

## PHYSICS 221

### EXPERIMENT 5 : Magnetic Field

#### INTRODUCTION :

This experiment will examine the properties of magnetic fields. Magnetic fields can be created in a variety of ways, and are also found in some naturally occurring materials. We will create some magnetic fields using induction, and then study how various materials are affected by magnetic fields. We will also study how magnetic fields act upon charged particles. The ratio of charge to mass of an electron,  $e/m$ , will be measured using magnetic fields. Finally, we will explore the effect of a magnetic field on a wire that carries electric current.

## PART A : THE HALL EFFECT PROBE

We will use the Hall Effect probe to measure the strength of magnetic fields. Before using such a device, let us examine how it operates. A brief description of the Hall effect is presented here, but refer to your physics text for a more comprehensive explanation.

Consider a small slab of semiconductor (shaded rectangle in Figure 1) such as silicon or germanium. Note: all conductors exhibit Hall effect, but only with semi-

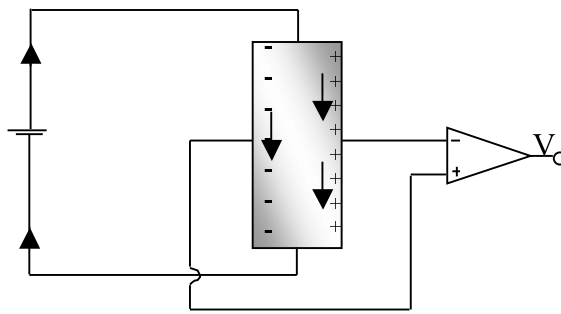


Figure 1: Schematic Diagram of the Hall Probe.

conductors is the effect large enough to be convenient for practical use. A magnetic field (in this case it is coming out of the page) induces an electric potential across the semiconductor. Since the Hall voltage is too small to be measured directly with a regular voltmeter, it must be amplified by voltage differential amplifier (triangular object). It takes the voltage difference between the two terminals and amplifies it by a factor of 10 – 20.

Before use, the Hall probe first must be calibrated. The probe and its power source come as a plug-in unit to the amplifier. A digital voltmeter should be connected to the output terminals of the amplifier. The balance knob has to be set to have a reading of zero in the absence of a field (assuming the magnetic field of the earth is negligible). Use the probe in the ‘100’ position of the 10-100-1000 slide switch.

A calibration is obtained by inserting the probe into a slot containing a permanent magnet producing a known induction of 0.075 T (750 Gauss). There is a polarity to be

respected, as indicated by a cross and a dot. The probe must be seated all the way into a pivot hole.

The gain of the amplifier can be then adjusted to give an output of 7.5 V, making all the further measurements easy: 1 V = 100 Gauss = 10 mT. The DC Bias knob of the amplifier has to be trimmed to get a reading of zero when the probe is out of the calibration slot. You may have to iterate a few times between zero field and 75 mTs to get a consistent pair of readings.

[Note: The Hall probe is sensitive to its orientation with the external magnetic field. Make sure it is always perpendicular to the direction of the magnetic field. If you are unsure of the direction of the field lines, change the orientation of the probe until you obtain the largest voltage reading.]

## PART B : MAGNETIC FIELD STRENGTH OF A CURRENT LOOP

Magnetic fields can also be created by current loops. A current loop has magnetic field lines similar to a bar magnet (see Figure 2).

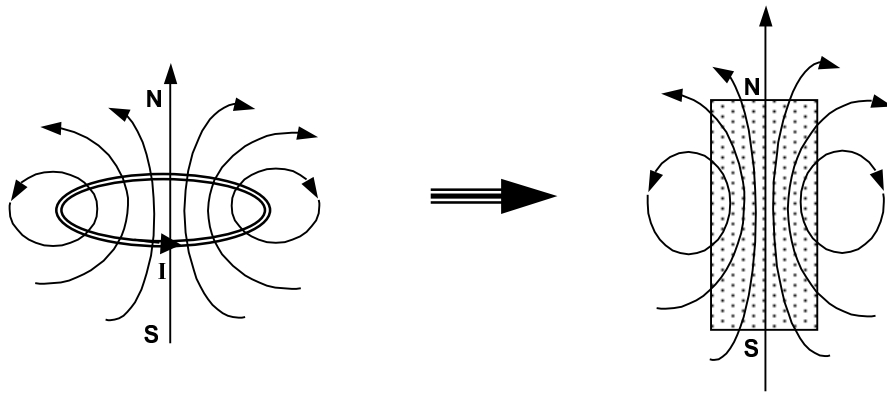


Figure 2 : Magnetic Field Lines of a Current Loop and a Bar Magnet.

The magnitude of the magnetic field  $B$  along the axis of a loop (the N-S line) carrying current  $I$  can be expressed as

$$B(z) = \frac{\mu_0 I R^2 N}{2(R^2 + z^2)^{3/2}} \quad (1)$$

where the  $z$ -axis is along the N-S line,  $N$  is the number of turns in the current loop,  $R$  is the radius of the loop and  $\mu_0$  is the permeability of free space.

## PROCEDURE :

1. You are given a coil of wire to create a magnetic field. Record the number of turns  $N$  in this coil of wire and its radius  $R$ .
2. Connect the coil of wire to a DC power source. Set a current of 1 A to flow through the coil (you may need to use an ammeter in your circuit to obtain an accurate reading of the current).
3. Measure the magnetic field along the axis of the coil using the Hall probe (do not forget the note above regarding the orientation of the probe). You may use the available plastic frame apparatus to facilitate the measurements. Measure the field in front and behind of the coil along the axis until the probe reads essentially zero value.
4. Record in a table the distance  $z$  along the axis from the plane of the coil, and the magnitude of the magnetic field  $B$ . If you made measurement at identical distances in front and behind the coil, then find the average value of  $B$  at that distance.

## ANALYSIS :

1. Add to your data table a column consisting the value of  $1/(R^2 + z^2)^{3/2}$ .
2. Plot a graph of  $B(z)$  versus  $1/(R^2 + z^2)^{3/2}$ .
3. Find the slope of the best-fit line from your graph. From Equation 1, this slope should correspond theoretically to  $\mu_0 I R^2 N/2$  (prove this in the theory section of your report). Compare the two values.

## PART C : MAGNETIC FIELD AT THE CENTER OF A HELMHOLTZ COIL

We can create a stronger and more uniform magnetic field by aligning two identical current loops. A particular configuration that we will be using is known as a Helmholtz coil. This consists of two current loops, each with  $N$  turns and radius  $R$ . The two loops are aligned along their axis and are separated by a distance  $R$ , identical to the radius, each carrying equal currents in the same direction (see Figure 3). It can be shown that the magnetic field at the center of this configuration (point O) is

$$B(z = 0) = \frac{8}{5\sqrt{5}} \frac{\mu_0 IN}{R} \quad (2)$$

where the symbols have the same definitions as before.

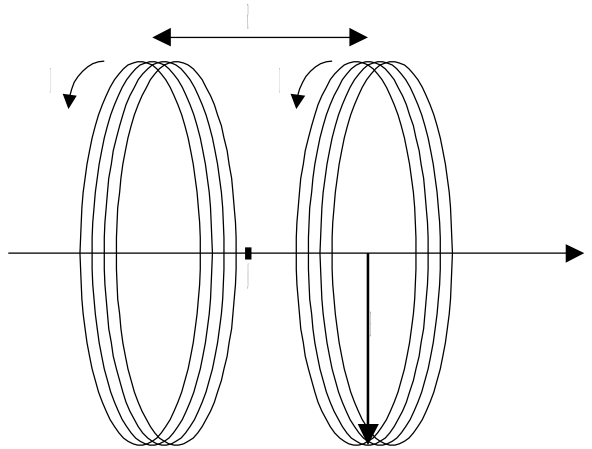


Figure 3: Helmholtz Coil.

### PROCEDURE :

1. Measure the radius of the Helmholtz coil and record the number of turns.
2. Connect the Helmholtz coil to the DC power supply. You may want to connect an ammeter to the circuit to accurately determine the current.

3. Using the Hall probe, measure the field at the center of the Helmholtz coil for current values from 0 A to 1 A, in 0.1 A increments.
4. Your data table should consist of the different values of  $I$  and  $B(0)$ .

### ANALYSIS :

1. Plot of a graph of  $B(0)$  versus  $I$ .
2. Find the slope of the best-fit line.
3. From Equation 2, the slope of this line should correspond to the value of

$$\frac{8}{5\sqrt{5}} \frac{\mu_0 N}{R}.$$

Prove this in the theory section of your report. Compare the slope of your graph with this value.

### PART D : CURRENT BALANCE

In this experiment, we will study the force exerted on a length of a current-carrying wire with varying (i) current and (ii) wire length. The magnetic force on a length of wire is described by the Lorentz force equation

$$\mathbf{F} = \mathbf{I} l \times \mathbf{B} \quad (3)$$

where  $\mathbf{I}$  is the current vector,  $l$  is the length of the wire, and  $\mathbf{B}$  is the magnetic field vector (see Figure 4). The magnitude of this force can be expressed as

$$F = I l B \sin \theta \quad (4)$$

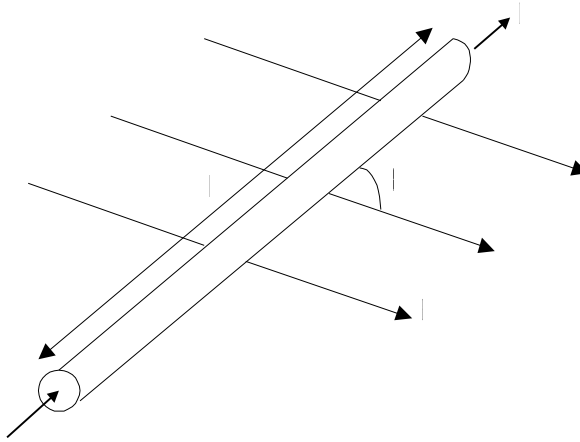


Figure 4: Current Flow in a Magnetic Field.

where  $\theta$  is the angle between  $\mathbf{I}$  and  $\mathbf{B}$  as shown in the figure. Since the magnetic field is assumed to be perpendicular to the direction of current flow throughout this experiment, Equation 4 then simplifies to

$$F = I l B. \quad (5)$$

The current will flow through the prefabricated current “loops” as shown in Figure 5. Several current loops are available with different lengths of the 3-4 segment (see Table 1). Points 1 and 6 are connected to a DC power supply. If the magnetic field is in the direction shown in the figure (going into the page), then the current in 3-4 segment of the loop should be in the direction shown to produce the desired direction of the force on the magnet assembly (more on this in the Procedure section).

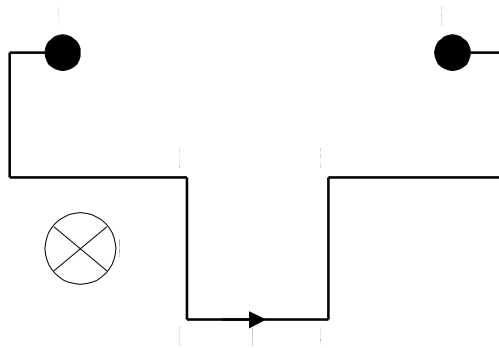


Figure 5: Current Loop.

**CAUTION:** The current flowing through the current loops should never exceed 4A! Furthermore, each current loops **MUST** be handled with care especially when changing one loop to another.

Current Loop	Length
SF 40	1.2 cm
SF 37	2.2 cm
SF 39	3.2 cm
SF 38	4.2 cm
SF 41	6.4 cm
SF 42	8.4 cm

Table 1: Length of 3-4 Segment of Current Loops (notice that the part number does not go in sequence with the length)

### PART D1 : Magnetic Force With Varying Current

#### PROCEDURE :

1. Select the current loop for which the 3-4 section is the longest. Record this length.
2. Plug the current loop to the ends of the main unit, with the foil extending down. Make sure the plane of the loop is hanging down vertically (see Figure 6).

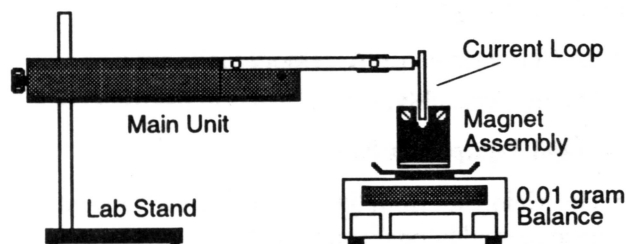




Figure 6: Setting Up the Current Balance (Side View).

3. Place the magnet assembly on a balance scale. Position the magnet so that the 3-4 segment of the current loop passes through the pole region of the magnet assembly. The current loop should *never* touch the magnets. Make sure the magnet assembly is parallel to the plane of the current loop.
4. With no current flowing through the current loop, record the mass of the magnet assembly. Note that if you are using a triple beam balance, the vertical position of the magnet assembly may have changed after you made the mass measurement. Readjust the height of the main unit if necessary.
5. Connect the power supply and ammeter as shown in Figure 7.

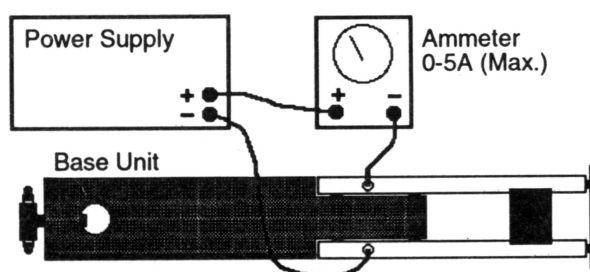


Figure 7: Connecting the Ammeter and Power Supply (Top View).

6. Increase the current flowing through the current loop by 0.5 A increments, up to a maximum of 4.0 A. At each value of the current, find the “new mass” of the magnet assembly. Note that if the mass of the magnet assembly is *decreasing* as the current increases, the direction of the current with respect to the magnetic field is not the same as described in Figure 5. If this happens, reverse the electrical connection to the main unit.
7. Your data table should consist of the current values, and the corresponding mass reading from the scale.

**ANALYSIS :**

1. Subtract the mass of the magnet assembly from the mass value in your data table. This is the “net” mass. Record these values as a column in your data table.
2. Multiply the net mass by  $g = 9.8 \text{ m/s}^2$ . This is the magnetic force  $F$ .
3. Plot a graph of the magnetic force  $F$  versus the current  $I$ .
4. Find the slope of the best-fit line from your graph.
5. From Equation 5, the slope of the best-fit line should correspond to  $lB$  (product of the length of the 3-4 segment and the magnetic field strength - prove this in the theory section of your report). Using the slope of your graph, find the magnetic field strength of the magnet. Verify this by using the Hall probe and find the percentage difference.

**PART D2 : Magnetic Force with Varying Length**

1. Without dismantling the setup from the previous part, set the current to 3 A.
2. Record the mass reading for this length.
3. Reduce the current zero.
4. Swing the main arm of the main unit up to raise the current loop out of the magnetic field gap. Pull the current loop gently from the arms of the base unit.
5. Replace the current loop with a new current loop having a different length of the 3-4 segment.
6. Carefully lower the arm to reposition the current loop in the magnetic field.
7. Increase the current back to 3 A record the mass.
8. Repeat this procedure until all the current loops have been used.
9. Your data table should consist of the length of the 3-4 segment (see Table 1) and the corresponding mass reading.

**ANALYSIS :**

1. Repeat Analysis 1 and 2 from Part D1.
2. Plot the magnetic force  $F$  versus the length  $l$ .
6. Find the slope of the best-fit line from your graph.
7. From Equation 5, the slope of the best-fit line should correspond to  $IB$  (product of the current and the magnetic field strength - prove this in the theory section of your report). Using the slope of your graph, find the magnetic field strength of the magnet. Compare this with the value obtained by using the Hall probe and that obtained from Part D1.

**QUESTION:** Parts of segment 2-3 and 4-5 of the current loop are also within the magnetic field of the assembly. Why are we justified in ignoring the force acting on these segments? [Hint: consider the direction and magnitude (approximately) of the magnetic force acting on each segment in question.]