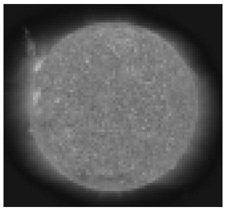
LIVE FROM THE AURORA

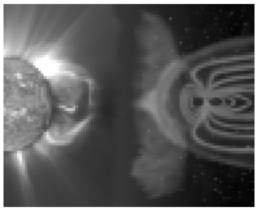
2003 EDUCATOR'S GUIDE

FEATURING:

Student Observation Network (S.O.N.)

TABLE OF CONTENTS





INTRODUCTION

As with all good research, we will start with a question: *Do visible signs of the Sun-Earth Connection exist?* The inquiry-based activities in this book are designed to encourage students to formulate questions related to the existence of the Sun-Earth Connection.

- What are sunspots?
- What is the solar wind?
- Are there visible signs that the Sun and the Earth are connected?
- What can auroras tell us about the Sun-Earth Connection?

WARNING!!! It is never safe to look directly at the Sun because the Sun's rays can damage your eyes. It is safe to study the Sun's surface if you use a telescope to project the Sun's image onto a piece of paper.

THE STUDENT OBSERVATION NETWORK (ONLINE)

The Student Observation Network is a combination of four separate on-line programs providing students with the necessary tools to observe the dynamic connection between the Sun and the Earth. By using the Student Observation Network along with the activities in this book, students will be able to:

- Safely observe the Sun
- Make use of real-time NASA data
- Collect and share observations with other students around the country
- Make solar predictions
- Examine how the Sun is related to the aurora

S.O.N. URL:

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http://sunearth.gsfc.nasa.gov/sunearthday/2003/network.htm

LIVE FROM THE AURORA: EDUCATOR'S GUIDE

The material in this book is divided into four main content areas, each reflecting a component of the Student Observation Network. All activities are designed to challenge students into further investigating the dynamic nature of the Sun and its connection to the Earth.

The activities included in this educator's guide:

- Reflect each component of the online Student Observation Network.
- Include connections to National Math, Science and Technology standards.
- Encourage participation at all grade levels.
- Allow students to study each content area regardless of location. (Auroral Friends uses real NASA data available online.)
- Provide background for better understanding of the Sun-Earth Connection.

Main areas of content (Network Component) :

- **Sunspots (Sunspotters)**
  Grade Level: K-2, 3-5, 6-8
- **Radio Waves (Radio JOVE)**
  Grade Level: 6-8, 9-12
- **Magnetism (Magnetometer - MagNet)**
  Grade Level: 9-12
- **Solar Storms and the Aurora (Auroral Friends)**
  Grade Level: 9-12

Notes:

- The activities in this book can be used independently from the Student Observation Network.
- For additional background resources and activities in all grade levels including teacher-guided and student-directed Web quests, go to: *http://sunearth.gsfc.nasa.gov/sunearthday/2003/network.htm*

PASSPORT TO KNOWLEDGE AND NASA SUN-EARTH CONNECTION EDUCATION FORUM PRESENT:

Two spectacular new science specials will debut on participating PBS stations and NASA Television—free for all educational networks, noncommercial cable systems, schools, and science centers and planetariums. They are supported by teacher-tested hands-on activities and Web resources connecting real-world science to the National Science Education Standards.

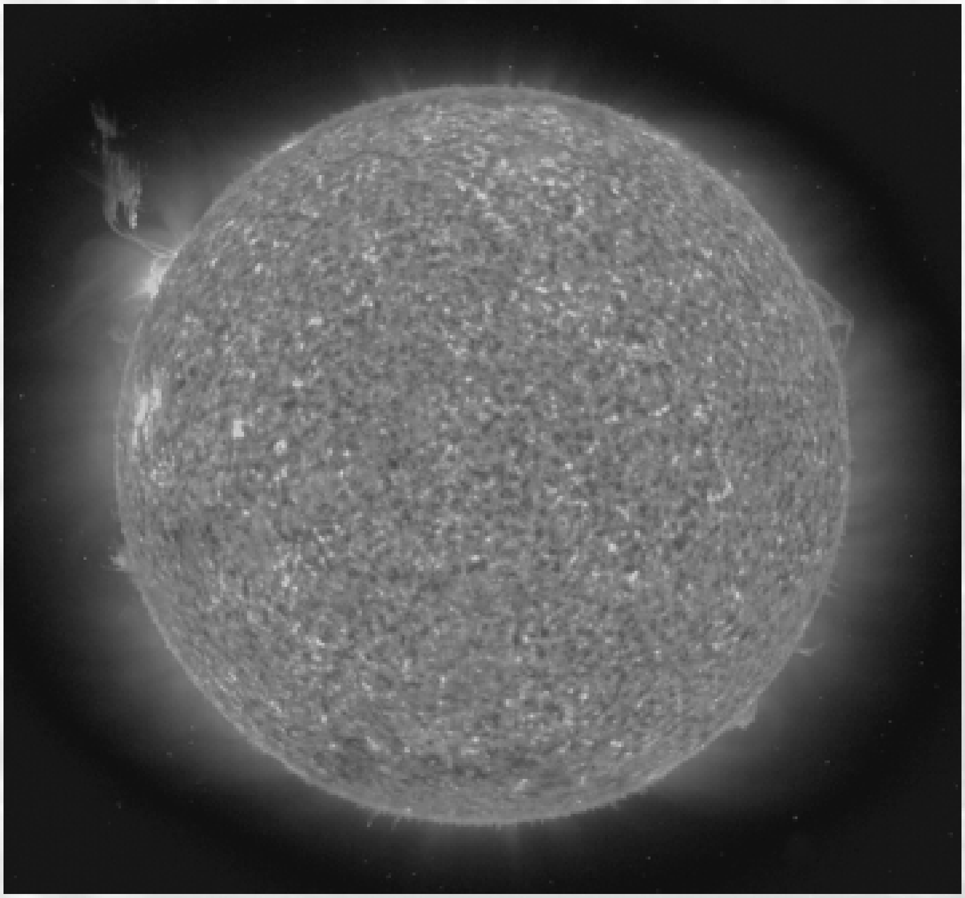
Documentary

Auroras: Living With A Star
Tuesday, February 11, 2003
1:00 p.m.-2:00 p.m. Eastern Time

Auroral Topics Covered: Background Science, Views from Earth and Space, Myths and Legends, Societal Impact.

Web Cast

Live From the Aurora 2003
Tuesday, March 18, 2003
1:00 p.m.-2:00 p.m. Eastern Time



SUNSPOTS

BACKGROUND:

While other ancient cultures did not share this conclusion, by the early 1400's Western religious, philosophical, and observational evidence supported a perfect, unchanging, Earth-centered universe. Therefore, the argument by Copernicus for a Sun-centered universe in 1543 and the amazing appearance of a new star (a nova) in 1572 were extremely challenging to the European world view. However, many more challenges were to come from Galileo Galilei (1564-1642). While Galileo systematically challenged many aspects of contemporary scientific views, his pioneer work in astronomy with a telescope provided evidence to anyone who cared to look with open eyes and open mind that all was not as previously thought in the heavens. Jupiter had moons, Saturn had rings, the Moon had mountains and craters, and the Sun had blemishes–spots that moved across the face of the Sun. Using his telescope, Galileo projected the image of the Sun onto parchment and drew the spots on the parchment. He and others recorded sunspots on many consecutive days, revealing a progressive motion across the Sun. Whether sunspots were on the Sun or satellites circling close to the Sun was debated for some time. For more information on Galileo and the other observers of sunspots, visit the Web site *http://es.rice.edu/ES/humsoc/Galileo/Things/sunspots.html.*

Many individuals contributed to early research of these strange spots on the Sun in the early 1600's. However, sunspot activity decreased from 1645 until 1715. With so few sunspots, people lost interest. However, in 1843 Heinrich Schwabe discovered the number of sunspots increased and decreased in a cycle. The cycle shows peaks of high sunspot number about 11 years apart. The long period with few sunspots occurred during a period called the "Little Ice Age" in which temperatures decreased globally. This coincidence of the lack of sunspots with a decrease in global temperatures is not sufficient proof of a cause-effect relationship. It does raise interesting questions. More accurate measurements have found the sunspot cycle to be, on average, 11.1 years with ranges between 8 and 16 years.

The causes of solar features such as sunspots have become better understood because of NASA missions such as Ulysses, ACE (Advanced Composition Explorer), Yohkoh, SOHO (Solar and Heliospheric Observatory), and TRACE (Transition Region and Coronal Explorer). However, there is much that scientists hope to learn from future missions such as Solar-B, STEREO (Solar Terrestrial Relations Observatory), SDO (Solar Dynamics Observatory), and Sentinels. Sunspots are regions in the photosphere of the Sun that are relatively cooler than the brighter parts of the photosphere. Sunspots are only about 3700 K compared to 5700 K for the surrounding photosphere. About the size of the Earth or larger, sunspots usually last several days, although very large ones may last for weeks. Sunspots occur at regions of intense local magnetism. Possibly the magnetic fields suppress the movement of hot material upward from the underlying convective zone.

Observations of sunspots led to the conclusion that the Sun rotated. The average time of rotation is 27 days. This isn't the whole story, however. Because the Sun's outer zones are not solid, the equator rotates faster than the poles. At the equator the Sun rotates in about 25 days. At about 40° latitude the rotation takes 28 days and at the poles the rotation is in 36 days.

In this lesson students will be able to observe sunspots safely and discover changes in the number and position of sunspots over time. Students will be able to observe the rotation of the Sun, and, in a math extension, will be able to calculate the period of rotation.

NATIONAL STANDARDS:

National Science Education Standards (NSES)

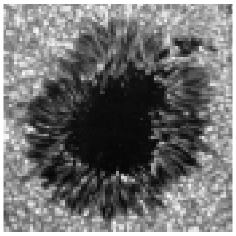
Content Standards (Grades K-4)

- Abilities necessary to do scientific inquiry.
- Objects have many observable properties, including size, weight, shape, color, temperature, and the ability to react with substances.
- An object's motion can be described by tracing and measuring its position over time.
- The Sun, the Moon, stars, clouds, birds, and airplanes all have properties, locations, and movements that can be observed and described.
- The Sun provides the light and heat necessary to maintain the temperature of the Earth.
- People have always had questions about the world. Science is one way of answering questions and explaining the natural world.
- Men and women have made a variety of contributions throughout the history of science and technology.
- Tools help scientists make better observations, measurements, and equipment for investigations.
- Objects in the sky have patterns of movements.

Benchmarks for Science Literacy-Project 2061

Grades K-2

- Raise questions about the world around them and be willing to seek answers to some of them by making careful observations and trying things out.
- Describing things as accurately as possible is important in science because it enables people to compare their observations with those of others.



- Describe and compare things in terms of their number, shape, texture, size, weight, color, or motion.
- Circles, squares, and triangles and other shapes can be found in nature and in things that people build.
- Numbers and shapes can be used to tell about things.
- The Sun can only be seen in the daytime, but the Moon can be seen sometimes at night and sometimes in the day. The Sun, Moon, and stars all appear to move slowly across the sky.
- Shapes such as circles, squares, and triangles can be used to describe many things that can be seen.
- Magnifiers help people see things they could not see without them.
- Simple graphs can help to tell about observations.
- Some events can be predicted well and some cannot.

Benchmarks for Science Literacy-Project 2061

Grades 3-5

- The Earth is one of several planets that orbit the Sun, and the Moon orbits the Earth.
- Scientists' explanations about what happens in the world come partly from what they observe, partly from what they think.
- Telescopes magnify the appearance of some distant objects in the sky, including the Moon and the planets. The number of stars that can be seen through telescopes is dramatically greater than can be seen by the unaided eye.
- Like all planets and stars, the Earth is approximately spherical in shape.
- The rotation of the Earth on its axis every 24 hours produces the night and day cycle. This turning of the planet makes it seem as though the Sun, Moon, and stars are orbiting around the Earth once each day.
- Tables and graphs can show how values of one quantity are related to values of another.
- Graphical display of numbers may make it possible to spot patterns that are not otherwise obvious, such as comparative size and trends.

National Educational Technology Standards (NETS)

- Students use technology to locate, evaluate, and collect information from a variety of sources.

Mathematics Standards (NCTM)

Grades K-2

- Understand patterns, relations, and functions.
- Analyze characteristics and properties of two- and three-dimensional geometric shapes and develop mathematical arguments about geometric relationships
- Understand measurable attributes of objects and the units, systems, and processes of measurement
- Represent data using concrete objects, pictures, and graphs.

Grades 3-5

- Build and draw geometric objects.
- Create and describe mental images of objects, patterns, and paths.
- Identify and draw a two-dimensional representation of a three-dimensional object.
- Understand the need for measuring with standard units and become familiar with standard units in the customary and metric systems.
- Collect data using observations, surveys, and experiments.
- Describe, extend, and make generalizations about geometric and numeric patterns.

INSTRUCTIONAL OBJECTIVES:

Students will learn to observe the Sun safely and will discover that the Sun has spots that appear and disappear over time. Students will discover that the Sun rotates. According to their grade level, students need to be aware of certain facts about the Sun, telescopes, and sunspots.

Grades: Kindergarten-2

1. The nine planets revolve around the Sun, which is the center of our solar system. Even though our Sun is millions of miles away, it is our closest star. The Sun is really a huge bright sphere made up of gas. One hundred nine Earths could fit across the diameter of the Sun. The energy created by the Sun goes out in to space. It gives us heat and light and supports life on Earth. It ultimately is the source of all food and fossil fuel. The Sun also causes the seasons, the climate, the currents in the ocean, the circulation of the air, and the weather on Earth.
2. A scientist named Galileo discovered sunspots about 400 years ago using a telescope. You should never look directly at the Sun even if you are wearing sunglasses or using binoculars or a telescope. You could burn your eyes and damage your eyesight.
3. Sunspots are dark areas on the Sun. They are really magnetic storms on the surface of the Sun. Sunspots are different sizes and shapes. They move across the Sun because the Sun rotates. Sunspots can last from a few days to several weeks. They can affect communication and weather here on Earth.

Grades 3-5:

1. The Sun is made up of hot gases, mainly hydrogen (90%), but has other elements present such as helium, carbon, nitrogen, and oxygen. The Sun's temperature is 10,000 degrees Fahrenheit on the surface and 27,000,000 degrees Fahrenheit in the center. The average distance from the Earth to the Sun is 93 million miles. It takes 8 1/2 minutes for light to travel from the Sun to the Earth. The Sun is large enough to hold over 1 million Earths. The diameter of the Sun is 870,000 miles, 109 times larger than Earth. The Sun is a medium-sized star called a yellow dwarf star. It gives off radio waves, ultraviolet rays, and xrays in addition to visible light. The Sun rotates, or spins on its axis, about once every 27 days. It has 4 layers—the core (center), the radiation layer, the convection layer, and the photosphere (the surface). There are 2 layers above the surface—the chromosphere and the corona.
2. In Italy in 1610, Galileo Galilei, known simply as Galileo, was the first scientist to observe sunspots with a telescope. He did this by making daily observations of the Sun and recording them.
3. Sunspots are irregularly shaped dark areas on the face of the Sun. They are really magnetic storms on the surface, or photosphere, of the Sun. Sunspots can be up to 8 times larger than the size of the Earth and can last a few days to several weeks. They are cooler than the area around them. Sunspots are dark in the center and lighter around the edges. The amount of sunspots changes on an 11-year cycle. Sunspots can cause power outages, interfere with radio communications and satellites, and affect the Earth's weather.

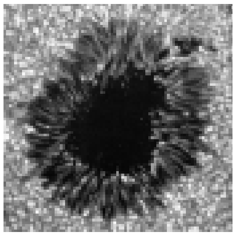
MISCONCEPTIONS ABOUT THE SUN:

- The Sun revolves around the Earth.
- The Sun disappears at night and reappears in the morning.
- The surface of the Sun is solid, smooth, and yellow.
- The "rays" of the Sun are lines out in space.

VOCABULARY:

Grades K-2

binoculars
communications
galaxy
gas
harmful
helpful
magnetic
orbit
revolve
solar
sphere
sunspot
telescope



ACTIVITIES:

1. Pre/Post Assessment
   Student worksheet to assess the student's prior knowledge of the Sun and sunspots.
2. Background information on the Sun and sunspots
   Read and discuss the NASA booklet Our Very Own Star: The Sun listed in the Internet Guide. See Internet sites #1, 5, 10, 11, 12, 14, 15, and 16, page 22.
3. What is the Sun?
   Student worksheet to review basic facts about the Sun–its type, shape, distance, and size.
4. Helpful and Harmful
   Student worksheet to discuss the helpful and harmful effects of the Sun.
5. Making a Homemade Sunspot Viewer
   Teacher worksheet that gives directions on how to assemble and use the sunspot viewer. The class needs to complete this activity with teacher direction. Teacher should then save the tracing sheets in order to complete the sunspot viewer review.
6. Sunspot Viewer Review
   This is a teacher-led discussion of the tracings of the Sun and the sunspots. See Internet site #9.
7. Sunspot Flip Book
   The teacher should precut the Sun pictures and the students could then assemble the booklet themselves or just lay them in numerical order on the table. See Internet site #3.
8. Sunspot Flip Book Journal
   This worksheet could be used by the teacher to lead a class discussion of the results from the Sun and sunspot drawings.
9. Sunspot Numbers
   Student worksheet that demonstrates the 11-year cycle of sunspots. For the younger students enlarge this chart and data table and complete this activity with the whole class. Individual students could then come to the board and add the correct data to the chart.

Name ______________________________

PRE/POST ASSESSMENT ACTIVITY

Draw a picture to show your answer.

1. What do you think the Sun looks like?

2. How does the Earth revolve around the Sun?

Fill in the blanks with a yes or no.

3. The Sun is shaped like a square. . . . . ______________

4. The Sun is solid. . . . . ______________

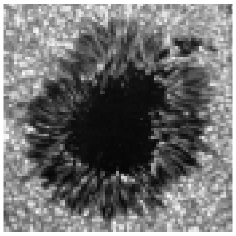
5. The Sun has spots. . . . . ______________

6. The Sun gives us heat and light. . . . . ______________

7. The Sun causes day and night. . . . . ______________

8. The Sun is our closest star. . . . . ______________

9. You can study the Sun and sunspots with a telescope. . . . . ______________



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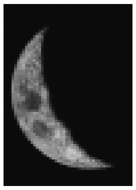
Name ___________________________________

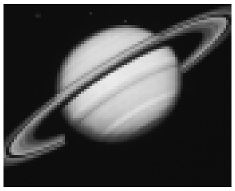
WHAT IS THE SUN?

Circle the correct answer.

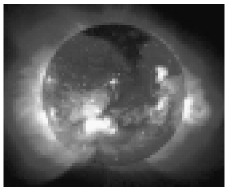
1. What is the Sun?



a moon

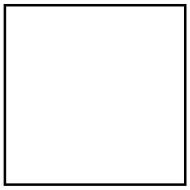


a planet



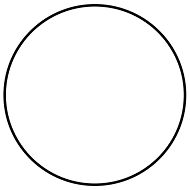
a star

2. What is the Sun shaped like?



a square

a ball



a circle

Fill in the blank with the underlined words.

3. Is the Sun the star closest to the Earth or farthest from the Earth?

The Sun is the star ____ the Earth.

4. Is the Sun bigger than or smaller than the Earth?

The Sun is ____ the Earth.

Name ____________________________________

HELPFUL AND HARMFUL

Draw one picture of how the Sun could be helpful and one picture of how the Sun could be harmful. Then fill in the blanks at the bottom of the page describing your pictures.

HELPFUL	**HARMFUL**

The Sun is helpful because

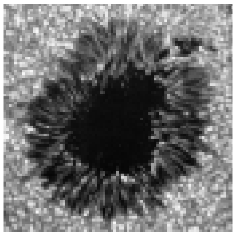
____

____

The Sun is harmful because

____

____



Name ___________________________________

MAKING A HOMEMADE SUNSPOT VIEWER

MATERIALS NEEDED:

Telescope
12-inch square piece of cardboard
Pencil/scissors/tape
White poster board
Building, tree, or adjustable music stand
Tracing paper

WARNING!!! It is never safe to look directly at the Sun because the Sun's rays can damage your eyes. It is safe to study the Sun's surface if you use a telescope to *project* the Sun's image onto a piece of paper.

PROCEDURE:

1. Set up a telescope *as if* you were looking at the Sun.
2. Cut a small hole in the center of the 12-inch square piece of cardboard.
3. Tape the cardboard with the hole in the center onto the large lens of the telescope. This cardboard serves 2 purposes. First, the outline of the cardboard will cast a shadow onto the second piece of paper which will make it easier to see the Sun's image. Second, the hole in the center will focus the image of the Sun on the second piece of paper.
4. Tack a piece of white poster board to a building or tree. If none are available, use an adjustable music stand. Focus the image of the Sun onto the piece of white poster board.
5. If the distance and focus are correct, on the poster board you should see a circle of light (the Sun's image) that is brighter at the center and darker around the edges. Inside the circle you should see some small dark spots which are sunspots. Trace the Sun and any sunspots that you see on the tracing paper.
6. Trace the Sun and it's sunspots every day for 10 days if possible, weather permitting. Be sure to date each paper. Try to trace the Sun at the same time each day. Label your dots A, B, C, etc., to show their movement.

RESULTS:

When the distance and focus are correct, you should expect to see a circle of light (the Sun), which is brightest at the center and darker around the edges. Inside the circle, generally toward the middle of the Sun, you will see small black dots; these are sunspots!

Name ___________________________________

SUNSPOT VIEWER REVIEW

Your class made many drawings of the Sun and the sunspots using the telescope. Lay your drawings on the floor or on a table. Arrange them in the same order they were made. Answer the following questions about your observations.

1. Does the Sun appear to change shape? What shape is it?

   ____

   ____

2. Do the sunspots appear to be moving?

   ____

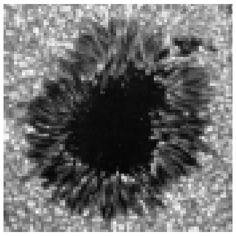
3. Which direction are the sunspots moving—horizontal (across) or vertical (up and down)?

   ____

4. If the sunspots continue to follow the same pattern, draw what you think the next Sun and sunspots would look like.

5. Are all the sunspots the same shape? The same size?

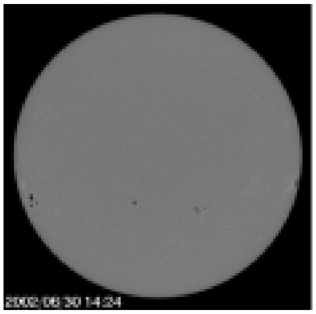
   ____



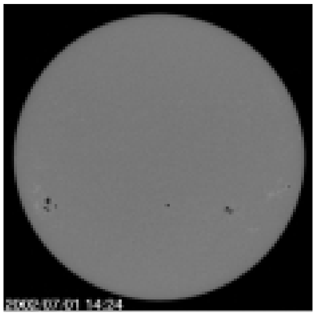
Name ___________________________________

SUNSPOT FLIP BOOK

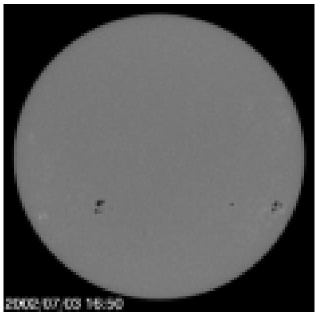
Cut out each picture. Arrange the pictures in order on top of each other. Staple into a flip book.



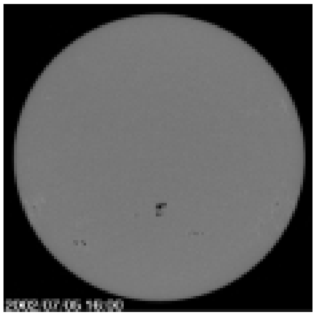
Picture 1



Picture 2

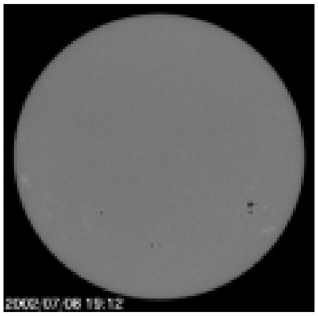


Picture 3

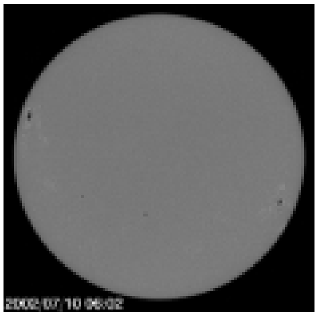


Picture 4

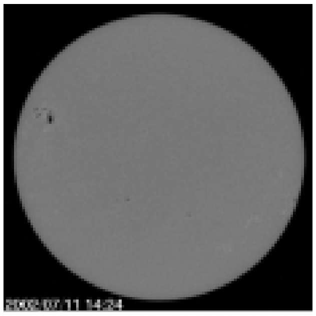
Picture 5



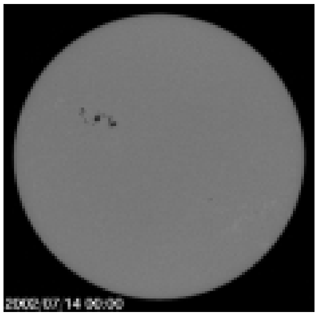
Picture 6



Picture 7



Picture 8



Picture 9

Name ___________________________________

SUNSPOT FLIP BOOK JOURNAL

After making your sunspot flip book, flip the pages quickly. Do this several times. Observe the pictures of the Sun and the sunspots. Answer the following questions about your observations.

1. Does the Sun appear to change shape? What shape is it?

   ____

2. Do the sunspots appear to be moving?

   ____

3. Which direction are the sunspots moving—horizontal (across) or vertical (up and down)?

   ____

4. If the sunspots continue to follow the same pattern, draw what you think the next Sun and sunspots would look like.

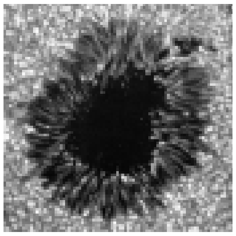
5. Are all the sunspots the same shape? The same size?

   ____

6. Were any of your answers the same for the drawings that you made with the telescope and your answers using the flipbook? Why or why not?

   ____

   ____



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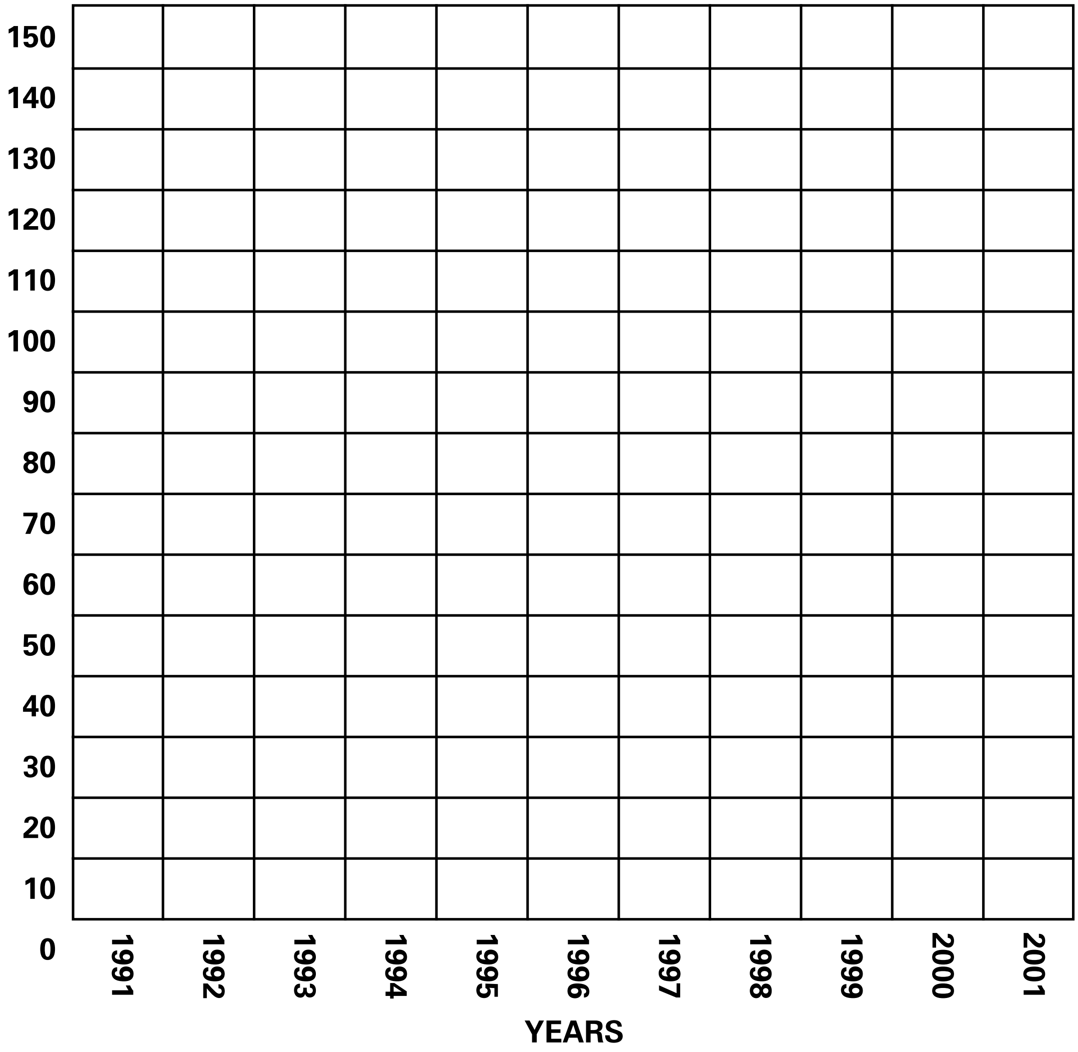
Name ___________________________________

SUNSPOT NUMBERS

Astronomers have found out that the number of sunspots increases and decreases every 11 years. Make a pictograph of the number of sunspots seen for each of the years listed below.

Draw a ☀ for every 10 sunspots.

1991-144 sunspots
1992-82 sunspots
1993-48 sunspots
1994-26 sunspots
1995-10 sunspots
1996-13 sunspots
1997-41 sunspots
1998-81 sunspots
1999-84 sunspots
2000-104 sunspots
2001-132 sunspots



GRADES 3-5

Vocabulary:

axis
chromosphere
convection layer
core
cycle
diameter
dwarf
element
observation
photosphere
radiation layer
satellite
sphere
ultraviolet rays

Activities:

1. Pre/Post Assessment

   Student worksheet to assess the student's prior knowledge of the Sun and sunspots.

2. Background information on the Sun and sunspots

   Read and discuss the NASA booklet *Our Very Own Star: The Sun* listed in the Internet guide and the book *The Sun* by Herbert Zim listed in the resource guide. Use this information for a class discussion and review about facts about the Sun—its type, shape, distance, size, etc. See Internet sites #1, 10, 11, 12, 14, 15, and 16, page 22.

3. Galileo Sees the Light

   Information and question sheet on Galileo, his telescope, and experiments observing the Sun, sunspots, and the planets. See Internet sites #3, 8, and 11.

4. Sunspot Poems

   After reading the books and reviewing the Web sites in activity #2, students will write a poem about sunspots. See Internet site #11—Solar poetry.

5. Layers of the Sun Worksheet

   Student worksheet that has the student labeling the 4 layers of the Sun and the 2 layers of the Sun's atmosphere. See Internet sites #6, 11, 12, and 14.

6. Our Very Own Star: The Sun puzzle

   Student worksheet reviewing basic facts about the Sun and sunspots. (Activities #7-10 are found in the grades K-2 section.)

7. Making a Homemade Sunspot Viewer

   Teacher worksheet that gives directions on how to assemble and use the sunspot viewer. The class needs to complete this activity with teacher direction. Teacher should then save the tracing sheets in order to complete the sunspot viewer review. See Internet site #2.

8. Sunspot Viewer Review

   Student worksheet to discuss tracings of the Sun and the sunspots.

9. Sunspot Flip Book

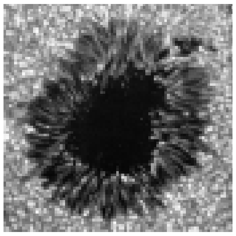
   Students will assemble the Flip book.

10. Sunspot Flip Book Journal

    Student worksheet analyzing the results of the sunspot flip book.

11. Sunspot Numbers

    Student worksheet that demonstrates the 11-year cycle of sunspots. See Internet sites #7, 11, and 17.



Name ________________________________

PRE/POST ASSESSMENT ACTIVITY

1. The Sun is so important to life on Earth. List 2 ways the Sun's light can be helpful and 2 ways it can be harmful.

   Helpful:

   a. ____

   b. ____

   Harmful:

   c. ____

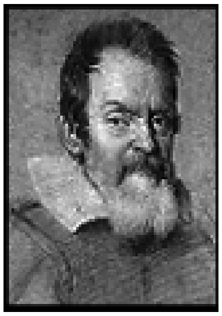
   d. ____

2. Draw how the Earth revolves around the Sun.

TRUE OR FALSE

3. The Sun gives off radio waves, ultraviolet waves, and x rays. . . . . .__________
4. Galileo observed the Sun and sunspots through a telescope in the 1600's. . . . . . .__________
5. Sunspots do not affect life on Earth or in space. . . . . .__________
6. Sunspots are really magnetic storms on the surface of the Sun. . . . . .__________
7. The Sun has 3 layers—the core, the chromosphere, and the convection layer. . .__________
8. The Sun is made up mainly of oxygen. . . . . .__________
9. Sunspots appear on the surface of the Sun in a regular pattern—an 11-year cycle.__________
10. The Sun rotates, or spins on its axis, about every 27 days. . . . . .__________
11. The Sun is a solid. . . . . .__________

Name ________________________________



GALILEO SEES THE LIGHT

Adapted from Thursday's Classroom
http://www.thursdayclassroom.com/03feb00/articlela.html

If you go outside at night and watch the stars for a long time, you will see that they move across the sky. They move because the Earth is turning. Long ago, many people thought that the Earth did not move. They thought that the stars, the Moon, and the Sun moved around the Earth! If you think that sounds silly, remember, these early scientists did not have any telescopes. All they had were two eyes, curiosity, and a star-filled sky.

Four hundred years ago, a scientist named Galileo loved to study the stars. At first he looked at the stars and planets with his eyes, but he wanted to see more. He decided to build a telescope. It wasn't the first telescope, but it was the best telescope in the world.

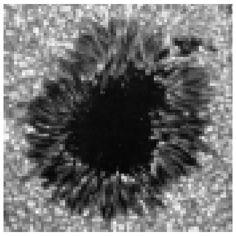
Can you imagine his excitement as he pointed his new telescope towards the stars? He could see that our Moon had mountains and valleys! He saw moons around Jupiter. His telescope amazed people all over Europe. Galileo showed his telescope to many famous people and let them look through it.

Galileo also used his telescope to study the Sun. During the summer of 1611, instead of going to the beach, he studied spots on the Sun. At first Galileo looked at the Sun through the telescope. What a mistake! It hurt his eyes.

Then, one of his students had a great idea. He pointed the telescope at the Sun and made an image of the Sun on a piece of paper. Galileo had already hurt his eyes, but this made it possible to study the sunspots safely.

Every day, he carefully drew pictures of the sunspots on the Sun. By looking at his drawings, he could tell that the sunspots were moving. He studied the drawings. He added up his numbers. Wow! The Sun must be spinning! He figured that the Sun spins around once every 27 days.

Galileo spent a lot of time looking at the planets. When he pointed the telescope at Jupiter, he also saw four tiny points of light. Each day the lights moved, but they were always around Jupiter. Galileo had discovered Jupiter's four biggest moons! This discovery made him famous.



Doing experiments made Galileo even more famous. Before Galileo, scientists did not do experiments. They thought and reasoned. Galileo made up experiments to prove his ideas.

Galileo also looked at the planet Venus. He was surprised by what he saw. Sometimes Venus looked like a crescent; sometimes it was full (like phases of the Moon). The only way that could happen would be if Venus moved around the Sun! In those days many people thought that the Earth was the center of everything. The Earth stood still and everything moved around our planet. The phases of Venus and the moons of Jupiter proved that the planets move around the Sun.

In Galileo's time, most people believed that the Earth stood still. Galileo's ideas were strange and exciting. There was a group of people that had the job of guarding people against bad ideas. This religious group was called the Inquisition. The Inquisition did not want Galileo to teach that the Earth moved around the Sun. They told Galileo that he could no longer teach those ideas. They thought that Galileo was wrong!

Now, we know that the Earth is not at the center of our solar system. Like all the other planets, the Earth moves around the Sun.

Thanks to Galileo and other brave scientists, we know the truth. The Earth is not at the center of everything. The most important thing Galileo taught us was a new way of doing science. By watching and experimenting you can learn a lot about nature. Galileo was a great scientist.

Fill in the blanks with these vocabulary words.

experiments 27 Sun sunspots Galileo telescope

Many years ago people thought that the Earth did not move. They thought that the stars, Moon, and the Sun moved around the Earth. Galileo used his ___________________ to study the Sun. By making an image of the Sun on a piece of paper, Galileo could study __________________ safely. By looking at his drawings, __________________ could tell that the sunspots were moving. He discovered that the _____________ must be spinning. He figured out that the Sun spins on its axis once every _____________ days. Galileo taught us a new way of doing science—by doing __________________.

Name ___________________________________

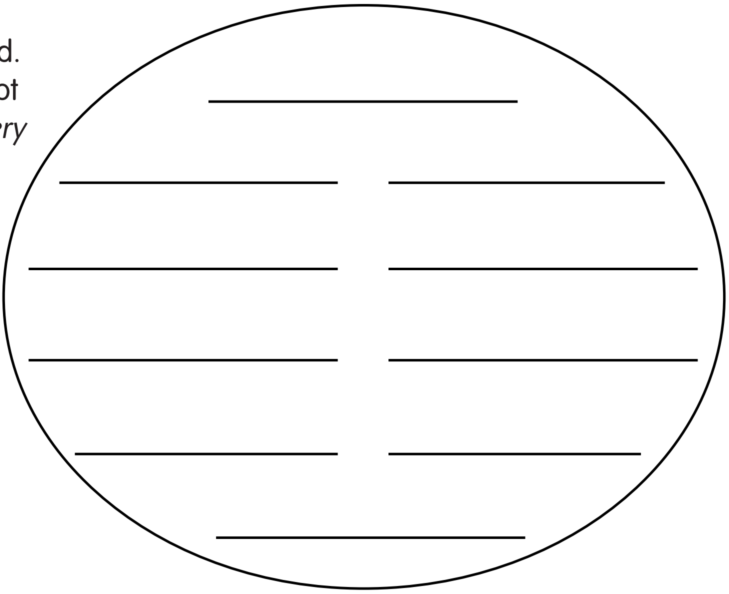
SUNSPOT POEMS

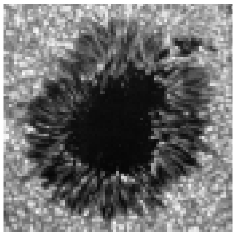
SOME LIKE IT HOT!

Did you ever learn in school
That sunspots are really cool?
They are!
The Sun is hot
But not that spot
Or at least not as hot as the burning Sun.
Everyday, scientists are having fun
Counting those sunspots,
Watching solar flares run,
Waiting for the time when the spots are none.
Studying the star.
Studying the spots.
Seeing how hot each spot has got.
They have really learned a lot!

From Thursday's Classroom *http://www.thursdaysclassroom.com/14oct99/activity4.html*

Poems are fun to read, write and find. Have you ever found a poem? It does not have to rhyme. Look in the book, *Our Very Own Star: the Sun,* for ten words that seem interesting, fun, or crazy. Put them in the blanks in the Sun. Read it to a friend.



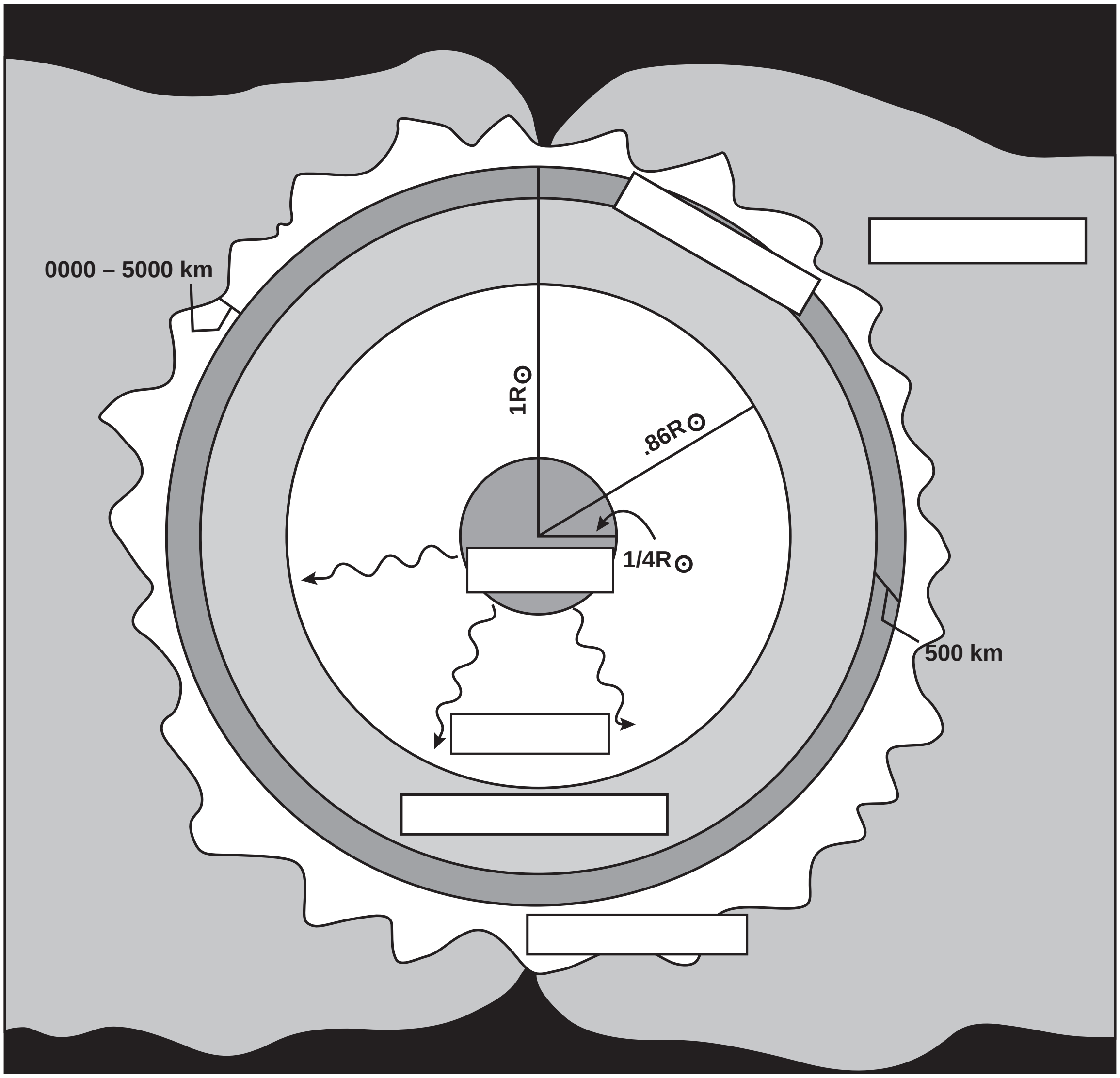


Name ___________________________________

LAYERS OF THE SUN

Label the 4 inner layers and 2 outer layers of the Sun in the box for the layer you are labeling. Use these vocabulary words:

Core	**Radiation layer**	**Convection layer**
Photosphere	**Corona**	**Chromosphere**



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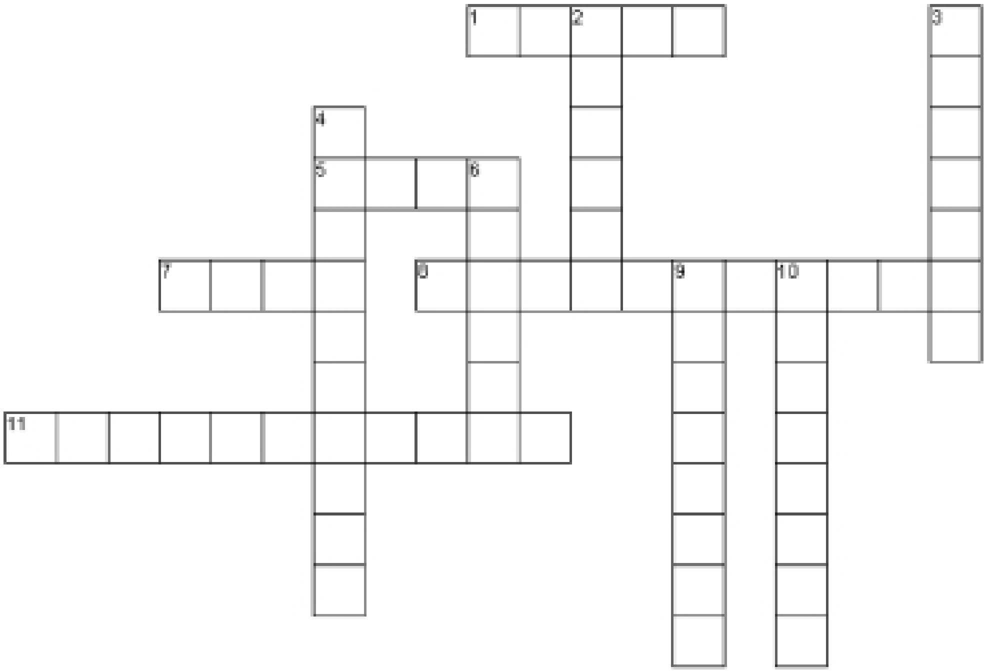
OUR VERY OWN STAR: THE SUN



ACROSS

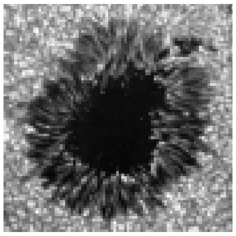
1. Our Sun is a medium yellow________ star.
5. The Sun spins on its_______________.
7. The center of the Sun is the ___________.
8. The __________is the surface of the Sun.
11. The Sun gives off ________ rays.

DOWN

2. Sunspots can __________ the Earth's weather.
3. ___________ was the first scientist to observe and record sunspots.
4. We get valuable data about the Sun from ____________.
6. The Sun is in the shape of a ___________.
9. _____________ are irregularly shaped dark areas on the Sun.
10. The Sun is made up mainly of _________.

VOCABULARY

Ultraviolet
Photosphere
Core
Axis
Dwarf
Affect
Hydrogen
Sphere
Satellites
Gallileo
Sunspots



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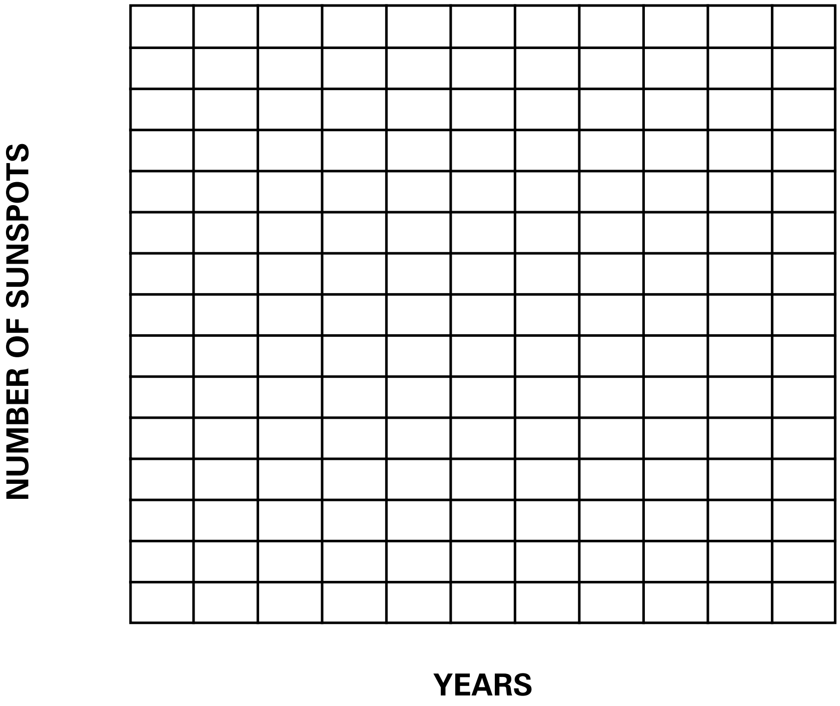
Name ________________________

SUNSPOT NUMBERS

Astronomers have been observing and recording the number of sunspots for hundreds of years. After analyzing the data, astronomers have determined that sunspots increase and decrease over an 11-year cycle. Listed below are the amount of sunspots seen in December of each year over an 11-year period. Make a line graph of the number of sunspots seen for each of the years listed below. Be sure to add the years and the scale for counting the number of sunspots.

1991-144 sunspots
1992-82 sunspots
1993-48 sunspots
1994-26 sunspots
1995-10 sunspots
1996-13 sunspots
1997-41 sunspots
1998-81 sunspots
1999-84 sunspots
2000-104 sunspots
2001-132 sunspots

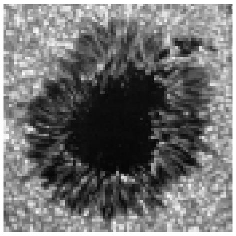


Answer the following questions about your data and the graph.

1. According to this data, in what year did astronomers see the most amount of sunspots? The least? ____
2. If the amount of sunspots seen follows the same pattern, what do you predict will be the number of sunspots seen in 2006? 2012? ______________________________________ ____
3. As the number of sunspots increases, what do you think will happen on Earth? ____

INTERNET CONNECTIONS

1. Information on Galileo and sunspots *http://es.rice.edu/ES/humsoc/Galileo/Things/sunspots.html*
2. Information on the Homemade Sunspot Viewers *http://stp.gsfc.nasa.gov/educ_out/summer01_pr/activities/Sunspot_Viewer.pdf*
3. Information on SOHO (Solar and Heliospheric Observatory) and daily images of the Sun *http://sohowww.nascom.nasa.gov*
4. Information on the size of the Sun compared to the size of the Earth *http://inspire.ospi.wednet.edu:8001/curric/space/sun/sunearth.html*
5. Information on sunspot numbers *http://science.nasa.gov/ssl/pad/solar/greewch/spot_num.txt*
6. Information on the layers of the Sun *http://www.genesismission.org/product/genesis_kids/aboutgenesis/solar_model.html*
7. Information on the rotation of the Sun including SOHO images *http://solar-center.stanford.edu/spin-sun/spin-sun.html*
8. Lessons on sunspots and ancient and modern solar science *http://cse.ssl.berkeley.edu/segwayed/abtsunspots.html*
9. Stories of NASA science and research that are easily understood by the nonscientist *http://science.nasa.gov*
10. Copies of the booklet *Our Very Own Star: The Sun* *http://stp.gsfc.nasa/gov/educ_out/kids_booklet/EP-2002-1-014_GSFC_Eng.pdf*
11. Lesson plans and educational activities from NASA *http://www.thursdaysclassroom.com* and *http://www.thursdaysclassroom.com/14oct99/activity4.html*
12. Overview of sunspots including their history and tips on how to safely view sunspots *http://www.exploratorium.edu/sunspots/*
13. Resource of space educational services, instructional materials, NASA projects and news *http://spacelink.nasa.gov*
14. Basic information on the Sun and layers of the Sun. Includes video clips of the Sun. *http://starchild.gsfc.nasa.gov/docs/StarChild/shadow/solar_system_level2/sun.html*
15. More factual information about the Sun. Also includes a timeline of Sun observations. *http://spacekids.hq.nasa.gov/osskids/animate/sun.html*
16. Easy to read information on sunspots, sunspot cycles, and ultraviolet light *http://kids.msfc.nasa.gov*
17. Current information on the present solar cycle *http://sunspotcycle.com/*



NATIONAL STANDARDS:

National Science Education Standards (NSES)

Content Standards 5-8

- Abilities necessary to do scientific inquiry.
- The motion of an object can be described by its position, direction of motion, and speed. That motion can be measured and represented on a graph.
- Most objects in the solar system are in regular and predictable motion. Those motions explain such phenomena as the day, the year, phases of the Moon, and eclipses.
- Many individuals have contributed to the traditions of science. Studying some of these individuals provides further understanding of scientific inquiry, science as a human endeavor, the nature of science, and the relationships between science and society.
- In historical perspective, science has been practiced by different individuals in different cultures. In looking at the history of many peoples, one finds that scientists and engineers of high achievement are considered to be among the most valued contributors to their culture.
- Tracing the history of science can show how difficult it was for scientific innovators to break through the accepted ideas of their time to reach the conclusions that we currently take for granted.

Benchmarks for Science Literacy

- Scientific knowledge is subject to modification as new information challenges prevailing theories and as a new theory leads to looking at old observations in a new way.
- Some scientific knowledge is very old and yet is still applicable today.
- Important contributions to the advancement of science, mathematics, and technology have been made by different kinds of people, in different cultures, at different times.
- Telescopes reveal that there are many more stars in the night sky than are evident to the unaided eye, the surface of the moon has many craters and mountains, the Sun has dark spots, and Jupiter and some other planets have their own moons.
- Thinking about things as systems means looking for how every part relates to others. The output from one part of a system (which can include material, energy, or information) can become the input to other parts. Such feedback can serve to control what goes on in the system as a whole.

National Educational Technology Standards (NETS)

- Students use technology to locate, evaluate, and collect information from a variety of sources.

Mathematics Standards (NCTM)

- Work flexibly with fractions, decimals, and percents to solve problems.
- Use two-dimensional representations of three-dimensional objects to visualize and solve problems.
- Select and apply techniques and tools to accurately find length, area, volume, and angle measures to appropriate levels of precision.
- Solve problems involving scale factors, using ratio and proportion.
- Apply and adapt a variety of appropriate strategies to solve problems.

INSTRUCTIONAL OBJECTIVES:

Students will learn to observe the Sun safely and will discover that the Sun has spots that appear and disappear over time. Students will discover that the Sun rotates. This activity can be extended to determine the average time of rotation of the Sun.

VOCABULARY:

- **Convective zone** - the outer most region of the interior of the Sun. The convective zone lies just below the visible surface of the Sun (the photosphere) and is about 200,000 km thick. Within this region energy is transferred through the mass motion of plasma. Hotter plasma moves upward and cooler plasma sinks.

- **Magnetic field** - the region of magnetic influence around a magnetic object such as a bar magnet, a current carrying wire, the Sun, Earth and of the magnetic planets.
- **Photosphere** - the lowest layer of the solar atmosphere where the Sun's visible spectrum of light is released. It is the visible "surface" we see in white-light images of the Sun.
- **Plasma** - One of the four states of matter. (The other three are solid, liquid and gas.) Consists of a gas of positively charged and negatively charged particles with approximately equal concentrations of both so that the total gas is approximately charge-neutral. A plasma can be produced from a gas if enough energy is added to cause the electrically neutral atoms of the gas to split into positively and negatively charged atoms and electrons.
- **Sunspot** - An area seen as a dark spot on the photosphere of the Sun. It appears dark because it is cooler than the surrounding photosphere.

PREPARING FOR THE ACTIVITY:

Student materials

- Galileo's sunspot drawings
- 4x6 index cards with reference circle (use Circle Template provided p. 27)
- Pencils
- Sunspotter® for each group
- Sunspot Observation Graphs (p. 28)

Teacher Materials

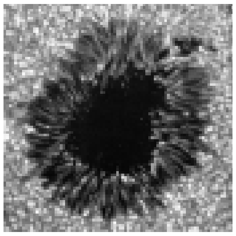
- Sun
- Copies of sunspot drawings from Galileo Web site
- Daily images of sunspots taken by SOHO (Solar and Heliospheric Observatory) spacecraft from the past 5 days

Time

- 2 full periods (40 - 50 minutes), one at the beginning and one at the end
- 3 sunspot-viewing sessions (at least) of 15-20 minutes each on consecutive days (or as nearly as possible) and the same time of day, if possible.

Advance Preparation

- A critical component of this activity is a device to project an image of the Sun on a piece of paper. **Remember: never look directly at the Sun, especially through a telescope or binoculars unless you have specially prepared solar filters.** One of the best devices is a commercial product, the Sunspotter®, available directly from Learning Technologies, Inc (800-537-8703). This lesson is designed for use with the Sunspotter®, however, you can use a small telescope or binoculars to project the image of the Sun. Instructions are available on the Solar Terrestrial Probes Education website *(http://stp.gsfc.nasa.gov/educ_out/summer01_pr/activities/Sunspot_Viewer.pdf).*
- Practice with the Sunspotter® before class! The Sunspotter® must be pointed correctly at the Sun. The image of the Sun will move due to the Earth's rotation, so the Sunspotter® must be constantly adjusted.
- Read **Background** (p. 1) with this lesson. (If you do not know very much about Galileo, the Galileo Web site referenced in the Background is highly recommended.)
- Prepare 4x6 index cards with reference circle (use Circle Template provided p. 27).
- Prepare sunspot drawings from Galileo Web site. *(http://es.rice.edu/ES/humsoc/Galileo/Things/g_sunspots.html)* Print two sets of at least four drawings from consecutive days. Keep a master with the dates for yourself. Then randomly rearrange the pictures of the second set, white out the dates and label them A, B, C, D, etc., and make copies for each group of students.
- Print the daily images of the Sun taken by SOHO showing sunspots from the last 5 days *(http://sohowww.nascom.nasa.gov)*. At the SOHO site click on *The Sun Now* in the upper left hand corner. You want images of the MDI Continuum, so click on *More MDI Continuum* (second row, left side). Try to get images that were taken at the



same time of day. The date and time are provided for each image. Click on the image you want, and then print the enlarged image.

- Prepare Student Observation Graphs for each student.

The Activity:

1. Assign groups according to the number of Sunspotters® available to enable participation for all students. Provide each student with a 4x6 card, a pencil, and a Sunspot Observation Graph.
2. Tell students about Galileo and his observations of the Sun. However, do not tell the students that Galileo discovered that the Sun rotated. Pass out the Galileo drawings of sunspots with the dates erased and randomly arranged (see Advanced Preparation). Tell the students the pictures were drawn on consecutive days, but you accidentally dropped the drawings and the pictures are out of order. Within their assigned groups, have them make a prediction about the correct order of Galileo's original drawings. Tell them this is only a prediction. Have each group record its prediction of the order of drawings on the board. After every group has recorded predictions, have each group explain their rationale for its prediction. This will tell you what they know about the topic. (Collect Galileo drawings at the end of the discussion for use later.)
3. Use the images taken by the SOHO spacecraft. Identify the sunspots charted for the previous few days. Discuss the differences you see and make predictions for observations you will take during the next few days. Don't forget to relate these observations to the Solar Cycle and predict where you think we are in the cycle now, and what you think the solar activity will be for the next year. Will it increase or decrease? Why do they think so?
4. Configure the Sunspotter® in an area of direct sunlight. Assign each of the student groups to one Sunspotter®. Have each student place his or her 4x6 card in the Sunspotter® and draw the sunspots he or she sees. Encourage discussion of other physical characteristics if any. **Always remind the student to never look directly at the Sun.** Have students record the number of sunspots on the Sunspot Observation Graph. Remind students that the day axis refers to the number of days since the beginning of observations. If a day is skipped because of a weekend or cloudy weather, that day must be skipped on the graph.
5. Encourage small group discussions, especially if one drawing varies from the others.
6. Have one student go to the SOHO Web site address listed above and check the image for that day. If a printer is available, print a copy and post it in the classroom for comparison and discussion.
7. Repeat steps 4-6 for the next 3-5 consecutive days or longer, depending on the weather. After the first day the observations will take only 15-20 minutes, so you should plan other activities about the Sun.
8. On one of the observing days have each student choose a favorite sunspot and estimate its size. They could use their own drawings, or, for greater accuracy, use the SOHO images. It is often useful to compare the size of a sunspot to the size of Earth. They will need to do some research on the size of the Sun and the size of the Earth. The "Sun and Earth Size Comparison" as part of the Athena Curriculum *(http://inspire.ospi.wednet.edu:8001/curric/space/sun/sunearth.html)* could be a good place to start this exploration.
9. Students can create their own "flip" book of index cards to see how the sunspots have changed position.
10. Have each student complete the Sunspot Observation Graph. Then have students access the International Sunspot Number compiled by the Sunspot Index Data Center in Belgium at *http://science.nasa.gov/ssl/pad/solar/greenwch/spot_num.txt*. (The numbers tabulated are the monthly averages of Sunspot Number (SSN) and standard deviation (DEV) derived from the International Sunspot Numbers.) Have students graph the last 3 to 5 years of data. You may wish to have students graph different years and then put all graphs together to observe long-term trends. Students should be aware that official sunspot numbers will probably be higher than their count. Researchers use a different system for deter-

mining sunspot numbers (see *http://www.sunspot.noao.edu/IMAGES/sunspot_numbers.html)* and their equipment is better. Ask students to compare the pattern they observed for numbers of sunspots on the Sunspot Observation Graph with the trend they can see on the graph of data from the International Sunspot Number data. (If you wish to become more involved in contributing to counts of sunspots, you can find out more at the SPA (Society for Popular Astronomy) Solar Section *(http://www.popastro.com/sections/solar/intro.htm)*.)

11. Facilitate a large group discussion on the last day to analyze final observations and compare charts. Students may observe that the size or number of sunspots may change. Students should observe that the sunspots change position in a regular way. This observation is the most important for this investigation. Ask the students to provide an explanation for the change in position of the spots. Several explanations are common: that the Sun rotates (correct), that the Earth's daily rotation is responsible, or that the Earth's orbit around the Sun is responsible. (Hopefully, no one will suggest that the spots are alien craft motoring in the plasma sea of the photosphere.)

    If they believe that the Earth's rotation is responsible, draw a circle with a dot in it on the board to represent the Sun and a sunspot or use a ball with a dot on it. Ask a student to stand at the back of the room and face the board. Then ask the student to turn around until he/she is facing the board again. Ask the student if the sunspot changed position. It hasn't!

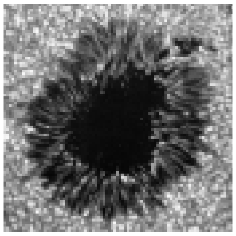
    It is more difficult to show that the Earth's orbit isn't responsible for the observed motion. Scale is important to this argument. You would need to have a ball of about 21.2 cm (or draw a circle on the board). The Earth would be the size of a peppercorn (a little less than 2 mm) about 23 m away. The peppercorn Earth would then move about 40 cm a day in a circle centered on the ball Sun. (You can divide all dimensions by one half or one third to fit the demonstration into the classroom.) Students can see that the small amount the Earth moves each day cannot explain the motion of the spots.

    If any student proposes that each spot is self-powered, see if anyone can realize this is unlikely because the spots all move together.

12. Hand out Galileo drawings from the first day and again ask each group to determine the correct order for the drawings and reflect upon their original predictions. Have each group record its solution of the order of drawings on the board. After every group has recorded results, have each group explain their rationale for its solution.
13. Assign readings about Galileo. Visit *http://es.rice.edu/ES/humsoc/Galileo* for more information.

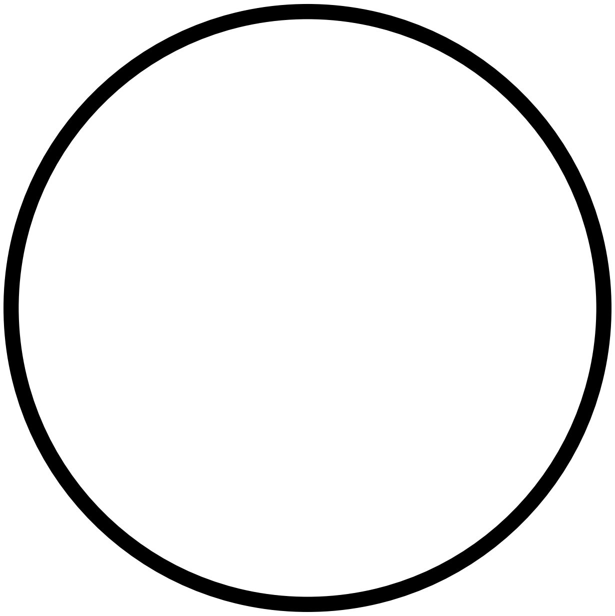
EXTENSIONS:

1. Celebrate Sun-Earth Day 2003 - "Live from the Aurora" *(http://sunearth.gsfc.nasa.gov/sunearthday/)*. Enroll your school in the Student Observation Network (SON) *(http://sunearth.gsfc.nasa.gov/sunearthday/2003/network.htm)* and participate with other schools in obtaining information on sunspots, changes in the Earth's magnetosphere and ultimately observation of auroras. Join the fun and help your students conduct long-term research!
2. The data obtained from the student investigations or from the SOHO images can be used to calculate the period of rotation in an excellent math lesson. The Stanford Solar Center offers *The Spinning Sun. (http://solar-center.stanford.edu/spin-sun/spin-sun.html)*
3. The Science Education Gateway (SEGWAY) Web site offers excellent activities to extend the students' understanding of sunspots and their dynamics in a lesson called "Sunspots." This lesson covers solar science, ancient and modern, features an interactive research exercise in which students attempt to correlate the areas of sunspots with those of x-ray active regions. Self-guided sections on history and modern study include researcher interviews. *(http://cse.ssl.berkeley.edu/segwayed/abtsunspots.html)*.

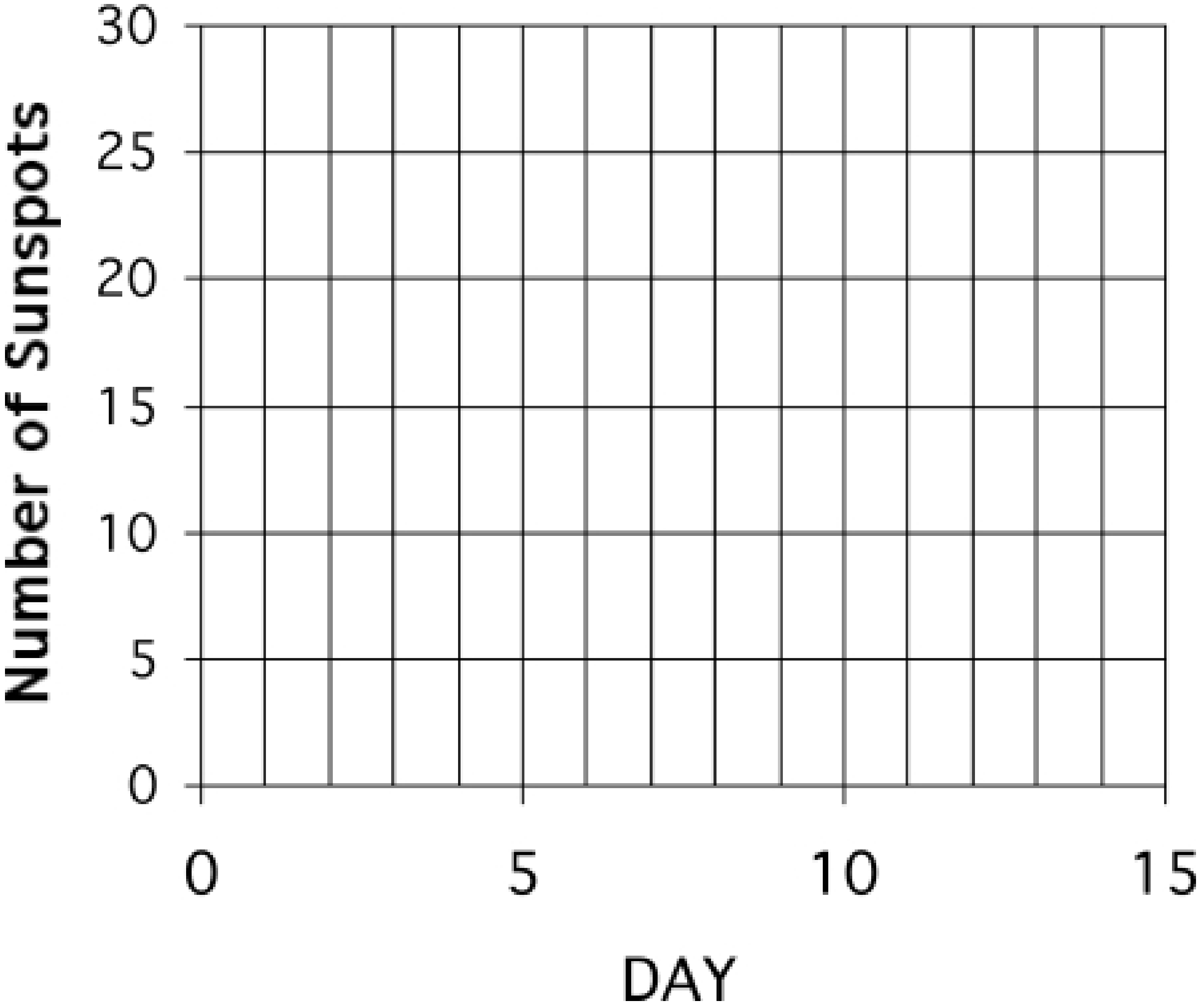


Circle Template:

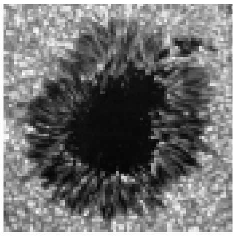
Below is a circle the size of the Sun's image on the Sunspotter®. Copy this image onto the 4x6 index cards before the observations.



Sunspot Observation Graph



What can you conclude from this graph?



RADIO WAVES

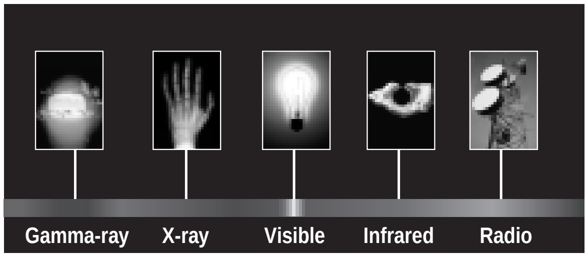
BACKGROUND:

The **electromagnetic spectrum** consists of waves of many **wavelengths** ranging from very long wavelength radio waves to very short wavelength **gamma rays**. Visible light, consisting of short wavelength waves, is placed near the middle of this spectrum.

Visible light can pass through window glass, but a solid wall will absorb a portion of the light and reflect the remaining portions. Scientists would say that glass is transparent to visible light, but a wall is opaque.

Since the atmosphere is transparent to visible light (while absorbing some of the light), astronomers who use telescopes can see things from far away using visible light to form images.

Earth's atmosphere, however, acts as an opaque barrier for much of the electromagnetic spectrum. The atmosphere absorbs most of the wavelengths shorter than



ultraviolet, most of the wavelengths between infrared and microwaves, and most of the longest radio waves. For radio astronomers this leaves only short wave radio to penetrate the atmosphere and bring information about the universe to our Earth-bound instruments. The main frequency ranges allowed to pass through the atmosphere are referred to as the radio window. The radio window consists of frequencies that range from about 5 MHz (5 million hertz) to 30 GHz (30 billion hertz). The low-frequency end of the window is limited by signals being reflected by the ionosphere back into space, while the upper limit is caused by absorption of the radio waves by water vapor and carbon dioxide in the atmosphere. As atmospheric conditions change the radio window can expand or shrink. On clear days with perfect conditions signals as high as 300 GHz have been detected.

It is the effects of the ionosphere on the lower end of the radio spectrum that we will investigate in this exercise.

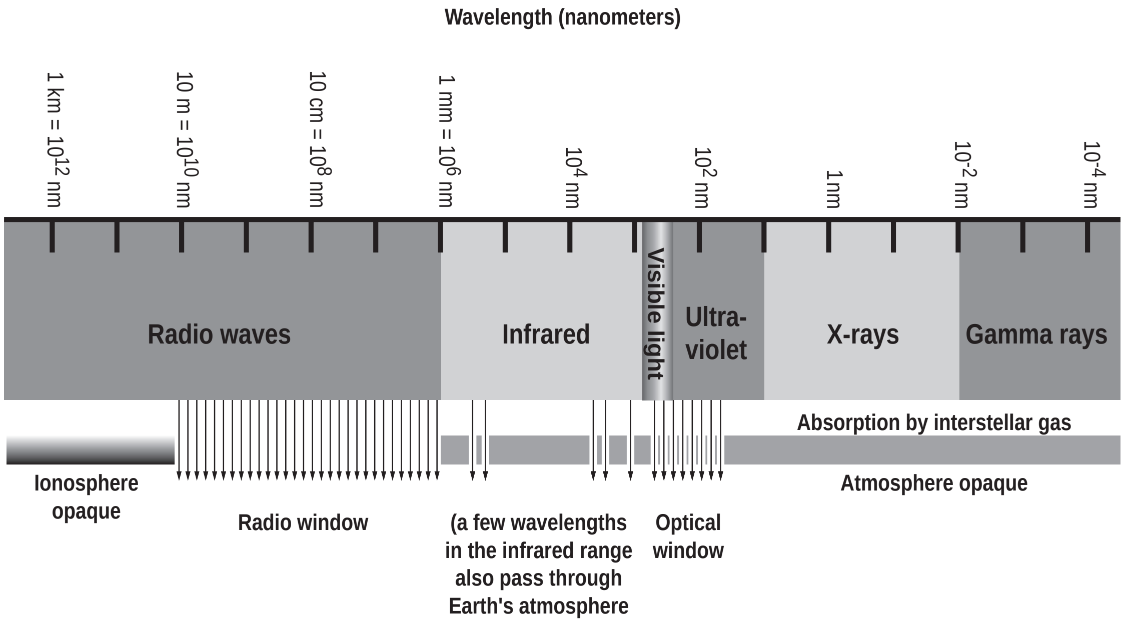
THE IONOSPHERE

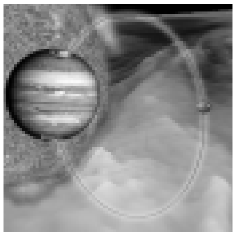
The ionized part of the Earth's atmosphere is known as the ionosphere. **Ultraviolet light** from the Sun collides with atoms in this region knocking electrons loose. This creates ions, or atoms with missing electrons. This is what gives the Ionosphere its name and it is the free electrons that cause the reflection and absorption of radio waves.

How does this affect our observations?

When the Sun is overhead during the day, most of the ionosphere is ionized due to the large amount of ultraviolet light coming from the Sun. As radio waves enter Earth's atmosphere from space some of the waves are absorbed by the electrons in the ionosphere while others pass through and are detectable to

Atmospheric Windows to Electromagnetic Radiation





ground-based observers. The frequency of each of these waves is what determines whether or not it is absorbed or able to pass through the atmosphere. Low-frequency radio waves do not travel very far through the atmosphere and are absorbed rather quickly. Higher frequency waves are able to pass through the atmosphere entirely and reach the ground.

This process also works in reverse for radio waves produced on the Earth. The high-frequency waves pass through the ionosphere and escape into space while the low-frequency waves reflect off the ionosphere and essentially "skip" around the Earth.

The diagram below will help illustrate this.

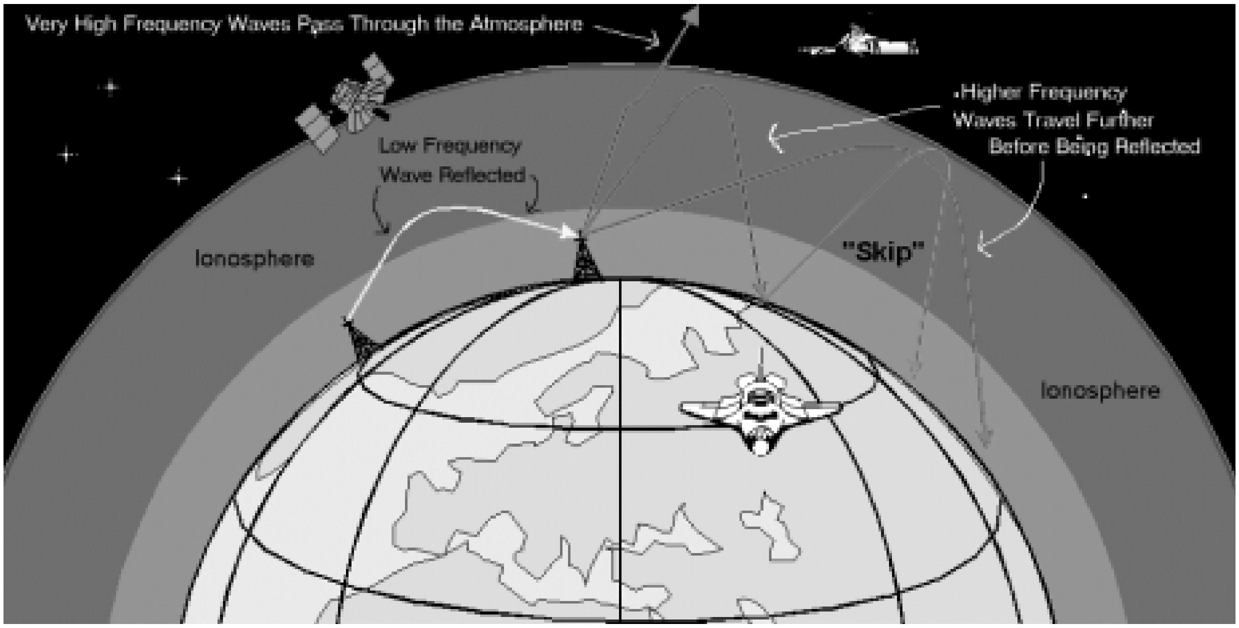
What's all this talk about high-frequency and low-frequency radio waves? What types of things fall in each range?

Astronomical radio sources emit over a wide range of frequencies. Their emission can be measured ranging from low frequencies to high frequencies. Jupiter for example emits radio waves from about 10 kHz up to about 300 GHz, while the Sun emits radio waves in all wavelengths. This emission is broken into several groupings. The lowest being the kilometric emission that ranges from 10 kHz up to 1000 kHz. Other frequency groups include hectometric (1000 KHz to 3 MHz), decametric (3 MHz to 40 MHz), and decimetric (100 MHz to 300 GHz). It is the decametric emissions that we are concerned about with Radio Jove. The Radio Jove receiver is tuned to a frequency of 20.1 MHz.

Radio waves produced on Earth are mostly man-made and are often at one specific frequency. In fact, this is one way astronomers can tell a signal created on Earth apart from an astronomical signal. If they are able to tune their receivers to a slightly higher or lower frequency and the signal disappears it is most likely an Earth-based signal. Radio waves fall into three main categories with a variety of uses:

H.F. (High Frequency 3 to 30 MHz)

- Long range communications. Shipping, aircraft, world broadcast communications, radio amateurs.
- Use involves reflecting the signal off the ionosphere back down to waiting receiving stations. Prone to atmospheric changes causing fading and noise.
- Range from 500 to thousands of kilometers.



V.H.F. (Very High Frequency 30 to 300 MHz)

- Medium-range communications. Fleet vehicles, mobile, coastal shipping and air-to-tower communications.
- Range 70-100 km (aircraft several hundred km).

U.H.F (Ultra High Frequency 300 to 3000 MHz)

- This is the domain of such things as police hand-held radios, cell phones, T.V., and spacecraft-to-ground communications. In the high U.H.F. range the signal can "bounce" off buildings and reflect until it is detected by a receiver.

See additional activity:

http://radiojove.gsfc.nasa.gov/class/educ/radio/tran-rec/exerc/iono.htm

NATIONAL STANDARDS:

National Science Education Standards (NSES)

Grades 5-12

Middle school students grades 6-8 can learn about the electromagnetic spectrum, including the assertion that it consists of wavelike radiations. Wavelength should be the property receiving the most attention but minimal calculations.

High school students are ready to add the power of mathematics. Students at a sufficient minimum should develop semi-quantitative notions about waves—higher frequencies have shorter wavelengths and those with longer wavelengths tend to spread out more around objects. (Project 2061)

Mathematics (NCTM) Standards

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems.
- Use mathematical models to represent and understand quantitative relationships.
- Apply appropriate techniques, tools and formulas to determine measurements.
- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them.
- Develop and evaluate inferences and predictions that are based on data.

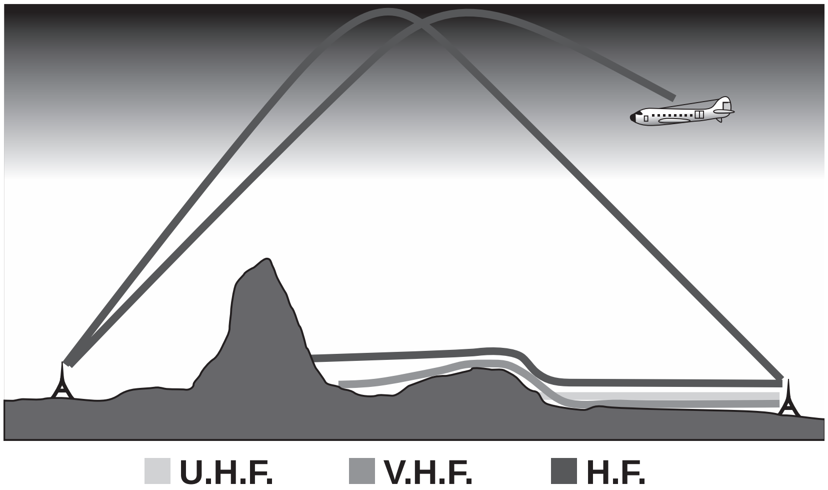
Science (NSE) Standards

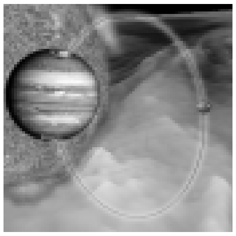
- Abilities necessary to do scientific inquiry.
- Understandings about scientific inquiry.
- Earth in the solar system.
- Understandings about science and technology.

Benchmarks for Science Literacy (Project 2061)

Grades 6-8

- Vibrations in materials set up wavelike disturbances that spread away from the source. Sound and earthquake waves are examples. These and other waves move at different speeds in different materials.





Grades 9-12

- Accelerating electric charges produce electromagnetic waves around them. Varieties of radiation are electromagnetic waves: radio waves, microwaves, radiant heat, visible light, ultraviolet radiation, x-rays, and gamma rays. These wavelengths vary from radio waves, the longest, to gamma waves, the shortest. In empty space, all electromagnetic waves move at the same speed—the "speed of light."

Technology for All Americans (ITEA) Standards

- Develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

Technology (NET) Standards

- Select and use appropriate tools and technology resources to accomplish a variety of tasks and solve problems.

INSTRUCTIONAL OBJECTIVES:

- Students will identify radio waves on the electromagnetic spectrum.
- Students will utilize radio waves as a method of predicting the visual connection of the Sun and Earth, an aurora.

VOCABULARY:

- **Electromagnetic spectrum** consists of waves of many wavelengths ranging from very long wavelength radio waves to very short wavelength gamma rays. Visible light, consisting of short wavelength waves, is placed near the middle of this spectrum.
- **Radio waves** are energy waves produced by charged particles naturally emitted by the Sun, other stars and planets.
- **Visible light** can pass through window glass, but a solid wall will absorb a portion of the light and reflect the remaining portions. Scientists would say that glass is transparent to visible light, but a wall is opaque. Visible light is the region of the electromagnetic spectrum that can be perceived by human vision.
- **Ionosphere** is the ionized part of the Earth's atmosphere. Ultraviolet light from the Sun collides with atoms in this region knocking electrons loose.

ACTIVITIES:

ACTIVITY 1-A Scientific Notation and the Speed of Light

Radio waves, like all electromagnetic waves, travel at the speed of light–300,000,000 meters per second (3 hundred million meters per second). The speed of light is obviously a large number. In working with this number, and other large numbers, it is convenient to express it in scientific notation. In **scientific notation**, powers of ten are used to represent the zeros in large numbers. The following table shows how this is done.

Number	Name	Power of ten
1	one	10^0
10	ten	10^1
100	hundred	10^2
1000	thousand	10^3
10000	ten thousand	10^4
100000	hundred thousand	10^5
1000000	million	10^6
10000000	ten million	10^7
100000000	hundred million	10^8
1000000000	billion	10^9

If you examine the first and last columns, you can see that the power of ten is the same as the number of zeroes in the number. So the speed of light, which is 3 followed by 8 zeroes, becomes 3 x 10^8 meters per second. The standard symbol for the speed of light is **c**, so we can write:

$$c = 3 \times 10^8 \text{ m/s}$$

Since radio waves travel at a constant speed, the distance traveled is given by:

distance = speed times time

or $d = c\,t$

where d = distance in meters
t = time in seconds
$c = 3 \times 10^8$ meters per second

Example Problem: How far does a radio wave travel in 5 minutes?

$t = 5$ min $= 5(60) = 300$ s $= 3 \times 10^2$ s
$c = 3 \times 10^8$ m/s
$d = ?$ m

$d = c\,t$
$d = (3 \times 10^8)\,(3 \times 10^2)$
$d = (3 \times 3) \times 10^{8+2}$
$d = 9 \times 10^{10}$ m

RULE: to multiply, MULTIPLY the numbers, ADD the powers of 10

Problems:

1. How far does light travel in 20 seconds?
2. How far does light travel in 30 minutes?
3. How far does light travel in 4 hours?
4. How far does light travel in 2 days?

If you know the distance and the speed (c), you can find the time it takes for radio waves to travel that distance using:

$$d = c\,t$$

$$t = \frac{d}{c}$$

where d = distance in meters (m)
c = speed of light (3×10^8 m/s)
t = time in seconds (s)

Example Problem: How long does it take radio waves to travel from Earth to the moon, a distance of 400,000 kilometers?

$d = 400{,}000$ km $= 400{,}000{,}000$ m $= 4 \times 10^8$ m
$c = 3 \times 10^8$ m/s
$t = ?$

$t = \frac{d}{c}$

$t = \frac{4 \times 10^8}{3 \times 10^8}$

$t = \frac{4}{3} \times 10^{8-8}$

RULE: to divide, DIVIDE the numbers and SUBTRACT the powers of 10 (Subtract the bottom power from the top)

$t = 1.33 \times 10^0$ (NOTE: $10^0 = 1$)

$t = 1.33$ s

Example Problem: How long does it take radio waves to travel from Mars to Earth when Earth and Mars are on the same side of the Sun?

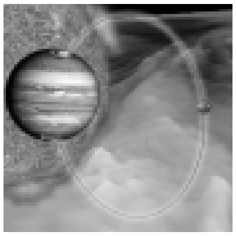
For this problem, we will be working with large numbers that have several nonzero digits. In this case, the power of ten indicates how many places to move the decimal to the right rather than the number of zeroes to add. We will also round off the values so that there are only three nonzero digits with one digit to the left of the decimal. This is called **standard form**.

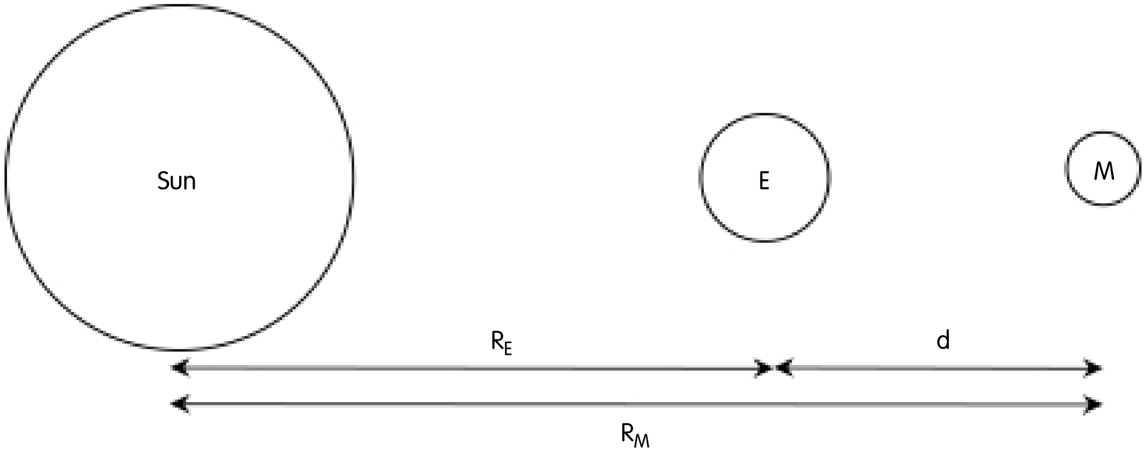
radius of Mars' orbit

$R_M = 227{,}940{,}000$ km $= 2.28 \times 10^8$ km $= 2.28 \times 10^{11}$ m

radius of Earth's orbit

$R_E = 149{,}600{,}000$ km $= 1.50 \times 10^8$ km $= 1.50 \times 10^{11}$ m





RULE: to subtract, IF the powers of ten are the same, SUBTRACT the numbers and the power of ten remains the SAME

$d = R_M - R_E$

$d = 2.28 \times 10^{11} - 1.50 \times 10^{11}$

$d = 2.28 - 1.50 \times 10^{11}$

$d = .78 \times 10^{11}$

$d = 7.8 \times 10^{10}$ m (NOTE: standard form)

$t = \frac{d}{c}$

$t = \frac{7.8 \times 10^{10}}{3 \times 10^{8}}$

$t = 2.6 \times 10^{10-8} = 2.6 \times 10^{2}$

$t = 260$ s (4 minutes 20 seconds)

Use the following table for Problems 5-8.

Planet	Radius of orbit
Mercury	57,910,000 km
Venus	108,200,000 km
Earth	149,600,000 km
Mars	227,940,000 km
Jupiter	778,330,000 km
Saturn	1,429,400,000 km

In the following problems, assume that the planets are on the same side of the Sun (as close to one another as possible).

Problems:

5. How long would it take radio waves to travel from Jupiter to Mars?
6. How long would it take radio waves to travel from Jupiter to Venus?

On these last two problems, be careful when you subtract the distances. They should have the same power of ten. (HINT: one distance will not be in standard form.)

7. How long would it take radio waves to travel from Jupiter to Saturn?
8. How long would it take radio waves to travel from Mercury to Mars?

Answer key for Activity 1.

1. 6 x 109 m
2. 5.4×10^{11} m
3. 4.32×10^{12} m
4. 5.18×10^{13} m
5. 1.83×10^{3} s (30.6 minutes)
6. 2.23×10^{3} s (37 minutes)
7. 2.17×10^{3} s (36 minutes)
8. 5.6×10^{2} s (9.4 minutes)

ACTIVITY 1-B
Scientific Notation on the Calculator

The rules for working with numbers in scientific notation are not complicated:

- **MULTIPLICATION:** multiply the numbers and add the powers of ten
- **DIVISION:** divide the numbers and subtract the powers of ten
- **ADDITION/SUBTRACTION:** powers of ten must be the same; add/subtract the numbers; power of ten remains the same
- **STANDARD FORM:** the number part must be between 1 and 10.

The handheld scientific calculator does all of these steps automatically. The following example calculations were done using a Texas Instruments TI-30X SOLAR calculator. Steps on other calculators are similar although some key names and procedures are different. Consult the manual if you are using a different calculator.

(NOTE: When it says to "PRESS," that refers to a calculator key. If a number is being entered, simply press the digits in order.)

The following are the "Example Problems" from Activity 1.

Multiply 300 x 300,000,000

PRESS	**CALCULATOR DISPLAY**
2nd 5	$0.^{00}$ (Scientific Notation Mode)
300 X	$3.^{02}$
300000000 =	$9.^{10}$

Divide: 4000000 / 3×10^8

PRESS	**CALCULATOR DISPLAY**
2nd 5	$0.^{00}$ (Scientific Notation Mode)
400000000 ÷	$4.^{08}$
3 EE 8 =	1.333333333^{00}

Subtract: $2.28 \times 10^{11} - 1.50 \times 10^{11}$

PRESS	**CALCULATOR DISPLAY**
2nd 5	$0.^{00}$ (Scientific Notation Mode)
2.28 EE 11 —	2.28^{11}
1.50 EE 11 =	7.8^{10}

Additional Examples:

Subtraction when the numbers have different powers of ten.

Subtract: $4.6 \times 10^{10} - 3.9 \times 10^{9}$

PRESS	**CALCULATOR DISPLAY**
2nd 5	$0.^{00}$ (Scientific Notation Mode)
4.6 EE 10 —	4.6^{10}
3.9 EE 9 =	4.21^{10}

Notice that all answers are given in standard form automatically. Also, in the last example there is no need to change the numbers to the same power of ten–that is done by the calculator.

ACTIVITY 2
Wavelength and Frequency

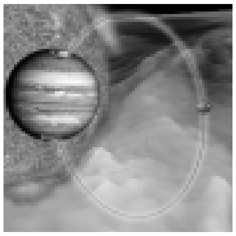
The frequency of a wave is defined as the number of waves created per second. As the waves propagate away from the source, the frequency also represents the number of waves that will pass a point per second. The unit of frequency is the hertz (Hz).

The wavelength, or length of a wave, is defined as the distance from one point on a wave to the corresponding point on the next wave. Since wavelength is a distance, the unit of wavelength is the meter (m).

Frequency, wavelength and speed are related by the equation:

$$c = \lambda f$$

where c is the speed of light (3×10^8 m/s),
λ (lambda) is the wavelength in meters (m),
and f is the frequency in hertz (Hz).



From this equation we can see that a long wavelength will have a low frequency while a short wavelength will have a high frequency since the product of these two quantities is constant.

Example problem: Find the wavelength of a radio wave with a frequency of 900 kHz.

$f = 900 \text{ kHz} = 900 \times 10^3 \text{ Hz} = 9 \times 10^5 \text{ Hz}$
$c = 3 \times 10^8 \text{ m/s}$
$\lambda = ?$

$c = \lambda f$ (Solve for λ)

$$\frac{\lambda}{f} c = \lambda f \frac{1}{f}$$

$$\lambda = \frac{c}{f}$$

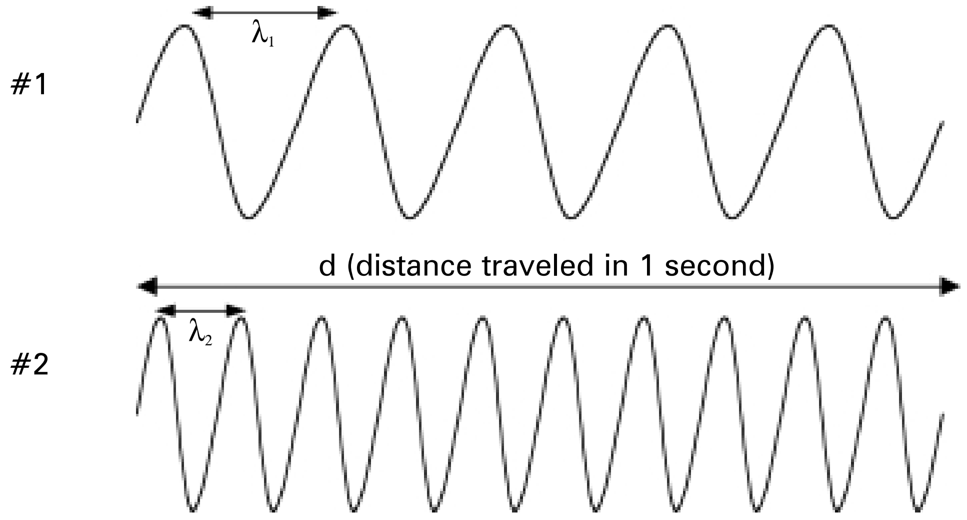
$$\lambda = \frac{3 \times 10^8}{9 \times 10^5}$$

$\lambda = .33 \times 10^3 = 3.3 \times 10^2$ m (330 m)

Problems

1. Find the wavelength of a radio wave with a frequency of 650 kHz.
2. Find the wavelength of a radio wave with a frequency of 1300 kHz.
3. Find the wavelength of a radio wave with a frequency of 90 MHz.
4. Find the wavelength of a radio wave with a frequency of 101.5 MHz.
5. AM radio stations have frequencies from 540-1700 kHz.
   a) Find the shortest wavelength AM radio signal.
   b) Find the longest wavelength AM radio signal.
6. FM radio stations have frequencies from 88-108 MHz.
   a) Find the longest wavelength FM radio signal.
   b) Find the shortest wavelength FM radio signal.

In this diagram, the distance (d) indicated represents the distance the waves travel in 1 second.



Wave #1 has 5 complete waves passing by in one second, while Wave #2 has 10 waves passing by in the same time. If you were to watch Wave #1 pass a point, the frequency would be 5 waves per second – 5 Hz. Wave #2 would have a frequency of 10 Hz. Wave #1 has half the frequency of Wave #2 and two times the wavelength. For both waves, the product of the wavelength and frequency are the same.

Answer key for Activity 2

1. 4.6×10^2 m (460 m)
2. 2.3×10^2 m (230 m)
3. 3.3 m
4. 2.96 m

5a. 1.76×10^2 m (176 m)

5b. 5.56×10^2 m (556 m)

6a. 3.4 m

6b. 2.8 m

ACTIVITY 3
Jupiter...

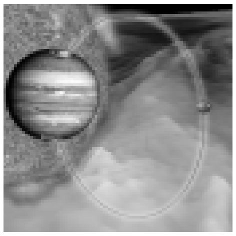
- The distance from the Sun to Jupiter is 778,330,000 km.
- The distance from the Sun to Earth is 149,600,000 km.
- In the following problem, assume that the planets are on the same side of the Sun (as close to one another as possible).

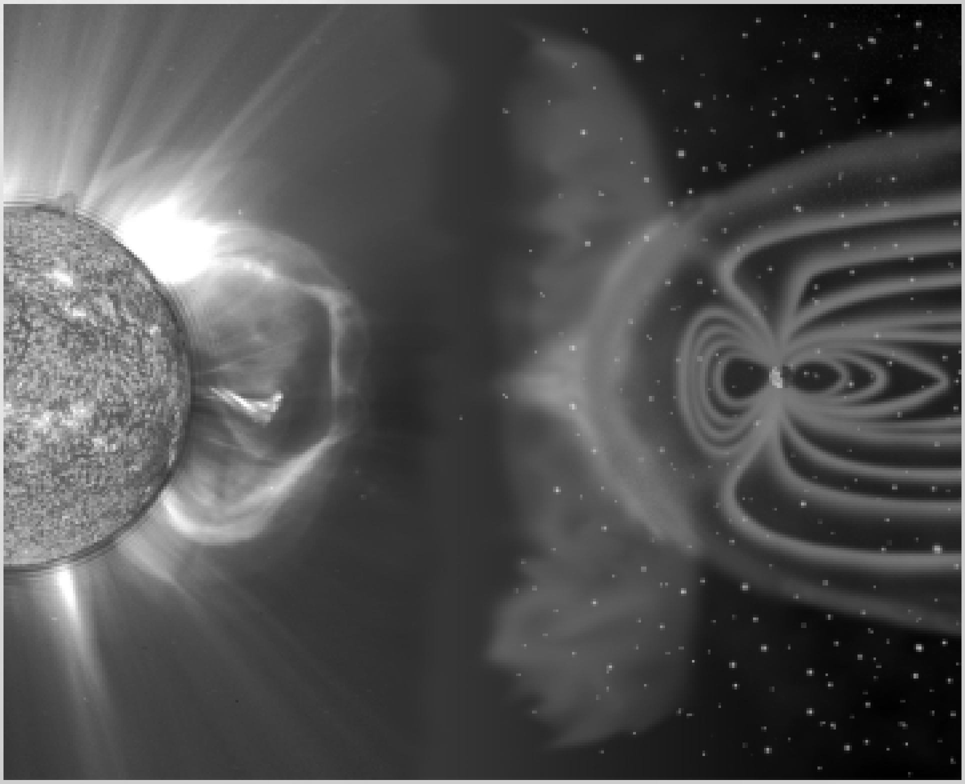
1. How long does it take for radio signals to travel from Jupiter to Earth?

   The frequency range of Jupiter radio emissions that can be detected on Earth is 8 MHz to 40 MHz.
2. Find the shortest wavelength Jupiter radio wave that can be detected on Earth.
3. Find the longest wavelength Jupiter radio wave that can be detected on Earth.
4. Find the wavelength of the Jupiter radio wave that has a frequency of 20.1 MHz.

Answer key for Activity 3

1. 2.1×10^3 s (34.9 minutes)
2. 7.5 m
3. 37.5 m
4. 14.9 m



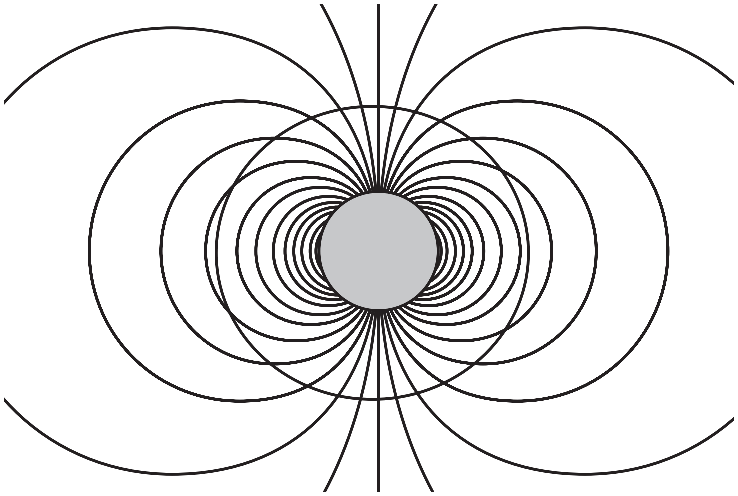


MAGNETISM

BACKGROUND:

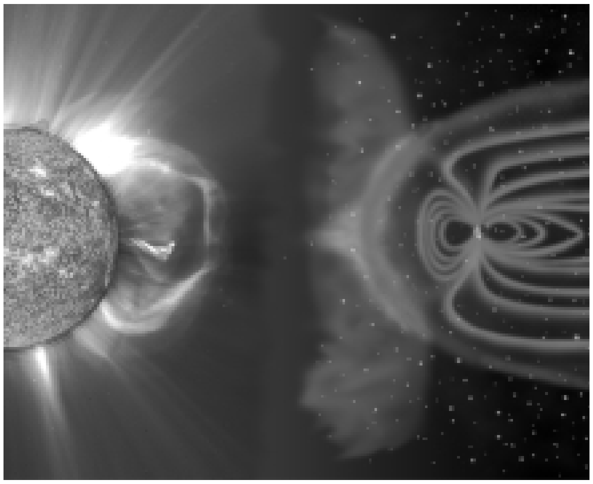
A spherical magnet in an otherwise empty region of space would have a magnetic field approximately modeled in the figure on the next page.

The Earth's magnetic field close to the Earth can be thought of approximately as a spherical magnet. Notice that at the poles the field is nearly vertical and at the equator it is nearly horizontal. More than 90% of the Earth's magnetic field measured is generated internal to the planet in the Earth's outer core. This portion of the geomagnetic field is often referred to as the Main Field. The Main Field creates a cavity in interplanetary space called the magnetosphere, where the Earth's magnetic field dominates in the magnetic field of the solar wind. The magnetosphere is shaped somewhat like a comet in response to the dynamic pressure of the solar wind. It is compressed on the side toward the Sun to about 10 Earth radii (R_E is 6400 km) and is extended tail-like on the side away from the Sun to more than 100 Earth radii.



The inner circle represents the outer core of the Earth. The outer circle represents the surface of the Earth

The shape of the Earth's magnetic field is formed by the interaction of several important features. One feature is, of course, the Earth's internal magnetism. Another feature is the interplanetary magnetic field. This magnetic field arises at the Sun and extends into interplanetary space. The interplanetary magnetic field is formed by currents of plasma within the Sun and within the solar wind. This magnetic field pattern spirals outward from the Sun to fill space throughout the solar system. The third significant feature contributing to the shape and activity of the Earth's magnetic field is the solar wind, the plasma streaming constantly from the Sun in all directions.



Humans have been aware of and made use of the magnetic field of the Earth for the past 2 millennia. Mariners, following the example of the Chinese, used the magnetic properties of magnetite and magnetized metals to find their way relative to the fixed orientation of the compass needle in the Earth's magnetic field. Today, we use magnets in a variety of ways, from floating fast spinning CDs in our computers, stereos and TVs, to magnetic resonance imaging, to sticking paper to our refrigerators. Magnetism is a noncontact force. The magnet can affect materials across an intervening space. That is, we do not have to be at the location of the source object to detect it. We say that a magnet creates a magnetic field or a region of influence in the space around the magnet.

In the following activities, students will investigate the shape of the magnetic field of a bar magnet and extend their understanding of magnetism to a more complex magnetic system—the Sun-Earth system. The bar magnet is the prime example of a dipole magnet. Data will be collected in Activity 1 by placing a student-made magnetometer at various locations relative to a bar magnet and recording the direction of alignment of the magnetometer. Students will learn about magnetic field direction by examining the data. During the Activity 2, students will be prompted to consider whether the magnetic field of the Earth is represented in their data, and be further prompted to remove the effect. Of course, the magnetic field of the Earth is always present, but it is overwhelmed by the dipole field close to the source magnet. Due to the field strength of the bar magnet decreasing as the cube of the distance to the magnet, the influence of the Earth's field will easily be seen within 50 centimeters of the bar magnet. Activity 3 asks students to use the magnetometer to map the combined field of two aligned dipoles and two anti-aligned dipoles. This sets the stage nicely for an investigation into the interacting magnetic fields of the Sun and of the Earth in Activity 4.

NATIONAL SCIENCE STANDARDS:

National Science Standards (NSES)

Content Standards (Grades 9-12)

- Scientists conduct investigations for a wide variety of reasons. For example, they may wish to discover new aspects of the natural world, explain recently observed phenomena, or test the conclusions of prior investigations or the predictions of current theories.

  This is done if the student is considered to be a scientist discovering a new aspect of the world (magnetism) in order to understand aurora and other Sun-Earth interactions.
- Scientists rely on technology to enhance the gathering and manipulation of data. New techniques and tools provide new evidence to guide inquiry and new methods to gather data, thereby contributing to the advance of science. The accuracy and precision of the data, and therefore the quality of the exploration, depends on the technology used.

  Addressed through the building of the magnetometer and analysis of maps generated from magnetometer.
- Scientific explanations must adhere to criteria such as a proposed explanation must be logically consistent; it must abide by the rules of evidence; it must be open to questions and possible modification; and it must be based on historical and current scientific knowledge.

  The discussion questions are designed to create the above environment of explanation.

Benchmarks for Science Literacy

Project 2061 (Grades 9-12)

- Magnetic forces are very closely related to electric forces and can be thought of as different aspects of a single electromagnetic force. Moving electric charges produce magnetic forces and moving magnets produce electric forces. The interplay of electric and magnetic forces is the basis for electric motors, generators, and many other modern technologies, including the production of electromagnetic waves.

  As we relate the solar wind (stream of charged particles) to interaction with magnetosphere, we address this.
- Scientists assume that the universe is a vast single system in which the basic rules are the same everywhere. The rules may range from very simple to extremely complex, but scientists operate on the belief that the rules can be discovered by careful, systematic study.
- We are studying experiments in a lab to understand Sun-Earth interactions. What we do in the lab must explicitly replicate and inform about these interactions.

  Use tables, charts, and graphs in making arguments and claims in oral and written presentations.

  Explicitly built in to creation of maps and interpretation of maps.

Grade 8:

- Electric currents and magnets can exert a force on each other.

  Explicitly built into lessons.
- When similar investigations give different results, the scientific challenge is to judge whether the differences are trivial or significant, and it often takes further studies to decide. Even with similar results, scientists may wait until an investigation has been repeated many times before accepting the results as correct.

  As students predict multidipole fields, differences in maps will need to be accounted for.

National Educational Technology Standards (NETS)

Grades 9-12

- Technology research tools.
- Students use technology to locate, evaluate, and collect information from a variety of sources.

  Use of Internet as information collection tool explicitly built in.
- Technology problem-solving and decision-making tools.
- Students use technology resources for solving problems and making informed decisions.

  Explicitly addressed in activity about solar wind and magnetosphere interaction.

Mathematics Standards (NCTM)

Grades 6-8

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them.
- Formulate questions, design studies, and collect data about a characteristic shared by two populations or different characteristics within one population.
- Select, create, and use appropriate graphical representations of data, including histograms, box plots, and scatterplots.
- Develop and evaluate inferences and predictions that are based on data.
- Use observations about differences between two or more samples to make conjectures about the populations from which the samples were taken.
- Use conjectures to formulate new questions and plan new studies to answer them.

  Mapping of multiple dipole fields addresses these standards.

Measurement Standard for Grades 9-12

Understand measurable attributes of objects and the units, systems, and processes of measurement.

Apply appropriate techniques, tools, and formulas to determine measurements.

- Analyze precision, accuracy, and approximate error in measurement situations.

Discussion leads students through understanding what magnetometer measures. Measuring ambient field and finding local variations due to other sources and applying this knowledge to reinterpretation of dipole maps address this standard.

Communication Standard for Grades 9-12

- Organize and consolidate their mathematical thinking through communication.
- Communicate their mathematical thinking coherently and clearly to peers, teachers, and others.
- Analyze and evaluate the mathematical thinking and strategies of others.

Connections Standard for Grades 9-12

- Recognize and apply mathematics in contexts outside of mathematics.

Representation Standard for Grades 9-12

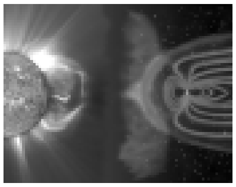
- Use representations to model and interpret physical, social, and mathematical phenomena.

INSTRUCTIONAL OBJECTIVES FOR ACTIVITIES 1 AND 2

Students will use the magnetometer to map the field of a bar magnet. The map will indicate direction of field only, and will resemble a dipole field. Students will use the magnetometer to map the ambient field due to the Earth. Students will analyze the maps produced for patterns and trends. Students will identify and examine methods for removal of the Earth's magnetic influence on the measurements used to make the map.

VOCABULARY:

- **Magnetic force:** The fundamental force exerted by a source magnet which will cause the motion of



a test magnet to change or to cause its orientation relative to a fixed direction to change.

- **Orientation:** The direction that defines the position of one object in relation to another. Within this activity, we take the definition of direction as the line joining the poles of a magnet relative to a fixed line (often determined by another set of magnetic poles.)
- **Magnetic Field:** An abstract representation of the effect of a magnet on the space in which it is found. The field is often represented by lines that show how a test magnet would align itself within a source field. This is different from the electrostatic field that represents the direction along which a positive particle would feel a force. For magnetism, the field line represents the direction along which a magnet feels a torque of Zero Nm.
- **Dipole:** A situation where two conjugate sources of field are in proximity and together influence the space around them. Magnetism is found in dipole constructions at its simplest occurrence. That is, one cannot separate the conjugate poles, often termed the North and South poles, of a magnet. In electrostatics, a positive charge is one monopole, a negative charge is the conjugate monopole, and each can be found independently of the other. In gravitation, a mass is a self-conjugate pole.
- **Super-position Principle:** The principle tells us that when two similar phenomena occur at the same time and place, we will see the sum of the two phenomena, rather than the original 2 separately. Vector addition is exploited to represent this principle.

ACTIVITIES:

Preparing for the Activity

Student Materials:

Materials for one magnetometer—4 students per group

- 2-liter soda bottle or tennis ball canister
- 2 ft. of sewing thread
- 1 small bar magnet
- 1—3 x 5 index card
- 1 mirrored dress sequin
- 1 adjustable high-intensity lamp
- scissors
- 1 meter stick
- super glue
- 1—1 inch piece of soda straw

Mirror sequins may be obtained from any craft store.

Bar magnets may be obtained from this Web site: *http://www.wondermagnet.com/dev/magnets.html* Item #27, $2.01 each.

Students could bring in 2-liter soda bottles.

A desk lamp could be substituted for the high-intensity lamp.

Additional materials for Activities 1-4

- Cow magnet (source: *www.mastermagnetics.com*, part # DMCP5). A strong bar magnet may be substituted.
- 3-4 sheets of poster paper, at least 2 ft on edge, per group.
- Tape
- Wall space for hanging and displaying student generated maps.

Time

5-6 class periods (45-50 minutes)

4 homework periods

Advance Preparation

- Students will need large, flat, clean and dry areas to work on. The floor is acceptable if sufficient table surface is not available.

- Scout the room for extraneous sources of magnetic fields. Computers, electrical lines, any operating electrical equipment, refrigerators, and of course magnets, are all items that will lead to systemic errors. While some can be minimized or removed, some cannot. Anticipate this when guiding the discussion following data collection.
- Practice before class using a magnetometer and making a dipole map for the recorded observations. Even a few minutes will give you significant insight for assisting students.

Activity 1
Mapping the Field of a Dipole Magnet

Teacher Instructions

1. Assignment for the evening before Activity 1

Please discover when magnetism was first noticed and exploited by human kind. What was done with the discovery? How was it explained? Was it put to general use or was it seen as a curiosity?

Suggested Web sites:

- Dr. David Stern (NASA) has an online book on magnetism at *http://www-spof.gsfc.nasa.gov/Education/Imagnet.html*
- From the official Web server of the State of Hawaii Schools *http://gamma.mhpcc.edu/schools/hoala/magnets/history.htm*
- A Timeline of Magnetism (and Optics) Phenomena *http://history.hyperjeff.net/electromagnetism.html*
- From the University of Washington, a Web site built by a graduate student *http://www.ocean.washington.edu/people/grads/mpruis/magnetics/*

2. Setting the Stage—opening discussion. Ask the question, "Where does a magnetic force begin and end in space around a magnet? What evidence reveals that a magnetic force is present." Try to elicit these responses from students' previous experience with magnets.
    - Magnets affect other magnets and metals.
    - Magnetic influence or strength is not related to size of magnet.
    - Magnetic influences extend through space, but get weaker with distance.
    - Magnets have well differentiated ends or poles. There are two poles.
    - Like poles repel; unlike poles attract.

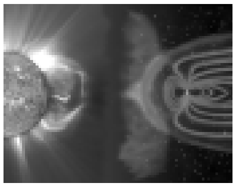
3. Handout materials and instructions for construction of magnetometer—see page 47.

When students have completed the magnetometer, hand out materials and instructions for remainder of activity. Give students 20-30 minutes to complete a map. Circulate, answering questions. Questions can be asked motivating students to think critically about the data and the data collection procedure. Some suggestions follow.

- Where on the line segment is the measured magnetic field direction best represented?
- Is the measured magnetic field parallel to the entire drawn directed line segment or just some part of the drawn arrow?
- What technique did you use to insure you made your arrow directly below the pivot or center point of the sensor magnet?
- Can you state the resolution (the smallest difference in position that also shows a difference in magnetic field direction) of your procedure?

One of the potentially challenging tasks is to draw a set of smooth curves on the maps representing the overall pattern revealed. Certain measurements may not fit the general curve. These individual measurements may have to be ignored, but a solid reason for doing so is required. It is pedagogically useful to prompt students to repeat measurements or to ask several other groups to make some measurements at the same location (but obscure the original troubling one to avoid bias!). This again gets back to the scientific method and it also raises the qualities of collegiality and cooperative effort, both celebrated qualities of work in groups and science labs.

The smooth curves should be approximately tangent to the arrow drawn at a location. This can be hard, and will be affected by such things as "lack of artistic talent," learning disabilities affecting hand-eye coordination and spatial awareness/representation. The goal is NOT a map that emulates the textbook



drawings of magnetic fields. The process is to have students collect data, identify patterns in the data, and to represent the patterns. The smooth curves are the representation of the pattern.

4. Assign the following questions for homework.

What is a dipole? It is the simplest representation of a magnetic field. Look at this site for some drawings of magnetic fields (ignore the formulas if you like) as produced by various sources. Do you recognize any? What is the difference between the field map for a single electric charge and for a bar magnet? A single electric charge is a source of electrostatic field, and is considered a monopole when it is not paired with an opposite charge.

http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/elemag.html#c1

In class, you made a map of the magnetic field of a bar magnet. What is a field, as used in a physics statement like the previous statement? What, exactly, does the magnetic field map show someone looking at it?

What happens when two or more sources of magnetic field are interacting? How do they mutually influence space? Will an observer see each separate influence? Will an observer see some combination of the influence of the sources? How might someone with knowledge of the sources go about predicting what an observer with a magnetometer would record as the field of the combination? How would you represent the overlapping influences? If two magnetic field lines intersect, how would a magnetometer react (what direction would it choose to point) if placed at that location?

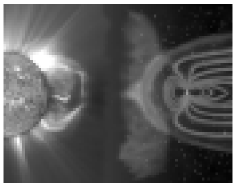
5. Conduct a discussion after students have completed all work and have answered the questions in the student activity.

Two approaches are possible to analyzing the data collected. One is to have student groups work with just the group map and compare answers across groups later, drawing out how data in isolation can lead to varying conclusions. An important part of science is cross-fertilization of thinking among separate groups. A second method is to place all maps on public display (perhaps with names obscured) and have the students examine all the results as they answer the questions. This will require that students add some set of information to the map, including orientation and symbol keys, a critical element of communication of scientific information.

Ask students to interpret, in writing and/or verbally, some or all of these questions.

- **What is a map representing? Is this data?** {Suggested response: The source magnet has created a preferred direction in the space represented by the map. The arrows show the direction a magnetic pole will point at that location.}
- **What is happening at locations between map arrows?** {Suggested response: Similar patterns of change of direction would be seen. These patterns would line up with those documented by direct observation.}
- **Is the change of directionality continuous or are there places where sudden changes or breaks occur?** {Suggested response: While the change of directionality ought to be continuous, concentrations of metal, other magnets disturbing the local field during the observations, current sources being accessed or stopped could all produce an odd or discontinuous change in field direction. Repeating the observation for the point and surrounding points may lead to an adjustment. Repeating the observation after moving the mapping station to a different location may lead to an adjustment but would also require redoing the entire map.}
- **By connecting adjacent observations in a smooth curve, sketch out the complete map appearance.** {Suggested response: This ought to result in the commonly seen dipole field graphic. In any event, the critical discussion questions should be, "How is this consistent? How do you explain the regularity (or irregularity) represented? Is this the most elegant (or simple) explanation or extrapolation consistent with the data that can be made? Is this the only possible appearance of the extrapolation of the data? How do you choose between different representations?"}

- **Place your map on the wall next to those made by others. Identify similarities and differences. Decide if the trends seen across all the maps reveal a generally applicable phenomenon or not. Give significant reasons for your decision.** {Suggested response: Barring excessive error or egregiously sloppy data collection, the maps should be very similar in appearance. The conclusion ought to be that as different observers using different magnets and magnetometers got very similar maps, the standard of repeatability has been met for this observational technique. That suggests that we are seeing a real phenomenon and not some sort of random effect.}
- **If you rotated your source magnet 90 degrees, what sort of changes would you expect in the map if you did new observations?** {Suggested response: The map would be rotated 90 degrees in the same direction. But, the observation lines would not be rotated exactly 90 degrees as the field of a magnet is not circular but rather lobe shaped.}
- **You were not able to do this, but what would you expect to see if you made observations at points inside the source magnet?** {Suggested response: A continuation of the field connecting the poles.}
- **Suppose you were able to map the field in a plane 30 cm above the plane of the source. What sort of a map would you predict seeing? Can you use the map you have made to demonstrate your prediction is reasonable?** {Suggested response: Similar map. You can simply rotate the plane of the map already made to make a reasonable prediction for what the map would look like for different planes in space. This assumes, naturally, that the magnet is a symmetrical shape.}
- **How much has the magnetic field of the Earth altered the map of the field produced by the source?** {Suggested response: The effect will depend on the orientation of the source relative to geomagnetic north. At the outer edges of the map, a trend may be seen which is slightly different from the trend seen near the source. It is possible that students will not see this if they were not particularly precise in recording observations.}
- **How might we identify and remove the effect of the Earth's magnetic field on the map you produced?** The goal of this question is to develop an experimental design and technique for handling combined data sets. This is a lead-in for strategies to combine field maps. {Suggested response: If we make a map of the field of a source magnet, then remove the source from the room and map the Earth's magnetic field at the same location as the original map, we will have an indication of the directional influence of the Earth's field on the map of the source magnet. N.B.: Without knowing the strengths of the magnetic fields mapped, we cannot directly add or subtract these measurements}.



Student Activity
Constructing the Magnetometer

1. Obtain a dry label-free 2-liter soda bottle. Slice the bottle 1/3 the way from the top.
2. Cut the index card so that it fits inside the bottle without touching the sides to create a sensor card.
3. Glue magnet at the center of the top edge of the card. Cut a 1-inch piece of a soda straw and glue to top of the magnet. (See Figure 1.)

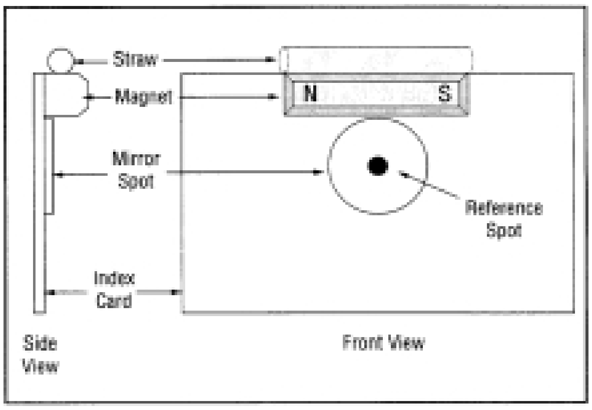


Figure 1. Sensor card set-up, IMAGE poetry

4. Glue the mirror sequin to the front of the magnet. Mark a spot in the middle of the sequin with a permanent marker. This is called the reference spot that will be seen as a dark spot on the wall.
5. Pull the thread through the soda straw and tie it into a small triangle with 2-inch sides.
6. Tie a 6-inch piece of thread to top of the triangle in #5 and thread it through the hole in the cap. Secure the string on the outside of the bottle with tape.
7. Put the bottle top and bottom together so that the "Sensor Card" is free to swing (not touching the bottle) with the mirror spot above the seam.
8. Tape the bottle together and glue the thread through the cap. (Figure 2)

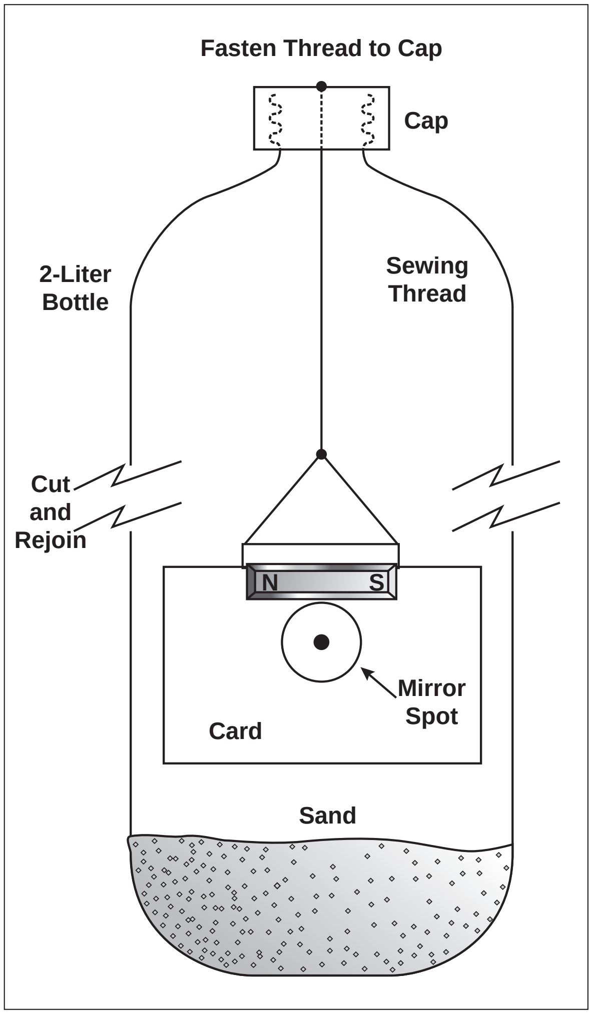


Figure 2. Constructed soda bottle magnetometer, IMAGE poetry

Student Activity 1
Mapping the Field of a Dipole Magnet

Goal: Obtain a good quality representation of the total magnetic field around a bar or dipole magnet.

In today's activity, you will work with a partner using a magnetometer to collect data on how a source magnet affects a test magnet in its vicinity. The test magnet will be the magnet in your magnetometer. The source magnet will be a magnet provided by your teacher. The data you will collect is the direction along which the test magnet lines up at different locations in the vicinity of the source magnet.

What you are mapping is the magnetic field in the vicinity of the source magnet.

Materials:

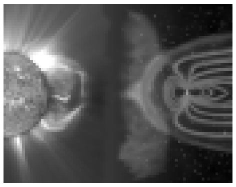
1. Magnetometer
2. Bar magnet
3. Large sheet of paper
4. Meter stick
5. Pencil

Data Collection Procedure:

- Along all edges of the paper, mark points separated by 10 cm and use them to draw a grid on the paper.
- Place the paper on a lab desk. Use tape to mark the position of the 4 corners so that you could place another paper in exactly the same position. Also use the tape to help keep the map in place.
- Place a source magnet horizontally in center of paper. Tape it to paper.
- Outline the position of the source magnet on the paper. The particular orientation you choose is not under experimental control. That is, place the magnet at any angle you desire relative to the grid you drew. The orientation of the source relative to the paper and the room should be noted.
- Decide which ends of the test magnet in the magnetometer are the front and back.
- Use the magnetometer to determine the direction of the magnetic field at each grid point.
- Record the direction of alignment by drawing a short directed line segment that accurately shows the direction the magnetometer magnet is pointing at that location. The line segment should be centered on the point directly below the center of the magnetometer and should be about an inch long.
- Repeat at each grid intersection.
- Put a legend on the completed map that includes information about the orientation of the map relative to some fixed reference point in the room (a wall clock or a door for instance).
- Put a title on the map as follows: Bar Magnet Map, date, and your group identification

Data analysis questions to be completed by you and your partner. Write out your answers in your notebook..

1. Are all the arrows on your map pointing in the same direction? Why or why not?
2. How did you define the direction of an arrow? What observation was translated into the arrow direction?
3. Explain why you think your data are correct or incorrect. Are there any individual measurements that don’t seem to fit the general pattern? Explain how they don’t fit the pattern and what the causes might be.
4. If you put one magnet near the magnetometer, the direction the magnetometer points is changed. If you put two magnets near the magnetometer but at different locations, will you measure the combination of the effect of the two magnets or just the effect of one of them? Which one? Write a convincing argument!
5. While gathering data, did you record the effect of just the source magnet or the source magnet and other things contributing interfering sources of magnetic influence? Name the things that might have affected your measurements and state how they changed the direction the magnetometer indicated. Look closely at the lab table, top and bottom, for possible sources of these effects. Consider what you know about magnets from previous experiences for hints about what could be an interfering source of magnetic influence.
6. Can you subtract or otherwise remove the unwanted effects to get the effect of just the bar magnet? Design a procedure to do this. Identify assumptions you are making about magnetism in the design of the procedure. Identify the limitations of your procedure.
7. The magnetometer measures direction. Based on the map, what might you conclude about the strength of the magnet at different distances from a particular pole?



Activity 2
Mapping the Ambient Magnetic Field

Teacher Instructions

1. Setting the Stage—opening discussion

We mapped the field of a dipole magnet. We achieved a bi-lobed representation of the influence the source magnet would have on a test magnet placed near it. A field is an abstract means of describing how an object affects the space and objects around it. Our maps and the term field are deliberate attempts to describe graphically and verbally the response to a force of a sensitive object placed at a particular location in the space. Our maps show only direction and not magnitude. Recall that we know a magnet is affecting another object by the change of motion induced in the object (moved away from or toward magnet) or by the fact that the object did not fall in a gravitational field when placed against the magnet. Both of these are examples of thinking with Newton's Laws, of course.

Do all objects create fields? Does a chair influence the motion of objects in its vicinity?

Remind students of vectors.

The nature of motion and force is that each requires two elements for a complete description: direction and quantity. That is, motion and force are both intrinsically VECTOR quantities.

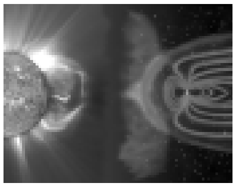
Close discussion by asking students if magnetism demonstrates vector or scalar characteristics. {Vector properties, as it has both strength (magnitude) and direction.}

2. Hand out materials and Student Activity—Mapping the Ambient Magnetic Field. Allow 20 minutes for mapping activity. Students have several questions to answer as part of the activity.
3. Review answers to questions in activity and lead post-activity discussion.
   - **Does the Earth map influence how you interpret the bar magnet map?** {Suggested response: The simple answer is "Yes." The scientific process demands we understand how and to what extent the Earth field affects the mapping of the Bar Magnet field.}
   - **Does the magnetic field of the Earth become more important as we get closer or farther from the dipole magnet?** {Suggested response: The field of the dipole magnet gets weaker with distance. Therefore, the farther the measurement is made from the bar magnet, the larger the influence of the Earth's field on the measurement.}
   - **How far from the bar magnet does the effect of the bar magnet disappear?** {Suggested response: This is a predict-and-check question that reveals a common problem that arises in science. We are measuring the bar magnet field while immersed in the Earth's magnetic field. Thus, one must remove the extra field in order to reveal the true field of the bar magnet. As one gets farther from the source, the magnetic field of the Earth begins to dominate. The key is to determine the field of the Earth, and to subtract it from the measured field to reveal the true field of the bar magnet. The task is frustrated by our not being able to tell if we are in a zero field just from the behavior of the magnetometer: it will always point in some direction! Fortunately, the field of the Earth is very weak (a few gauss) while the field of the bar magnet is relatively strong (10-100 gauss) and thus the Earth's field does not need to be removed until you get out to several lengths of the bar magnet. This question gets back to a fundamental part of magnetism: a dipole field depletes as the inverse cube of the distance between the dipole and the measurement location.
   - **Can the observation be made in such a way that the effect of the Earth's field on the observed bar magnet field is eliminated?** {Suggested response: The students may propose many methods. We suggest that you ask them to carefully develop the hypothesis and logic behind their proposed method. Of special interest is the question, "How will you know you have made a good measurement of the field of just the dipole?" This question opens the student to an opportunity to discuss experi-

mental design and technique. There is no simple way to achieve a measurement of the pure field due to just the dipole. In any technique, the Earth's field must be subtracted from a total measured field OR the experiment must be in a location free from external magnetic fields. While it is possible to create a field that exactly opposes and thus cancels the effect of the Earth's field, it is quite hard to do.}

- **If we are always immersed in the Earth's magnetic field, how can we be sure we are detecting just the magnetic field of the object or magnetic phenomenon we are studying?** {This is the above question rewritten. Simply, we expect to see a certain phenomenon and see something different when a particular new element is added to the system. The change is correlated to the added element. We modify the element (say, by halving and by doubling it) and observe changes in the effect produced.}
- **Use the set of all maps made of the Earth's magnetic field to produce a general map for the entire room. Is the magnetic field in the room entirely due to the Earth?** Explain your answer. {If the extrapolation of the maps leads to a distribution of field lines with a constant direction throughout the room, it is possible that the only contributor to the ambient magnetic field is the Earth. If there are variations in direction, we may presume local sources of magnetic field are perturbing the Earth's field to produce the local ambient field. }
- **How does the sensitivity of the magnetometer effect your interpretation of the maps?** {More sensitive measurements will reveal more small local influences. More sensitive magnetometers may reveal a less uniform ambient field.}

4. Assign "Earth's Magnetic Field and Animals."



Student Activity 2
Mapping the Ambient Magnetic Field

Goal: Obtain a good quality representation of the background magnetic field at location of Activity 1.

Materials:

- Magnetometer
- Large sheet of paper
- Meter stick
- Pencil

Data Collection Procedure:

- Along all edges of the paper, mark points separated by 10 cm and use them to draw a grid on the paper.
- Place and tape paper in the same location as in Activity 1.
- Use the magnetometer to determine the direction of the ambient or background magnetic field at each grid point.
- Record the direction of alignment by drawing a short directed line segment that accurately shows the direction the magnetometer magnet is pointing at that location. The line segment should be centered on the point directly below the center of the magnetometer and should be about an inch long.
- Repeat at each grid intersection.
- Put a legend on the completed map that includes information about the orientation of the map relative to some fixed reference point in the room (a wall clock or a door, for instance).
- Put a title on the map as follows: Ambient Magnetic Field Map, date, and your group identification.

Data Analysis Questions to be completed by you and your partner. Write out your answers in your notebook.

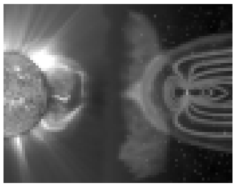
1. Are all the arrows on the Ambient Magnetic Field Map pointing in the same direction? Explain why you think your data is correct or incorrect.
2. Are any of the arrows pointing in the opposite direction, or approximately so, as adjacent arrows? Propose a reason for such variations.
3. Under what conditions can the effect of a magnet change?

Student Activity 2
Earth's Magnetic Field and Animals

Please take a look at some articles (links follow) that look at an intersection of biology and physics: magnetic navigation in animals. The goal here is to understand how your magnetometer is very similar, in some respects, to what is found in some animals. While the way animals detect magnetic fields along with the associated receptor organs (magnetoreceptors or ferro-vesicles) are not well understood, perhaps you can "ferret" out how they work in comparison to your magnetometer. Write a half of a page on the similarities and differences in magnetoreceptors and the compass as developed by the Chinese. Does the consistently seen model of a bit of matter swinging about due to magnetic influence limit the ability of researchers to see when animals are sensing magnetic fields or what they are using the information for?

- A popular news article from ABC News on July 23, 1999, about animals using magnetic navigation. *http://abcnews.go.com/sections/science/DailyNews/magneticnavigation990722.html*
- A story from Science Frontiers Online that begins: *" When magnetite particles were found in organisms from bacteria to bats..."* can be read at *http://www.science-frontiers.com/sf084/sf084b99.htm*
- The abstract of an article in European Biophysics Journal (don't bother with the entire article as you need a subscription to read it.) *http://link.springer.de/link/service/journals/00249/bibs/9028005/90280380.htm*
- A page on magnetic navigation in birds from the National Institutes of Health Resource for Macromolecular modeling and Bioinformatics *http://www.ks.uiuc.edu/Research/magsense/ms.html*
- The page of J Kimball, a biology student, on magnetoreceptors in specific animals. Be sure to follow the link on this page to the micrograph of magnetite particles in a bacterium (at the bottom of the page)! *http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/M/Magnetoreceptors.html*

- A cool picture of the Magnetobacterium bavaricum, a beastie with built-in magnetometers. *http://www.geophysik.uni-muenchen.de/groups/biomag/research/bavaricum.htm*
- An article about the search for magnetoreceptors in the fossil record. *http://www.gps.caltech.edu/users/jkirschvink/magnetofossil.html*
- This site gives a graphical picture of the Earth's magnetic field as measured in Norway. *http://geo.phys.uit.no/realtime.html*



Background for Activities 3 and 4

The students have learned about simple mapping of magnetic dipole fields. In Activity 2, the students saw that along with the dipole field, there was an underlying ambient field, produced largely by the Earth and partially by minor sources within the lab area. In homework, the students have looked at how animals sense the magnetic fields around them and exploit the information in an effort to survive.

In these next two activities, students will look at the union of multiple magnetic fields. Activity 3 is to explicitly map the combined field of two aligned dipoles and two anti-aligned dipoles. For homework, students will predict what happens for other arrangements of two dipoles. In Activity 4, students will check their predictions and learn about the Sun-Earth magnetic interactions. Homework will be to look at the magnetic field mixing in the solar system between the solar wind and Earth. An extension activity is provided which looks at the solar wind interaction with Jupiter and the Jupiter-Io magnetic interaction leading to 20 MHz radio signals received by radio astronomers on Earth.

Activity 3
Mapping the Field of Multiple Dipoles

Teacher Instructions

Goal: Students will map fields of two dipoles in the same map. Students will understand the field representation does not allow field lines to cross. Students will be able to predict the field map resulting from increasingly complex arrangements of 2 dipole magnets.

Materials per student:

- 2 cow magnets per student
- 2 large sheets of paper
- Student magnetometer
- Pencil/pen

Teacher Preparation:

- Assemble materials
- Assemble homework sheets
- Check Web sites for inactive links
- Prepare a clean and clear map of both parallel and anti-parallel dipole alignments. This will be shown to the students at the end of class if discussion has not proceeded to the point of consensus agreement of what the student-made maps should look like.

Vocabulary

- Geomagnetic field
- Dynamo

1. Discuss homework with students.
2. Assign *Mapping of the Field of Multiple Dipoles*. In this activity, students will be asked if they can tell when the magnetic influence or field at the location of the magnetometer is nonexistent. They cannot. It is an important part of understanding the limits of the magnetometer and analyzing the data collected.

In this mapping exercise, there may be several locations where the direction of the magnetic field is very sensitive to the position of the magnetometer. The limit of spatial resolution by a magnetometer is probably on the order of a centimeter. Students may not recognize until the discussion that they have encountered a limit of the equipment. This is a good opportunity to underscore the limits on the precision of the procedure and its effect on drawing conclusions, and finally the need to extrapolate through logic to make hypotheses and predictions for the areas where instrumental resolution does not allow observations.

3. Discuss activity and results as a class group.

- **Did removing the ambient field lead to significant changes in the field maps?** {Suggested response: Especially in regions between the anti-aligned dipoles, the removal is problematic as we are not sure of the relative strengths of the dipoles, and how the strength decreases with distance away from the dipole. We can make two guiding assumptions: (a) far from the dipoles, the field is completely background or ambient; (b) somewhere between two anti-aligned dipoles occurs a point where the total field strength is again only due to the background as the two dipoles contribute equal and opposite field strengths. By logic, this point should be on a plane intersecting the line joining the dipoles. If we can find and identify these two regions, we can begin to make intelligent guesses about the relative strength of field contributions from each dipole at any point in the mapping area. While this is a difficult and imprecise process, it is also one that yields a reasonably accurate result.}

- **If two sources of magnetic field had equal strengths and opposite alignments at some location in space, and you placed a magnetometer at that location, what observation about the local magnetic field would you report? Can you distinguish between a location with no magnetic field and a location where all the magnetic fields exactly cancelled each other?** {Suggested response: At this time, no, the students cannot distinguish between these situations. The magnetometer magnet will have a natural position that is related to the torsional strength of the string, the details of the mass distribution of the hanging magnet structure, and the details of the attachment of the magnet to the string.}
- **Show how the magnetic fields of separate dipoles add to produce the 2-dipole fields you have mapped. That is, show through some means of adding directional indicators from the single dipole maps made two days ago how the 2-dipole (aligned and anti-aligned) maps are foreseeable results.** {Suggested response: By overlaying the single dipole maps, offset by the distance between the dipoles in the 2-dipole maps, and making an approximate addition of the nearby direction data on each layer, one can generate a procedure for predicting how a 2-dipole map should appear. Some simple rules should result, as follows.

For Parallel Alignment

Dipole 1 produces Field 1 while Dipole 2 produces Field 2 at the indicated point. The result of adding F1 and F2 is Sum, the actual observed orientation of the students' magnetometer. The arrow overlaying the smaller dipoles 1 and 2 indicates how aligned dipoles mimic a single larger dipole.

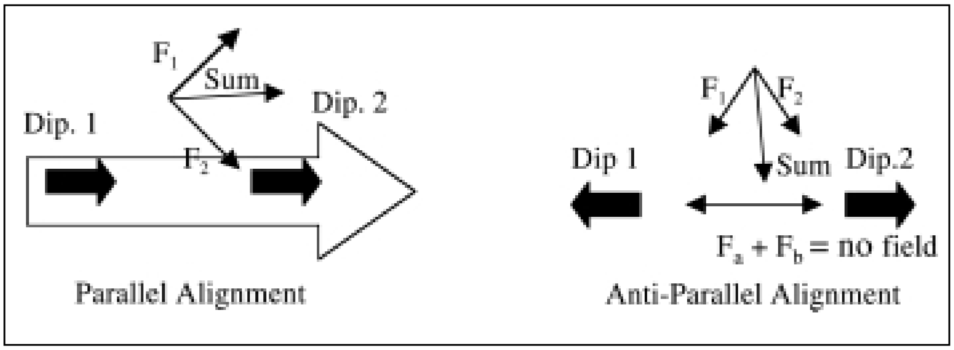
For the Anti-Parallel Alignment

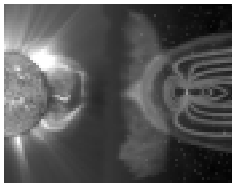
Notice in this example two locations are exhibited. Dipole 1 produces measured fields F1 and Fa, at the respective points, while Dipole 2 produces measured fields F2 and Fb at the respective points. The measured fields F1 and F2 add up to a measurement called Sum, which points between the source magnets. The measured fields Fa and Fb are in opposite directions. If they are of equal magnitude, they will combine to create a zero magnitude field at that point.

We note that zero magnitude magnetic field is a very hard spot to find, however, as the magnetometer does not distinguish a zero strength field, and a slight movement of the magnetometer lets it line up on the closer of the dipoles. That is, at this location, it should seem as if the magnetometer cannot "make up its mind" about what direction to point.

When you have a completed map of the anti-aligned orientation, you will have mapped a Quadrapole field.

3. Assign *Magnetic Field Mapping Exercise*





Student Activity 3
Mapping the Field of Multiple Dipoles

Goal: If two dipole magnets are positioned near each other, what will the map of the field look like? How does the orientation of the magnets affect the shape of the field? How can you predict the field map resulting from increasingly complex arrangements of 2 dipole magnets?

Background: The minimum source of magnetic field is the dipole. That is, there are no individual poles of magnetic "charge." One must get a South attached to every North. The magnetic field encountered in life and industry is rarely just a single dipole field. The fields seen are combinations of many dipoles. This is analogous to the field produced by a large amount of positive charge: The electrostatic field seen is a combination or "sum" of all the single charge fields. The shape of the field is symptomatic of the arrangement of the charges forming it.

Basic task:

In groups of two, map the field of two dipoles in a given arrangement and remove the effect of the background field to get a more accurate map.

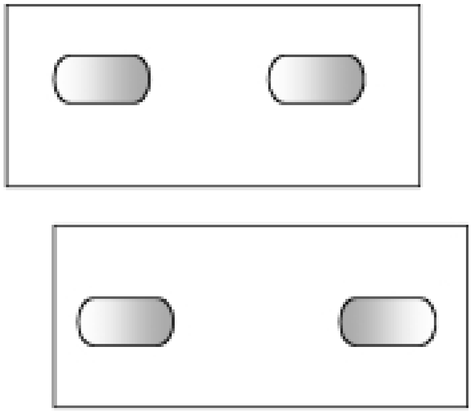
Lab supplies:

Each student group will need the following materials:

- 3 large sheets of paper
- 2 cow magnets
- 1 magnetometer
- Pencil and tape

Procedure for mapping two dipoles

1. Determine and label the ends of the cow magnets as N/S.
2. Mark off a 10-cm grid on all sheets.
3. Identify the specific location where you will be making your maps. Mark the edges carefully with tape.
4. Map background field at this location.
5. Map the combined magnetic field of the pair of parallel, aligned dipoles on the same sheet of paper as used in (4).
6. Repeat (4) and (5) on a new sheet of paper with the poles oppositely aligned, as shown in the diagram below.



The dark part of the oval is the opposite pole of the lighter part. The poles are not close enough to cause one magnet to move away from the other one.

7. Using your knowledge of the ambient field, can you correct the maps made in (5) and (6) so that they show just the field of the dipole arrangements? Estimate what the corrected field would look like.
8. Draw smooth curves showing the shape of the combined dipole magnetic fields and add arrows to indicate field direction.
9. Title the maps with date, time, group names, and information about the orientation of the map in the room, the alignment of the dipoles, and whether the ambient field has been removed.

Questions to be answered in your lab notebook before class discussion.

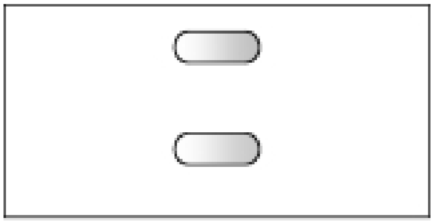
a. Write down the procedure you used to insure that the dipole field maps were made in the same location as the ambient field maps.
b. Write down the procedure you used to remove the effect of the ambient field map from the dipole fields. Write down the factors that make you confident in your results and those that make you less confident.

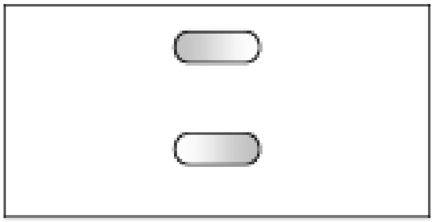
c. Make a chart of the similarities and differences between the maps. Look for big things and look for details.

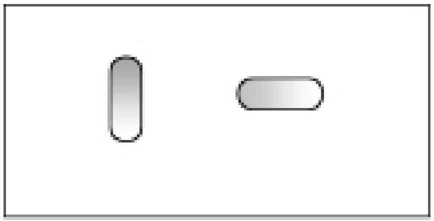
d. Present your work to the teacher for checking.

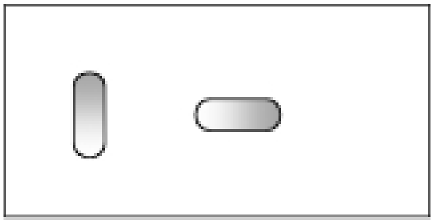
Student Activity 3
Magnetic Field Mapping Exercise

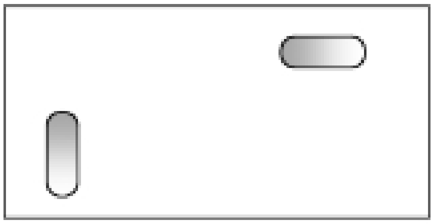
You have mapped the magnetic field of aligned and anti-aligned dipoles. Using what you have observed and the understanding your class came to in the discussion, please predict what a mapping exercise would show for the following configurations of dipole magnets. Note: the ovals are the magnets and the white-to-gray gradient denotes the magnetic poles. All magnets are the same strength. Draw a sufficiently large set of lines to show the field map at all points.

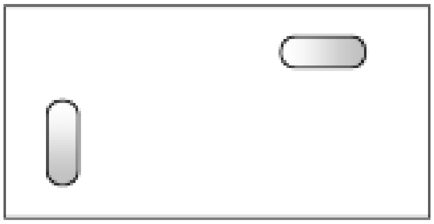


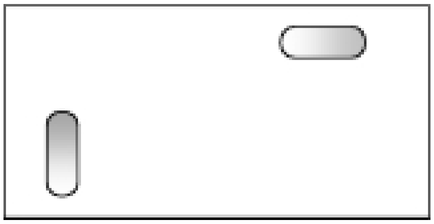


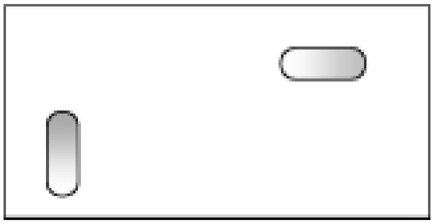


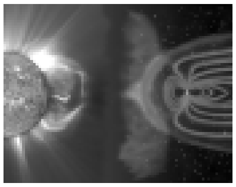












Activity 4
Earth's Magnetic Field From Space

Teacher Instructions

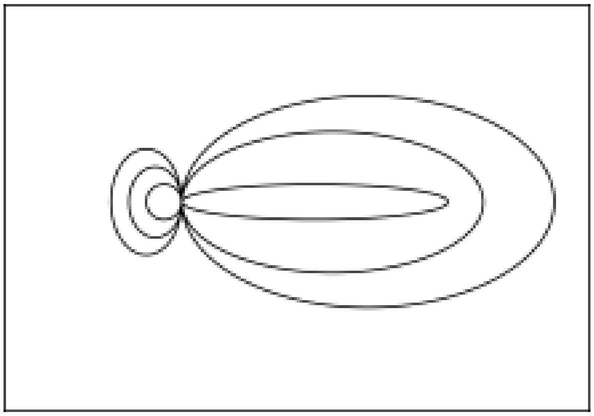
Goal: Understand that the interaction between the solar wind and Earth's magnetic field is influential to shape of the Earth's magnetosphere.

Background: Scientists often designate regions of interest by the geometric shape that they occupy and a Latin or Greek root detailing the property of interest that motivated the designation. Around the spherical Earth, one finds the spherically shaped atmosphere (see the word sphere along with the Greek atmos in "atmosphere"). The Earth's atmosphere can be subdivided into many other regions based on a particular physical property of interest. We are going to concern ourselves with the Earth's magnetosphere. The magnetosphere is not part of the atmosphere. It is actually much larger, and physical processes that happen because of the magnetosphere are as influential to our lives as the presence of oxygen in the lower atmosphere, or troposphere. The troposphere extends to about 16 kilometers above the Earth. The magnetosphere extends about 10 Earth radii (an Earth radius is 6400 km) on the Sun side of the Earth to about 100 Earth radii on the side of Earth away from the Sun.

1. Review homework maps. Student homework was to predict maps of various configurations. If time permits, you might spend some time using the magnetometers to verify the fields seen due to the suggested arrangements of dipoles. It is of pedagogic value to point out that the various configurations can be seen as stretching of the basic arrangements mapped in class the previous day. Certain maps ought to merge into others if you imagine shifting a magnet. One should not see antiparallel lines next to each other. One should not see magnetic field lines crossing. It is suggested that consensus be reached on the homework predictions through discussion and logic. The testing of predictions is left to the teacher's discretion.
2. Following resolution of homework, a deformed magnetic field map is presented for student analysis (following pages).
3. **Main Activity**—hand out *The Earth's Magnetic Field From Space* activity.

Given a magnetic field map, can we say something about the number and type of dipoles needed to produce such a map?

Consider this map:

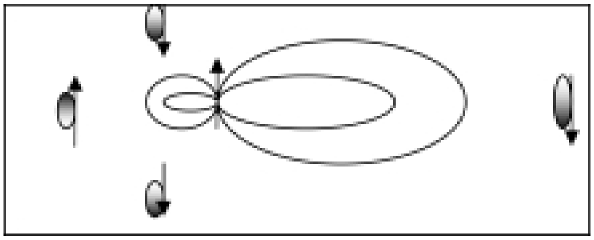


Let us assume that this is a representation of an actual magnetic field. This is similar to a dipole field, but shows a clear deformation. The minimum field of any magnetic configuration is dipole. Thus, somehow, at least two dipoles are combining to form the above representation.

4. Ask the students to form groups and create a scenario that would provide a hypothesis about how such a field might be formed. Budget 10-15 minutes for this activity. Students should be ready to present ideas in a "Board Meeting" format. Ask groups to present hypotheses on large sheets of paper or white boards. Allow 1-2 minutes for presentations. Presentations should consist of statements of known facts and logical extensions of the known facts that would, in combination, lead to the above field configuration.

Suggested answer: A subject pole is producing the expected symmetric field, oriented tangentially to the line along which all the field map ovals touch (the axis joining the poles of the subject dipole.) Two other dipoles are situated off the diagram, one to the right and one to the left. The one to the left is parallel to the subject and produces a repulsive field interaction with the subject dipole causing the subject field to be compressed from the left. The one to the right is anti-parallel to the subject dipole and produces an attractive field interaction causing the subject field to be stretched to the right.

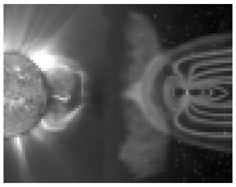
To explain the vertical compression on the left a set of two dipoles could be placed above and below the subject dipole (top and bottom of image page) so that there were repulsive interactions at each pole.



There may be many other answers given. The basic guide to "correctness" is that the directionality of the field interactions is respected, and students are able to cite the observations they have made in previous mapping activities.

An objection to this procedure may arise. To make a truly smooth field map, one might need many small magnets to overcome the little bumps and variations in the field one might expect where there are gaps between the outer magnets. This objection, whether stated by a student or brought in by the teacher, is needed. Use it to bridge to the idea of the solar wind as the carrier of magnetic field and the source of interaction with Earth's dipole field that produces a magnetosphere shaped somewhat like the above field diagram.

5. Discuss readings

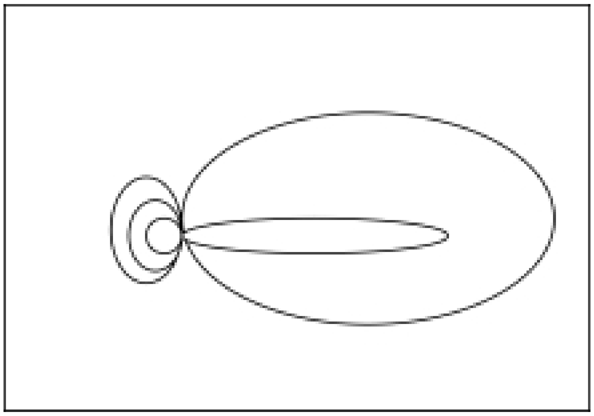


Student Activity 4
The Earth's Magnetic Field from Space

Goal: How does the interaction between solar wind and Earth's magnetic field influence the shape of Earth's magnetosphere?

Given a magnetic field map, can we say something about the number and type of dipoles needed to produce such a map?

Consider the following map:



Let us assume that this is a representation of an actual magnetic field. This is similar to a dipole field, but shows a clear deformation. The minimum field of any magnetic configuration is dipole. Thus, somehow, at least two dipoles are combining to form the above representation.

Working in small groups, propose an arrangement of magnets that would provide a hypothesis about how such a field might be formed. Prepare sufficient notes to enable a group representative to present the group solution to the rest of the class. The presentation should last just a minute or two. Presentations should consist of known facts and logical extensions of the known facts that would lead to the above field configuration.

The Earth has a magnetic field, as you know. Close to the surface of the Earth, it looks like a dipole field, although it is offset from the rotation axis. Satellite observations have shown that the magnetosphere of the Earth, several thousand miles above the surface of the Earth, looks like the magnetic field you just tried to model.

In small groups, develop a written explanation for the observed shape of the Earth's magnetic field. Your explanation must allow for a nearly dipole shape near the surface of the Earth and a highly deformed field far from the surface of the Earth. Your explanation must:

- Include an account of the various forces involved,
- Identify the objects or processes that could or might be providing the force.

Homework:

Visit the following Web sites to explore the Sun-Earth connection

- Space Weather
  http://sunearth.gsfc.nasa.gov/sechtml/tut.html
- Making Sun-Earth Connections
  http://sunearth.gsfc.nasa.gov/sunearthday/NewPresSplash.htm
- Solar Terrestrial Probes and Living With a Star Education
  http://stp.gsfc.nasa.gov/educ_out/educ_out.htm

Visit the following Web sites to learn about the solar wind.

- Solar wind & interplanetary magnetic field (IMF)
  http://www.oulu.fi/~spaceweb/textbook/solarwind.html
- Cosmic and Heliospheric Learning Center
  A resource on the solar wind with links to research data-driven activities.
  http://helios.gsfc.nasa.gov/sw.html
- Solar Physics; Science Directorate, Marshall Space Flight Center
  A resource about particular features of the solar wind.
  http://science.msfc.nasa.gov/ssl/pad/solar/feature4.htm

Visit the following Web sites to learn about the Earth's Magnetosphere

- The Earth Magnetosphere Art Gallery;
  A series of scientific images of the magnetosphere.
  http://image.gsfc.nasa.gov/poetry/art/primer
- Exploring Earthspace: The Magnetopause.
  A detailed and reasonably complete discussion of the interaction between the solar wind and the magnetosphere.
  http://www-spof.gsfc.nasa.gov/Education/Iexplore.html

SOLAR STORMS & THE AURORA

BACKGROUND:

This section is designed to model a systematic approach coordinating solar and terrestrial data NASA scientists utilize to understand the Sun-Earth Connection—the chain of cause-effect relationships that begin with solar activity and end in the deposition of energy in the upper atmosphere. In studying the composition and properties of the solar wind during solar maximum, scientists have traced the failure of space missions, blackouts/power outages on Earth, and emissions of dangerous radioactive particles to the solar wind's interactions with Earth's magnetosphere. From the classroom, students can quantify disturbances in the Earth's magnetic field near the ground caused by the solar wind and then use real-time satellite data to predict geomagnetic phenomenon such as the aurora.

Every day life begins and ends with our Sun. As the Earth has cycles (and seasons), our yellow dwarf star has an eleven-year cycle of its own—the solar cycle. During solar maximum, activity below the Sun's surface can generate a large number of sunspots and solar flares. On occasion, an enormous burst of energetic particles (plasma) is propelled from the Sun's corona (coronal mass ejection) and blows past Pluto. As the solar wind passes Earth it temporarily distorts our protective shield (the magnetosphere) causing charged particles to spiral down the Earth's magnetic field lines into auroral ovals above the poles.

Auroral sightings appear as streaks and curtains of colored light in the night sky commonly in high latitudes near the magnetic North Pole; however, during solar maximum a CME-induced geomagnetic storm (great disturbance in Earth's magnetic field) can result in aurora sightings as far south as Arizona. Once considered a supernatural phenomenon, the occurrence of auroras can be predicted with the use of planetary index, Kp, calculated by solar and terrestrial instruments to represent the effect of a particular change in Earth's magnetic field.

In the early 1990's, NASA collaborated with other space agencies to examine the structure and dynamics in the solar interior, the driving forces behind solar activity, and the effects of the Sun's variability on Earth. SOHO (Solar and Heliospheric Observatory) is a joint effort between NASA, ESA (European Space Agency) and ISAS (Institute for Space and Astronautical Space) of Japan that provides an uninterrupted view of the Sun allowing us to study its internal structure and outer atmosphere and the origin of solar wind. ACE (Advanced Composition Explorer) was designed to determine elemental and isotopic compositions of plasma particles along with their energy and resulting magnetic intensity. Another satellite, IMAGE (Imager for Magnetopause-to-Auroral Global Explorer) provides a window to view the Earth's magnetosphere and its interactions with the solar wind at night and day during geomagnetic storms. Coordinating data from these satellites enables NASA scientists to understand the complexities of space weather and agencies like NOAA (National Oceanic and Atmospheric Administration) to issue advance warning of approaching geomagnetic storms.

In these activities, students will learn how satellite data can be used to help NASA scientists measure the effect of Sun's variability on Earth through changes caused by magnetic fields. Students will also discover that they can detect changes in the Earth's magnetic field as a result of space weather by using a simple magnetometer. Through collecting and analyzing real-time data from satellites, students carry out the same duties as a NASA astronomer by using research, mathematics and technology.

Soda Bottle Magnetometer, the hands-on classroom activity, is student-created and aligned with the National Council of Teachers of Mathematics (NCTM) standards, the National Science Education (NSE) standards, and the National Educational Technology (NET) standards. Given a set of materials and instructions, students will work in groups to construct and collect data from an instrument that measures changes in the Earth's magnetic field. Through data analysis, acquisition of satellite data from the Internet, and interpretation, students will use properties of space weather to predict the occurrence and sightings of the Aurora Borealis worldwide.

Students will work in small teams to construct a device, make observations and collect data on the disturbance of Earth's magnetic field during a geomagnetic storm. Coordinating data from SOHO, ACE and IMAGE will allow students to predict the time and location of aurora sightings using a simple soda bottle magnetometer. The objectives of the activity are (1) to provide students with a concrete example of the technology used by NASA scientists, (2) to provide an opportunity to explore effects of solar variability on Earth, and (3) to discuss this phenomenon in terms of patterns and trends within real and viable data. This activity will enhance students' ability to recognize patterns in qualitative and quantitative information through data analysis and direct application in real-life occurrences.

NATIONAL STANDARDS:

Mathematical (NCTM) Standards

- Use mathematical models to represent and understand quantitative relationships.
- Analyze change in various contexts.
- Understand measurable attributes of objects and the units, systems, and processes of measurement.
- Apply appropriate techniques, tools, and formulas to determine measurements.
- Build new mathematical knowledge through problem solving.
- Solve problems that arise in mathematics and in other contexts.
- Communicate mathematical thinking coherently and clearly to peers, teachers, and others.
- Analyze and evaluate the mathematical thinking and strategies of others.
- Create and use representations to organize, record, and communicate mathematical ideas.
- Develop and evaluate inferences and predictions that are based on data.
- Use the language of mathematics as a precise means of mathematical expression.
- Recognize and apply mathematics in contexts outside mathematics.

National Science Education Standards (NSES)

- Science as Inquiry
  Abilities necessary to do scientific inquiry
  Understandings about scientific inquiry
- Magnetic fields
  Space weather and solar cycle
- Science and technology
  Understanding about science and technology
- History and nature of science
  Science as a human endeavor

Technology for All Americans (ITEA)

- Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.
- Students will develop an understanding of the role of society in the development and use of technology.
- Students will develop an understanding of the attributes of design.
- Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.
- Students will develop an understanding of and be able to select and use construction technologies.

Technology (NET) Standards

- Follow step by step directions to assemble a product.
- Recognize communication systems allow information to be transferred from human to human, human to machine, and machine to human.
- The use of symbols, measurements, and drawings, promotes clear communication by providing a common language to express ideas.
- Design involves a set of steps that can be performed in different sequences and repeated as needed.
- Brainstorming is a group problem-solving design process in which each person in the group presents ideas in an open forum.
- Modeling, testing, evaluating, and modifying are used to transform ideas into practical solutions.
- Use data collected to analyze and interpret trends to identify the positive or negative effects of a technology.
- Interpret and evaluate the accuracy of the information obtained and determine if it is useful.

INSTRUCTIONAL OBJECTIVES:

Students will be able to :

- Use metric system to construct and collect measurements from the magnetometer.

- Measure, record and graph relationships to interpret data from the soda bottle magnetometer .
- Analyze data to determine disturbances in Earth's magnetic field from data.
- Recognize a high-intensity magnetic field of solar wind using real-time satellite data.
- Analyze satellite data to verify changes in magnetic field from magnetometer measurements by comparing terrestrial with space instrumentation.
- Discuss correlations within satellite data and magnetometer data.
- Predict sightings of aurora in Northern and Southern Hemispheres using geomagnetic coordinate map.

VOCABULARY:

Here are some terms that are used throughout this activity and in resource materials with which your students may not be familiar. You may want to spend some time developing their understandings of the relevant concepts.

- **Aurora**—a glow in a planet's ionosphere caused by the interaction between the planet's magnetic field and charged particles from the Sun.
- **Auroral oval**—the circular band in the Northern or Southern Hemisphere where aurora are most intense at any given time.
- **Coronagraph**—a special telescope that blocks light from the disk of the Sun in order to study the faint solar atmosphere.
- **Coronal mass ejection (CME)**—a disturbance of the Sun's corona involving eruptions from the lower part of the corona and ejection of large quantities of matter into the solar wind; sometimes have higher speed, density, and magnetic field strength than is typical for the solar wind.
- **Electron**—a lightweight particle that carries a negative charge, responsible for most electric phenomena and light emission in solid matter and in plasmas.
- **Solar flare**—is a sudden and intense variation of brightness off the Sun's surface interplanetary matter, the material in between the planets in the solar system, including that within the Earth's radius and out to and beyond the outer planets.
- **Magnetic poles**—the points on Earth towards which the compass needle points; a concentrated source of magnetic force, e.g., a bar magnet has two magnetic poles near its end.
- **Geomagnetic storm**—a large-scale disturbance of the magnetosphere, usually initiated by the arrival of an interplanetary shock, originating on the Sun.
- **Magnetosphere**—the region around Earth whose processes are dominated by the Earth's magnetic field.
- **Plasma**—the fourth state of matter or low-density gas made of charged particles.
- **Solar cycle**—the regular increase and decrease (maximum and minimum) in the level of solar activity lasting 11 years.
- **Solar wind**—a continuous flow of gas and energetic charged particles.
- **Sunspot**—a dark region on the solar surface where the magnetic field is so strong that the flow of energy from below is suppressed.]

ACTIVITIES:

Preparing for the Activity

- The construction of one class soda bottle magnetometer (see instructions for construction in MAGNETISM section). Optional magnetometer is listed in Extensions.
- You can organize students in groups or pairs.

Materials

(for one magnetometer—4 students per group)

- 2-liter soda bottle or tennis ball canister
- 2 ft of sewing thread
- 1 small bar magnet
- 1-3 x 5 index card
- 1 mirrored dress sequin
- 1 adjustable high-intensity lamp

- Scissors
- 1 meter stick
- Super Glue
- 1-1 inch piece of soda straw

Mirror sequins may be obtained from any craft store.

Bar magnets may be obtained from this Web site – *http://www.wondermagnet.com/dev/magnets.html* Item #27, $2.01 each.

Students could bring in 2-liter soda bottles.

A desk lamp could be substituted for the high-intensity lamp.

For activity

- Instructions for magnetometer construction
- Photocopies of student worksheet
- Print out copies of Kp data and observatory data

Time

Overall, this activity will require two to three fourty-five minute periods, including:

- Construction of soda bottle magnetometer.
- Background discussion of space weather magnetic fields.
- Time to complete model; includes analysis of data and graphing activities.
- Acquiring observatory data and 3-day Kp plot from the Web.
- Time to analyze magnetometer data and predict where aurora will be seen.

Advance Preparation

- You may want to have the soda bottles already cut in half and prepared for the students.
- Drill holes in the caps of the soda bottles.
- Learn about magnetic fields and the magnetometer.
- Engagement and learning opportunities appear on the following url – *http://www-istp.gsfc.nasa.gov/istp/outreach/ed/*. Have students learn about magnetic fields while using the magnetometer to find the magnetic field lines around a bar magnet (see MAGNETISM). Also on this site are instructions for an additional magnetometer. Instructions include using a tennis ball canister to encase the sensor card instead of a soda bottle. If these are accessible to you (or from a nearby high school tennis team), then this may be easier for students to transport home.
- Photocopies of the worksheet, charts and graphs should be made for students to complete all tasks.

ACTIVITY 1

Introduce the Activity

Begin the activity by asking the students about today's weather and how it will affect any planned activities. Lead into the need for NASA scientists to know about space weather and how it may affect human activities. Also explain that NASA scientists use satellites not only to examine interplanetary matter but also to forecast space weather by measuring the effects of solar variability toward Earth. Point out that astronomers, satellite specialists and space physicists explore patterns in data gathered from solar wind. Utilizing mathematics is paramount in helping us and NASA scientists alike in examining and describing patterns and trends.

Completing the Model

1. Students will be examining a model approach to predicting aurora which will first include comparing data from solar and terrestrial instruments to describe magnetic fields. Solar data from the ACE magnetometer describes the magnitude of the magnetic field component, B_z. The more negative the values means the greater the potential of the field to interact and disrupt the Earth's magnetosphere. See Example 1 Answer Sheet.
2. Observatory data measures the Earth's magnetic field from the ground which will detect any changes in Earth's magnetic field. Students should be looking for large amounts of disruption and instability in the magnetic field demonstrated by the plots for data approximately within the same time period. See Example 2 Answer Sheet.
3. Once the correlation is confirmed and the time of disruption has been noted, then students may conclude that a geomagnetic storm had taken place.

4. To find the strength of the storm, students must then use the 3-day Kp plot for that time period to find the strength of the storm. Each Kp value comprises data in three-hour intervals for a total of eight values for each day. The higher the Kp value the greater the strength and effect of the geomagnetic event. Kp values are an indicator of how far south the aurora may be seen past the magnetic North Pole. [Note: It is important students understand that since geomagnetic storms cause changes in the Earth's magnetic field, using geographic coordinates is obsolete.] The enclosed chart of Kp index demonstrates the relationship between geomagnetic latitude and where the aurora may be seen.
5. Students are to use the chart with auroral boundaries and Kp indices to draw dark curved lines on the enclosed Mercator map according to the geomagnetic latitudes. Geographic coordinates are not included on the map. See Example 3 Answer Sheet. [Note: It is imperative that this map be used since the magnetic North Pole as a reference point for this kind of map moves as much as 1-20 kilometers per year.]
6. Using the city locations already plotted on the chart students should place in a chart where the aurora resulting from this particular geomagnetic event may be seen that day. Suggestion: Instead of saying the aurora may be seen at a particular time, ask students to supply whether it will be seen. Tell them possible restraints on seeing the aurora may be bright lights (Moon, Sun during daytime, and street lights in large cities).

Using the Magnetometer

Show how the direction of the sensor card changes as a cow magnet is moved back and forth around the bottle. Explain that Earth's magnetic field is strong so the card will always return to its original position once the cow magnet is removed. Point out that the device you are working with when used properly is a good tool for predicting when and where a geomagnetic storm from solar wind may cause an aurora. The magnetic field from the solar wind interacts with Earth's magnetic field and causes movement of the sensor card of your magnetometer. The interactions of the two magnetic fields will result in the release of a pocket of energy displayed in the sky as the astronomical event over the poles called the aurora.

Make sure you tell the students that when data is collected the magnetometer must be placed near an undisturbed part of a room away from large appliances and windows near heavy traffic. There must also be efficient light to make accurate markings on the centimeter scale dark enough so that the reflected light spot can be seen on the scale.

Focus questions for opening discussion:

1. What is a magnetic field? Identify some things that may produce a magnetic field.
2. What causes the sensor card of the magnetometer to change direction?
3. Describe what happens when opposite poles of a magnet are put together. What about when two of the same poles are put together?
4. Why does the needle of a compass always point in one direction while you are still? What does this imply about the "North Pole"?

Collecting Data

1. Place the magnetometer in an undisturbed location of your home where the high-intensity lamp can also be placed. Do not place near another magnetometer, major appliance, or near a window on a busy street. Moving currents and electricity have their own magnetic fields.
2. Place the bottle on a level surface and point the lamp so that a reflected spot shows on a nearby wall about 2 meters away (See Figure 3). You should be able to see the reference spot in the middle of a light spot on the scale.
3. On white paper make a centimeter scale with zero (0) in the middle. Make tick marks up to 20 cm on each side. Keep your ruler level.
4. Tape the centimeter scale on the wall directly across from the magnetometer so the mirror spot reflects light onto the scale. (Make sure you can see the light spot during the day and have a light source to make measurements if the area is dark. Be sure the light source is not close to the magnetometer.)
5. Line up the magnetometer 2 meters away from the wall.
6. The first point is the reference point (most preferably zero). Note: If the bottle is moved, then a new reference point must be made.
7. Every 30 minutes for the duration measurements should be taken. Mark the position of your reference spot within the light spot.
8. You could test that the magnetometer is working by moving a cow magnet or handful of iron nails at various distances from the reference point.
9. The sensor card points at an angle to a horizontal surface—the direction of the magnetic North.
10. When taking measurements write down the time and movement of the sensor card in centimeters from the scale.
11. Mark the original position of the mirror spot on the scale as your reference point for measuring. Place the cow magnet about 0.5 meters away from the wall near the scale. Mark where the mirror spot has moved on the centimeter scale and note the time as the particular hour of the day.

Collecting Data–Teacher's Notes

12. Show students how to record the data and remind them of the frequency in which it should be done. Relay to them that all measurements are important and should be taken even if there is no change in the motion of the sensor card. In addition students should know if they move or change the direction of the magnetometer they must find another reference point.
13. Also tell them it is important to always keep the magnetometer 2 meters away from the wall. (Have a think quest or student competition as to the conversion of meters to feet or inches.) Ask them how they think the magnetometer's distance from the wall will change data values.
14. If students are taking measurements from the magnetometer at home make sure they start at the same day and hour.

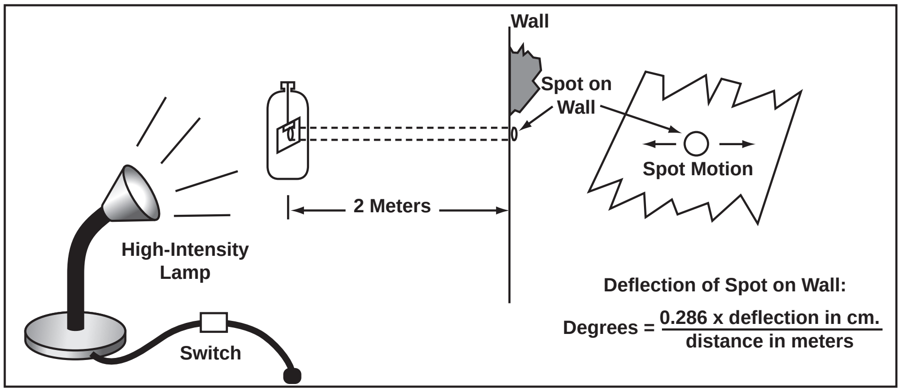


Figure 3. Set-up to collect data, IMAGE poetry

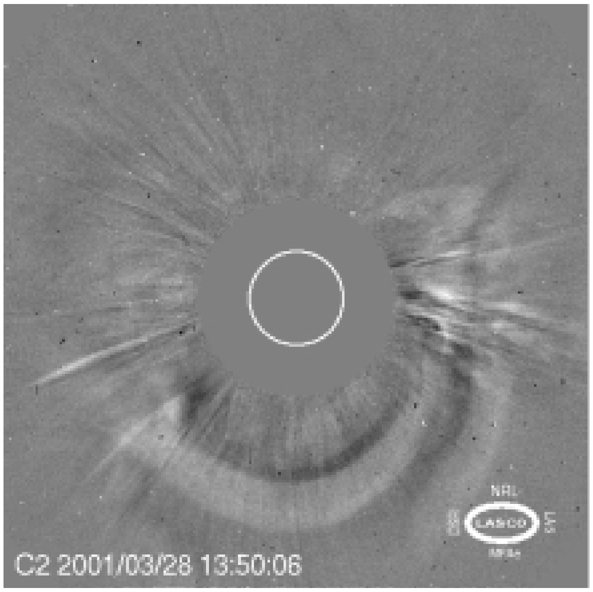
Analyzing Magnetometer Data

1. The magnetometer data should at least be taken over a 2-day period so variability in Earth's magnetic field can be detected.
2. Once students have made the plots with magnetometer data, it should be graphed at the same plane. See Example 4 Answer Sheet.
3. You should obtain observatory data for that day if the kids are to use the changes in Earth's magnetic field. This is for verification as you should not depend solely on one source to make conclusions. You can obtain observatory data for a specific day by going to the following url: *http://www.geolab.nrcan.gc.ca/geomag/e_digdat.html*

   Suggestion: This data is updated every minute. It is a good idea to obtain plots for the day before students began measuring. Each day must be submitted separately.
4. The Kp, planetary index, of the Earth's magnetic field is calculated from data collected by 13 geomagnetic observatories. A three-day plot of Kp indices for any date after 1996 can be obtained from NOAA's Web site at: *http://www.sec.noaa.gov/ftpmenu/plots/kp.html*. The name of the file for the sample Kp data plot (Example 5 of Teacher Answer Sheet) was 20010401_kp.gif which ranged from 3/30-4/2/2001. The Kp plot for the days under examination should be copied and distributed to student groups.
5. Students may then use the Kp values from the 3-day plot for that time period to predict where the aurora may be seen. They can refer back to the geomagnetic map to predict where the aurora is seen.
6. Magnetometer follow-up: Groups comprising students from different schools compare and analyze data taken from a constructed magnetometer during the school year. Data is put onto the MagNet (*http://sunearth.gsfc.nasa.gov/sunearthday/2003/network.htm*) and can be compared to the Kp values to monitor solar activity.

Extensions:

1. If it is possible to view the aurora in your area during geomagnetic storms, then you may want to use real-time data and compare that to the magnetometer. This would be done in the same manner as using observatory data; however, use observatory data as the verification when comparing to ACE solar data. Real-time data from ACE can be obtained at *http://www.sel.noaa.gov/ace/index.html*.
2. How long will it take a CME to reach Earth? SOHO images and ACE data could be used in conjunction to predict how long it will take a CME to reach Earth. This would require obtaining coronograph pictures from the LASCO instrument from the SOHO Web site. LASCO cameras in the image below captured the time (in UST) a full-halo CME entered space from the Sun. Images can be obtained from the following Web site—*http://lasco-www.nrl.navy.mil/cgi-bin/halocme_parse.* Real-time movies are available as well.



ACE data from the swepam instrument provides the speed of the solar wind (bulk speed component) in kilometers/second. You may use the same directions for acquiring ACE magnetometer data, however,

choose data for that day from "swepam" and not "mag." Since the distance from the Sun to Earth is approximately 150,000,000 km, to find the arrival time the "speed = distance/time" calculation is used.

Example data from swepam is provided below. If the measured solar wind speed is 750 kilometers/second from the data, the times it takes the CME to reach Earth and cause a disturbance in the Earth's magnetic field can be calculated. Students can then predict when an aurora will occur. Moreover, the correct CME from the SOHO image could be identified as the cause for the magnetic storm.

3. Exactly where was the aurora seen? Pictures from the Polar spacecraft would produce an image showing the auroral oval over the magnetic North Pole and its latitudinal boundaries.
   http://www-pi.physics.uiowa.edu/www/vis/
4. Images could be used to indicate the arrival of charged particles from CME to Earth's magnetosphere. Pictures show the auroral oval pervading the northern latitudes during day and night times by UV-ray analysis. The captured times on the images should correlate to the rise and fall of magnetic intensity of magnetic field, proton density, and wind speed from ACE data.
5. Students could use graphing calculator to learn the concept of maxima and minima, trends, and patterns in the data collected from ACE data.
6. The position for the magnetic North Pole serves as a reference point for auroral boundaries on the magnetic latitude. The magnetic North Pole shifts between 1 and 20 km/yr. Magnetic storms can shift a compass needle by 10 degrees or more, so it is important to know the pole's present location. Activity is found at the following url :
   http://image.gsfc.nasa.gov/poetry
7. A direct activity correlating solar activity to Kp index which involves graphing and data analysis can be found at the following url :
   http://image.gsfc.nasa.gov/poetry

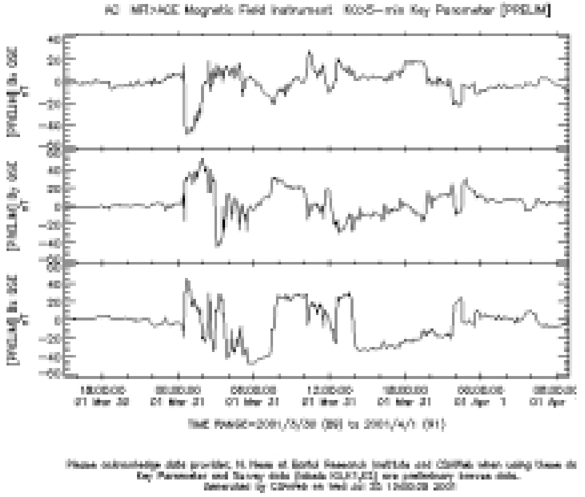
Teacher Answer Sheet

The following includes sample data retrieved from Web sites and also examples of what data should be used in each activity.

Analyzing Observatory Data

Bear Lake Observatory in Canada shows the Earth's magnetic field fluctuating mainly on March 31st. Prior to that date the magnetic field seems to be stable. This can be inferred from looking at how the maximum and minimum values for each component are not changing significantly. There also seems to be a large short-term disturbance on April 1st at 6 hours UST.

The plot could be analyzed in the same manner as above.



Example 1. Sample of Retrieved B_Z plot from CDAWeb

Analysis of Solar Data:

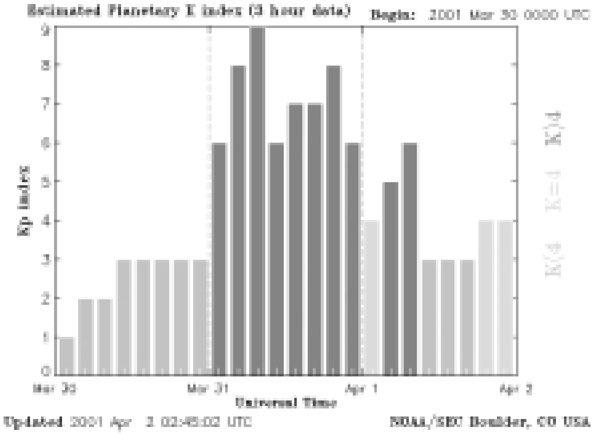
After drawing the zero line through the lines on each plot, students can see that values of each component can be negative or positive.

When examining the B_Z component, students can see the largest negative value at 06:00 UST, March 31. At this time the solar wind would have the greatest effect on Earth's magnetic field.

The observatory data shows a great disturbance in the Earth's magnetic field at the same time solar wind has been measured to have the greatest effect or interaction with Earth's magnetosphere. Other correlations can be made with specific times and magnetic field intensity values.

Predicting Aurora Location

After retrieving the 3-day Kp plot for the dates the magnetometer was utilized, it was possible to align the enormous disturbance in Bz magnetic field component and times of day on March 31, 2001, when Kp values were highest.



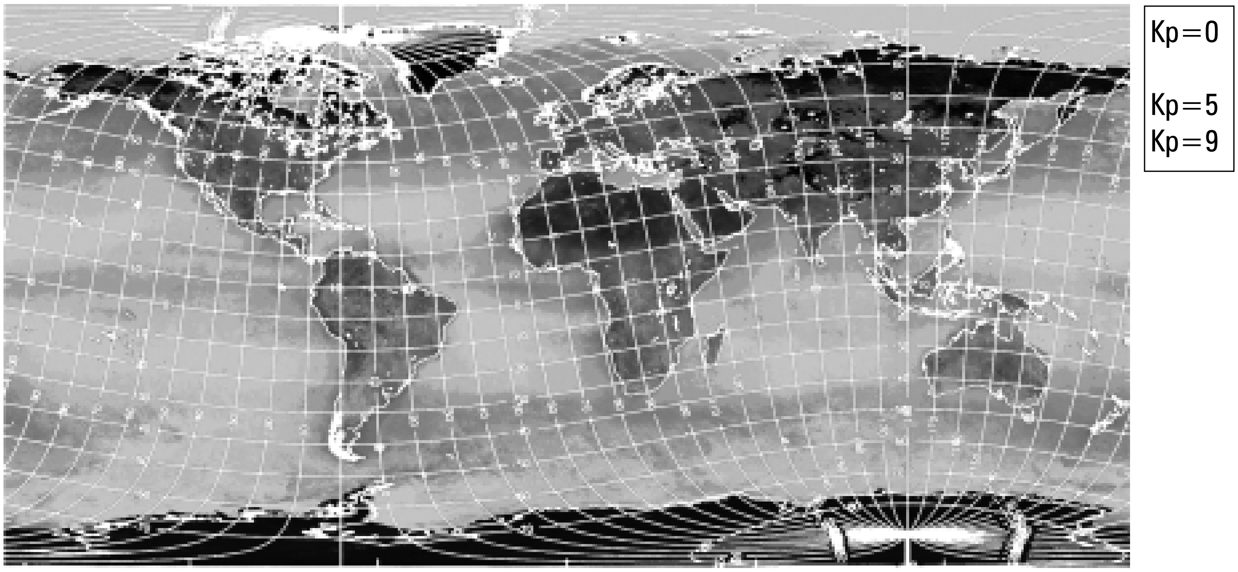
Example 2. Sample of Retrieved Data Plot for Kp indices from March 30 - April 2, 2001, Geomagnetic Event

The Kp plot for March 30th through April 1st shows high Kp values for the whole day on March 31st. When Kp values are greater, then geomagnetic disturbance is considered large. This confirms that a magnetic storm had a large effect on Earth's magnetosphere.

Kp indices drawn on the map according to magnetic latitude indicate the southernmost sighting of an aurora. Students can then predict which cities have a high probability of viewing the aurora.

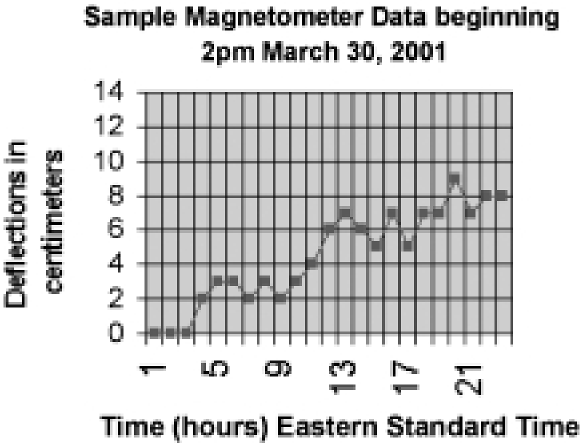
Using Magnetometer Data

Since the Kp values were as high as 8-9, the aurora boundaries may have reached as far south as Manhattan or even Washington, DC. Other places such as Tucson, Arizona, which are at lower magnetic latitudes, reported aurora sightings as well.



Example 3. Global Geomagnetic Coordinates

The probability of seeing an aurora at this latitude decreases as urbanization increases, due to city lights in the nighttime sky. Other factors include increased cloud cover and aurora appearing during daylight hours. In Alaska, it is difficult to see an aurora in the summer because there are mostly daylight hours.



Example 4. Soda Bottle Magnetometer Data

The soda bottle magnetometer data should be graphed as above. Make sure the students have noted what time they started taking measurements.

STUDENT WORKSHEET

Objective: To use model of analyzing geomagnetic storm in predicting aurora sighting

Complete model for Analyzing a Geomagnetic Storm

In the first part of the activity, you must look at the data as a NASA scientist does and decide if there are similarities or differences.

NASA scientists who study space weather obtain data about the Earth's magnetic field from a variety of sources. They often use solar (from space) and terrestrial (from the surface) instruments which gather data. Terrestrial data is acquired from an observatory whose main function is to monitor changes in the Earth's magnetic field. Solar data is retrieved from satellites that orbit around the Earth to measure the properties of solar wind.

Observatory Data Plot of Earth's Magnetic Field

To interpret changes there is need to look at a particular plot. Use data in Figure 1.

1. Pick any component (x, y, or z) and state the differences between the plots for the 3 days in question.

2. Do you think there are any changes? If so then what does that imply about the Earth's magnetic field? Justify your reasoning.

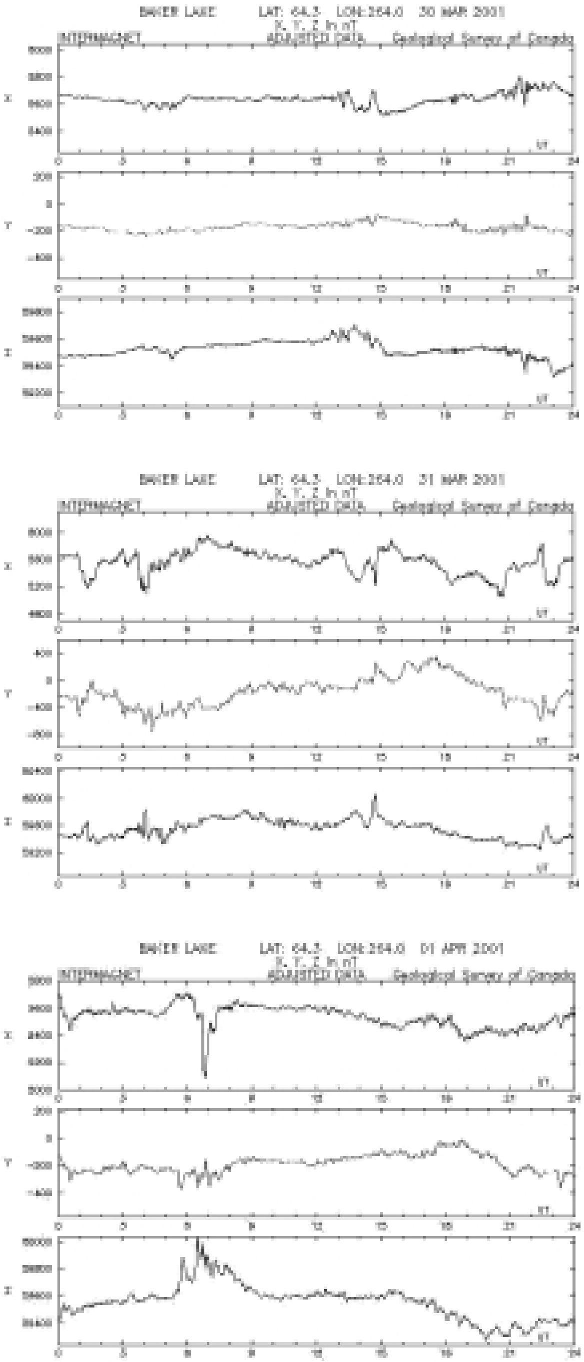


Figure 1. Bear Lake Observatory Data of Earth's Magnetic Field from March 30 - April 1, 2001

Note: Remember, we are only interested in observing changes/fluctuations in the data over a 3-day period.

Solar Data

ACE magnetometer shows the magnitude of the magnetic field component. Large negative values of the B_z component will determine the effect the solar wind will have on the Earth's magnetosphere. Examine the bottom plot, the B_z component.

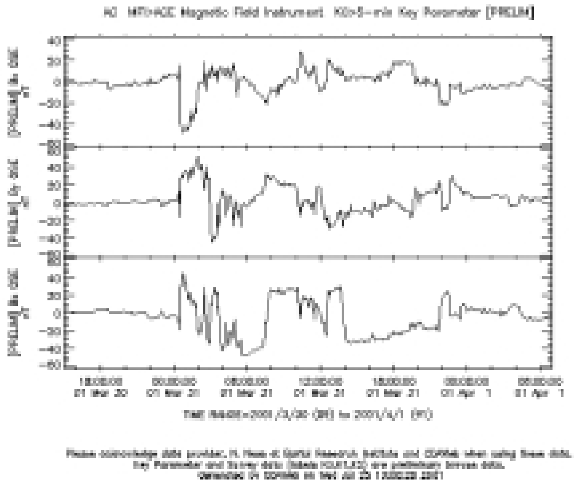


Figure 2. ACE Plot of Solar Wind Magnetic Field

Note : We are only interested in increasingly negative values for B_z plot.

3. Draw a horizontal line through point zero on the B_z axis. What does the plot tell you about the values of the magnetic field components?

4. The B_z component pertains to the direction of the magnetic field embedded in the solar wind. As B_z becomes increasingly negative, the solar wind's magnetic field will have the greatest effect on the Earth's magnetosphere. What time period does the data show the solar wind having the greatest effect?

5. Is there a noticeable pattern between the changing magnetic field of the solar wind and Earth's magnetic field from the Observatory Data? If so, then explain what the correlation(s) may be. Justify your conclusions with actual data from the table.

Predicting Aurora Location

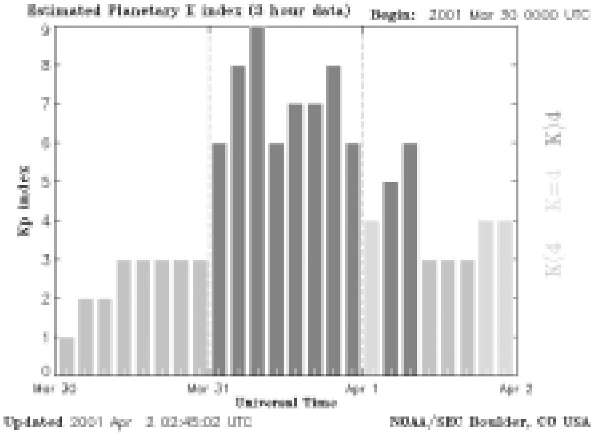


Figure 3. Sample of Retrieved Data Plot for Kp indices from March 30 - April 2, 2001, Geomagnetic Event

6. At what times are the Kp, planetary index seem to be the highest? What does this mean?

7. Kp indices drawn on the map according to magnetic latitude indicate the southern-most sighting of an aurora. Predict which cities have a high probability of viewing the aurora. Refer to the geomagnetic map.

Comparison of Auroral Boundaries from Kp at Local Midnight

Magnetic Latitude	Kp Index
66.5	0
64.5	1
62.4	2
60.4	3
58.3	4
56.3	5
54.2	6
52.2	7
50.1	8
48.1	9

Probable Aurora Sightings according to Magnetic Latitude

Place	Magnetic Latitude
Greenland	66.1
Yukon Territory	63.1
Anchorage, AK	60.8
Montreal, Quebec	56.4
Stockholm, Sweden	55.7
Chicago, IL	52.6
Moscow, Russia	51.4
New York City, NY	51.3
Washington, DC	49.8
Boulder, CO	48.9

Place measurements from magnetometer in table.

Magnetometer Measurements

Time (hours)	Movement in centimeters

8. What times seem to have the greatest movement?

9. Convert the times of greatest movement to Universal Standard Time (UT)

UT = Greenwich Mean Time—5 hours =
Eastern Standard Time
a. -6 hours = Central Standard Time
b. -7 hours = Mountain Standard Time
c. -8 hours = Pacific Standard Time
d. -9 hours = Alaska Standard Time

Example: If the UT is 18:00 hours then Eastern Standard Time would be 13:00 hours or 1 p.m.

10. On the grid, plot the magnetometer data with movement in centimeters on the vertical axis against time (hours) on the horizontal axis.

Verifying the magnetometer data from satellite data

Use data from Canadian Magnetic Observatories in order to verify the data you collected. Go to *http://www.geolab.nrcan.gc.ca/geomag/e_digdat.html* and choose an observatory from the list and specify the dates you wish to compare.

Time UT (hours)	Magnetic Intensity, B_z (nanoTeslas)

11. How closely does the observatory data correlate with your magnetometer data?

Correlating the strength of the storm to aurora sightings

Use the 3-day Kp plot bar (from *http://www.sec.noaa.gov/ftpmenu/plots/kp.html)* to identify the date and hours with the highest Kp indices. Kp values below 5 are not significant. Place in the table below.

Kp Chart	
Hours	Kp

Place in the table below names of cities from those most likely to see an aurora to those least likely to see the aurora. Check Auroral Friends Network as to where the predicted aurora may have been sighted.

Probable Auroral Sightings According to Magnetic Latitude	
City	Magnetic Latitude

List the factors that may affect aurora sightings in the cities you've chosen.

RESOURCES

Books and CDROMS

Campbell, Wallace H. (1997). Introduction to Geomagnetic Fields. New York: Cambridge University Press.

Web sites

Earth's Magnetic Field and the Aurora

http://www.gfz-potsdam.de/pb2/pb23/niemegk/kp_index/kp.html

http://space.rice.edu/hmns/dlt/Earthmag.html

http://www.sec.noaa.gov/info/kp-aurora.html

http://www.geo.mtu.edu/weather/aurora/

Space Weather/Solar Activity

http://sohowww.nascom.nasa.gov/explore/faq/flare.html

http://www.mtwilson.edu/Science/HK_Projects

http://www-istp.gsfc.nasa.gov/

Data Archives/ Geomagnetic Conversions

http://sunearth.gsfc.nasa.gov/

http://nssdc.gsfc.nasa.gov/space/cgm/cgm.html

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

http://www.sec.noaa.gov/sources.html

http://www.census.gov/

http://cdaweb.gsfc.nasa.gov

http://www.sel.noaa.gov/wind/rtwind.html

Education Materials

http://sd-www.jhuapl.edu/ACE/ACE_factsheet.html

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

http://soho.nascom.nasa.gov

http://helios.gsfc.nasa.gov/ace/ace_mission.html

http://www.exploratorium.edu/learning_studio/auroras/happen.html

http://www.istp.gsfc.nasa.gov/istp/nicky/cme-chase.html

http://www.sec.noaa.gov/weekley/index.html

Interactive Activities

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