

## Experiment 8: Magnetic Fields and Forces

### Introduction

In class you learned that a magnetic force  $\mathbf{F}_B$  is exerted on a charged particle as it moves through a magnetic field  $\vec{B}$ . It shouldn't surprise you that a current carrying wire also experiences a force when placed in a magnetic field, since a current is just a collection of charged particles in motion. To demonstrate the magnetic force acting on a current carrying wire, we will suspend a wire vertically in a magnetic field located between the ends of a horseshoe magnet, as seen in Figure 1a. For simplification purposes, only the field entering the south end of the horseshoe magnet is shown. When the current is zero, the wire remains vertical with no forces acting on it. However, when a current is directed upwards, the wire is deflected to the left, as shown in Figure 1b. If the current was in the downward direction, the wire would be deflected to the right.

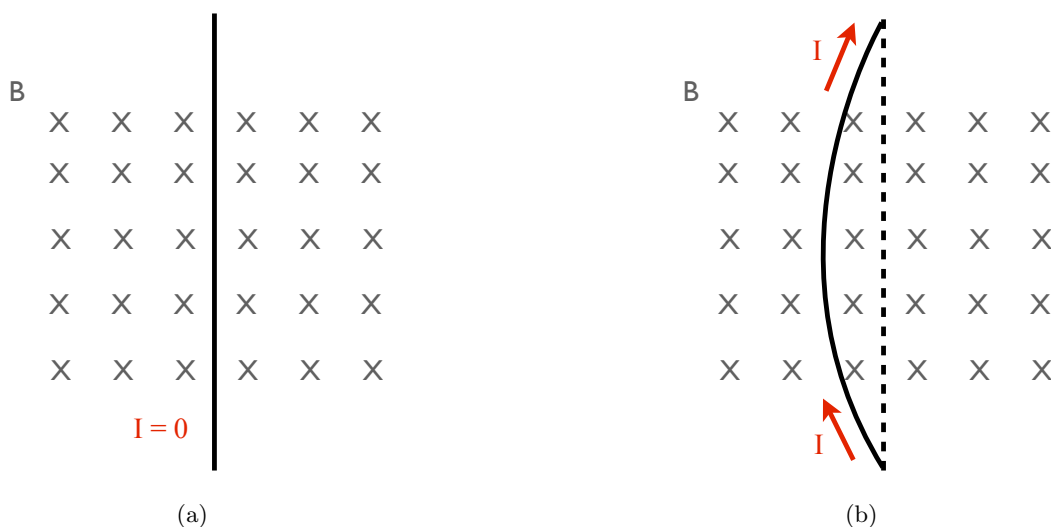


Figure 1: A wire is placed in a magnetic field  $\mathbf{B}$ . The field is going into the page.

The magnetic force acting on a charged particle  $q$  moving with a drift velocity  $\mathbf{v}_d$  through a magnetic field  $\mathbf{B}$  is given by  $q\mathbf{v}_d \times \mathbf{B}$ . To find the force acting on a current carrying wire of length  $L$  and cross-sectional area  $A$ , in a magnetic field  $\mathbf{B}$ , we can multiply  $q\mathbf{v}_d \times \mathbf{B}$  by the number of charges in the wire segment  $nAL$ , where  $n$  is the number charges per unit volume. Noting that the current in the wire is given by  $I = nqv_dA$ , we see that the magnetic force on a current carrying wire is described by

$$\mathbf{F}_B = I\mathbf{L} \times \mathbf{B} \quad (1)$$

where  $\mathbf{L}$  is a vector that points in the direction of the current with a magnitude equal to the length of the wire. The magnitude of the force is given as

$$F = ILB\sin(\theta) \quad (2)$$

where  $\theta$  is the angle between  $I$  and  $B$  as shown in Figure 2. If the magnetic field is assumed to be perpendicular to the direction of current flow, Equation 2 will simplify to  $F=ILB$ .

In this Lab, we will study the force exerted on a length of a current-carrying wire with varying current and wire length. We will also observe the magnetic fields produced by a current carrying wire.

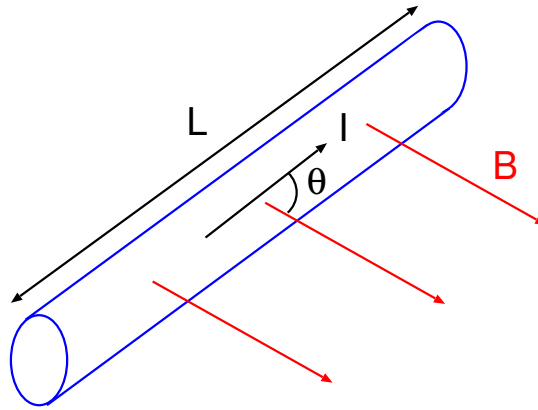


Figure 2: A segment of a current carrying wire in a uniform magnetic field  $B$ .

### Part 1 - Magnetic Fields of Current-Carrying Wire

In this experiment we will observe the magnetic fields produced by a current carrying wire. A long wire is suspended vertically, passing through a horizontal platform. The wire is connected to a power supply, allowing a current of 5.0 Amps to flow. A compass is placed on the platform stand near the vertical wire. When no current is present in the wire, the compass needle points in the same direction any where around the wire due to the Earth's magnetic field. When a current flows through the wire, the compass needle deflects in a direction tangent to a circle, which is the direction of the magnetic field created by the current carrying wire.

**Your task** is to map out the magnetic field produced by the current carrying wire using the compass. Use the grid on the platform and matching grid paper to log the compass deflection at many locations near the wire. Show that the direction of the magnetic field is reversed when the current in the wire is reversed. Are your observations of the magnetic field produced by the current consistent with the right-hand rule?

### Part 2 - Current Balance

In this part of the lab you will investigate the magnetic force acting on a current carrying wire by observing the changes in a horseshoe magnet's weight ( $F_g = mg$ ). The current will flow through the prefabricated current "loops" as shown in Figure 3. 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 show 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). In this experiment we apply Newton's 3rd Law by observing the equal and opposite force on the field, rather than the force on the wire since we will be holding the wire rigid.

#### Part 2A Procedure - Magnetic Force with Varying Current:

1. Use the magnetic field sensor (Hall probe) to measure the field strength of the horseshoe magnet. Ask your TA or refer to the manual for detailed instructions on how to use the device.
2. Select the current loop for which the 3-4 section is the longest. Record this length.
3. Plug the current loop to the ends of the main unit, with the current loop extending down. Make sure the plane of the loop is hanging down vertically (see Figure 4a). 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 not touch the magnets.

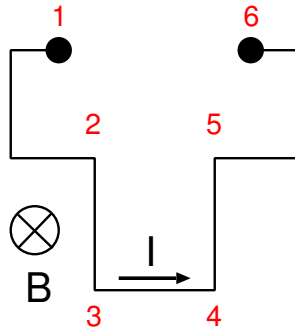


Figure 3: Current loop with connection points.

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: Various wire lengths. Note: the part number doesn't go in sequence with the length.

4. With no current flowing through the current loop, record the mass of the magnet assembly. Use the compass to find the polarity of the magnet. Connect the power supply and ammeter as shown in Figure 4b.
5. Increase the current flowing through the current loop by 0.5 A increments, up to a maximum of 5.0 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. *Caution:* The current flowing through the current loops should never exceed 5A! Furthermore, each current loop MUST be handled with care especially when changing from one loop to another.
6. Your data table should consist of the current values, and the corresponding mass reading from the scale.

**Analysis:** Answer the following questions in your lab report:

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. Multiply the net mass by  $g = 9.8 \text{ m/s}^2$ . Why does this value equal the magnetic force  $F_B$ ?
2. Plot a graph of the magnetic force  $F$  versus the current  $I$ , and find the slope of the best-fit line from your graph.

- From Equation 2, 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.

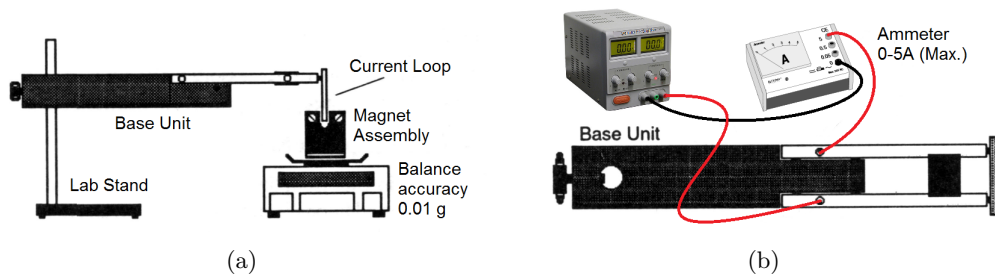


Figure 4: (a) Setting up the current balance, side view. (b) Connecting the ammeter and power supply to the current balance, top view.

### Part 2B Procedure - Magnetic Force with Varying Length:

- Without dismantling the setup from the previous part, set the current to 5 A. Record the mass reading for this length.
- Reduce the current to zero. 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.
- Replace the current loop with a new current loop having a different length of the 3-4 segment.
- Carefully lower the arm to reposition the current loop in the magnetic field. Increase the current back to 5 A and record the mass.
- Repeat this procedure until all the current loops have been used. Your data table should consist of the length of the 3-4 segment (see Table above) and the corresponding mass reading.

**Analysis:** Answer the following questions in your lab report:

- Repeat an analysis similar to steps 1 and 2 from Part 2A for each current loop segment. Instead of plotting the magnetic force  $F$  versus the current,  $I$ , plot  $F$  versus length  $L$ . Find the slope of the best-fit line from your graph.
- From Equation 2, the slope of the best-fit line should correspond to  $IB$ , the 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 2A.
- Segments 2-3 and 4-5 of the current loop (see Fig 3.) are also within the magnetic field of the assembly. Why are we justified in ignoring the force acting on these segments?