  Graphical Analysis 31

The Magnetic Field of a   
Permanent Magnet

A bar magnet is called a dipole because it has two poles (commonly labeled north and south). Breaking a magnet in two does not produce two isolated poles; each fragment still has two poles. Similarly, two magnets together still exhibit only two poles. Since, to our knowledge, there are no magnetic monopoles, the dipole is the simplest possible magnetic field source.

The dipole field is not limited to bar magnets, for an electrical current flowing in a loop also creates this common magnetic field pattern.

The magnetic field, Baxis (measured in tesla), of an ideal dipole measured along its axis is



where μ0 is the permeability constant (4π × 10–7 T•m/A), d is the distance from the center of the dipole in meters and μ is the magnetic moment. The magnetic moment, μ, measures the strength of a magnet, much like electrical charge measures the strength of an electric field source. Note that the distance dependence of this function is an inverse-cube function, which is different from the inverse-square relationship you may have studied for other situations.

In this experiment, you will examine how the magnetic field of a small, powerful magnet varies with distance, measured along the axis of the magnet. A magnetic field sensor will be used to measure the magnitude of the field.

Simple laboratory magnets are approximately dipoles, although magnets of complex shapes will exhibit more complex fields. By comparing your field data to the field of an ideal dipole, you can see if your magnet is very nearly a dipole in its behavior. If it is nearly a dipole, you can also measure its magnetic moment.

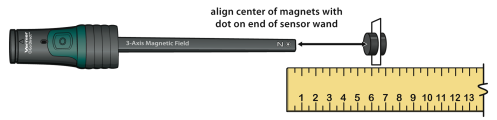


Figure 1

Objectives

* Measure the field of a small magnet.
* Compare the distance dependence of the magnetic field to the magnetic dipole model.
* Determine the magnetic moment of a magnet.

Materials

Chromebook, computer, or mobile device

Graphical Analysis 4 app

Go Direct 3-Axis Magnetic Field

masking tape

2 neodymium or ceramic magnets

tape measure or meter stick

index card

preliminary question

Place one magnet on a table and hold the other in your palm, well above the first. From directly above, slowly lower the upper magnet toward the first. Watch for the moment when the lower magnet jumps toward the back of your hand. Try it again. From the sudden jump of the lower magnet, what can you conclude about the way the magnetic force between the magnets varies with distance?

Procedure

1. Launch Graphical Analysis. Connect the Go Direct 3-Axis Magnetic Field Sensor to your Chromebook, computer, or mobile device.
2. Set up the data-collection mode.
   1. Click or tap Mode to open Data Collection Settings. Change Mode to Event Based.
   2. Enter Distance as the Event Name and m as the Units. Click or tap Done.
3. Position the meter stick and the magnetic field sensor as shown in Figure 1. The body of the magnetic field sensor should be parallel to the meter stick, with the x-axis tip of the wand pointing in the direction of increasing distance. Identify the location of the sensor (marked with dots approximately 0.5 cm back from the tip) and align this location with the zero mark on your meter stick. When everything is in place, tape the sensor and meter stick to the table.
4. As a convenient way to measure to the center of the magnet, and to ease handling of the small magnets, allow the two magnets to attract one another through the card, about 0.5 cm from either edge near the corner. The magnets should stay in place on the card. The card will serve to mark the center of the magnet pair.
5. Zero the magnetic field sensor when the magnets are far away from the sensor in order to remove the effect of Earth’s magnetic field and any local magnetism. The magnetic field sensor will be zeroed only for this location. Instead of moving the sensor in later steps, you will move the magnet.
   1. Move the magnets at least 1 m from the sensor.
   2. Click or tap the X Magnetic Field meter and choose Zero.
6. Collect magnetic field data as a function of distance.
   1. Start data collection.
   2. Position the magnets so the card is perpendicular to the tip of the magnetic field sensor, 3 cm from the dots that mark the sensor’s location (see Figure 1).
   3. Monitor the readings. If necessary, reverse the magnets so the magnetic field values are positive, and then reposition the magnets. If the reading is 5 mT, then increase the distance until the reading is below 5 mT.
   4. When the reading has stabilized, click or tap Keep.
   5. Enter the distance to the magnet. To make later calculations easier, enter the distance in meters (e.g., 3 cm is 0.03 m). Click or tap Keep Point to save this data pair.
7. Collect 10 additional data points.
   1. Taking care not to move the magnetic field sensor or meter stick, move the magnet 0.25 cm (0.0025 m) farther from the sensor.
   2. Click or tap Keep and enter the distance (in meters). Click or tap Keep Point.
   3. After the 11th point, stop data collection. The graph is the magnetic field vs. the distance from the magnet. The field should drop off rapidly.

Data Table

|  |  |
| --- | --- |
| Power regression parameter, a |  |
| Power regression parameter, b |  |
| Power regression equation |  |

|  |  |
| --- | --- |
| Magnetic moment | |
| μ (A•m2) |  |

Analysis

1. A graph of magnetic field vs. distance is displayed. Is the data consistent with the equation for the magnetic field of a dipole described in the introduction?

Compare your data to the inverse-cube model shown below using a power regression curve fit in Graphical Analysis



* 1. Click or tap Graph Tools, , and choose Apply Curve Fit.



* 1. Select Power as the curve fit and click or tap Apply.
  2. A curve is fit to your data and parameters are shown on the graph. Record the parameter values in the data table and use them to write the power regression equation.
  3. Export, download, or print the graph.

1. How well does the power regression fit your experimental data? An inverse cube function has b = 3. Does your data approximately follow an inverse cube function? From the comparison, does your magnet show the magnetic field pattern of a dipole?
2. Graphical Analysis adjusted parameter a so the equation’s curve comes close to your data points. Relating the parameter a to the field expression for a magnetic dipole, we see that



The factor of 103 is present because the magnetic field was measured in mT rather than T. Use your value of a to determine the magnetic moment μ of your magnet, if the power regression fits your experimental data.

Extensions

1. Find other magnets such as refrigerator magnets, horseshoe magnets, and cow magnets, and see if they also show the magnetic field of a dipole.
2. Measure the dipole moment of just one neodymium magnet, or four stuck together. Is the dipole moment additive when you use two or more magnets attracted together?
3. Show that the units of the magnetic moment are A•m2 (ampere meter2).
4. The units of μ may suggest a relationship of a magnetic moment to an electrical current. A current flowing in a closed loop is a magnetic dipole. A current, I, flowing around a loop of area πr2 has a magnetic moment μ = I πr2. If a single current loop had the same radius as your permanent magnet, what current would be required to create the same magnetic field? (You will be surprised.) Are there currents flowing in loops in the permanent magnet?