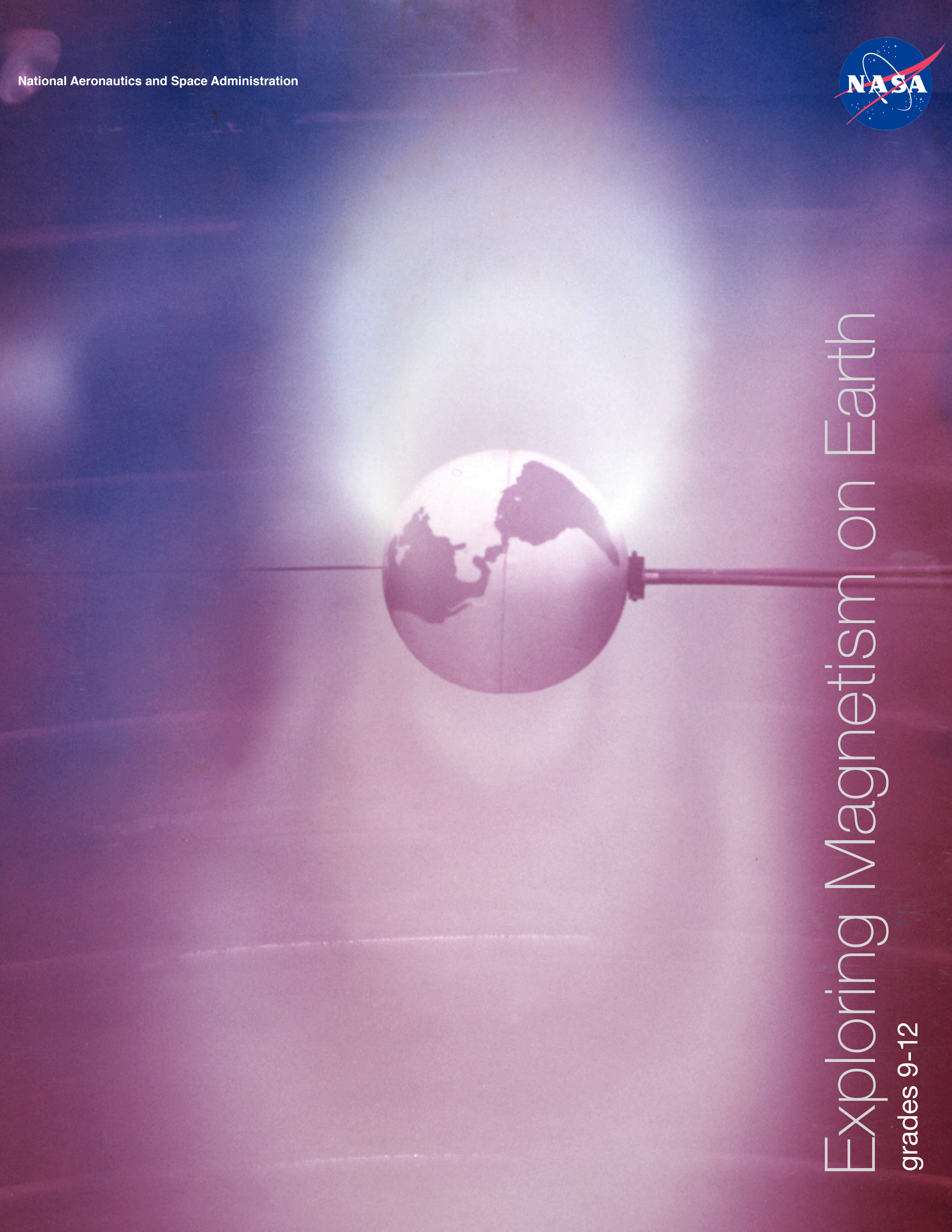
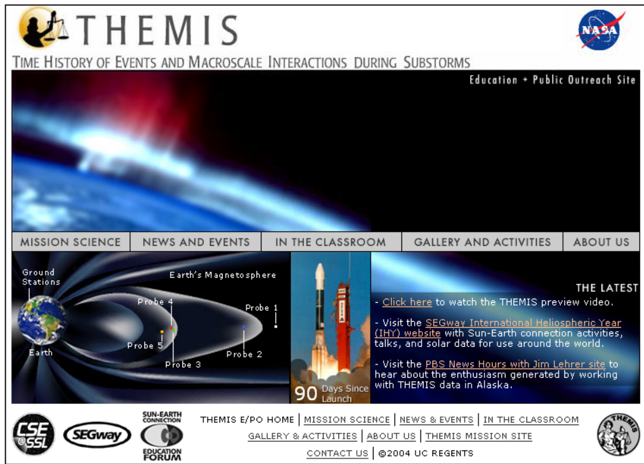
National Aeronautics and Space Administration



Exploring Magnetism on Earth

grades 9-12



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

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

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Contents

National Science Education Standards

Standards Key

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

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

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

Activity	A	B	C	D	E	F	G	Emphasis
5 - Nav. the Earth w/ a Com-pass				i	m		m	E: Students should demonstrate thoughtful planning for a piece of technology or technique. G: In history, diverse cultures have contributed scientific knowledge and technologic inventions.
6 - Polar Wander	m			i			m	A: Identify questions and concepts that guide scientific investigations. G: In history, diverse cultures have contributed scientific knowledge and technologic inventions.
7 - The Declining Magnetic Field	m			i		m m		A: Identify questions and concepts that guide scientific investigations. F: (Environmental Quality). Many factors influence environmental quality F: (Natural and Human-Induced Hazards) Normal adjustments of earth may be hazardous for humans… there are slow and progressive changes that… result in problems for individuals and societies.
8 - Magnetic Reversals	M			i			m	A: Identify questions and concepts that guide scientific investigations. G: (Nature of Scientific Knowledge). Scientific explanations must meet certain criteria. First and foremost, they must be consistent with experimental and observational evidence about nature, and must make accurate predictions, when appropriate, about systems being studied.

National Math Standards

NUM.9-12.1 (Numbers and Operations). Understand numbers, ways of representing numbers, relationships among numbers, and number systems.

NM-NUM.9-12.3: (Numbers and Operations). Compute fluently and make reasonable estimates.

NM-ALG.9-12.1: (Algebra). Understand patterns, relationships, and functions.

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

NM-GEO.9-12.2: (Geometry). Specify locations and describe spatial relationships using coordinate geometry and other representational systems.

NM-GEO.9-12.4: (Geometry). Use visualization, spatial reasoning, and geometric modeling to solve problems.

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

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

NM-DATA.9-12.1 (Data Analysis & Probability). Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer.

NM-DATA.9-12.3: (Data Analysis & Probability). Develop and evaluate inferences and predictions that are based on data.

NM-PROB.COMM. PK-12.2: (Communication - Grades Pre-K - 12)**.** Communicate their mathematical thinking coherently and clearly to peers, teachers and others.

NM-PROB.CONN. PK-12.3: (Connections - Grades Pre-K - 12). Recognize and apply mathematics in contexts outside of mathematics.

Standards Key

M - major emphasis

m - minor emphasis

Activity	NM-NUM. 9-12.1	NM-NUM. 9-12.3	NM-ALG. 9-12.1	NM-ALG. 9-12.4	NM-GEO. 9-12.2	NM-GEO. 9-12.4	NM-MEA. 9-12.1	NM-MEA. 9-12.2	NM-DATA. 9-12.1	NM-DATA. 9-12.3	NM-PROB. COMM. PK-12.2	NM-PROB. CONN. PK-12.3
5 - Nav. the Earth w/ Compass					M	M	m	m			m	
6 - Polar Wander		M		M			M	M				m
7 - The Declining Magnetic Field		M		M			m			M	m	M
8 - Magnetic Reversals	m	M	m	M			m		M	M	M	M

Introduction to the THEMIS Magnetism Series

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

All of these guides have been:

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

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

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

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

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

3. **Magnetic Mysteries of the Aurora** is a prerequisite to using magnetometer data in the way students will in the next guide, **Earth's Magnetic Personality**. **Magnetic Mysteries of the Aurora**

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

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

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

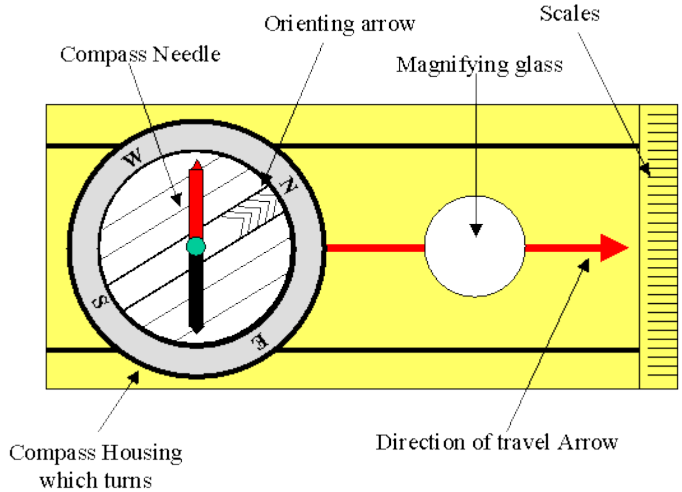
Activity 5 - Navigating the Earth with a Compass

Teacher's Guide

For centuries, navigators at sea relied on compass bearings to guide them safely back to port after long ocean journeys. A slight change in these bearings, even by a degree, could result in hundreds of extra miles added to a voyage, or deadly encounters with coral reefs and shoals under foggy conditions. Compasses are oriented to the Earth's magnetic field. In 1600, the English scientist Gilbert wrote a book called **De Magnete** that described why Earth is like a magnet. Since then, the idea that Earth is a giant magnet has been pretty well taken for granted, and used to great advantage by merchants, hikers and scientists!

Goals

1) Students will learn how to use a compass to take simple bearings on landmarks around their school.
2) Students will appreciate that slight differences in bearings can lead to dramatic changes in where you are planning to travel.



Materials

- Compasses. May be found at:
  http://www.rei.com
  http://www.ebrasingtons.com

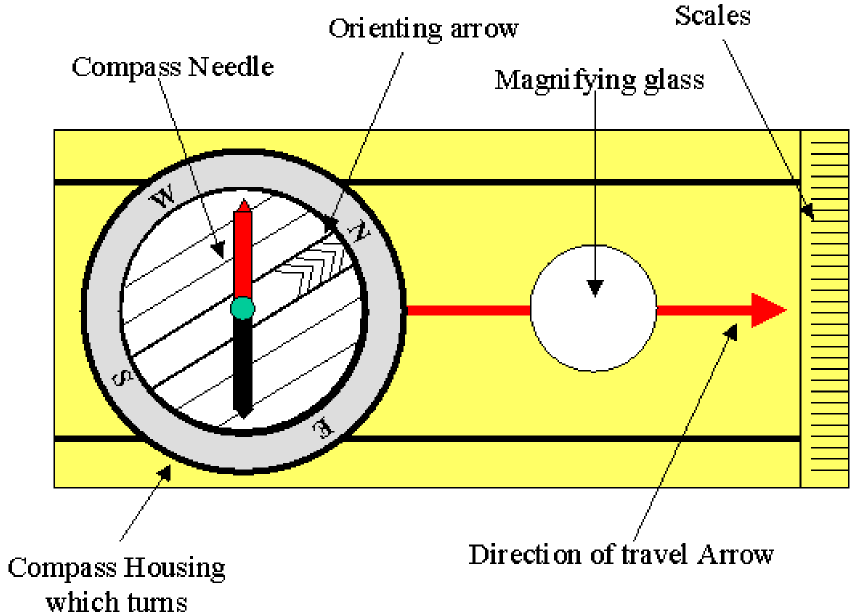
Procedure

To use a compass, one holds the compass level (horizontally) so the needle is free to move. You face the object or direction of travel so that the "direction of travel" arrow points to it. You rotate the compass housing so that the orienting arrow is on top of the red section of the compass needle, which points to the magnetic pole in the Northern Hemisphere. Then you read out the degree number along the red line of the arrow. Students can treat this as a game. First, a student takes a bearing of an object outside the schoolroom. Other students then guess the object, based on the bearing degrees the first student gives them. The student should only give this one clue. Note: If you do not know how to use a compass, you may want to briefly review the excellent orienteering page at http://www.learn-orienteering.org/old/

Next is an inquiry lesson where students work together in teams to come up with a way to determine if a magnetic storm is in progress by using their compass. The students should test out their idea over several days when there is a magnetic storm to see if it worked. See the storm dial on this webpage to determine whether or not a magnetic storm is occurring: http://sprg.ssl.berkeley.edu/dst_index/. The students then write up their results in a paper or share with the class what they discovered.

Student Name ______________________________ ***Date*** ________

Navigating the Earth with a Compass



A compass, like the one sketched above, is one of the oldest pieces of human technology that is based on measuring something 'invisible' – Earth's magnetic field. Navigators have used compasses for centuries, and learned quite a lot about how they work and what Earth's magnetic field looks like. This activity will get you acquainted with Earth's magnetism in a very direct way. Your teacher will review with you the basic use of a compass. Use the above figure of a typical compass to "get your bearings."

Part A: In your school yard, and without letting anyone see you, take a bearing on a particular object (tree, building, car, etc.) located a few hundred yards away. Note the bearing in "degrees," and write the answer in the box below:

Hand this paper to your classmate and have them stand in the same spot you did, and use the bearing to figure out the object at which you were looking. Don't make it easy for them by selecting an isolated object!

Part B: During a "magnetic storm," bearings can suddenly change by up to 5 degrees. Work with a partner to develop a way to determine if a magnetic storm is occuring by using a compass. Write up your idea. Test it over several days by comparing your results with the magnetic storm dial on the following website: http://sprg.ssl.berkeley.edu/dst_index/. Write up a description of whether or not your idea worked.

Activity 6 - Geomagnetism I: Polar Wander

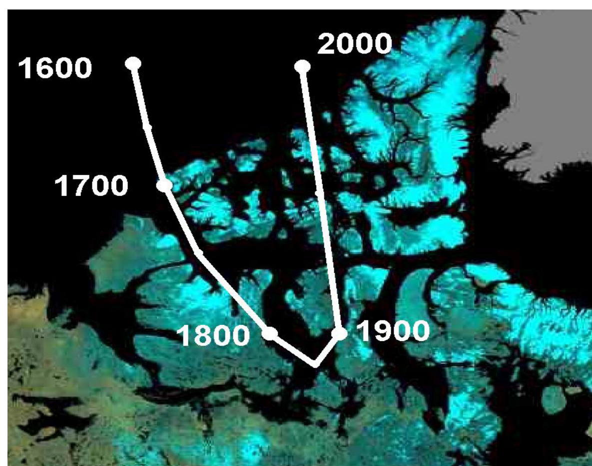
Teacher's Guide

In the previous exercise, students became aware of how a compass operates, and how it relies on the fact that it points in the same direction at all times (Magnetic Pole in the Northern Hemisphere) in order to calculate a "bearing." This exercise introduces students to the idea that our magnetic poles are not fixed in space and time. Since the 1700's, map-makers have known that the bearings for seaports and other fixed landmarks change in a varying manner from decade to decade, so that maps often have to be re-drawn to reflect the new bearings. Geologists call this phenomenon "polar wander." The graph below shows how the magnetic pole in the Northern Hemisphere has moved since 1600 AD.

An alternative, interactive map is provided at:
http://bbs.keyhole.com/ubb/showflat.php/Cat/0/Number/200028/an//page//vc/1
which allows students to measure the polar locations with higher resolution than from the graph provided here.

Goals

1) Students will know Earth's magnetic field is not fixed in space or time.
2) Students will recognize how the magnetic poles of Earth move in complex ways over time.
3) Students will solve equations which demonstrate that the speed of these changes is not constant.



A plot of the movement of Earth's magnetic pole in the Northern Hemisphere since 1600 AD (From http://geo.phys.uit.no/articl/roadto.html)

Materials

- String or wire

Procedure

Ask students to study this figure and answer some quantitative questions related to the distance and speed of the movement of Earth's magnetic pole in the Northern Hemisphere. To measure the distance (along the time track) that the magnetic pole has wandered, have students use a piece of string laid along the track, and then measure the length of the track in centimeters. The scale of their figure is about 163 km/cm, so multiplying the string length by this scale factor, they can compute the track length and answer the questions. Students will also need to compute the speed of the pole movement between the years indicated on the map, by dividing the relevant track interval they measured by the difference in the years.

Wire may be substituted for string to improve measurement accuracy to the nearest millimeter. Have students work in teams of three or four, each taking a turn at measuring the distances in centimeters. Have each team average their answers to each question before reporting a final value. The answers from each team may then be averaged together to obtain a class average. This also allows for a discussion of measurement significant digits. You could also calculate the standard deviation from the average to show the students how to determine a good measurement.

TEACHER ANSWER KEY

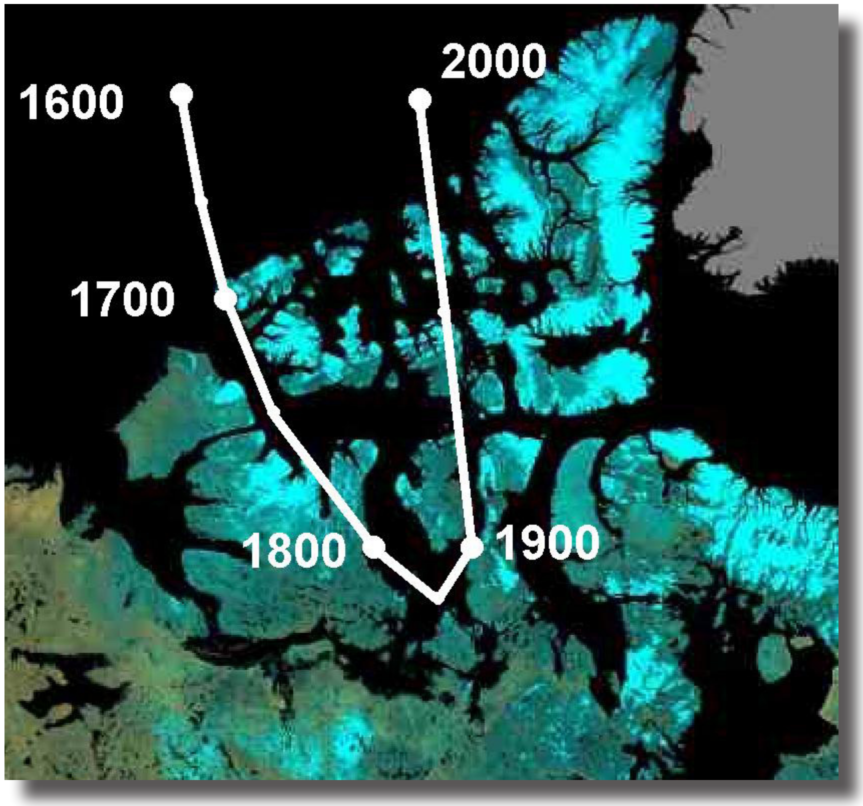
1) What is the total distance that the magnetic pole wandered from 1600 AD to 2000 AD?
   Answer: About 13.5 cm x 163 km = 2,200 km.

2) What is the average speed of the wander from 1600 AD to 2000 AD?
   Answer: Speed = 2,200 km/400 years = 5.5 km/year.

Inquiry Problem: The probability of seeing an aurora is highest in a circular belt centered on the Magnetic Pole, with a radius of 800 km. Explore how the viewing of aurora will change over the next 100 years, at the present rate of polar wander.
Answer: Students will notice that the Magnetic Pole will shift to Siberia, and that the auroral oval will no longer be over Canada by about 2050, making the current auroral sightings much less frequent in North America.

Student Name ___________________________ *Date* _______

Geomagnetism I: Polar Wander



The Earth rotates around an axis through its center. This axis passes through the surface at the North and South Geographic Poles. The magnetic North and South poles are not the same as the geographic poles. In fact, the magnetic poles change in strength and move over time. The curve in the figure above gives the location of Earth's magnetic pole in the Northern Hemisphere as it has moved during the last 400 years! The scale of the above plot is approximately 1 centimeter represents 163 km.

1) What is the total distance that the magnetic pole wandered from 1600 AD to 2000 AD?

2) What is the average speed of the wander from 1600 AD to 2000 AD?

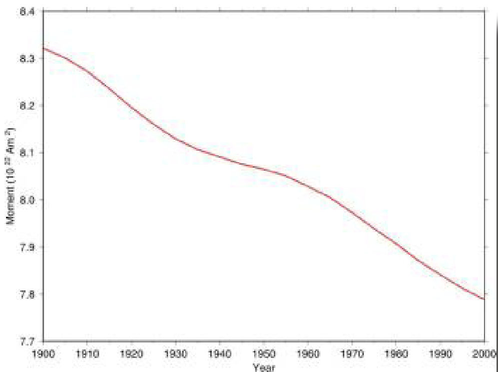
Inquiry Problem: The probability of seeing an aurora is highest in a circular belt centered on the Magnetic Pole, with a radius of 800 km. Explore how the viewing of aurora will change over the next 100 years, at the present rate of polar wander.

Activity 7 - The Declining Magnetic Field

Teacher's Guide

Goals

1) Students will analyze how the strength of Earth's magnetic field is declining.
2) Students will predict what effects would take place if Earth's magnetic field vanished temporarily.



Measurements have been made of the Earth's magnetic field more or less continuously since about 1840. If we look at the trend in the strength of the magnetic field over this time (for example the so-called dipole moment shown in the graph) we can see a downward trend. Indeed projecting this forward in time would suggest zero dipole moment in about 1500-1600 years time. (Figure from http://www.geomag.bgs.ac.uk/reversals.html)

Procedure

In this activity, students will analyze a plot of the most recent field measurements to estimate how long it will take Earth's field to decline to zero strength and perhaps trigger the next magnetic reversal. The units are in multiples of 10^{22} Ampere x meters^2.

Note: This activity has students calculate the slope of the curve on a data plot. Review the definition of the slope of a line. Also make sure the students understand that the numerical value for a slope has mixed units (e.g., miles per hour).

The slope of a line that extends from Point A to Point B is defined as the difference between the vertical axis value at Point B minus the value at Point A - divided by the difference in the horizontal axis value at Point B and Point A.

$$\text{Slope} = \frac{Vb - Va}{Hb - Ha}$$

where 'V' is the vertical axis and 'H' is the horizontal axis

Students will need to select two points on the curve and determine their difference in magnetic field strength, B, and their difference in Years. This will require using a ruler and interpolating data values on the vertical or horizontal axis. It is easiest of they select two years such as '1900' and '2000' and determine the values for B in each case. Then divide the difference in the B values by 100 years to get the slope.

Teacher Answer Key

Question 1 – By how much has the field changed in intensity between 1900 and 2000?
Answer – From about 8.32 to 7.79, which is a difference of – 0.53. This also equals (0.53/8.32) x 100% = 6.4% decline from its initial value in 1900.

Question 2 – What has been the magnetic field's rate of change per year in terms of its percentage per year?
Answer – The decline was 0.53 units in 100 years or 0.0053 units per year. In terms of percentage, this is a change of 6.4% in a century or 0.064% per year.

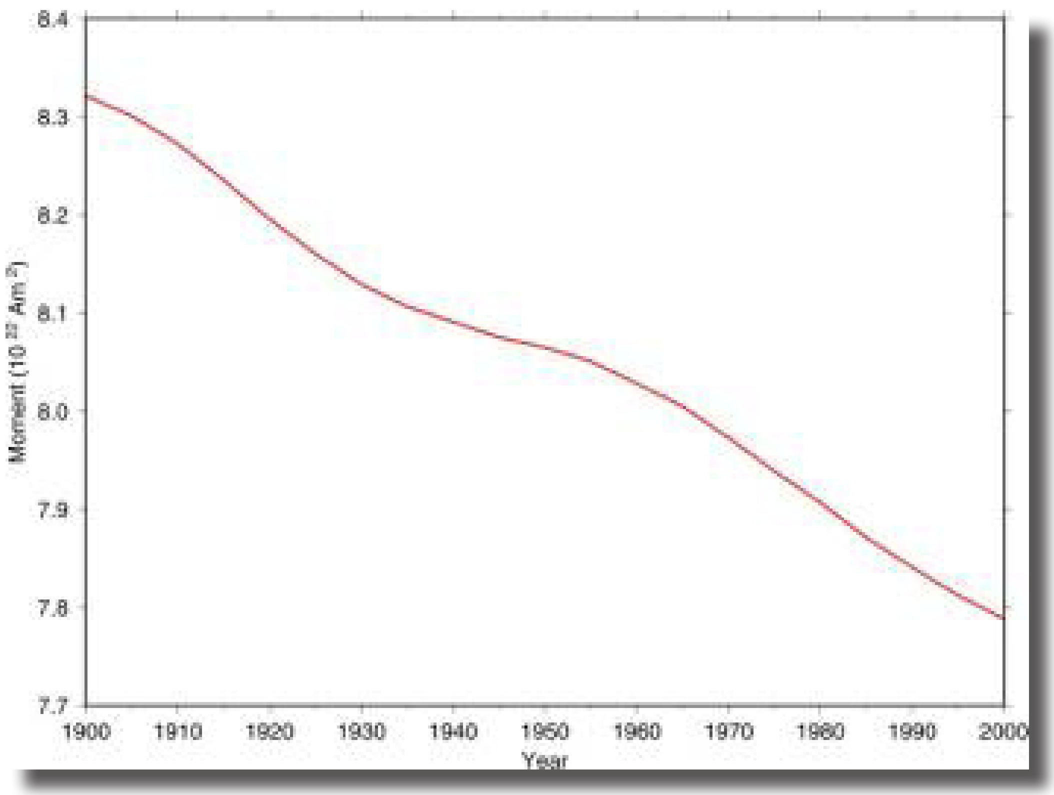
Question 3 – Based on your answer to Question 2, how many years from now will it take for the field to decrease to zero strength?
Answer – It has to decline by another 7.79 units, and at a rate of 0.0053 units per year, it will take (7.79/0.0053) = 1469 years. Students may also replot this graph and by using a ruler, extend the line from 1900-2000 to 1469 years in the future in a "linear extrapolation."

Question 4 – What year will it be when the field reaches zero strength?
Answer – 2000 + 1469 = 3469 AD.

Inquiry Problem – What effects do you think will happen when Earth's field vanishes temporarily for a few decades or centuries?
Answer – No more spectacular Northern Lights. No more magnetic storms. Higher levels of cosmic rays entering atmosphere. Solar wind may penetrate to upper atmosphere and cause additional heating. Some animals may experience navigation problems. No one will die and the rotational poles remain intact.

Student Name ______________________ *Date* ________

The Declining Magnetic Field



Earth's magnetic field is declining in strength. Some scientists think that it may actually vanish in the near future, and be replaced by a growing magnetic field with an opposite magnetic polarity – a phenomenon called a Magnetic Reversal. The above graph shows the measured strength of Earth's magnetic field since 1900, measured in multiples of 10^{22} Ampere x $meters^{2}$.

Question 1 – By how much has the field changed in intensity between 1900 and 2000?

Question 2 – What has been the rate of this change per year, in terms of its percentage change per year?

Question 3 – Based on your answer to Question 2, how many years from now will it take for the field to decrease to zero strength?

Question 4 – What will be the year when the field reaches zero strength?

Inquiry Problem – What effects do you think will happen when Earth's magnetic field vanishes temporarily for a few decades or centuries? Support your conjecture with evidence from relevant information sources.

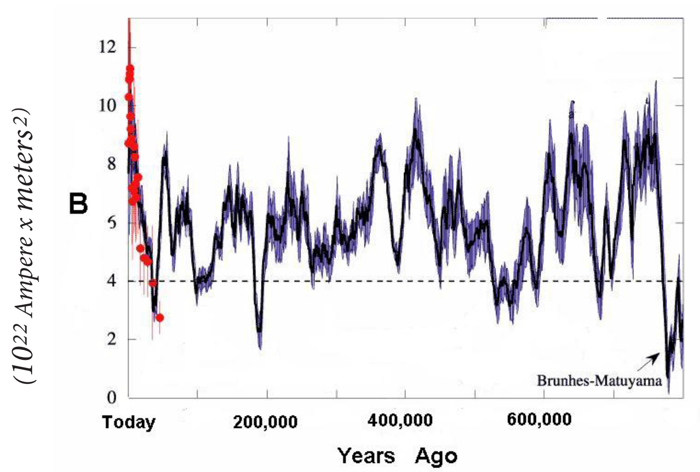
Activity 8 - Geomagnetism II: Magnetic Reversals

TEACHER'S GUIDE

Earth's magnetic field does, in fact, flip its poles every 300,000 years or so. Currently the South Magnetic Pole is in the Northern Hemisphere in northern Canada. Magnetized compass needles marked with 'N' are actually north-type magnetic poles that are attracted to the south-type polarity of the South Magnetic Pole. About 800,000 years ago, it was Earth's North Magnetic Pole that was located in our Arctic Region. The plot below shows that there have been many times in the last 800,000 years when the strength has dipped well below 50% of its current value (8.0 x 10^{22} Ampere x meters^2). During the last magnetic reversal that happened 780,000 years ago, the value of B reached almost zero. Also, the rate of change of the field was very rapid. Is there a magnetic reversal in our future? This seems very likely, but it's nearly impossible to predict exactly when this might happen.

GOALS

1) Students will recognize how Earth's magnetic field strength has changed over the last 800,000 years.
2) Students will determine at what time Earth's magnetic field will reach zero.



MATERIALS

- Graph paper

PROCEDURE

In this activity, students will plot the changes in Earth's magnetic field during the last 800,000 years, and investigate answers to some important questions about past magnetic variations and future magnetic reversals. The data for the student table used in this study and plotted in the figure above are from the research by Yohan Guyodo and Jean-Pierre Valet at the Institute de Physique in Paris and were published in the journal ***Nature*** on May 20, 1999 (pages 249-252). Note, the units used in the figure above to represent the magnetic dipole strength, B, are 10^{22} Ampere x meters^2. The dashed line represents the approximate lowest intensity of the magnetic field for which reversals are not likely to be a significant issue.

Student Name ______________________________ ***Date*** ________

Geomagnetism II: Magnetic Reversals

Geologists have measured the strength of Earth's magnetic field going back thousands of years. They do this by measuring its fossil traces left in the rock deposits around the world whose ages can be accurately dated. These measurements are shown in the table below. The units used to represent the magnetic dipole strength in the table below are 10^{22} Ampere x meters^{2}. Today's strength (Time = 0.0) has a value of 8.0 x 10^{22} Ampere x meters^{2} on the vertical scale. The "Time" columns indicate how many thousands of years *before* the present time that the field was at the indicated strength. For example, the first table entry '20' means 20,000 years ago, at which time the strength was 12.0 x 10^{22} Ampere x meters^{2}.

Create a graph of Time (in years) versus Magnetic Field Strength using the table below. Remember to mark your x- and y-axis with labels and units.

Time	Strength	Time	Strength	Time	Strength	Time	Strength
0	8.0	220	5.7	440	6.3	660	7.0
20	12.0	240	6.5	460	7.0	680	3.5
40	3.2	260	4.5	480	6.0	700	5.0
60	5.0	280	5.0	500	5.7	720	5.5
80	6.6	300	6.0	520	4.6	740	8.2
100	3.8	320	5.8	540	3.8	760	6.5
120	4.3	340	6.4	560	4.2	780	0.5
140	6.5	360	8.5	580	4.7	800	3.4
160	6.3	380	5.0	600	6.0		
180	2.2	400	7.5	620	5.5		
200	6.0	420	8.4	640	8.5		

From the tabulated entries above, answer the following questions:

1. What is the range of the magnetic field strength?
2. What is the average value of the magnetic field strength?
3. How many times has the magnetic strength dipped below 1/2 of its current value of 12.0 x 10^{22} Ampere x meters^{2} ?
4. When was the last time that the magnetic field strength reached 1/3 of its current level?
5. When was the last time the magnetic strength was close to zero?
6. When did the fastest change in the magnetic field strength occur in the last 800,000 years?

Inquiry Problem: Do you think the magnetic field strength will actually reach zero? Using the plotted data, explain your reasoning.

Teacher Answer Key

(The students' graphs should look approximately like the one on page 6).

1. What is the range of the magnetic strength?

   Answer: [0.5, 12.0] range = 12.0 – 0.5 = 11.5 x 10^{22} Ampere x $meters^2$.

2. What is the average value of the strength?

   Answer: Add all 40 'Strength' numbers together and divide by 40, to get 5.7 x 10^{22} Ampere x $meters^2$ after rounding.

3. How many times has the magnetic strength dipped below ½ of its current value of 12.0 x 10^{22} Ampere x $meters^2$?

   Answer: The half-way strength is 6.0 units, so there are 10 occasions in the following periods: 120,000; 180,000 ; 220,000 ; 280,000 ; 320,000 ; 380,000 ; 540,000; 620,000 ; 680,000 and 780,000 years ago.

4. When was the last time that the strength reached ⅓rd of its current level?

   Answer: This level corresponds to $^{12}/_{3}$ = 4 x 10^{22} Ampere x $meters^2$. These two events happened 180,000 and 780,000 years ago.

5. When was the last time the magnetic strength was close to zero?

   Answer: 780,000 years ago.

6. When did the fastest change in the magnetic field strength occur in the last 800,000 years?

   Answer: Students have to look for the biggest change in strength in the shortest amount of time. Between 40,000 and 20,000 years ago, the intensity changed from 3.2 to 12.0 x 10^{22} Ampere x $meters^2$. This equals 12.0-3.2 = +8.8 x 10^{22} Ampere x $meters^2$ in 20,000 years. By comparison, after the last reversal between 780,000 and 760,000 years ago, the change was 6.5 – 0.5 = +6.0 x 10^{22} Ampere x $meters^2$ in 20,000 years.

7. Inquiry Problem: Do you think the magnetic strength will actually reach zero? Explain your reasoning.

   Answer: From the above data, students might conclude that the field has increased and decreased in strength many times, and only rarely reaching near-zero conditions. It may simply continue to decline for a few centuries, and then begin to increase again as it has done before. However, the last time it changed as rapidly as it has in the last 40,000 years, was during the last reversal — 780,000 years ago!

IMAGE (acronym)

Frequently Asked Questions about Earth's Magnetism:

- http://image.gsfc.nasa.gov/poetry/ask/amag.html

Exploring Magnetism:

- http://image.gsfc.nasa.gov/poetry/magnetism/magnetism.html

Exploring Earth's Magnetic Field:

- http://image.gsfc.nasa.gov/poetry/magbook.html

The Magnetospheric System:

- http://image.gsfc.nasa.gov/poetry/tour/AAAmag.html

Non-NASA Resources

This Canadian site discusses the position of the north magnetic pole:

- http://www.mala.bc.ca/~earles/polar-wander-jan00.htm

This site discusses polar wander with respect to continental drift (this is often confusing with students who are studying Earth Science and are trying to reconcile the displacement of the continents and paleomagnetism. This is an important concept to distinguish between magnetic field wandering and the relative positions of the continents.

- http://www.mq.edu.au/scienceresearch/lackie.htm

PBS Nova special called *Magnetic Storms* is a good way to introduce students to the topic of Earth's changing magnetic field.

- http://www.pbs.org/wgbh/nova/magnetic/

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