# Lab 7: Force on a current carrying wire placed in a magnetic field

#### 1 Introduction

During the course of this lab, you will be able to measure the force on a current carrying segment of wire placed in a magnetic field. Your measurements will enable you to infer the strength of the magnetic field in which it is placed. You will be using a sensitive balance to measure this force. You will also be able to test the dependence of the force on the current through the wire, and the length of the wire.

The magnetic field due to a finite current carrying wire can be found using the Biot-Savart law. When another current carrying wire is placed in this magnetic field, it will experience a force. The direction of this force depends on the directions of the currents in both wires. You will study this force by placing a current carrying wire in the magnetic field produced by a set of permanent magnets rather than in a magnetic field produced by another current carrying wire.

It might interest you that the force that you will measure finds widespread applications. For example, this force is used to magnetically levitate, guide, and propel trains that can run at speeds in excess of 300 km/hr.

The force that you will study is often (misleadingly) termed as the magnetic force on a current carrying wire. Actually, the motion of charge carriers (current) in a wire placed in a magnetic field will cause the charge carriers to experience a magnetic force, and pile up on one side of the wire. This causes a charge separation in the wire. The resulting electric field exerts a force on the lattice of ions that make up the wire. Therefore, the entire wire experiences a force.

#### EXERCISE 1 PERTAINS TO THE BACK-GROUND CONCEPTS AND EXERCISES 2-4 PERTAIN TO THE EXPERIMENTAL SEC-TIONS.



Figure 1: Force on a current carrying wire placed in a uniform magnetic field

### 2 Background

When a current carrying wire is placed in a uniform magnetic field  $\overrightarrow{B}$ , the moving charges in the wire experience a magnetic force. For a single charge q that moves with a drift velocity  $\overrightarrow{v_d}$ , the force  $\overrightarrow{F}$  is given by,

$$\overrightarrow{F} = q \overrightarrow{v_d} \times \overrightarrow{B} \tag{1}$$

The total number of charge carriers in a wire of infinitesimal length  $\vec{dL}$  and cross-sectional area A is  $nA(\vec{dL})$ , where n is the number of charge carriers per unit volume. Therefore, the total magnetic force on the wire segment of length  $\vec{dL}$  can be written as,

$$\overrightarrow{F} = nA(\overrightarrow{dL})q\overrightarrow{v_d} \times \overrightarrow{B}$$
<sup>(2)</sup>

Since a total charge  $Q = nA(\vec{dL})q$  flows through the length  $\vec{dL}$  in time  $\Delta t = \frac{\vec{dL}}{v_d}$ , the current I flowing through the wire  $(I = \frac{Q}{\Delta t})$  is,

$$I = nAq\overrightarrow{v_d} \tag{3}$$

As a result, the magnetic force on the current carrying wire simplifies to the following expression,

$$\overrightarrow{F} = \int I(\overrightarrow{dL}) \times \overrightarrow{B} \tag{4}$$

The magnitude of the force on a wire of length L placed in a uniform magnetic field can therefore be written as,

$$F = BIL \tag{5}$$

The direction of the force (shown in figure 1) depends on the direction of the current and the direction of the magnetic field.

**Exercise 1:** What is the direction of the magnetic force on the current carrying segment shown in figure 2? Arrows indicate the direction of current flow. Which part of the wire segment contributes to the magnetic force? (Hint: Not all segments of the wire contribute to the force. Why?)



Figure 2: Wire segment in a uniform magnetic field

#### 3 Suggested Reading

Refer to chapters on Current and Resistance and the Magnetic Field,

R. Wolfson and J. Pasachoff, **Physics with Modern Physics** (3rd Edition, Addison-Wesley Longman, Don Mills ON, 1999)

D. Halliday, R. Resnick and K. S. Krane, **Physics** (Volume 2, 5th Edition, John Wiley, 2002)

#### 4 Apparatus

Refer to Appendix E for photos of the apparatus

- Swivel mount for current carrying wire segments
- Six connecterized wire segments mounted on PC boards
- Magnet assembly with six permanent magnets
- Variable power supply
- Beam balance
- Lab Stand
- Banana wires

Table 1: Wire segment measurements

Current Loop	Length (cm)
SF 40	
SF 37	
SF 39	
SF 38	
SF 41	
SF 42	

5 Experiment I: Force on a current carrying wire as a function of current

Connect the power supply to the swivel mount as shown in figure 3a. Mount the wire segment labeled SF 38 on the swivel mount. Measure the length of the wire segment that contributes to the force. Next, place the magnet assembly on the balance. Make sure that the wire segment does not touch the magnet assembly, and that it is centered within the magnet assembly as shown in figure 3b.

**NOTE:** Ensure all the magnets in the magnet assembly are positioned in the same direction. (i.e. the red side of the magnets should be on the red side of the assembly and the white side of the magnets on the white side of the assembly.)

When the power supply is turned on, the current carrying wire experiences an upward or downward force depending on the direction of the current and the direction of the magnetic field. According to Newton's third law, the wire exerts an equal and opposite force on the magnet assembly. This force will cause the weight measured by the balance to change. This experiment allows you to measure the change in the weight as a function of the current flowing through the wire.

Measure the weight of the magnet assembly in the absence of current flow. Increase the current through the wire segment in steps of 0.5A (up to 4.0A) and determine the corresponding weight of the magnet assembly in each case. Calculate the change in weight for each measurement. Record your results in the form of a table.

**Exercise 2:** Plot a graph of force on the wire segment as a function of current. Interpret your graph. Using



Figure 3: Experimental setup, top view (a) and side view (b)

your graph, find the magnetic field in which the wire was placed in (based on equation 5).

# 6 Experiment II: Force as a function of the length of the wire segment

Measure the lengths of the six wire segments provided. Record your values in the form of a table such as table 1.

**NOTE:** Record only the length of each segment that contributes to the force.

First measure the mass of the magnet assembly in the absence of a current flow. Record this value. Now, attach one of the current loops to the swivel mount. Set the current to 2.0 A. Measure the weight of the magnet assembly and calculate the change in weight. Repeat the experiment for each of the current loops for the same value of the current. Tabulate your data.

**Exercise 3:** Plot a graph of the force as a function of the length of the wire segment placed in the magnetic field. Find the value of the magnetic field from your

graph (based on equation 5). Compare the value of the magnetic field to the value obtained in exercise 2.

## 7 Experiment III: Qualitative studies

For a fixed value of the current, measure the magnetic force on the wire segment SF 42.

**Exercise 4a:** How does the force change if the current from the power supply is reversed? Explain your results.

**Exercise 4b:** How does the force change if the direction of the magnetic field is reversed? Explain your results.

**Exercise 4c:** Explain the results obtained when you remove one or more of the magnets on the magnet assembly.

**Exercise 4d:** Explain the results obtained if the directions of the magnetic fields due to adjacent magnets on the assembly are reversed.

**NOTE:** ONCE YOU HAVE COMPLETED THE EXPERIMENT, PLEASE ENSURE THE MAGNETS ARE PLACED IN THEIR ORIGINAL POSITIONS (I.E. ALL THE MAGNETS IN THE SAME DIRECTION.)

#### Your lab report should include:

Answers to exercises 1-4 with relevant data tables, graphs, figures and qualitative comments.

Refer to Appendix D for Maple worksheets.