Objective

• Investigate how the magnetic force on a current carrying wire is related to current, length of wire and magnetic field strength.
• Determine experimentally the magnetic field strength of the magnets used.

Equipment List

• “Force-on-a-conductor” balance
• Magnetic assembly with five permanent horseshoe magnets
• A wire loop
• DC power supply
• Rheostat

Theory

If a charged particle moves with velocity \( \vec{v} \) through a uniform magnetic field \( \vec{B} \), it experiences a magnetic force given by

\[ \vec{F} = q\vec{v} \times \vec{B} \tag{1} \]

where \( q \) is the amount of charge on the particle. If the angle between the particle’s velocity and the direction of the magnetic field is \( \theta \), the magnitude of the magnetic force can be rewritten as

\[ F = qvB \sin \theta. \tag{2} \]

The direction of the magnetic force may then be found with the familiar right-hand rule. Notice that the magnitude of the magnetic force is a maximum when \( \vec{v} \perp \vec{B} \) and is identically zero when \( \vec{v} \parallel \vec{B} \).

Consider a straight segment of a wire carrying a current \( I \) within a uniform magnetic field \( \vec{B} \). The magnetic force on each charged particle is then given by

\[ \vec{F} = q\vec{v}_d \times \vec{B}, \tag{3} \]

where \( \vec{v}_d \) is the drift velocity of the charged particles. The volume of the wire that exists within the magnetic field is \( A\ell \), where \( A \) is the wire’s cross-sectional area and \( \ell \) is the length.
of the wire that is embedded within the magnetic field. If we define \( n \) to be the number of charged particles per unit volume, the total amount of charges within that segment of wire will be given by \( na\ell \) at any instant. The magnetic force acting on the wire can then be expressed as

\[
\vec{F} = naq \left( \vec{v}_d \times \vec{B} \right).
\] (4)

Since the current flowing in a conductor is given as \( I = nqv_dA \), the magnetic force acting on a current-carrying wire becomes

\[
\vec{F} = I\vec{\ell} \times \vec{B},
\] (5)

where \( \vec{\ell} \) is the vector length of wire that points in the direction of the current \( I \). Note that the direction of the current is defined as the direction in which positively charged objects move. The magnetic force will be a maximum if \( \vec{\ell} \) and \( \vec{B} \) are mutually perpendicular then we have

\[
F = I\ell B.
\] (6)

In this experiment, the magnetic force is measured by means of a “force-on-a-conductor” balance as shown in Figure 1. The balance consists of a wire loop mounted on a beam which can be placed on two pillars. The “zero adjustment mass” is positioned so that the beam is horizontal with the end section BC lying inside the magnetic field produced by the magnets. When a current passes through the wire loop, via the terminals on the pillars, the force on the end section BC of the wire loop causes it to be rotating with respect to the pillars. This rotating effect can then be counter-balanced by the movement of a rider along the wire loop. When a balance is achieved, the position of the rider will give a measurement of the magnetic force on the wire.

![Figure 1: “Force-on-a-conductor” balance.](image)
4 Laboratory Work

Part A: Force versus Current

In this part of the experiment, the length of the wire and the strength of the magnetic field will be kept constant. We will investigate the magnetic force acting on a current-carrying wire as a function of the current passing through it.

A-1. Place all five magnets in position with the poles with black dot-mark on the same pole-piece. Slide the magnetic assembly so that it overlaps with the end section of the wire loop, i.e. BC, completely.

A-2. Put the rider at the zero position of the scale. With no current flowing through, balance the beam with the “zero-adjustment mass” so that the wire loop is horizontal.

Note: The “sensitivity adjustment mass” can be raised or lowered to change the sensitivity. For this experiment, an 1 mm movement of the rider should produce a noticeable deflection.

A-3. Now turn on the DC power supply and adjust the power supply to a voltage output of 10 V. Do not change this voltage setting for the rest of the experiment.

A-4. Vary the rheostat to have a current of 0.5 A in a direction such that the wire moves upwards. Reverse the polarity of the current if it moves downwards.

A-5. Adjust the rider until balance is achieved. The displacement $x$ of the rider then gives a measurement of the force acting on the wire section BC. Record the rider position when the wire section BC is balanced in Data Table 1.

A-6. Continue varying the rheostat to increase the current in 0.5 A steps to a maximum of 3.0 A and repeat step A-5 each time.

CAUTION:
The voltage output of the DC power supply will be set at 10 V for the whole experiment. Varying the rheostat to obtain any desired current on the wire. This is NOT to increase the output voltage for the increment of current. By this mean, the power supply will spoil and lot of carbon will be created on the pillars of the conductor.
Part B: Force versus Length of Wire

In this part of the experiment, the current and the strength of the magnetic field will be kept constant. The variation of the magnetic force acting on a current-carrying wire with the length of the wire will be investigated.

B-1. Slide the magnetic assembly so that it overlaps with the end section of the wire loop, i.e. BC, completely.

B-2. Put the rider at the zero position of the scale. With no current flowing through, balance the beam with the “zero-adjustment mass” so that the wire loop is horizontal.

B-3. Vary the rheostat to have a current of 3 A in a direction such that the wire moves upwards. Reverse the polarity of the current if it moves downwards.

B-4. Adjust the rider until balance is achieved. Record the rider position when the wire section BC is balanced in Data Table 2.

B-5. Slide the magnet assembly to overlap the wire BC by successive smaller amount and repeat step B-4 each time.

B-6. Repeat the procedure until the wire BC is completely out of the magnetic assembly.

Part C: Force versus Length of Wire

In this part of the experiment, we will investigate the dependence of the magnetic force on the strength of the magnetic field with a fixed length of the wire.

C-1. Place all five magnets in position with the poles with black dot-mark on the same pole-piece. Slide the magnetic assembly so that it overlaps with the end section of the wire loop, i.e. BC, completely.

C-2. Put the rider at the zero position of the scale. With no current flowing through, balance the beam with the “zero-adjustment mass” so that the wire loop is horizontal.

C-3. Vary the rheostat to have a current of 3 A in a direction such that the wire moves upwards. Adjust the rider until balance is achieved and record the position of the rider in Data Table 3.

C-4. Remove the magnets one by one and repeat step C-3 each time.

Note: Make sure that the magnet assembly is placed centrally under the wire section BC before making each measurement.

REMEMBER: Before leaving the laboratory,

- record down the mass of the rider as \( m \) and the distance of the wire \( BC \) from the pivot as \( y \) in the laboratory worksheet.
- reduce the voltage output of the dc power supply to 0 volt and turn off the power supply.

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