Science Objectives

- Students will map and describe the magnetic field around a permanent magnet or electromagnet.
- Students will determine the direction and strength of the force a magnet exerts on a current-carrying wire or loop.

Vocabulary

- magnetic field
- magnetic permeability constant
- magnetic moment

About the Lesson

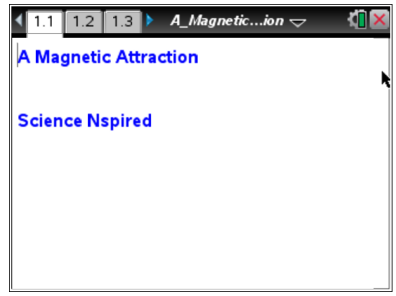
- In this activity, students will investigate the relationship between magnetic field strength and distance.
- As a result, students will:
  - Develop a mathematical model of magnetic field strength.
  - Use the model to calculate the magnetic moment of the field.

TI-Nspire™ Navigator™

- Send out the *A_Magnetic_Attraction.tns* file.
- Monitor student progress using Screen Capture.
- Use Live Presenter to spotlight student answers.

Activity Materials

- *A_Magnetic_Attraction.tns* document
- TI-Nspire™ Technology
- magnet
- meterstick
- Vernier Magnetic Field Sensor
- Vernier EasyLink™or Go!®Link interface
- pen or pencil
- blank sheet of paper
- tape



TI-Nspire™ Technology Skills:

- Download a TI-Nspire document
- Open a document
- Move between pages
- Collect data with Sensors

Tech Tips:

Access free tutorials at http://education.ti.com/calculators/pd/US/Online-Learning/Tutorials

Lesson Files:

Student Activity

- A_Magnetic_Attraction_Student.doc
- A_Magnetic_Attraction_Student.pdf

TI-Nspire document

- A_Magnetic_Attraction.tns

Discussion Points and Possible Answers

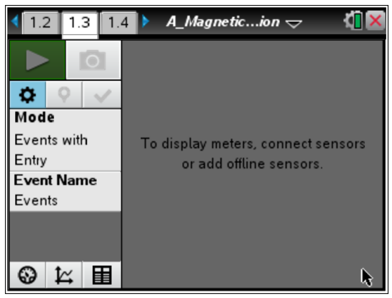
Students will probably be familiar with the effects of magnets, but may not know the quantitative relationships between magnetic field strength and distance. Before beginning this activity, review the concepts of magnetic field strength, magnetic moment, and magnetic permeability with students.

You should experiment with the magnets students will be using to determine which units (gauss or millitesla) students should use. In general, unless students are using a very strong magnet, gauss is the most appropriate unit. You should also experiment with appropriate distances for students to use.

Move to page 1.2.

1. Students should read the first page. They will then place a meterstick on a flat, level surface. They should place the Vernier Magnetic Field Sensor at the zero end of the meterstick. Tell students to orient the sensor so the white dot is pointing along the axis of the meterstick. They should tape the sensor in place so that it does not move during the experiment.

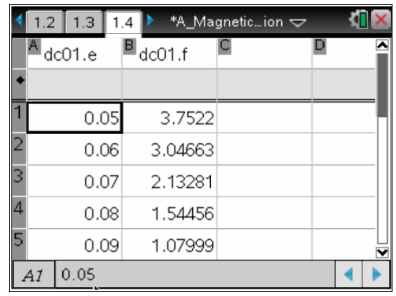
Move to page 1.3.



2. Page 1.3 is a blank DataQuest application. Students should connect the Vernier Magnetic Field Sensor to an EasyLink interface (if using a handheld) or a Go!Link interface (if using a computer). They then will connect the EasyLink or Go!Link to their handheld or computer.
3. Tell students to use mT units for this lab. Students can change the units from the Sensors menu **(Menu > Experiment > Set Up Sensors > Change Units > Magnetic Field)**.
4. Students should make sure there are no magnets near the sensor and then zero the sensor. **(Menu > Experiment > Set Up Sensors > Zero)**.
5. Next, students set up the data collection software to **Events with Entry** mode **(Menu > Experiment > Collection Mode)**. Students change the name of the event to "Distance" and units to "cm."
6. Tell students where to place the Magnetic Field Sensor for the initial measurement. They should keep the same orientation between the magnet and the sensor for all measurements. The magnet should have its South pole facing the white dot of the sensor, with the magnet's axis (the line connecting the North and South poles) parallel to the meterstick. Readings will be collected every 1 cm starting from the starting point. For the sample data shown at the right, readings were collected every 1 cm starting at the 5 cm mark. Students press **Start Collection** to start collecting data, and then will click on the **Keep Button** to keep the data collected.
7. Students move the magnet to the next mark and repeat the data collection, taking care to maintain the same orientation between the magnet and the sensor.
8. Students repeat the data collection eight more times. Once they have collected ten data points, they

can click on **Stop Data Collection** and disconnect the sensor.

Move to page 1.4

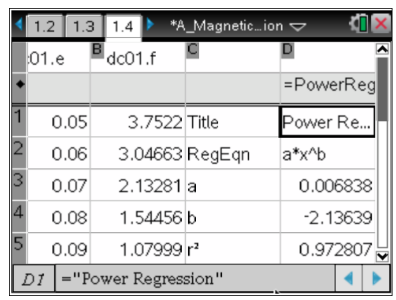


9. Page 1.4 contains a blank *Lists & Spreadsheet* application. Students set Column A to display the distance data they collected (press [var] > **Link To:** select the variable from the list). They set Column B to the magnetic field strength data they collected.

Move to page 1.5

10. Page 1.5 contains a blank *Graphs & Geometry* application. Students press **Menu > Graph Type > Scatter Plot**, then [var] > **Link To:** to select the distance variable for *x*. They repeat this to select the magnetic field strength variable for *y*, and then press [enter]. To adjust the scale for the graph, they may need to press **Menu > Window/Zoom > Zoom – Data**.

Return to page 1.4



11. Students highlight Columns A and B. They press **Menu > Statistics > Stat Calculations > Power Regression**. This function tells the handheld to calculate an equation of the form $y = ax^b$ that best fits the highlighted data. Students select **OK** to carry out the regression.

Move to page 1.5.

12. Students change the plot type to **Function** (**Menu > Graph Type > Function**). They select **f1(x)** from the function list at the bottom of the screen and press [enter] to plot the regression equation on the graph. Students record this equation on a separate sheet of paper.

Part 2: Building a Model for the Relationship

Move to page 1.5

1. On page 1.5, students hide the graph of **f1(x)** using the **Show/Hide** tool **(Menu > Actions > Hide/Show)**. They click on the graph to hide it and then use the **Trace** tool (**Menu > Trace > Graph Trace**) to determine and mark the coordinates of the leftmost point. As established in Part 1, magnetic field strength and distance are related by an inverse-cube law. That is, the equation relating field strength (*I*) and distance (*d*) takes the form $B = \frac{k}{d^3}$, where *k* is a constant. Students use substitution to find the value of *k* that makes the equation above true for the leftmost point on the graph. They record the value of *k* on a separate sheet of paper.

2. Students place a text box (**Menu > Actions > Text**) somewhere on the page. They type the value of *k* that they calculated into this text box and press [enter]. Then, they click once on the value (it should be highlighted in gray) and press [var]. They select **Store Var,** type **k,** and press [enter]. This will assign the number in the text box to the variable **k**.

3. In the **f2(x)** line of the function bar on page 1.5, Students type **k**/x^3 and press [enter]. (They may need to change the graph type to **Function** in order to see the function bar.) A graph of the estimated equation relating magnetic field strength to distance should appear on the screen.

4. Students can vary the value of **k** (by editing the text box) to produce a better fit to the data. They record the best-fit value of **k** on a separate sheet of paper.

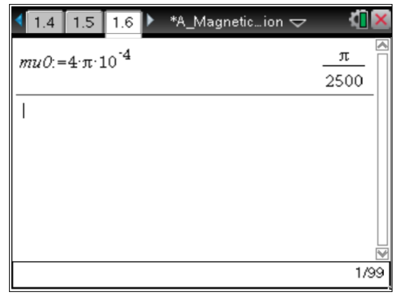
Part 3: Determining the Magnetic Moment

The equation relating magnetic field strength (*B*) to distance (*d*) is given below (μ_0 is the magnetic permeability constant, and μ is the magnetic moment of the field).

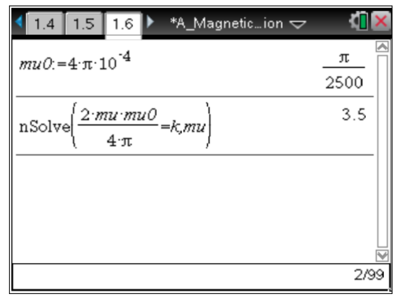
$$B = \frac{\mu_0}{4\pi} \text{ g } \frac{2\mu}{d^3}$$

In Part 2, students approximated this equation with the function $B = \frac{k}{d^3}$, and then calculated the value of *k* for their data. They will now use this value of *k* to calculate the magnetic moment of the field using the equation : $\frac{2\mu\mu_0}{4\pi} = k$.

Move to page 1.6.



5. This page contains a *Calculator* application. The magnetic permeability constant, μ_0, is equal to $4\pi \times 10^{-4}$. Define the variable **mu0** as $4\pi \times 10^{-4}$ as shown. You should make sure to use the := notation when you define the value of the constant.



6. Next, students use the **nSolve** function to solve the equation above for μ, entering the expression as shown at the right. They then record the calculated value of μ on a separate sheet of paper. (In this equation, μ_0 and μ are constants.)

Have students answer questions on the activity sheet.

Q1. How well do the results of the power regression support the "ideal" relationship between field strength and distance: $B = \frac{\mu_0}{4\pi} \text{ g } \frac{2\mu}{d^3}$? Explain your answer.

<u>Answer</u>: The results of the power regression agree with the "ideal" relationship. The ideal relationship indicates that magnetic field intensity should decrease in inverse proportion to distance cubed, and the power regression yields an exponent of nearly –3.

Q2. What is the value of *k* that you calculated from the data?

<u>Answer</u>: Students' values of *k* will vary.

Q3. What is the value of μ that you calculated from the data?

<u>Answer</u>: Students' values of μ will vary.

Q4. Electric currents produce magnetic fields. For a single loop of wire, the magnetic moment of the field is $\mu = IA$, where μ is the magnetic moment, *I* is the current, and *A* is the area of the loop through which the current flows.

Suppose the magnetic field in this activity were produced by a round magnet with a radius of 29 mm. What current would be required to produce an equivalent magnetic field in a loop of wire with the same radius as the magnet? (Note: The units of μ that you calculated are m^2 • A.)

<u>Answer</u>: If the radius of the wire loop is 29 mm (0.029 m) and the magnetic moment of the field is 0.4995 m^2 • A, the current in the loop can be calculated as follows:

$$\mu = IA = I(\pi r^2)$$

$$0.4995\ \text{m}^2\text{gA} = (I)(\pi)(0.029\,\text{m})^2$$

$$I = \frac{0.4995}{0.00264} = 189\ \text{A}$$

TI-Nspire Navigator Opportunities
Use the Ti-Nspire Navigator System to collect, grade, and save the .tns file to the Portfolio. Use Slide Show to view student responses.

Wrap Up

The students should collect data on the .tns file. When students are finished with the activity, pull back the .tns file using TI-Nspire Navigator. Discuss activity questions using Slide Show.

Assessment

- Formative assessment will consist of questions in the activity sheet.
- Summative assessment will consist of questions/problems on the chapter test.