Magnetic Fields and Their Effects

Introduction

This experiment is intended to give you some hands-on experience with the effects of, and in some cases the creation of, magnetic fields. You will detect, and in some cases measure, magnetic fields with a variety of sensors, and observe a variety of magnetic field effects.

1. Investigating the earth’s magnetic field

Introduction

In this part of the experiment, you will measure the Earth's magnetic field using a computerized magnetic field probe. To do this successfully, you need to understand the operation of the probe. The actual sensing element is the small rectangular device at the end of the transparent plastic tube. The front face of the sensing element has a white dot on it. When a magnetic field enters the back face of the sensing element and exits the front face, as depicted in Figure 1, the sensor develops a potential difference which is proportional to the flux of the magnetic field through the sensor in the direction indicated by the arrow. The flux of the magnetic field through the sensor is maximum when the field vector is perpendicular to the face of the sensor, and is considered positive when the field vector is coming out of the white dot, as shown.

![Figure 1: Magnetic Field Probe](image)

However, in order to get an accurate measurement, the probe must be zeroed while oriented in such a way that no magnetic field is penetrating the sensor, in other words, so that the flux of the magnetic field through the sensor is zero.

The probe is connected to a dual-range amplifier, which in turn connects to the computer interface box (ULI). The high range of the amplifier is used when measuring weak magnetic fields and the low range when measuring fields of moderate strength.

We’ll begin by investigating the magnetic field of the earth.
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Procedure

- Open Logger Pro, find and open the folder labeled Magnetic Field Sensor and in it find and open the file Mag hi mT. Make sure the selector switch on the amplifier box is set to the High position.

- There should be a compass at your lab station. Stand about half a meter away from any sources of magnetic field (such as your computer, the power supply, or any pieces of iron or steel at your lab station) and use the compass to determine which way is (geographic) North in the lab room. Now take the magnetic field probe and hold it vertically with the sensing end toward the floor and the white dot facing North. Now watch the sensor reading at the lower right portion of your computer screen while you slowly rotate the probe so that the white dot is facing directly East. In this orientation, the flux of the Earth's magnetic field through the sensor is zero. Now zero the probe by clicking the "zero" button on the computer display.

- Now click the "collect" button. As soon as the computer begins taking data, slowly rotate the probe back so that the white dot is again facing North, then continue to rotate the probe in the same direction until the white dot is facing directly West. The measured magnetic field strength should have increased to a peak value when the probe was facing North, then dropped back to zero (or nearly so) as the probe faced West. Your peak value is the strength of the horizontal component of the Earth's magnetic field here in the Dearborn area. Print out your graph, and record your measurement of the horizontal component in Table 1.

<table>
<thead>
<tr>
<th>Horizontal Component of the Earth's Magnetic Field</th>
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Table 1

- You have now measured the horizontal component of the Earth's magnetic field. But is that the total field, or does the Earth's magnetic field also have a vertical component in our area? To find out, rotate the probe until the white dot is again facing North, and click "Collect". Now slowly tilt the probe downward so that the white dot is inclined more and more toward the floor, observing your graphical display as you do so. Find the orientation of the probe that results in the greatest measured magnetic field strength. This is the magnitude of the Earth's total magnetic field as it exists at your lab station, and the orientation of your probe indicates the direction of the field. The situation should look like Figure 2 below.

![Figure 2: Detecting Earth's total magnetic field](image)
• Print out your graph and record the magnitude of the Earth's total magnetic field in Table 2.

<table>
<thead>
<tr>
<th>Total Magnitude of the Earth’s Magnetic Field</th>
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Table 2

• Now calculate the angle of inclination ($\theta$) of the Earth's magnetic field vector. To do this, note that you have values for the magnitude of the total magnetic field vector and for the horizontal component. From the geometry, shown in Figure 3, you can calculate $\theta$. Show your work off to the side and record your result in Table 3.

\[ \theta \]

Horizonal Component

Total Field Vector

Figure 3

<table>
<thead>
<tr>
<th>Angle of Inclination of the Earth’s Magnetic Field Vector</th>
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Table 3

2. Investigating the field of a bar magnet

Introduction

According to the textbook, the magnetic field of a properly magnetized bar magnet should be a dipole field with the externally detectable field lines emerging from the bar's "North" pole and curving around to enter the bar's "South" pole, as shown in Figure 4.

Figure 4: Magnetic field of a bar magnet
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**Procedure**

- Place a bar magnet on a large piece of paper. Orient the magnet along a North-South line.

  *Note: The bar magnets used in this experiment may have their magnetizations reversed or have field patterns that are not a pure dipole. The pole markings on the magnets are not reliable. However, recall that the magnetic field probe gives a positive reading when the magnetic field vector protrudes from the white dot. This is equivalent to having a North pole behind the sensor or a South pole in front of it, as shown in Figure 5.*

![Figure 5](image)

Thus the polarity of the bar magnet can be found by placing the probe near either of the poles and determining the orientation that results in a positive magnetic field reading.

- Since the magnetic field of the bar magnet can be expected to be considerably greater than that of the Earth, it may be necessary to use the lower probe sensitivity. To do this, close file `MAG hi T`, open file `MAG lo T`, and switch the amplifier to the LOW x10 setting.

- Hold the probe vertically, face the white dot North, and zero the probe. This will cancel out the effects of the Earth's magnetic field and allow you to measure only the field of the bar magnet.

- Now map the magnetic field around the bar magnet by moving the probe around the paper to various locations around the magnet. At each location, hold the probe vertically, then rotate it until the magnetic field reading is maximized. Draw a small arrow at each location showing the direction of the magnet's field at that location. Repeat the measurement at many locations until you fill the paper with arrows.

- Now look at the pattern of the arrows you have drawn. Is it consistent with a dipole field as shown in Figure 4? If so, sketch in a family of field lines to represent the field around your magnet. If not, try to deduce what kind of pattern you do have, and sketch in field lines to show that pattern.

- The field lines emerging from the center of each pole face should be reasonably straight. Now investigate how the strength of the magnetic field along one of these straight field lines depends on the distance from the pole face of the magnet. To do this, begin by placing the probe as close as possible to the pole face without exceeding the measuring capacity of the probe. (It is easy to tell when this happens. Just watch the field reading as you move the probe closer to the pole. At some point, the field reading will stop increasing even when you move the probe closer to the magnet. Determine the distance at which this happens, and make all your measurements at distances farther away than this.) Measure the magnetic field at this point and the distance of this point from the end of the magnet and record your measurements in Table 4 below. Now move the probe 1.0 cm farther from the magnet and record the new field measurement and distance. Continue this process until the field becomes too small to measure.
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<table>
<thead>
<tr>
<th>Magnetic Field Magnitude (mT)</th>
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*Table 4*

- Plot your data using the *Graphical Analysis* program and use the curve fitting feature of *Graphical Analysis* to determine the power law which best fits your data. Print out your graph and record the power law equation that describes your data in the space below.

3. **Force on a current-carrying wire in a magnetic field**

**Procedure**

- At the front of the lab is a large magnet with a wire suspended between its poles. Briefly allow current to flow through the wire by connecting it to a 6-Volt battery. Note the direction in which the current flows, the direction of the magnetic field, and the direction in which the wire moves. Describe your results in the space below in terms of the vector force equation, $\vec{F} = \vec{i} \times \vec{B}$. 
4. **Effect of a magnetic field on a beam of electrons**

**Introduction**
A cathode ray tube (CRT) is a vacuum tube in which a beam of electrons is generated and directed to a screen at the front of the tube. The screen glows when the electrons hit it. There are several such devices set up in the lab.

**Procedure**
- Go to one of the CRT's and make sure it is operating. If it is not, inform your instructor.
- Bring your bar magnet near the CRT and observe the effect the magnetic field has on the location of the bright spot on the CRT screen. Your goal is to confirm the vector nature of the magnetic force law, \( \mathbf{F} = q \mathbf{v} \times \mathbf{B} \). To confirm that the direction of the force on the electrons agrees with the direction given by this equation, recall the right-hand rule. Remember also that the direction of the electron's velocity vector is from the back of the tube toward the screen, and that the electron is a negatively charged particle.
- Explore the effects of all possible orientations of the magnetic field. Try to predict the motion of the spot before you bring the magnet near.
- Each part of Figure 5 below depicts the face of a CRT. Assume the dot shows where the undeflected beam would hit the screen. Draw an arrow showing which way the beam would be deflected when a magnet is brought to the position shown in each figure.

![Figure 5: The right-hand-rule for magnetic force on a moving charge](image)

5. **The magnetic field of a coil**

**Procedure**
- At your lab station is a large coil. Connect it to your power supply and adjust the supply until about 0.5 A flows through the coil.
- Use the magnetic field probe to map the coil's magnetic field in the same way you did with the bar magnet. (At the end of the lab turn in your field map with the lab handout.)
- Note the direction of current flow around the coil, and confirm that the right-hand rule correctly accounts for the direction of the magnetic field.
- *Figure 6* depicts a large coil of the kind you investigated. Assume the current in the coil is flowing in the direction indicated. On the figure, sketch an accurate set of magnetic field lines around the coil. Clearly indicate the direction of the coil's magnetic field at several points on your field lines.
6. Electromagnetic induction

**Introduction**

You have seen that current produces a magnetic field. But can a magnetic field produce a current? Ampere searched for such an effect, but never found it. Michael Faraday worked in London for twenty years before he found the effect. Coincidentally, Joseph Henry, in America, found the effect at just about the same time. Today this effect is known as Faraday's Law of Induction.

**Procedure**

- Use the large coil with current flowing through it as a source of magnetic field.
- At your lab station there is a small plastic-coated coil. Connect the leads from this coil to a galvanometer. A galvanometer is a sensitive meter which can show the existence of small EMF’s or currents. Note that it is necessary to depress the button labeled 50µA in order for the galvanometer to function.
- Place the small coil into the opening in the large coil so that the axes of the two coils are parallel. Now press the button and observe the galvanometer. Does the magnetic field produce a current in the small coil?
- Faraday found that an EMF would be produced only if the magnetic field was changing in some way. While holding the galvanometer button down try connecting and disconnecting the leads from the power supply to the large coil. That turns the magnetic field on and off. Does the galvanometer show a deflection now?
• Now try quickly rotating the small coil through a 90° angle, or try quickly thrusting the small coil into and out of the large coil. Do either of these actions cause the galvanometer to show a deflection?

• Now disconnect the large coil from the power supply, disconnect the galvanometer from the small coil, and connect the galvanometer to the large coil. Now quickly thrust the bar magnet into and out of the large coil. Does this cause the galvanometer to show a deflection? How does it compare with the previous situations you tested? Stronger deflection? Weaker? Do you notice any differences between the magnet moving into the coil and being pulled out? Record your observations on the worksheet.

• Based on your observations above answer the following questions:
  If the magnetic field through a coil of wire is constant, will an induced current flow in the coil?

  Would it be possible for the Earth's magnetic field to induce a current in a coil? If not, state why, if so, explain how.