X...A Simple Magnetometer

Introduction

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

Objective

The students will create a magnetometer to monitor changes in the Earth's magnetic field for signs of magnetic storms. Just as students may be asked to monitor their classroom barometer for signs of bad weather approaching, this magnetometer will allow students to monitor the Earth's environment in space for signs of bad space weather

Materials

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

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

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

Teacher Notes:

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

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

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

Light Sources:

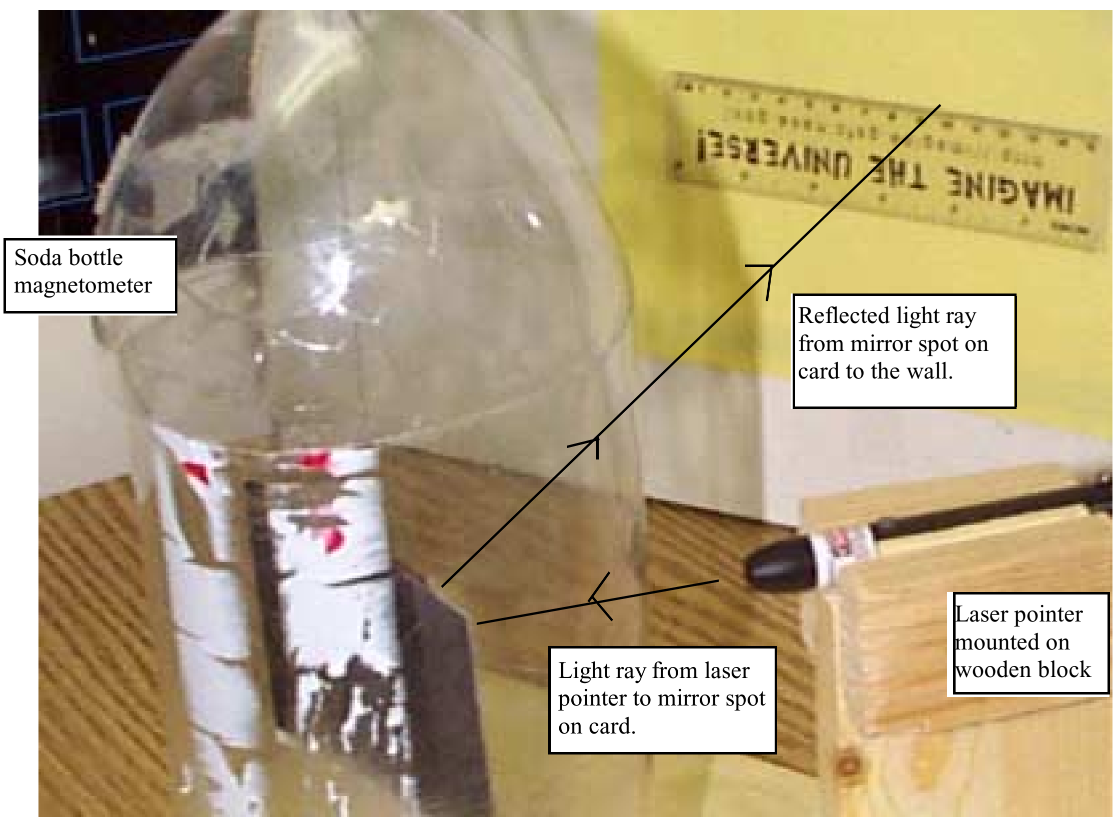
A goose neck high-intensity lamp with a clear bulb.

Alternative light source:

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

Procedure

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



Tips

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

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

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

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

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

Most of the time there will be few detectable changes in the spot's location, so you will have to exercise some patience. However, as we approach sun spot maximum between 1999-2002 there should be several good storms each month, and perhaps as often as once a week. Large magnetic storms are accompanied by major aurora displays, so you may want to use your magnetometer in the day time to predict if you will see a good aurora display after sunset. Note: Professional photographers use a similar device to get ready for photographing aurora in Alaska and Canada.

This magnetometer is sensitive enough to detect cars moving on a street outside your room. With a 1-meter distance between the mirror and the screen, a car moving 30-50 feet away produces a sudden deviation by up to 2 cm from its reference position. The oscillation frequency of the magnet on the card is about 4 seconds and after a car passes, the amplitude of the spot motion will decrease for 5-10 cycles before returning to its rest position. You can even determine the direction of the car's motion by seeing if the spot initially moves east or west! Also, by moving a large mass of metal...say 30 lbs of iron nails...at distances of 1 meter to 5 meters from the magnet, you can measure the amount of deflection you get on the spot, and by plotting this, you may attempt to recover the 'inverse-cube' law for magnetism. This would be an advanced project for middle-school students, but they would see that magnetism falls-off with distance, which is the main point of the plotting exercise.

Setting up to take data:

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

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

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

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

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

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

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

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

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

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

Making the measurements:

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

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

5:00 PM
5:30
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
10:30
11:00

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

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

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

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

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

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

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

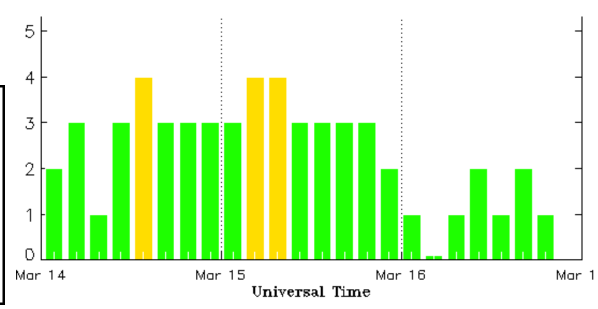
10) When your assigned time is finished, bring the data table and magnetometer back to school.

Sample Data. Case 1.

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

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

The Kp magnetic index plot for this preriod shows a mildly disturbed magnetosphere. The magnetometer shows some minor activity. Note that at this location, the measurements steadily decline (drift westward) between the morning and evening measurements. A possible 24-hour effect.



Visit

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

To see if any storms may be brewing before you begin taking measurements! Most days are usually very calm.

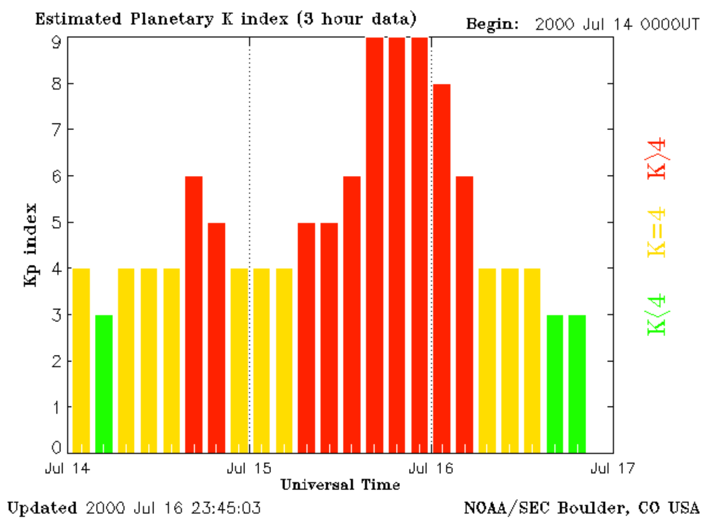
Sample Data: Case 2. A major geomagnetic storm.

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

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

The maximum magnetic deviation of the above storm from Maryland was (from the above plot) about 1.2 degrees and this swing took less than 15 minutes! A potentially stronger swing around 15:00 - 18:00 UT was, unfortunately, missed.

This is the geomagnetic Kp index plot for the 'Bastille Day' storm. It is significant because a Kp of 9 was determined for 9 hours straight which is very unusual.

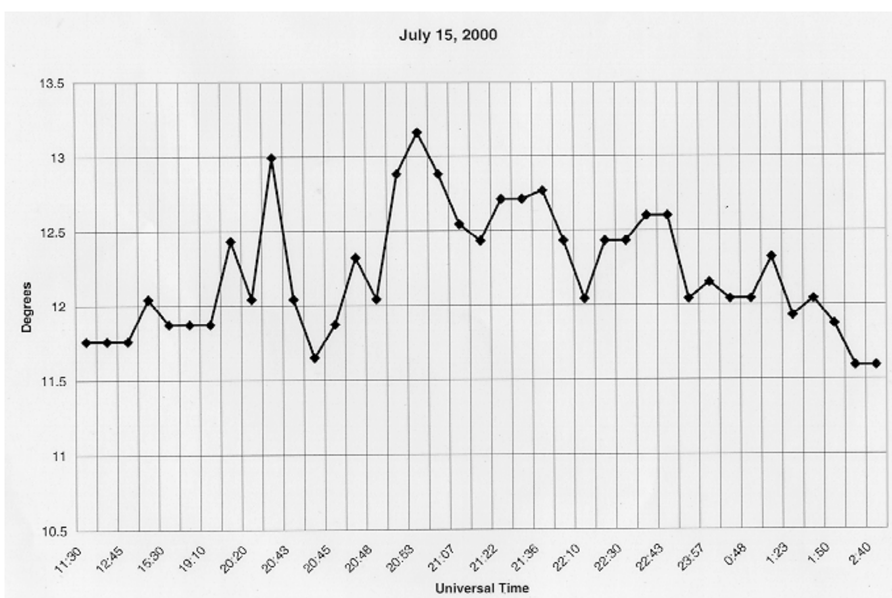


This is a plot of the deflections recorded using a 5-meter distance between the wall and the magnetometer, in the basement of my home in suburban Maryland.

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

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

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



XI...A Bit of Geometry

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

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

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

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

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

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

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