in the year 1996. These can be found at:

2000-Present:
http://www.sec.noaa.gov/ftpmenu/plots/kp.html

1996:
http://www.sec.noaa.gov/ftpmenu/plots/1996_plots/kp.html

2) Carry out the same counting procedure as you did in the previous activity, keeping the data separate for solar minimum and solar maximum.

3) Construct one bar graph of the Kp value and frequency for the solar minimum data, and one for the solar maximum data.

4) Answer the accompanying questions.

Objectives:

Students will discuss whether solar activity has any impact on the frequency of magnetic storms.

Questions:

1) Does the level of solar activity have any impact on how frequent magnetic storms are in the Kp rankings from 1-9?

2) How long would you have to wait, on average, for a magnetic storm with a Kp of 8 during solar maximum? During solar minimum?

3) What is the typical level of magnetic activity during solar maximum? During solar minimum? Can you explain what might be happening to cause this?

For the months of November, 2000 and November 1996 the following counts of instances were identified:

November, 2000

Kp............Number
9................0
8................0
7................0
6................15
5................11
4................26

November, 1996

Kp............Number
9................0
8................0
7................0
6................0
5................0
4................11

Extensions:

1) It is also possible to include counts for the Kp values of 1,2 and 3. This will be more tedious so students can each be individually assigned a month to process and the results for 12 students can be combined to get a full years statistics in 1996 and in 2000.

2) Students can also record the number of days in which Kp exceeded each of the values and compare the number of 'storm days' at various parts of the sunspot cycle. Generally there is more activity around March and September. The students monthly-averaged bar charts

More about Kp:

Geomagnetic disturbances can be monitored by ground-based magnetic observatories recording the three magnetic field components. The global Kp index is obtained as the mean value of the disturbance levels in the two horizontal field components, observed at 13 selected, subauroral stations . The name Kp originates from "planetarische Kennziffer" (= planetary index). Kp was introduced as a magnetic index by Bartels in 1949 and has been derived since then at the Institut für Geophysik of Göttingen University, Germany.

Here is what the Kp index actually looks like: **0o, 0+, 1-, 1o, 1+, 2-, 2o, 2+, ... , 8o, 8+, 9-, 9o**

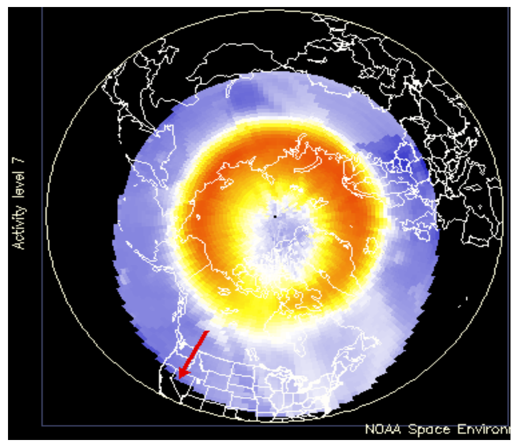
XIX...Magnetic Storms and Aurora

Introduction:

In the 1800's Alexander Von Humbolt discovered that magnetic storms are often correlated with sightings of bright aurora. From the ground, aurora look like curtains of light. From space they look like luminous donuts crowning the magnetic poles of a planet. The size and extent of these 'Auroral Ovals' change constantly during severe magnetic storms as particles from the distant magnetic tail of the Earth slam into the oxygen and nitrogen atoms in Earth's atmosphere. These currents dissipate electrical energy in the upper atmosphere and satellites such as the NOAA NPOES satellites can measure how much energy is released.

Objective:

Students will compare the amount of energy dissipated by an aurora in the northern hemisphere, with the recorded Kp index of magnetic storm severity.



NOAA-16(N)
January 22, 2001
Power Level (P) = 7

Procedure:

1) From the previous activity, note the dates and times of two or three magnetic storms with Kp values of 6,7,8 and if possible, 9.

2)Convert the date into a day number. Example:
January 1 =0, December 31 = 365.

3) Visit the archive of data from the NPOES satellite at:
gopher://solar.sec.noaa.gov/11/lists/hpi
where you will see text files listed as, for example, POWER_1978.TXT.

4)Click on the file for the year when you are seeking data for the first Kp value in #1 above. For example, on November 28, 2000, Kp = 7 on Day = 334 so open the file POWER_2000.TXT by clicking on it.

5) Scan down to the section that represents that day number. See the underlined example on the right for details on how to read the line of data.

6) Extract the peak power measurement for the northern hemisphere (N) at that time. Example, for November 29, 2000 (Day 334) when Kp = 7, the peak power was 253.3 gigawatts (see below sample).

8) Repeat this for each of the selected magnetic storms.

9) On a graph, plot the Kp value for each storm on the horizontal axis, and the power dissipated on the vertical axis. (See Activity XVII)

Satellite	Day UT	Power	P	F
NOAA-12(S)	3341359	74.8	9	1.298
NOAA-16(S)	3341424	44.1	8	1.075
NOAA-14(N)	3341428	208.6	10	1.287
NOAA-15(N)	3341428	253.3	10	1.279
NOAA-12(N)	3341449	107.3	10	1.179
NOAA-16(N)	3341515	32.1	7	1.228

Questions:

1) Does the severity of the Kp index correlate with the amount of dissipated power during an aurora?

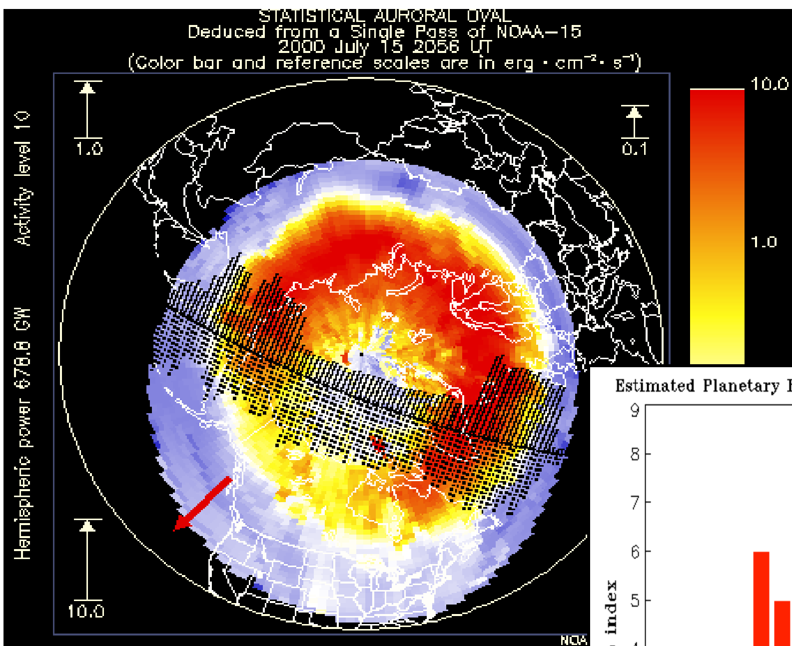
2) For each Kp index, what is the range of power dissipation levels that you recorded?

3) Is there a difference in the ranges of the power dissipation levels for each Kp? If so, which ones seem to have the narrowest range? The widest range?

4) If you were planning to travel to see an aurora in Alaska or Canada, for what value of Kp would you start planning your journey?

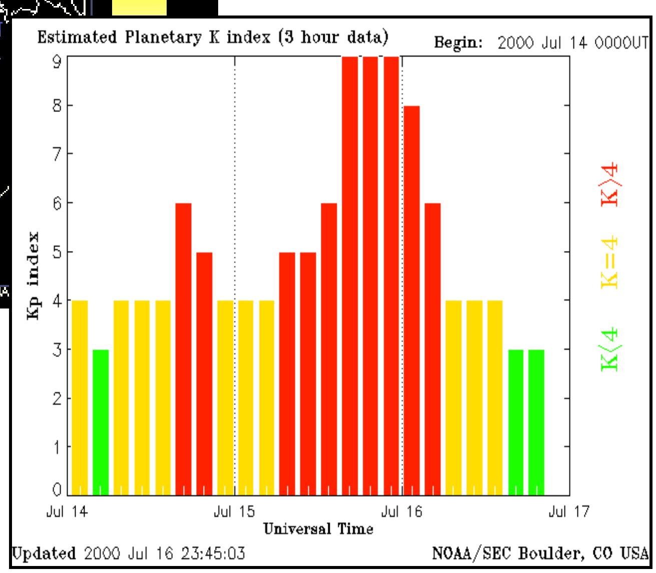
5) From the Kp plots for specific storms, how much warning would you have that a measurement of Kp=7 would lead to a spectacular Kp=8+ storm and a consequently spectacular aurora?

6) If you were a power plant or electrical utility, how much warning would you have to protect your equipment from geomagnetic damage using only the Kp index as a guide?



The Bastile Day Storm on July 14-15, 2000 was one of the most powerful storms during the current solar activity cycle.

The above image based on the NOAA-15 satellite data shows a powerful oval encircling the north magnetic pole. Total power dissipation was over 678 billion watts. The bar graph shows that during this time, the Kp was at a level of 9 for 9 consecutive hours. Each bar represents a single, planetary 3-hour average.



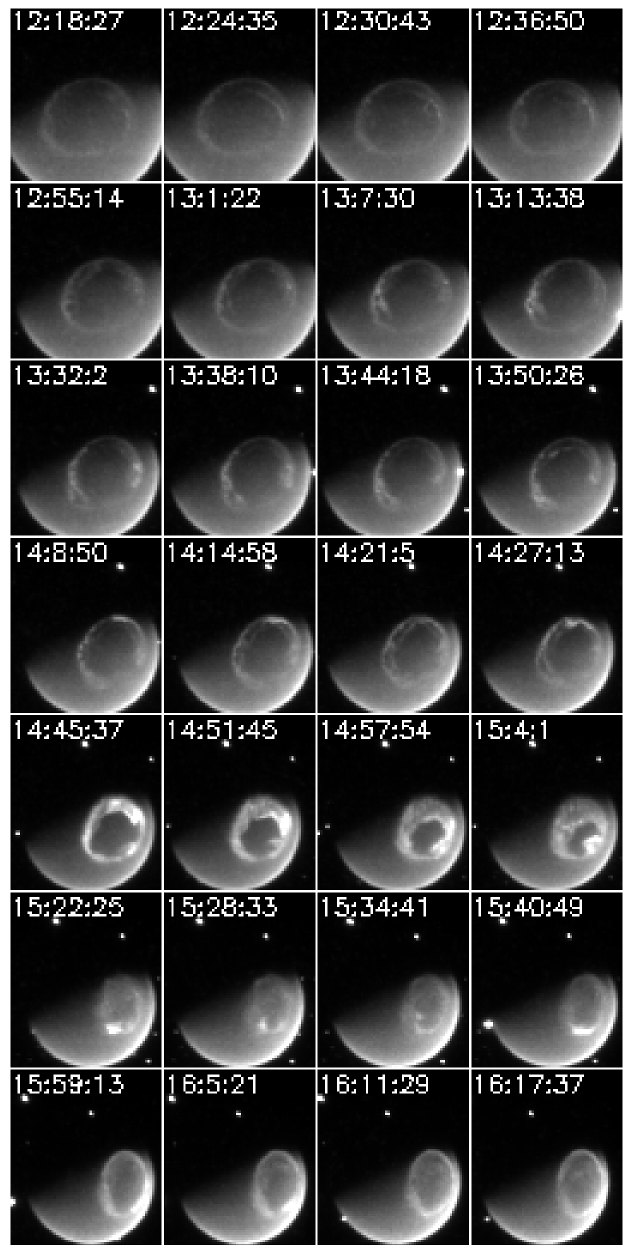
XX...Round the Clock Aurora Satellite Monitoring

Introduction:

During the 1990's, NASA has placed research satellites in orbit around Earth to keep the polar regions under almost constant surveillance for signs of auroral activity. This data helps scientists explore the connections between aurora and other phenomena in the solar and geospace environment which can cause them to brighten.

Objective:

Students will use data from the IMAGE satellite to see if there is a correlation between severe magnetic storms and larger auroral areas.



Procedure:

1) Visit the IMAGE, Far Ultraviolet Camera web site archive at
http://sprg.ssl.berkeley.edu/sprite/ago96/image/wic_summary/

2)Click on the archive for the month and year of interest. Example NOV_2000/

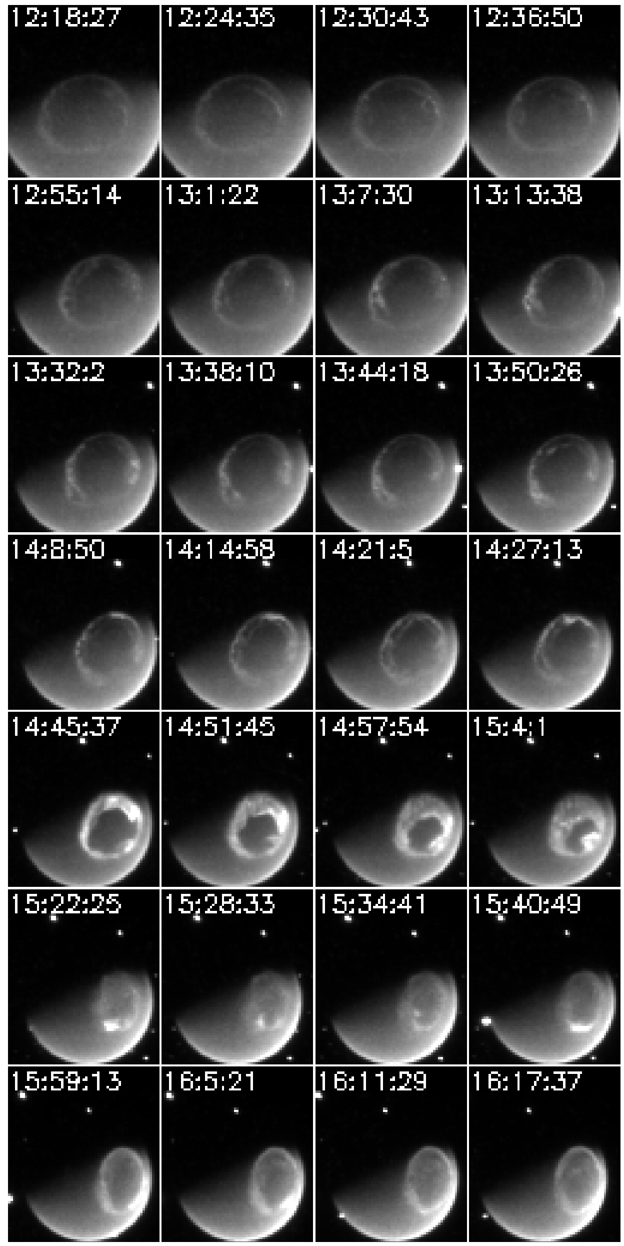
3)Click on the file for the day of interest. Example: WIC_2000_333_02.gif is for the 333 day of the year 2000, and it is the second archive of images for that day. [You will see a panel of images similar to the section to the right, obtained by the FUV instrument on July 15, 2000.]

4)Measure the diameter of the Earth disk with a millimeter ruler. Measure the diameter of the auroral oval. Given that Earth's radius equals 6,378 kilometers, calculate from the ratio of diameters, a linear diameter for the oval.

5) Plot the maximum linear diameter against the Kp index recorded for that date and time. Do more severe storms correlate with larger auroral areas?

XXI...The Evolution of an Aurora in Time

Introduction:



It has been known since the 1800's that auroras do not change randomly in time, but follow a very specific pattern of changes during the course of a night's observation. The reason for this sequence of changes has to do with the way that the magnetotail of Earth is changing as it tries to release its stored energy and tangled magnetic fields.

In this activity, students will study real auroral images from the IMAGE satellite and search for a pattern in time of how auroras change. They will learn how to use web-based data archives, extract the data they need to study a specific question, and organize the data to draw a conclusion. They will also study two or more magnetic storms from space data, construct a timeline of changes, and compare the storms for common elements.

Objective:

Students will use data from the IMAGE satellite to:

1...Clip out and order an auroral oval image in time.

2...Describe how an aurora changes during a storm

3...Construct a timeline of auroral changes.

4...Compare magnetic storms for common auroral elements.

Procedure:

1) Visit the IMAGE, Far Ultraviolet Camera web site archive at:

http://sprg.ssl.berkeley.edu/sprite/ago96/image/wic_summary/

2) You may either search the archive to find candidates to study, or select one of the dates below which contained a strong magnetic storm event an prominent oval.

Storm Dates: November 29-31, 2000, July 14-16, 2000, June 7-10, 2000. May 223-26, 2000.

3) Click on the archive for the month and year of interest. Example NOV_2000/

4) Convert the calendar date you are interested in, into a day number for that year. Example, November 29, 2000 = day 334. [Remember to add a day for Leap Years]

5) Click on the file for the day of interest. Example: WIC_2000_333_02.gif is for the 333 day of the year 2000, and it is the second archive (02) of images for that day. You will see a panel of images obtained by the FUV instrument. There may be several files to look at for that date.

6) Print out the relevant panels that show the auroral oval.

7) Clip out the individual auroral oval images being careful to note their time mark in the upper left corner. You will use this time mark to order the picture tiles in time order.

8) On a piece of paper, order the tiles in time order, making sure to include several tiles at the beginning and end that show little or no activity to establish a baseline for discussing the changes.

9) Compare the 'movie strip' in Step 6 for at least two or three different storm events.

10) On a table that gives the elapsed time from the start of the storm (the first picture in your movie will be defined as Time 0:0:0) in column 1, write an annotated description in columns 2, 3 ... of what changes were seen in the oval. Some of the things you should note are, for example:

1...When did the oval reach its maximum extension towards the equator?
2....When did the oval reach its maximum extension poleward?
3...When did the oval reach its brightest point?
4....When was the oval the thickest?
5....When did the oval show the most complex interior structure?
6....When did the oval show its narrowest thickness?
7....When did the oval begin to fade out?

There are also other things you may see as you look very carefully at the images.

XXII... Auroral Battery Electrical Circuit

Introduction:

Scientists have proposed that changes in the magnetic field in the magnetotail region, cause releases of energy that eventually supply the battery to 'light-up' the aurora on Earth. Let's explore this idea in more detail to see what they are talking about!

Part 1: How big a battery do you need?

Energy is stored in a magnetic field, and the amount depends on how strong the field is, and how big a volume it occupies. What we are going to do is estimate just how much magnetic energy is available in the magnetic tail region of Earth.

1) Let's suppose the volume of the magnetotail region is a cylinder with a height of 300,000 kilometers, and a radius of 120,000 kilometers. Use the formula for a cylinder to estimate the magnetotail volume, in cubic meters.

$$\begin{aligned} V &= \pi \times r^2 \times h \\ &= 3.14 \times (1.2\times10^8 \text{meters})^2 \times (3\times10^8 \text{meters}) \\ &= 1.3 \times 10^{25} \text{ cubic meters} \end{aligned}$$

2) The formula for the energy of a magnetic field is given by the formula to the right in which the strength of the magnetic field, B, is expressed in Teslas, V in cubic meters, and the energy will then be in units of Joules.

$$\boxed{E = \frac{10^7}{8\pi} B^2 \times V}$$

3) For a magnetic field with a strength of 2×10^{-8} Teslas [the typical strength of the magnetotail field] and the volume of space you just calculated in Part 1, the total energy of the magnetotail field is:

$$\begin{aligned} E &= 4.0 \times 10^5 \times (2 \times 10^{-8} \text{ Teslas})^2 \times 1.3 \times 10^{25} \text{m}^3 \\ E &= 2.1 \times 10^{15} \text{ Joules} \end{aligned}$$

Part 2: How much energy do you need to light-up the auroras in the Northern and Southern Hemispheres?

Auroras are powered by currents of electrons with currents of about 1,000,000 Amperes. Your home uses about 200 Amperes at 110 Volts. The atmosphere that this auroral current has to flow through has a resistance of about 0.1 Ohms.

Electrical power is calculated using a formula that relates resistance (R) and current (I) to the power (P) that they can produce in a circuit:

$$\mathbf{P = I^2 \times R \quad Watts}$$

where R is measured in Ohms, and I is in Amperes. From the information given and the power formula, you can calculate the power dissipated by an aurora:

$$\mathbf{P = (10^6 \text{ Amperes})^2 \times 0.1 \text{ Ohms}}$$

$$\mathbf{P = 10^{11} \text{ Joules/second}}$$

Part 3: How many seconds can the magnetotail 'battery' continue to supply energy to the aurora to keep them going?

The answer to the first question in Part 1 tells us how much energy is available. The answer to the second question tells us at what rate (energy per second) the aurora are converting energy into light and heat.

1) To find out how long this can continue, divide the answer from question one, by the answer from question two:

$$\mathbf{Time = \frac{2.1 \times 10^{15} \text{ Joules}}{10^{11} \text{ Joules/second}}}$$

$$\mathbf{= 21{,}000 \text{ seconds, or about } 5.8 \text{ hours}}$$

Although this is only an estimate, it comes very close to the most intense phase of an auroral display which often lasts an entire evening. There have been many approximations used in this “back of the envelope” calculation. Have your students identify them and consider other values. Which ones might be the most uncertain? (Example: dimensions of magnetotail region involved in the conversion of magnetic energy to particle energy, or the amperage of the auroral current.)

XXIII...The Magnetopause Boundary Distance

Introduction:

As the solar wind flows past Earth, it applies pressure to the magnetic field of Earth, sweeping it back into a comet-like shape on the nighttime side of Earth. The brunt of the solar wind pressure is exerted on the dayside field, compressing it. Only the restorative pressure of the magnetic field pushes against the solar wind, and a rough balance of these pressures occurs. Like a football scrimmage line, this balance moves towards Earth when the solar wind pressure increases, and it moves outwards toward the sun as the solar wind pressure slackens. Scientists call this invisible boundary the **magnetopause.**

Objective:

Students will algebraically solve distance equations to explain how the distance to the magnetopause balance point depends on the solar wind pressure.

Teacher Note:

These activities are suited for advanced students of physics and math. Algebraic manipulation is required.

Mathematics:

There are three basic equations that define the solar wind pressure, the pressure from a magnetic field, and the magnetic field strength of the earth in space are defined as follows:

Equation 1
Solar Wind Pressure

$$P_w = \frac{1}{2} DV^2$$

Equation 2
Magnetic Field Pressure

$$P_m = \frac{1}{8\pi} B^2$$

Equation 3
Magnetic Field Force

$$B = 0.6 \frac{1}{R^3}$$

Equation 1 defines the 'ram' pressure, P_w, produced by a wind with a density of D, moving at a speed of V. Equation 2 defines the pressure exerted by a magnetic field, P_w, which exerts a force of B. Equation 3 defines the magnetic force, B, in terms of the distance from the source of the magnetism, R.

1) Because we want to define the distance, R, at which the magnetic and wind pressures balance, we need to substitute Equation 3 into Equation 2, and then set this equal to Equation 3. The basic idea is that Equation 1 equals Equation 2 when the magnetic and wind pressures are equal. This defines the condition at the front of Earth's magnetic field as it feels the pressure of the wind. What we can determine by satellite observations is the value of the variable D and V, so this means we know what P_w is numerically. What we need to do, then, is to solve for R, which will tell us at what distance the pressure balance occurs.

Substituting Equation 3 into Equation 2 gives us:

$$Pm = \frac{1}{8\pi}\left[0.6\frac{1}{R^3}\right]^2$$

2) The next step is to balance the two pressures by setting their equations equal to each other so that $\mathbf{P_w = P_m}$. If we now set Equation 1 equal to Equation 4 we get:

$$\frac{1}{2}DV^2 = \frac{1}{8\pi}\left[0.6\frac{1}{R^3}\right]^2$$

3) We now use a little algebra to simplify this formula, and solve for R:

$$\frac{1}{2}DV^2 = \frac{0.36}{8\pi \ R^6}$$

Square the quantities inside the brakets.

$$R^6 = \frac{0.72}{8\pi D V^2}$$

Multiply both sides by R^6 to remove the factor from the right-hand denominator, then divide both sides by $1/2DV^2$ to remove this factor

$$R = \left[\frac{0.72}{8\pi D V^2}\right]^{\frac{1}{6}}$$

Raise both sides to the 1/6-th power, to obtain R on the left-hand side.

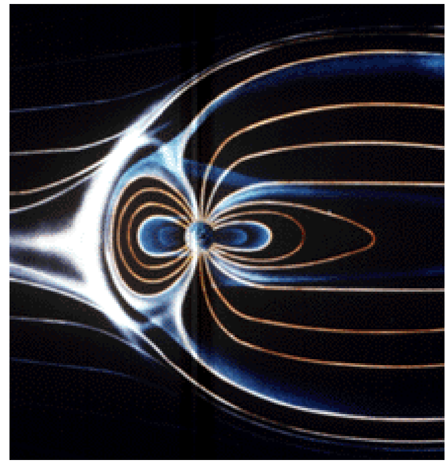
4) We are now ready to substitute some typical values for the solar wind density (D) and speed (V) to see what the average distance is to this equilibrium point in space. The equations have been simplified in their form by selecting the quantities D and V in terms of grams per cubic centimeter and centimeters per second. The equation will then provide a value for R in terms of the distance in units of Earth's radius (Re). Example, for R = 2.5 Re, this means that the distance is 2.5 times Earth's radius or 2.5 x 6378 kilometers = 15,945 kilometers.

The typical speed of the solar wind is 450 kilometers/second or **V= 4.5 x 10^7 centimeters/sec**. The typical density of the wind is about 5 hydrogen atoms per cubic centimeter. Since 1 hydrogen atoms has a mass of 1.6 x 10^{-24} grams, the density equals 5 x 1.6 x 10^{-24} gm/cm^3 or **D = 1.28 x 10^{-23} gm/cc**. If we substitute these values for D and V into the equation, we get:

$$R = (1105242.6)^{1/6} = 10.16 \text{ Earth radii.}$$

5) Plot on a scale model the following features looking down on Earth from above its North Pole:

1) The disk of Earth.
2) A selected direction to the Sun
3) The position of the day-night terminator on Earth.
4) The circular orbit representing the positions of the geosynchronous satellites at a distance of 6.4 Earth radii from the center of Earth.
5) The distance of the magnetopause calculated from Step 5. Note, it is located along the line connecting the center of Earth and the Sun at Local Noon on the day-side of Earth.



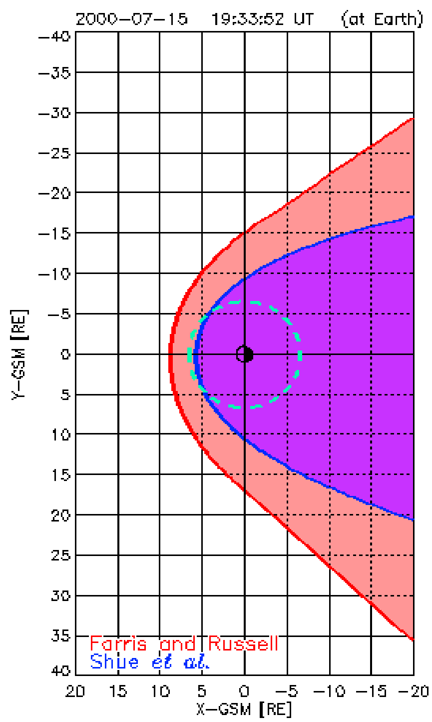
Assume that the shape of the magnetosphere is roughly a parabolic shape (called a *paraboloid* in 3-dimensions) with a focus at Earth's center, a vertex at the magnetopause distance, and fanning out towards the night-time side of Earth. Draw this as a dotted line on your scale model.

6) Visit the NASA, ACE satellite data archive at,

http:// www.sec.noaa.gov/ace/

and note the values for the solar wind speed and its density. Calculate D and V as in Step 4, and re-calculate the magnetopause distance for the solar wind conditions today. Plot a parabola with the vertex distance of the magnetopause.

7) During the July 14, 200 'Bastille Day' storm, the parameters for the solar wind were measured to be V = 1700 kilometers/sec and 95 atoms/cc. Calculate the magnetopause distance for this severe storm as in Step 6.



Questions:

1) Where was the magnetopause compared to the orbit of the geosynchronous communication satellites?
2) Which quantity has the strongest impact on changes in the magnetopause location, the density of the solar wind, or the speed of the wind?
3) If a solar wind monitoring satellite is located 1.5 million kilometers closer to the Sun than Earth's orbit, how much warning of the approaching solar storm would you get if the wind speed were 1,500 km/sec? 500 km/sec?

To see a real-time calculation of the magnetopause position based on NASA, ACE data, visit **http://pixie.spasci.com/**