

# Force on a Current Carrying Wire

## 1 Object

To determine the magnetic field between two disk shaped rare-Earth magnets with parallel faces by measuring the force the magnets exert on a current carrying wire.

## 2 Apparatus

Homemade "horseshoe" magnet, power supply capable of 20 A current output, high power resistor, multimeter, wires, ring-stand and clamp, and aluminum rod.

## 3 Theory

Recall that the magnitude of the force on a current carrying wire is given by  $F = I\ell B \sin \theta$ , where  $I$  is the current through the wire,  $\ell$  is the length of the wire that traverses the magnetic field,  $B$  is the magnitude of the magnetic field, and  $\theta$  is the angle between the direction of the current and the direction of the magnetic field.

If the wire is in a magnetic field it will experience a force in the direction dictated by the right-hand rule. While we could measure the force on the wire directly, it turns out to be easier to rigidly fix the wire (in this case an aluminum rod) and measure the force exerted on the horseshoe magnet by the current carrying wire. Remember, according to Newton's Third Law, the force that the magnet exerts on the wire is equal in magnitude and opposite in direction to the force that the wire exerts on the magnet. By placing the magnet on the pan of a triple beam balance, we can measure the force that the wire exerts on the magnet.

With no current in the wire, Newton's Second Law gives us  $\sum F = N - m_o g = 0$  for the magnet when it is in equilibrium.  $N$  is the force the balance exerts on the magnet,  $m_o g$  is the gravitational force on the magnet where  $m_o$  is the mass reading on the scale when it is balanced. Note that when there is no current,  $N = m_o g$ .

When the current is turned on, Newton's Second Law gives us  $\sum F = N + F_B - m_o g = 0$ , when in equilibrium. If we *re-balance* the scale, then we can say that the normal force is given by  $N = mg$ , where  $m$  is the new mass reading that balances the scale. Therefore,  $F_B = -(m - m_o)g$ .

Since the wire will be perpendicular to the magnetic field,  $\theta = 90^\circ$ . Therefore, the relationship between the magnetic force and the current is  $F_B = I\ell B$ . If we plot  $F_B$  vs  $I\ell$ , we can determine the magnetic field strength.

## 4 Procedure

A few words of caution to begin with. The magnets you are dealing with are fairly strong. Do not get them too close to the computers in the lab, your credit cards, or to your electronic devices. We will also be dealing with fairly high currents. Some caution and some common sense is essential.

To start, be sure that the power supply is turned off and the knob controlling the voltage is all the way down.

Measure the diameter of the surface of the rare-Earth magnet. Use a wooden or plastic meter stick or ruler as steel calipers will be attracted to the magnet and could result in damage. The diameter of the magnet face is approximately the length of the wire  $\ell$  that will be in the magnetic field.

Place home-made horseshoe magnet on the balance and record its mass  $m_o$ .

Be sure to orient the home-made horseshoe magnet so that the rigid aluminum rod is parallel to the faces of the magnet (and therefore perpendicular to the magnetic field).

The circuit consists of a power supply, a high power resistor, a digital multimeter to measure current, and a segment of wire that traverses an approximately uniform magnetic field, all of which are in series. The segment of the aluminum rod that traverses the magnetic field is rigidly fixed into place and the magnet is placed on the pan of a triple beam balance.

Turn on the power supply and turn the voltage up until the current reads approximately 1.0 A. Adjust the sliding masses to re-balance the scale. Record the current and the mass. Repeat this 13 times with increments of approximately 0.5 A.

CAUTION: The high power resistor may get hot. Avoid touching it.

CAUTION: Do not adjust the current through your circuit to more than about 10 A. Various circuit elements are only rated for slightly above this.

CAUTION: Make sure the alligator clips aren't touching the balance or in any other way shorting the circuit. Please pay attention to what you are doing.

## 5 Calculations

For each new current, calculate the magnetic force  $F_B$  and also the quantity  $I\ell$ . Make a graph of  $F_B$  versus  $I\ell$ . You should know how this graph should look. Determine theoretical values, and include this determination in your lab report. Compare to what you get from your graph on the graph itself in the usual way.

## 6 Questions

1. Draw a sketch of the part of the apparatus showing the wire and the magnet pole faces. Clearly label the directions of the following: the current in the wire; the force on the horseshoe magnet; the force on the wire; and the direction of the magnetic field.

2. The Earth's magnetic field has a value of about  $0.5 \times 10^{-4} T$ . Assume it points roughly horizontally. How should your apparatus be oriented to minimize the effect of the Earth's field? Explain; a sketch might help.
3. Assume your apparatus was oriented to maximize the effect of the Earth's magnetic field. First, state what that orientation is. Second, calculate how much the force due to the Earth's field could affect your experiment. Is this effect negligible? Justify your answer.