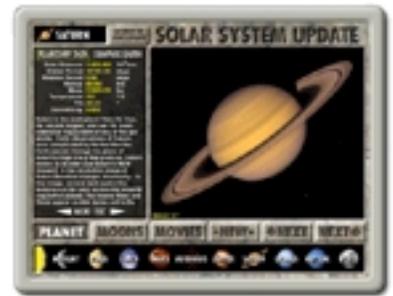


# Magnetic Sensor Activities with a Graphing Calculator

by Jerry Goldstein, Ph.D.

## Your Challenge:

1. To examine the relationship between magnetic intensity and distance for a simple system. Specifically, to show that the intensity of a bar magnet's magnetic field decreases with distance as  $X^{-3}$ , where  $X$  is the distance from the magnet.
2. To get experience taking data with the TI calculator/CBL combination.

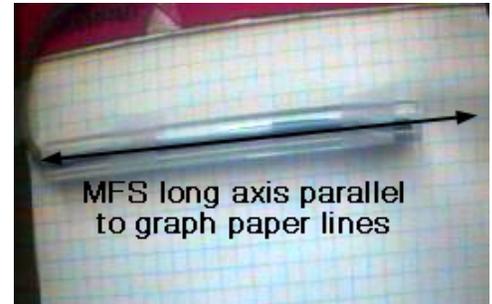


## Equipment

1. TI-83 Plus graphing calculator
2. TI CBL 2 Calculator-Based Laboratory
1. Vernier "Magnetic Field Sensor (MFS)"
4. A permanent magnet
5. Graph Paper and permanent marker

## Setup:

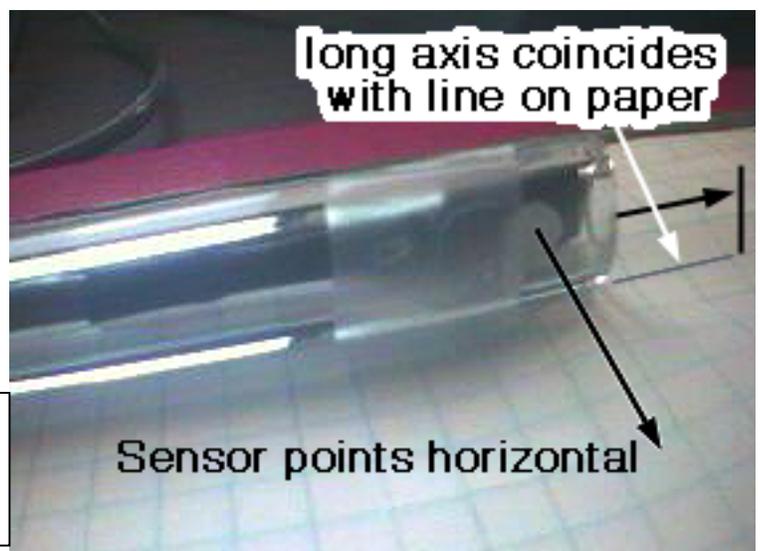
1. Connect the CBL 2 to the calculator. See the manual(s) for instructions. If the calculator complains about missing software, press the "transfer" button and it will send it.
2. Connect the Magnetic Field Sensor (MFS) to the CBL through the "~CH1" channel on the side of the unit.
3. (See Figs. 1-3) Tape a piece of graph paper to a smooth horizontal surface (such as a wooden table--do NOT use a metal surface!!). Tape the MFS sensor tube to the piece of graph paper so that it cannot move during the course of the experiment. Place the MFS sensor tube on top of the graph paper so that:
  - a. The long axis of the tube coincides with one of the lines of the graph paper. (See Fig. 3)
  - b. The "white dot" of the sensor (Fig. 2) points in the horizontal direction. (See Fig. 3)



**Fig. 1** Place the MFS sensor tube so that it is parallel to the graph paper lines. Tape it (and the graph paper) down so that things stay put for the duration of the experiment.



**Fig. 2** A close-up of the MFS tip. The actual sensor is the "White dot".



**Fig. 3** Be sure to place the sensor tube so that the long axis is directly above one of the graph paper lines, and so that the "white dot" points **horizontal**.

4. Draw lines on the graph paper, parallel to the sensor tube, regularly spaced. The distance between each line can be any number of graph squares, so long as you use the same number each time. (See Fig. 4)  
Label the lines on the paper, starting with "0" for the line coinciding with the sensor tube, "1" for the closest, "2" for the next one, etc.

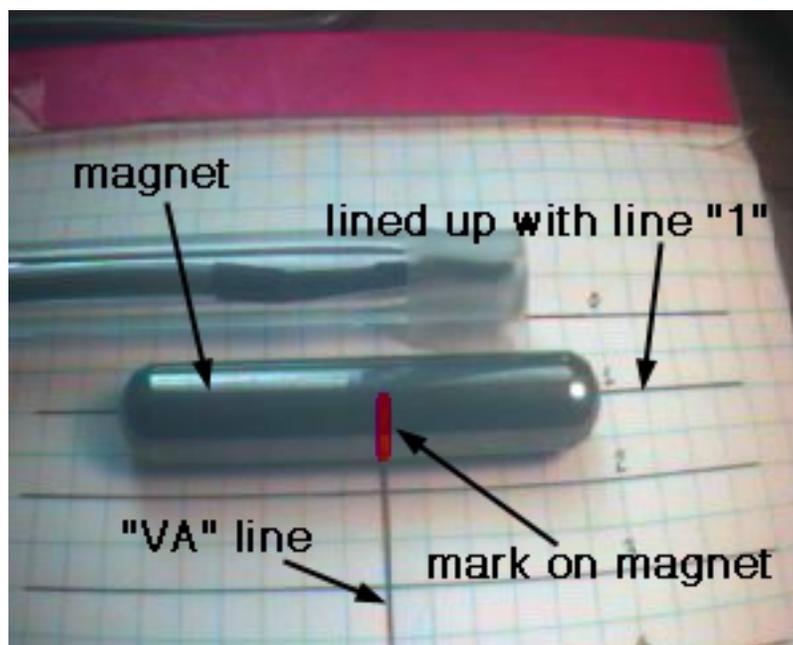


**Fig. 4** Draw regularly-spaced lines at five distances from the sensor tube. ("0" is "no distance" from the sensor, "1" is "one unit of distance from the sensor, etc.)

### Procedure:

1. Once the setup is complete, you are ready to begin taking data. First, make sure that the "Amplification" toggle switch on the MFS is set to "LOW x10".
2. Turn on the calculator. You should see a flashing black square. If you don't see the flashing black square, press "2nd" and then "CLEAR".
3. Press "APPS". You should now see a menu of options. Select "DataMate".
4. You should now see a screen with "CH 1: MAGNET F(MT) .42" at the top of it. The number "0.42" may vary. (A good range to expect is 0.3-0.5") This value 0.42 is the background magnetic field strength, in milli-Tesla (MT). We will call this number B. **Note the background field value "B", for later.** Also, make sure the magnet is at least 6 feet away from the MFS sensor before you note the "background" value B.
5. Check the "MODE:" line of the calculator display. It should say "EVENTS WITH ENTRY." If it does not, you must do the following:
  - a. Select "Setup."
  - b. Scroll down to the line that says "MODE" (Be patient. This part is really slow!). Press "ENTER"
  - c. Select "EVENTS WITH ENTRY"
  - d. Press "1" for "OK". This should put you back on the "CH 1: MAGNET F(MT) .42" screen.
6. If you're in "EVENTS WITH ENTRY" mode, then select "START".
7. Now you're in data-collecting mode. At the top of the screen, there should be a readout which says "PRESS [ENTER] TO COLLECT OR [STO] TO STOP". Below this line, there should be the number "1" and the current measurement, which should be the background B, which was 0.42 MT. This screen means that "measurement 1 is currently 0.42 MT."
8. Before you take some data, however, you must place the magnet appropriately.
  - a. Place the magnet on the paper so that it lies along the line labeled "1" on your paper. (See Fig. 5.) You can put the edge of the magnet along the line, or center the magnet on the line--but however you do it, it's crucial that you be *consistent* from one measurement to the next.
  - b. You'll want to draw a "visual aid" (VA) line, perpendicular to the numbered spacing lines, and place a small mark on the magnet (using the permanent marker) so that you always place the magnet on the same spot relative to the VA line.

- c. NOTE. The orientation of the magnet is very important, since the magnet may either "add" or "subtract" from the background magnetic field. **For simplicity, in this experiment, you should adjust the magnet position until the current value of the magnetic field is positive.** To be sure that this is the case, check the display at the top of the calculator screen, where the current data value is noted. (You'll notice this value has changed from the "background" value, now that the magnet is nearby.)



**Fig. 5** Placing the magnet on the page. Place the magnet along line "1", parallel to the line. Draw a "VA" (visual-aid) line as shown in the picture. Make a small mark on the magnet, using a permanent marker, where the magnet intersects the VA line.

9. Once you have the magnet properly placed along line "1", you are ready to take your first measurement. For the magnet shown in the picture, which is a "cow magnet", we got a value of 5.9 MT, quite strong.
- To record the measurement, press "ENTER"
  - The screen then says "ENTER VALUE ?". Press "1" for "first measurement, at line "1".
10. Now move the magnet to position (line) "2". Be sure that the mark on the magnet lines up with the VA line, and that the magnet is placed along the second line just as it was along the first. Press "ENTER" to record the measurement, and press "2" for the "ENTER VALUE?" field. Note that the calculator helps you keep track of what the previous measurement was, at the bottom of the screen.
11. Proceed to take measurements 3 through 5.
12. When done with measurement 5, press "STO" to quit data-taking. The screen should now show the "data-acquisition plot window" (DAPW), which contains a plot of your five magnetic intensity measurements, versus "X", the distance from the sensor.

## Data Analysis

- Press ENTER to leave the DAPW.
- Press "6" to quit the data-acquisition mode.
- Press ENTER to get away from the screen with "EVENTS IN L1" on the top line. You should now see the flashing square.
- Go into statistics mode by pressing "STAT"
- Press "1" to edit the data table you have created. You should now see your five measurements. Column L1 has the distances (1 through 5), and column L2 has the magnetic measurements.
- Press "GRAPH" to see a plot of this data. You may need to adjust the window to better display the plot. (To do this, press "WINDOW" and then scroll through the selections to modify things accordingly. See instructions that come with calculator.) See Fig. 6 for a shot of a sample plot.

19. Now the question is, does this data conform to a  $X^{-3}$  variation in intensity? In order to answer this, we must first note that the actual field measured was NOT just that of the permanent (bar) magnet. What we actually measured was where A is a constant which depends upon the strength of the magnet, B is the background value, and X is the distance. So, we should be able to draw a curve  $A X^{-3} + B$  which fits our five data points.

- The value B we obtained as our background field value.
- The constant A, we can get from our measurements. Go to the table of data values (press "STAT" and then "1"). In the L1 column are distances. At a distance of  $X = 1$ , the function  $A X^{-3} + B$  becomes simply  $A + B$ . So, the first measurement in column L2 (i.e. measurement 1), which we will call  $M_1$ , tells us what A is, namely  $A = M_1 - B$ . For our measurements,  $M_1$  was 5.9, and B was 0.42, so  $A = 5.48$ .
- Now press the "Y=" button. Press "CLEAR" to clear the first line, if necessary. Type in the function  $A X^{-3} + B$ , using the values of A and B from parts a. and b. For our values, we will type "5.48 / X ^3 + 0.42". (Note that the "X" is typed in using the "X,T,\_,n" button.)
- Press "Graph." The function you typed in should closely match the data points. (See Fig. 7)

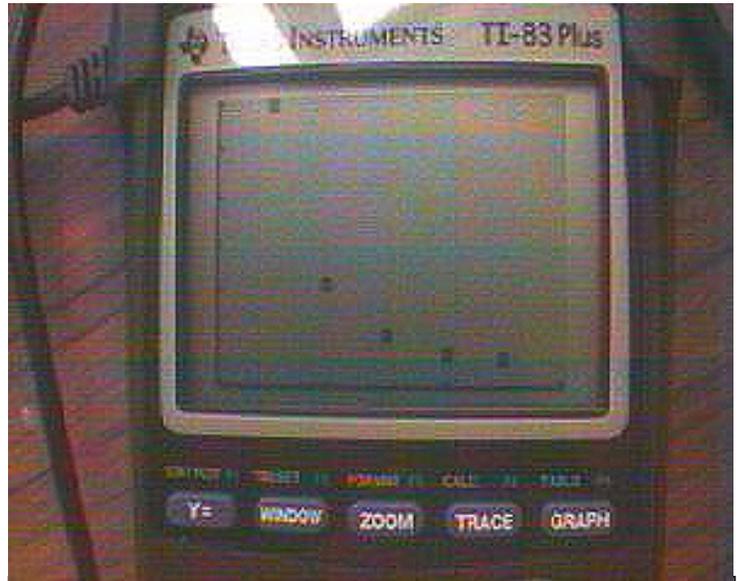


Fig. 6 Screen showing plot of 5 data points.

### Extra Exercises

Replot the plot using a logarithmic axis for X and/or for Y. Which gives a linear plot? (You may need to create a new data column for the logarithmic values).

Create a new data column with a new  $x_4 = 1/X^3$ . Will that give you a linear plot?

Try the data-collection with the magnet oriented in other ways; for example, at a 45-degree angle to the orientation shown in Fig. 5, or a 90-degree angle. Orient the magnet so that it "subtracts" from the background field. What plot do you get in this case?

Try measuring stacks of circle (washer) magnets.

Is the field of a stack of three magnets equal to three times the field of one magnet? What about four or five magnets?

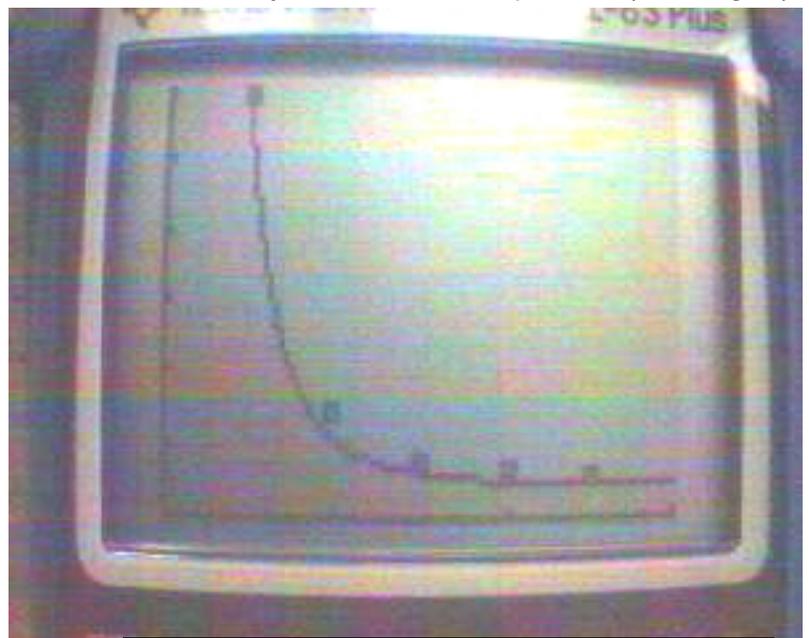


Fig. 7 The data, with the "theoretical" function  $A X^{-3} + B$  plotted over it as a solid line.