A Magnetic Attraction – ID: 8548

By Russell Brown

Time required
45 minutes

Topic: Electricity and Magnetism

- *Map and describe the magnetic field around a permanent magnet or electromagnet.*
- *Determine the direction and strength of the force a magnet exerts on a current-carrying wire or loop.*

Activity Overview

In this activity, students will investigate the relationship between magnetic field strength and distance. They will develop mathematical models of the relationship and use the models to calculate the magnetic moment of the field.

Materials

To complete this activity, each student will require the following:

- *TI-Nspire™ technology*
- *magnet*
- *meter stick*
- *Vernier Magnetic Field Sensor*
- *Vernier EasyLink™or Go!®Link interface*
- *copy of the student worksheet*
- *pen or pencil*
- *blank sheet of paper*

TI-Nspire Applications

Calculator, Graphs & Geometry, Lists & Spreadsheet, Notes

Teacher Preparation

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.*
- *The screenshots on pages 2–6 demonstrate expected student results. Refer to the screenshots on page 7 for a preview of the student TI-Nspire document (.tns file). The student worksheet is shown on pages 8–11.*
- ***To download the .tns file, go to education.ti.com/exchange and enter "8548" in the search box.***

Classroom Management

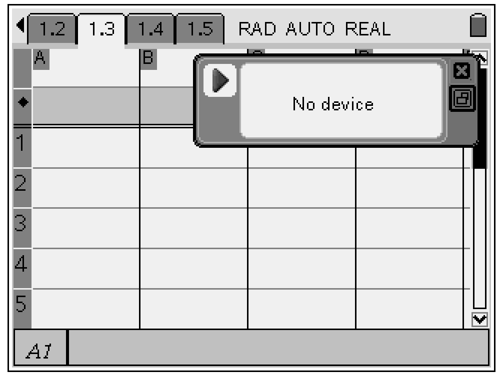
- *This activity is designed to be* ***student-centered****, with the teacher acting as a facilitator while students work cooperatively.*
- *In some cases, these instructions are specific to those students using TI-Nspire handheld devices, but the activity can easily be done using TI-Nspire computer software.*

The following questions will guide student exploration in this activity:

- What is the relationship between the strength of a magnetic field and the distance from its source?
- How can we create mathematical models based on quantitative data for this relationship?

Students will first collect data on the relationship between field strength and distance. They will then use two different methods to develop equations relating intensity and distance.

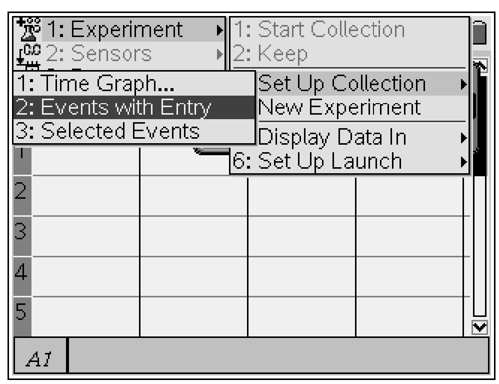
Part 1 – Using a regression to quantify the field strength-distance relationship



Step 1: Students should open the file **PhysWeek33_magstrength.tns** and read the first two pages. They should then place a meter stick on the floor or on another flat, level surface. They should place the magnet at the zero end of the meter stick. They should then connect a Vernier Magnetic Field Sensor to an EasyLink interface (if using a handheld) or a Go!Link interface (if using a computer).

Step 2: Students should move to page 1.3, which contains an empty *Lists & Spreadsheet* application, and insert a data collection box. They should then connect the EasyLink or Go!Link to their handheld or computer. Tell students which units (G or mT) to use. Students can change the units from the **Sensors** menu (**Menu > Sensors > Units**).

Step 3: Students should hold the sensor as far from any magnets as possible and then zero the sensor (**Menu > Sensors > Zero**).

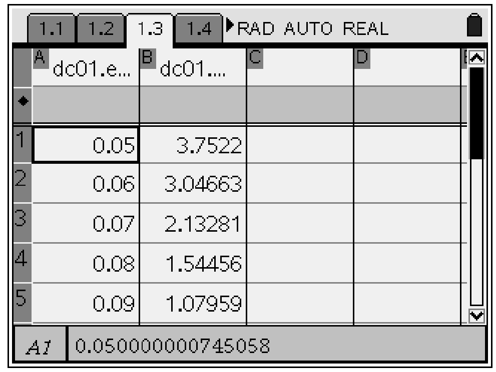


Step 4: Next, students set up the data collection software to **Events with Entry** mode.

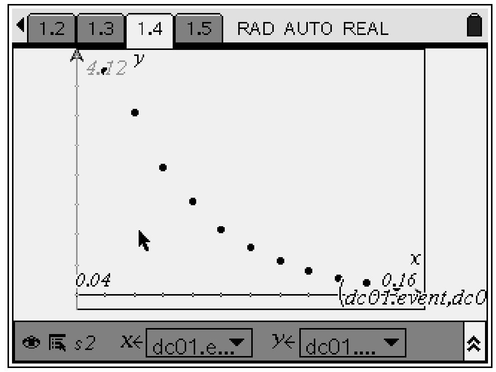
Step 5: Tell students where to place the Magnetic Field Sensor for the initial measurement. For the sample data shown here, readings were collected every 1 cm starting at the 5 cm mark.

Step 6: Students move the sensor to the next mark and repeat the data collection.

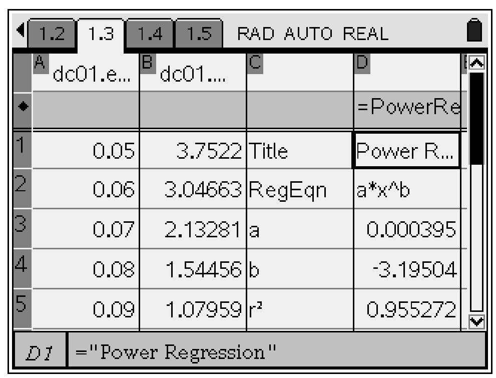
Step 7: Students repeat the data collection eight more times. Once they have collected ten data points, they can close the data collection box and disconnect the sensor.

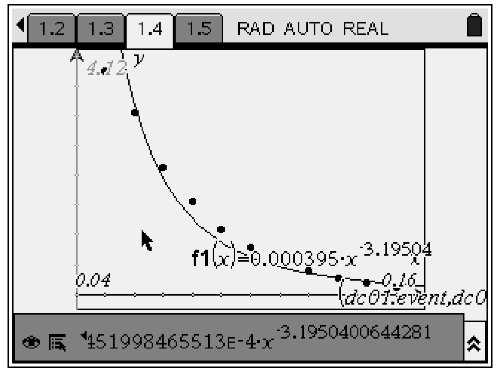


Step 8: Next, instruct the students to create a scatter plot of the data on page 1.4. They should use distance for the *x*-values and magnetic field strength for the *y*-values. They should use the **Zoom-Data** or **Window Settings** function to resize the graph window so all the data are visible, but there is no extra space around the edge of the graph. Discuss the shape of the graph with the students. Some students will probably assume that this is an inverse-square relationship. Ask them how they could determine whether an inverse-square function fits the data. They should reason that a power regression can provide information about the curve. You may need to guide them to this conclusion.



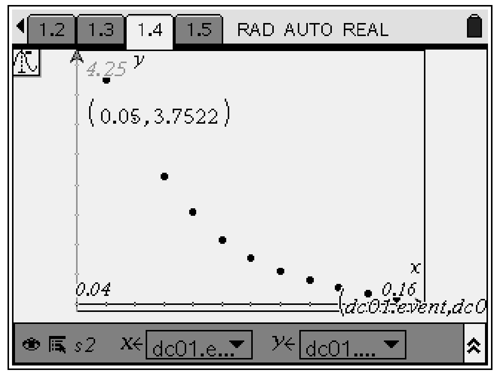
Step 9: Next, students will carry out a power regression (**Menu** > **Statistics** > **Stat Calculations** > **Power Regression**) on Columns A and B on page 1.3. They should use Column A for the *X List* and Column B for the *Y List*. They should store the values in Column C. Discuss the calculated value of variable *b* with students. They should conclude that the relationship is not, in fact, an inverse-square relationship. Instead, it is an inverse-cube relationship—that is, magnetic field strength decreases in direct proportion to distance cubed.



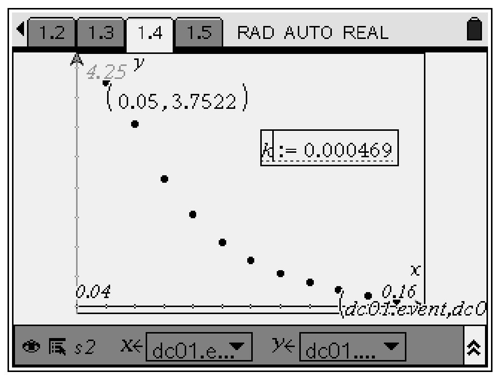


Step 10: Next, students graph the regression equation on the plot of the data on page 1.4. They will need to change the graph type to **Function**, then select **f1(x)** in the function bar. When they press [enter], the function should be plotted on the graph. Have the students record the equation on a separate sheet of paper. They should round the variables to three significant figures.

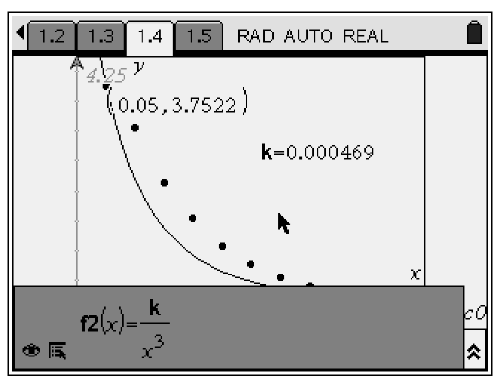
Part 2 – Building a model for the relationship



Step 1: Next, students will attempt to find the best-fit equation of the form $intensity = \frac{k}{d^3}$ to model the data. They should hide the graph of **f1(x)** using the **Show/Hide** tool. Then, they should use the **Trace** tool to locate and mark the coordinates of the leftmost point, as shown. Then, they should solve the equation above for *k*, using the coordinates of the leftmost point for *intensity* and *d*.

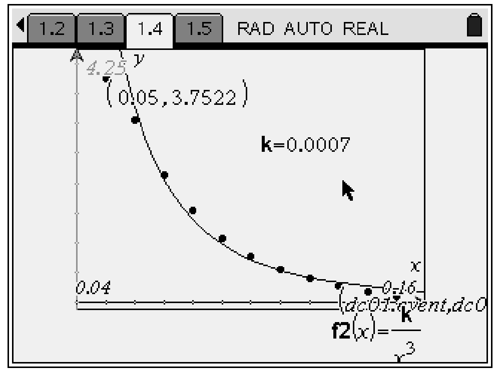


Step 2: Now, students should place a text box on the graph to contain the value of k. This will make it easier for them to vary *k* and observe the resulting changes in the graph. After placing the text box on the graph, they should enter their calculated value for *k* and press [enter]. Then, they should click once on the text box to highlight it and click [sto→ var]. They should select **Store Var** and type **k** to assign the variable **k** to this value.



Step 3: Next, students should plot the function they have estimated by clicking on the function bar at the bottom of the screen. (Students may need to first change the graph type to **Function** (**Menu > Graph Type > Function**).) They should enter the expression **k/x**^{3} in the *f2(x)* function bar. When they press [enter], the graph should update with the curve they have entered, as shown.

Step 4: Have students vary the value of **k** by editing the text box. They should attempt to find a value of **k** that produces the best fit to the data. Note that it will be impossible for students to find the absolute best-fit value of **k**. They should simply focus on finding a slightly better fit than the original value. Have students record the value of **k** they find on a separate sheet of paper.



Part 3 – Determining the magnetic moment

Next, students will calculate the magnetic moment of the field. 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):

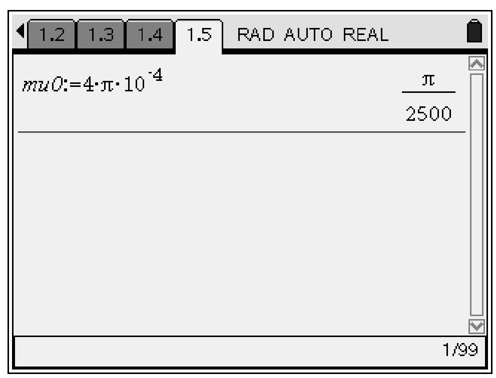
$$B = \frac{\mu_0}{4\pi} \cdot \frac{2\mu}{d^3}$$

In the previous steps, students have approximated this equation with the equation $intensity = \frac{k}{d^3}$ 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 following equation:

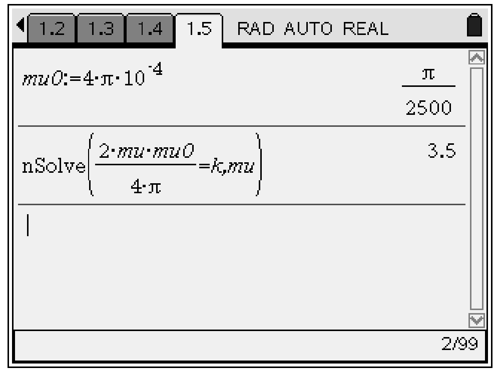
$$\frac{2\mu\mu_0}{4\pi} = k$$

The magnetic permeability constant, μ_0, is equal to $4\pi \times 10^{-4}$.

Step 1: Guide students through the derivation of the equation for μ. Then, have them move to page 1.5, which contains a blank *Calculator* application. They should use the *Calculator* to define the variable **mu0** (which will represent the magnetic permeability constant), as shown. Note: Make sure students use the **:=** notation (not just **=**) when entering the variable definition.



Step 2: Next, students will use the **nSolve** function to calculate the value of the magnetic moment by solving the equation above for *μ*, as shown. Note that students should not define the variable **mu** before entering it into the **nSolve** function. Students should record the value of *μ* that they calculate. The values they come up with will vary based on the best-fit values of **k** they found.



Finally, students should answer questions 1–4. The questions and their answers (in italics) are given below.

Q1. How well do the results of the power regression support the "ideal" relationship between field strength and distance given below?

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

(In this equation, μ_0 and *μ* are constants.) Explain your answer.

A. *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?

A. *Students' values of* k *will vary.*

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

A. *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 related to current by the following equation, in which *μ* is magnetic moment, *I* is current, and *A* is the area of the loop through which the current flows:

$\mu = IA$

The magnetic field in this activity was 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 $m^2 \cdot A$.)

A. *If the radius of the wire loop is 29 mm (0.029 m) and the magnetic moment of the field is 0.4995* $m^2 \cdot A$*, the current in the loop can be calculated as follows:*

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

$$0.4995\,m^2 \cdot A = (I)(\pi)(0.029\,m)^2$$

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

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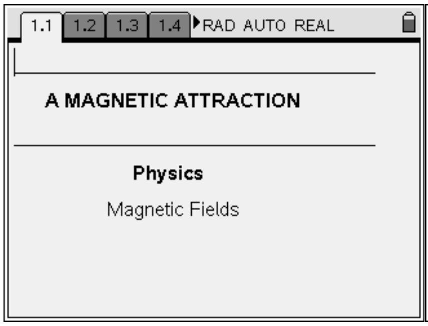
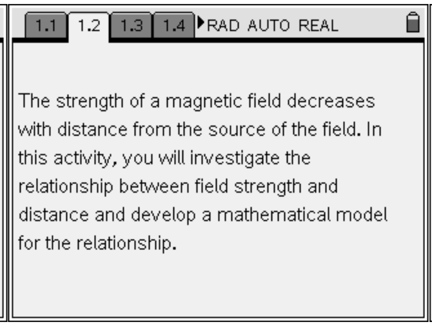
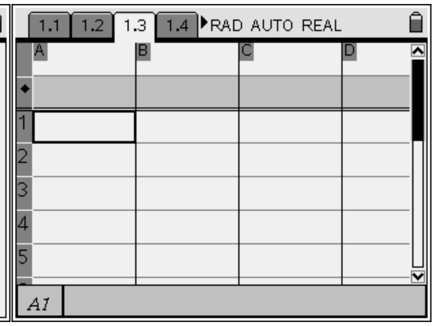
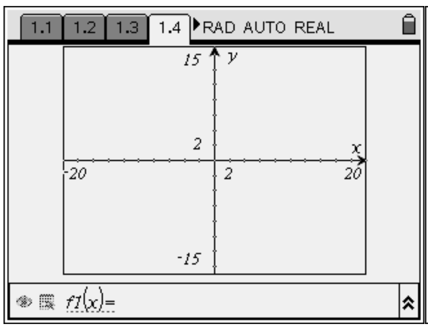
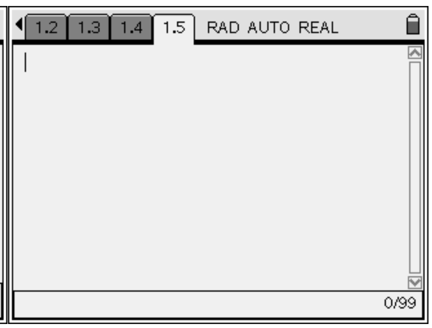
(Student)TI-Nspire File: *PhysWeek33_magstrength.tns*











A Magnetic Attraction

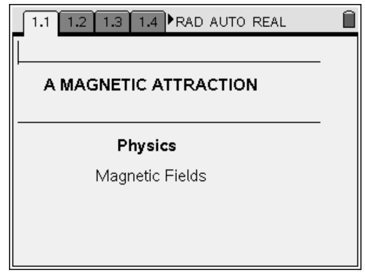
ID: 8548

Name ____________________

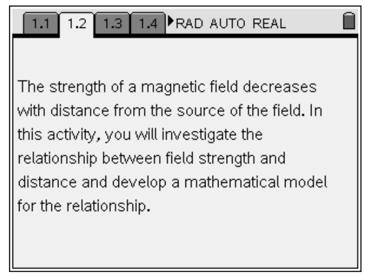
Class ____________________

In this activity, you will explore the following:

- *the relationship between magnetic field strength and distance*
- *how to make a mathematical model of a physical phenomenon*



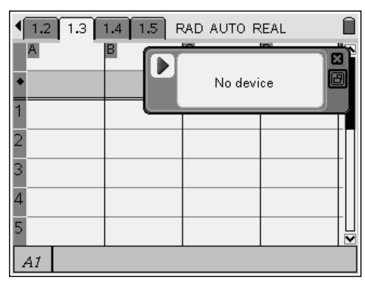
Open the file **PhysWeek33_magstrength.tns** on your handheld or computer and follow along with your teacher for the first two pages. Move to page 1.2 and wait for further instructions from your teacher.



The strength of a magnetic field decreases as you move farther from the source of the field. In this activity, you will determine the mathematical relationship between the magnetic field strength and the distance from its source.

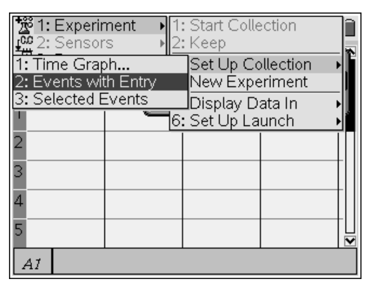
Part 1 – Using a regression to quantify the field strength-distance relationship

Step 1: Place the meter stick on the floor or another flat, level surface. Place the magnet at the zero end of the meter stick. Connect a Vernier Magnetic Field Sensor to an EasyLink interface (if using a handheld) or a Go!Link interface (if using a computer).



Step 2: Move to page 1.3, which contains an empty *Lists & Spreadsheet* application. Insert a new data collection box by pressing ctrl D. Connect the EasyLink or Go!Link interface to your handheld or computer. Data should appear in the data collection box. Your teacher will tell you which units to use (gauss (G) or millitesla (mT)).

Step 3: Hold the Magnetic Field Sensor as far from any magnet as possible. Wait for the magnetic field strength reading to stabilize, and then zero the sensor (**Menu > Sensors > Zero**).



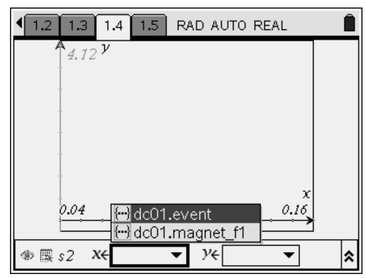
Step 4: For this experiment, you will need to collect data on field strength and distance at specific points. To set up the TI-Nspire to collect data in this way, select **Events with Entry** from the **Experiment** menu (**Menu > Experiment > Set Up Collection > Events with Entry**). Click the "play" button (►) to begin the experiment.

Step 5: Your teacher will tell you where on the meter stick to place the Magnetic Field Sensor. (You may need to hold it in place gently.) Wait until the field strength reading has stabilized, and then click the button in the lower right corner of the data collection box. A dialog box should appear. Enter the distance (in meters) between the sensor and the magnet in the box, and then click OK. For example, if your initial distance was 5 cm, you would enter 0.05 in the box.

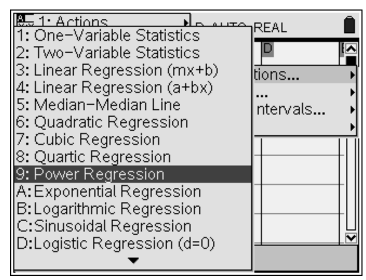
Step 6: Move the sensor to another distance as directed by your teacher. Wait until the field strength reading has stabilized, and then click the button in the lower right corner of the data collection box. A dialog box should appear. Enter the distance in the box, and then click OK.

Step 7: Repeat step 6 eight more times, moving the sensor farther from the magnet each time. Note: Make sure you keep the sensor in exactly the same orientation relative to the magnet at all times. Do not raise, lower, or tilt the sensor, or your data will not be accurate.

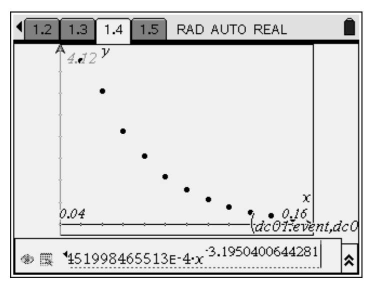
Step 8: Close the data collection box and disconnect the sensor. Then, move to page 1.4, which contains a blank *Graphs & Geometry* application. Use this application to create a scatter plot of the data in the spreadsheet on page 1.3. Use distance as your *x*-values and magnetic field strength as your *y*-values.



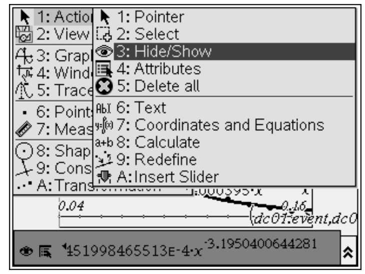
Step 9: Move back to page 1.3 and highlight Columns A and B. Select **Stat Calculations** from the menu and choose **Power Regression**. This function tells the handheld to calculate an equation of the form $y = ax^b$ that best fits the data you have highlighted. Select **OK** to carry out the regression.



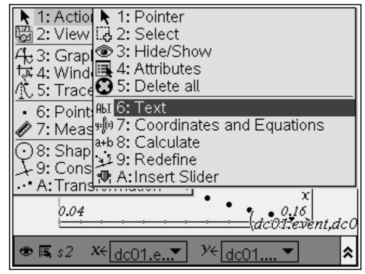
Step 10: Move to page 1.4 (the graph of field strength vs. distance) and change the plot type to **Function** (**Menu > Graph Type > Function**). Select **f1(x)** from the function list at the bottom of the screen to plot the regression equation on the graph. Record this equation on a separate sheet of paper.



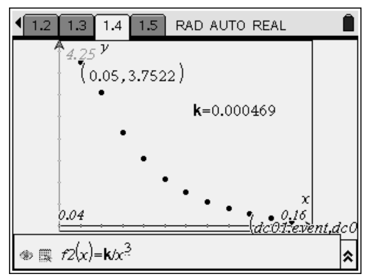
Part 2 – Building a model for the relationship



Step 1: On page 1.4, hide the graph of **f1(x)** using the **Show/Hide** tool. Use the **Trace** tool (**Menu > Trace > Graph Trace**) to determine and mark the coordinates of the leftmost point. As you 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 $I = \frac{k}{d^2}$, where k is a constant. Use substitution to find the value of k that makes the equation above true for the leftmost point on the graph. Record your value of k on a separate sheet of paper.



Step 2: Place a text box (**Menu > Actions > Text**) somewhere on the page. Type the value of k that you calculated into this text box and press [enter]. Then, click once on the value (it should be highlighted in gray) and press [sto→ var]. Select **Store Var** and then type **k**. This will assign the number you entered into the text box to the variable **k**.



Step 3: In the **f2(x)** line of the function bar on page 1.4, type **k**/x^3 and press [enter]. (You may need to change the graph type to **Function** in order to see the function bar.) A graph of the estimated equation relating field strength and distance should appear on the screen.

Step 4: Vary the value of **k** by editing the text box. Vary the value of **k** to produce a better fit to your data. 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).

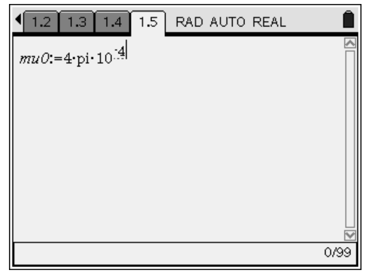
$$B = \frac{\mu_0}{4\pi} \cdot \frac{2\mu}{d^3}$$

In the previous steps, you have approximated this equation with the equation $intensity = \frac{k}{d^3}$ and then calculated the value of k for your data. You will now use this value of k to calculate the magnetic moment of the field using the following equation:

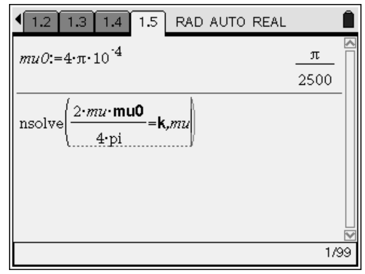
$$\frac{2\mu\mu_0}{4\pi} = k$$

The magnetic permeability constant, μ_0, is equal to $4\pi \times 10^{-4}$.

Step 1: Move to page 1.5, which contains a *Calculator* application. Define the variable **mu0** as $4\pi \times 10^{-4}$, as shown to the right. Make sure to use the := notation when you enter the equation.



Step 2: Next, you will use the **nSolve** function to solve the equation above for *μ*. Enter the expression as shown to the right. Record your calculated value of *μ* on a separate sheet of paper.



Q1. How well do the results of the power regression support the "ideal" relationship between field strength and distance given below?

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

(In this equation, μ0 and μ are constants.) Explain your answer.

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

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

Q4. Electric currents produce magnetic fields. For a single loop of wire, the magnetic moment of the field is related to current by the following equation, in which *μ* is magnetic moment, *I* is current, and *A* is the area of the loop through which the current flows:

$\mu = IA$

The magnetic field in this activity was 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.)

