Experiment 8: Magnetic Fields and Forces

Introduction

In class you learned that a magnetic force $\vec{F}_B$ 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.

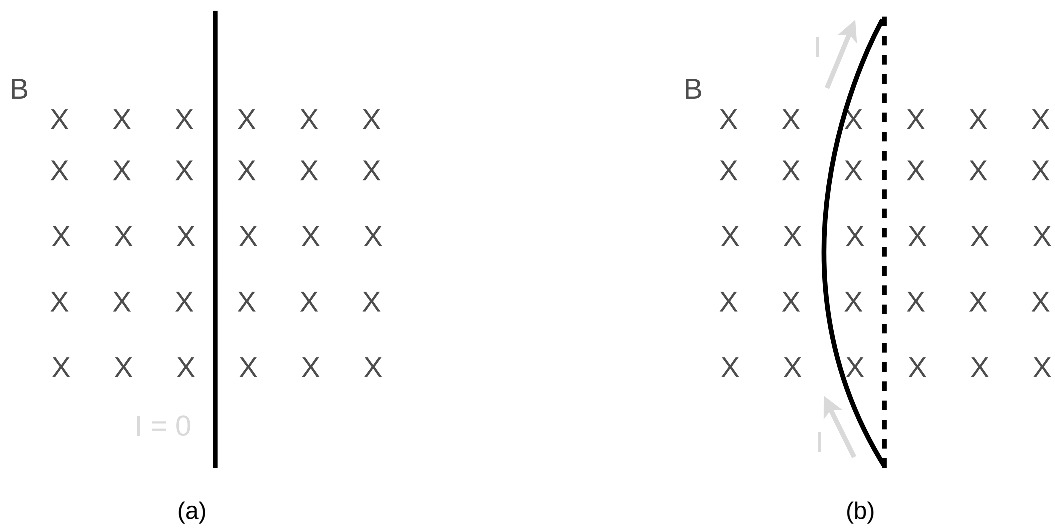


Figure 1: A wire is placed in a magnetic field B. The field is going into the page.

The magnetic force acting on a charged particle q moving with a drift velocity $\vec{v}_d$ through a magnetic field $\vec{B}$ is given by $q\vec{v}_d \times \vec{B}$. To find the force acting on a current carrying wire of length L and cross-sectional area A, in a magnetic field B, we can multiply $q\vec{v}_d \times \vec{B}$ 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

$$\vec{F}_B = I\vec{L} \times \vec{B} \tag{1}$$

where $\vec{L}$ 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

$$F = ILB\sin(\theta) \tag{2}$$

where θ 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.

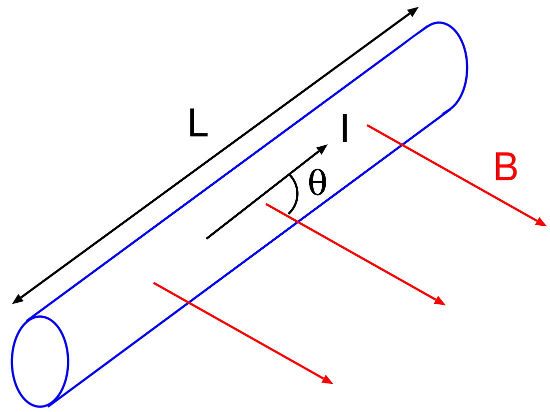


Figure 2: A segment of a current carrying wire in a uniform magnetic eld B.

Part 1 - Magnetic Fields of Current-Carrying Wire

In this experiment we will observe the magnetic elds 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 ow. 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 eld. When a current ows through the wire, the compass needle de ects in a direction tangent to a circle, which is the direction of the magnetic eld created by the current carrying wire.

Your task is to map out the magnetic eld produced by the current carrying wire using the compass. Use the grid on the platform and matching grid paper to log the compass de ection at many locations near the wire. Show that the direction of the magnetic eld is reversed when the current in the wire is reversed. Are your observations of the magnetic eld 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 ow through the prefabricated current \loops" as shown in Figure 3. Several current loops are available with di erent lengths of the 3-4 segment (see Table 1). Points 1 and 6 are connected to a DC power supply. If the magnetic eld is in the direction show in the gure (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 eld, 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 eld sensor (Hall probe) to measure the eld 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.

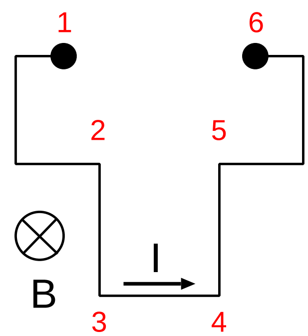


Figure 3: Current loop with connection points.

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 owing through the current loop, record the mass of the magnet assembly. Use the compass to nd the polarity of the magnet. Connect the power supply and ammeter as shown in Figure 4b.

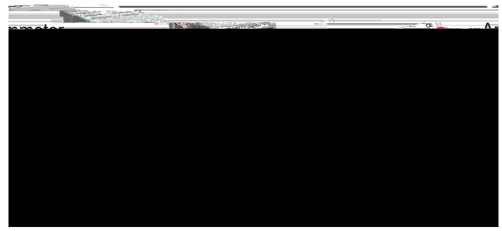
5. Increase the current owing through the current loop by 0.5 A increments, up to a maximum of 5.0 A. At each value of the current, nd the \new mass" of the magnet assembly. Note that if the mass of the magnet assembly is decreasing as the current increases, the direction of the current with respect to the magnetic eld is not the same as described in Figure 5. If this happens, reverse the electrical connection to the main unit. C[illegible] : The current owing 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

3. From Equation 2, the slope of the best- t line should correspond to LB (product of the length of the 3-4 segment and the magnetic eld strength - prove this in the theory section of your report). Using the slope of your graph, nd the magnetic eld strength of the magnet. Verify this by using the Hall probe and nd the percentage di erence.

(a)



(b)