Lab 12

Magnetic Field Demonstrations - An Exercise

The lab room has been set up with five lab stations; each involves a short experiment designed to demonstrate the characteristics of the magnetic field for various objects. Your group will move from table to table and carry out each of these experiments, making observations and collecting data as necessary. Listed below are questions which you should attempt to answer at each station. Instead of a lab report, you will need to write a half-page summary on each station. It should be thorough enough to explain the phenomenon to a colleague who missed today's lab.

You should form into four groups so that there is always an empty station. Take notes in your lab notebook, but then write up and turn in a formal document that discusses the relevant ideas for each station.

Warning 12.0.1. In all experiments, note that electronic equipment such as power supplies and computers produce magnetic fields that might impact your experiment. You should not measure your magnetic fields near other electronic devices. You should also be aware that strong magnetic fields can erase credit cards and other magnetic storage devices.

12.1 Data Studio's Magnetic Field Sensor (for reference, not an experiment)

To use the magnetic field sensor, turn on Data Studio, plug in the sensor, and activate the sensor in the usual manner. At the tip of the arm on the sensor are two white dots, one on the end of the tip and one on the side of the tip. Notice also the control buttons on the handle of the sensor. The first button has two settings: marked $\rightrightarrows$ and $\upuparrows$ and these are labeled [Radial/Axial]. The Radial setting measures magnetic field pointing into the side of the arm of the sensor, at the location of the white dot. The Axial setting measures magnetic field pointing into the end of the sensor, at the location of the white dot. Negative means that the magnetic field is out of the sensor instead of into the sensor.

When changing between Axial and Radial, the sensor must be tared. If you tare it while it is pointing in the direction of some magnetic field, then it cannot[1] measure that magnetic field.

12.1.1 Measuring the B of a Permanent Magnet

Determine the expected direction of the magnetic field. Set the sensor to either Radial or Axial, according to how you expect to hold it, and tare it. Verify that the scale is set to [1×] and plot in Gauss or Tesla, as appropriate. Place the tip of the sensor such that the white dot on the side (or top as necessary) is near the magnet pointing in the direction of the expected magnetic field.

[1] This is exactly analogous to tarring a scale with a cup on it; the scale only reads the mass of the material added to the cup after the tarring, not the mass of the cup itself.

12.1.2 Measuring the B of a Wire Loop

Use the right-hand rule to determine the expected direction of the magnetic field. Set the sensor to Axial and tare it. Verify that the scale is set to [1×] and plot in Gauss or Tesla, as appropriate. Place the tip of the sensor such that the white dot on the end is as close to the center of the wire loop as possible and points as perpendicular as possible to the plane of the coil.

If there is a cross-field (a field perpendicular to the field of the coil), then you might also try to measure that by removing the sensor from the vicinity of the coil, setting it to Radial, re-taring it, and then replacing the sensor into the center of the coil with the white dot on the side pointing in the direction of the cross field.

12.1.3 Measuring the B of a Solenoid

Use the right-hand rule to determine the expected direction of the magnetic field. Set the sensor to Axial and tare it. Verify that the scale is set to [1×] and plot in Gauss or Tesla, as appropriate. Place the tip of the sensor such that the white dot on the end is as close to the center of the solenoid as possible and points as close as possible along the axis of the solenoid.

You might also try to measure the radial component to the field by removing the sensor from the vicinity of the coil, setting it to Radial, re-taring it, and then replacing the sensor into the center of the solenoid with the white dot on the side pointing outwards towards the coil.

12.1.4 Measuring the B of a Long Straight Wire

Use the right-hand rule to determine the expected direction of the magnetic field. Set the sensor to Radial and tare it. Verify that the scale is set to [1×] and plot in Gauss or Tesla, as appropriate. Place the tip of the sensor such that the white dot on the side is in the vicinity of the wire pointing in the direction of the expected magnetic field.

If there is a cross-field (a field perpendicular to the field of the wire), then you might also try to measure that by removing the sensor from the vicinity of the wire, setting it to Radial, re-taring it, and then replacing the sensor into the center of the coil with the white dot on the side pointing in the direction of the cross field.

12.2 Magnetic Field of a Permanent Magnet - Iron Filings

You should have two cylindrical magnets, a coffee filter, a stiff plastic plate, some paper clips and nails, and a salt shaker of iron filings available at this station. Each magnet is labeled with either "N" or "S" to indicate the north or south pole of the magnet, respectively.

12.2.1 Magnets and Paper Clips

Consider how magnets and paper clips interact. In each of the following, you may replace the paper clips with nails if you like.

Exercise 12.2.1.

1. Describe any interaction you experience when you touch any pair of the paper clips together in the various possible orientations.

2. Describe any interaction you experience when you touch the magnets together in the various possible orientations.

   (a) Describe how you can pick one magnet up with the other.

   (b) Describe how you can knock one magnet over with the other (without making contact).

3. Describe any interaction you experience when you touch one of the magnets together with any one of the paper clips in the various possible orientations.

(a) Pick up one paper clip *with the narrow end* of one of the magnets so that the clip hangs straight out from the magnet. Then, while these are still in contact, touch a second paper clip with the end of the first clip. Now, while carefully holding the first clip near the magnet, carefully remove the magnet from the first clip. *After showing the result to your instructor*, describe and explain the result on the two paper clips.

(b) Predict what will happen if you brought either end of the magnet slowly towards the lower end of the dangling paper clip. Verify your predictions and provide an explanation for how and why your predictions were correct or incorrect. (Be sure to include comments about the orientation of the poles of the magnets as well as the poles of the paper clips.)

4. Explain why it is possible to stick either end of a paper clip to either end of a magnet, but you cannot stick one end of a magnet to either end of another magnet.

12.2.2 Magnets and Iron Filings

Iron filings act similarly to the paper clips. The iron filings are small enough that they allow us to "map" the magnetic field of an object. Each individual filing will align itself with the magnetic field.

Place the coffee filter on top of the clear, plastic plate. Sprinkle some iron filings on the coffee filter. Note: We are using a coffee filter because its shape allows us to minimize spilling the filings on the table, or worse, the floor. ***Be* very *careful not to spill the filings.*** Have one person hold the plate up with both hands high enough for another person to move one of the cylindrical magnets beneath it while you all watch what happens to the iron filings. Meanwhile, somebody else should place one of the cylindrical magnets underneath the sheet of paper so that everybody can observe the patterned displayed by the filings.

Exercise 12.2.2.

1. Determine if you can make any interesting patterns in the filings by placing or moving the magnet under the filings. When you think you have a good sense of the patterns, try to draw or describe some of what you found.

2. Without the magnet, try to smooth out the filings. (If you can't smooth them out well, then carefully hold the salt-shaker over the coffee filter and unscrew the cap, pour the filings back in, replace the cap, and re-sprinkle more filings onto the filter.) Predict what you should see if you had two magnets under the filings each with the North pole facing the other magnet. What if both South poles were facing each other? What if one North and one South pole faced the other?

3. While one person holds the plate with the filter and filings, have two people each hold a magnet under the filings as described in the previous question. Verify your predictions and provide an explanation for how and why your predictions were correct or incorrect.

12.3 Magnetic Field of a Permanent Magnet - Field Sensor

You should have a small, four-post, wooden stand with a hole in the top and a wooden cylinder taped to a ruler on a lab-jack. The wooden equipment was hand-made and is delicate; ***please be careful when handling the apparatus***.

Exercise 12.3.1.

1. Use the field sensor (as described in Section 12.1) set to Axial to measure (and record) the strength of the magnetic field *due to the permanent magnet* at various positions from the magnet. It will be useful to set the sensor 10.0 cm from the magnet and make a measurement at each 1.0 cm interval as you move towards the magnet.

2. Repeat this for the Radial setting.

3. Tabulate your results (you may also graph it *if you like*) and discuss the manner in which the field depends on distance. Is it linear? Polynomial? something else?

12.4 Magnetic Field of the Earth - Tangent Galvanometer

This station has a loop of wire connected to a power supply. There is also a compass needle balancing on a needle point located at the center of the loop. Verify that the power supply is connected to the wire. Without turning on the power supply, predict which way current will flow based on the connection. With the power supply off (not merely turned down), carefully and gently align the loop so that it rests along the line that the compass wants to rest. ***Before you turn on the power supply***, turn the voltage dial down to zero and the current dial up to some medium value. The HI-LO setting on the current dial should be set to LO. When current begins to flow through the coil, a magnetic field is generated whose direction can be found from the right-hand rule and whose magnitude can be calculated from

$$B_c = \frac{\mu_0 I N}{2R} \tag{12.1}$$

where B_c is the coil's magnetic field strength, I is the current (in amps), $\mu_0 = 4\pi \times 10^{-7}\ {}^{\mathrm{N}}\!/\!{}_{\mathrm{A}^2}$, N is the number of turns of the wire in the coil, and R is the radius of the coil (which you will have to measure).

Exercise 12.4.1.

1. Using components, resultants, magnitudes and directions, devise a technique to combine the controllable magnetic field due to the coil with the uncontrollable, but fixed, magnetic field of the earth in such a way as to calculate the magnitude of the Earth's magnetic field. Several hints are given below.

   (a) If the field due to the loop were the only field present, which way would the compass needle point after you turned on the current? What would happen if you changed the direction of the current?

   (b) If there were two magnetic fields present, along which (if either) would a compass point?

   (c) Can you control the direction of any magnetic field present? Why might you want the wire to line up with the direction that the compass points before turning on the current? How are the directions of the components of a vector "aligned"?

   (d) Can you control (and know the value of) the magnitude of any magnetic field present? What would the compass needle do as you slowly turn this up from zero to some very large value?

   (e) Can you relate components to resultants and vice versa?

2. Turn on the power and very slowly turn up the voltage while watching the ammeter; the ammeter should not go above 4 or 5 mA. Describe the effect this has on the compass needle. Predict and explain what *would* happen if you swap the direction, but not the magnitude of the current. ***Do not actually swap the direction of the current at this point.***

3. Let the compass needle settle into whatever orientation it likes while the power continues to be supplied to the circuit. While you wait, record the value of the current and use the field sensor (as described in Section 12.1) to measure (and record) the strength of the magnetic field *due to the loop* at the center of the compass. After the compass needle settles in, place a protractor on the top of the wire loop and measure (and record) the angle of the deflection. Without turning off the power supply, unplug the cables that provide current to the circuit *from the power supply, not from the wire loop, which should not be bumped*. Plug the cables in the other way to flip the current. Describe what happens to the compass. Remeasure (and record) the current, the magnetic field, and the angle of deflection for this direction. Calculate the magnetic field of the Earth based on the average measured B and the average deflected angle. Despite the large uncertainty, compare it to the known value.

12.5 Magnetic Field of a Solenoid

Before you turn on the power supply, set the current all the way down and the voltage up at some intermediate point. The HI-LO setting on the current dial should be set to LO.

12.5.1 The Small Solenoid

Exercise 12.5.1.

1. Without turning on the power supply, connect the positive and negative terminals of the power supply to the terminals of the smaller solenoid. Note the direction of current flow and predict the direction of the magnetic field.

2. Use the field sensor (as described in Section 12.1) set to Axial to measure (and record) the strength of the magnetic field *due to the solenoid*. Insert the sensor as far along the axis of the solenoid as possible and try to keep your hand as steady as possible. Turn on the power supply and slowly turn up the current to some intermediate value. Move the sensor around a little inside the solenoid and discuss the results.

3. Repeat the previous step with the sensor set to Radial. What variables does the magnetic field due to a solenoid depend on? Does it follow the predicted equation for a solenoid?

Turn the power supply off. Disconnect the wire from the solenoid.

12.5.2 Measurements with the Large Solenoid

Before connecting the large solenoid, measure the number of turns per length, $n = \frac{N}{L}$. Do not measure the full number of loops nor the full length. Find some portion of the coil and measure the number of coils and the length in that small sample size. When you calculate n, notice that the solenoid is wrapped four coils deep, so multiply your N by 4. In this problem, you can measure B and I in order to find μ_0 to verify the equation of a solenoid.

Exercise 12.5.2.

1. Connect the power supply in series with an ammeter and then the solenoid before completing the circuit back to the power supply. Be sure that the ammeter reads several amps. Insert the field sensor set to the appropriate settings as close as possible to the axis of the solenoid. Predict what you will measure for the Radial and Axial measurements above.

2. Measure the current from the ammeter, the magnetic field from the sensor and calculate a value for μ_0 based on the equation for a solenoid. Compare this to the accepted value in your book. Draw a conclusion about the equation of a solenoid.

12.6 Magnetic Field of a Wire

Before you turn on the power supply, set the current all the way down and the voltage up at some intermediate point. The HI-LO setting on the current dial should be set to HI. (You will be using a current of about 8 A.)

Notice that the wire connects are exposed. Be careful not to touch the connections when the current is on.

Exercise 12.6.1.

1. Without turning on the power supply, connect the positive and negative terminals of the power supply to opposite ends of one of the three wires inside the **Romex**™ cable. Be sure, based on color, to connect them to *the same* wire. Straighten a long section of the wire as well as possible. Note the direction of current flow and predict the direction of the magnetic field.

2. Use the field sensor (as described in Section 12.1) set to Radial to measure (and record) the strength of the magnetic field *due to the long straight wire*. The sensor should lie along the direction of the wire and must be touching the wire to make any measurement. Turn on the power supply and turn up the current to about 8 A. (You may change the current in order to see the effect of current on the size of the magnetic field.) Move the sensor to different radii and discuss the results. Place the sensor close to the wire and slowly vary the strength of the current using the knob on the power supply. Discuss the results.

3. Repeat the previous step with the sensor set to Axial.

4. Turn the power supply off. Disconnect the wire from the power supply. Connect the red terminal to one side of the white wire and the black terminal to the black wire so that both connections are at the same end. On the far end, connect the black and white wires (this is where the lamp goes and you should not actually do this at home where there is *significantly* more current able to flow! *Really*!). Predict what you will measure for the Radial and Axial measurements above.

5. Repeat Questions Question 12.6.1.2 and Question 12.6.1.3 for the two wire case. Verify your predictions and provide an explanation for how and why your predictions were correct or incorrect.

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A PDF version might be found at Magneticdemo.pdf (172 kB)