Experiment 9: Magnetic Force on Current-Carrying Wires

OBJECTIVES
To predict and verify the nature of the magnetic force acting on a current-carrying wire when the wire is placed in a magnetic field.

INTRODUCTION
The force on a segment $d\hat{s}$ of a wire carrying current $I$ in a magnetic field $\vec{B}_{\text{ext}}$ is given by

$$d\vec{F} = I d\hat{s} \times \vec{B}_{\text{ext}} \tag{9.1}$$

where $\vec{B}_{\text{ext}}$ is the magnetic field produced by an external source somewhere else (not the magnetic field caused by the wire segment itself). By performing the necessary integral, which will be a different integral for different situations, you can then find the magnetic force on any extended current-carrying wire sitting in any external magnetic field $\vec{B}_{\text{ext}}$. For a more detailed discussion of the forces on current-carrying wires of different configurations, see the 8.02T Study Guide, Section 8.3.

PROCEDURE
The source of the external field $\vec{B}_{\text{ext}}$ will be a strong “Rare-Earth” magnet, and the current in the wires will be provided by two 1.5-volt batteries.

THE RARE EARTH MAGNET IS EXTREMELY STRONG, STRONG ENOUGH TO WIPE YOUR CREDIT CARDS, STOP YOUR WATCH, OR DO SERIOUS DAMAGE TO YOUR COMPUTER, IF IT COMES CLOSE ENOUGH TO ANY OF THESE.

DO NOT REMOVE THE MAGNET FROM ITS PROTECTIVE PLASTIC CASE!

The field lines from this magnet are similar to those you found in the previous experiment, where the field lines due a bar magnet were mapped. For the purposes of this experiment, you may assume that the field lines of the rare-earth magnet are similar to those shown for a tightly-wound solenoid, as presented in the 8.02T Study Guide, Section 9.4, and Figure 9.4.1, reproduced here:
You will use the AC/DC Electronics Board to mount two 1.5-volt batteries, which will provide the current for the wires. You will use a piece of wire about a meter in length and a coil of wire. To determine the North/South poles of the rare-earth magnet, we will use the magnetic field sensor that was used last week, hooked up to the 750 Interface.

First, you are asked to make predictions about the direction of the force on the wire or coil; then you will compare your predictions to the forces you find acting on the wires.

PREDICTIONS

(Please reproduce your predictions, either words or figures, on the tear-off sheet at the end of these instructions.)

A. Magnetic Force on a Straight Wire

Prediction 1 (answer on the tear-sheet at the end!!): Suppose the rare-earth magnet in your experimental setup has its North magnetic pole on top. If a wire is located above the magnet as shown in the figure, with the current in the wire moving from left to right, predict the direction of the force on the wire, and draw it on Figure 9.1 and on the tear-sheet.

![Image of a wire above the magnet](image)

Figure 9.1 A wire located above the magnet
Prediction 2 (*answer on the tear-sheet at the end!!*): Suppose you now place the wire *in front* of the magnet in its midplane, as shown in the figure below, with the current in the wire again running from left to right. Now predict the direction of the force on the wire, and draw it on Figure 9.2 and on the tear-sheet.

![Figure 9.2 A wire in front of the magnet](image)

Prediction 3 (*answer on the tear-sheet at the end!!*): Suppose you place the wire *behind* the magnet in its mid-plane, with the current in the wire again running from left to right. Now what is the direction of the force on the wire? Is it into the page or out of the page?

**B. Magnetic Force on a Coil of Wire**

Prediction 4 (*answer on the tear-sheet at the end!!*): Suppose you now place a circular coil carrying current above the magnet and coaxial with it (see Figure 9.3), with the current in the coil running so that current moves *counterclockwise* as seen from above. Will the coil of wire be attracted to or repelled by the permanent magnet, or will it feel no force at all; that is, will the force on the coil be upwards, downwards, or zero? (Remember, the North pole of the magnet is assumed to be on the top.)
Question 1 (answer on the tear-sheet at the end!): Which of the two figurations below (A or B) represents the TOTAL magnetic field configuration in this case (field of both magnet and coil of wire)?

Prediction 5: Suppose that the current in the ring runs so that current moves clockwise as seen from the top (see Figure 9.4 next page). Will the coil of wire be attracted or repelled by the permanent magnet, or will it feel no force at all?
Figure 9.4 A circular coil placed above the magnet with current running clockwise as seen from the top.

Question 2: (answer on the tear-sheet at the end!!): Which of the two field configurations (A or B) shown on the previous page represents the TOTAL magnetic field configuration in this case?

EXPERIMENT

Use the Magnetic Field Sensor (also known as a “Hall Probe”) to determine which pole, North or South, is the upper pole on your magnet. Attach the magnet probe cable to the 750 Interface as was done in the previous experiment. Download the DataStudio Activity “exp09.ds” and save it on your desktop. Decide whether it’s best to use the sensor on AXIAL or RADIAL. First try the probe on 1×; use 10× only if your data trace is too small to see. If the results of your investigation suggest that the North pole of your magnet is upward, then all of your predictions above should be correct; if the South pole is upward, your predictions should all reverse sign.

Perform the five experiments that are described above, using your length of wire, battery and coil of wire to see if reality agrees with your predictions. Use leads to and from the “switch” on the AC/DC board, indicated by the red button. This will allow you to make the connections without having the current run until you’re ready to find the force direction. Since we are directly shorting out the batteries to get a high current, it is important that you do this so our batteries don’t run down rapidly.
Note: In looking for the force on a straight wire, bend your long wire into a long U shape so that there is plenty of length of wire to allow movement of the wire due to the magnetic force. If you use too short a piece of wire, it will be too rigid to flex enough to show the force clearly. Remember, you are only looking for a direction. The effect is not great, and may be hard to detect without a bit of care.

Question 3 (answer on the tear-sheet at the end!!): If any of your predictions were incorrect, briefly explain why.
Experimental Summary 9: Magnetic Force on Current-Carrying Wires

Group ______________________________________

Names ______________________________________

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PREDICTIONS

A. Magnetic Force on a Straight Wire

Prediction 1: With the current in the wire moving from left to right, predict the direction of the force on the wire, and draw it on Figure 9.1 __________________________

Figure 9.1 A wire placed above a magnet

Prediction 2: Now place the wire *in front* of the magnet in its midplane, with the current in the wire again running from left to right. Now predict the direction of the force on the wire, and draw it on Figure 9.2 __________________________

Figure 9.2 A wire placed in front of the magnet

Prediction 3: Suppose you place the wire *behind* the magnet in its mid-plane, with the current in the wire again running from left to right. Now what is the direction of the force on the wire, that is, is it into or out of the page? _____________________
B. Magnetic Force on a Coil of Wire

**Prediction 4:** You now place a coil above the magnet, with the current in the coil running *counterclockwise* as seen from above. Will the coil be attracted to or repelled by the permanent magnet, or will it feel no force at all? __________________________

![Figure 9.3 A circular coil placed above the magnet](image)

**Question 1:** Which of the two figurations (A or B) represents the TOTAL magnetic field configuration in this case (field of both magnet and coil of wire)?

A. ![Image A]  
B. ![Image B]

**Prediction 5:** The current in the ring now runs *clockwise* as seen from the top. Will the coil of wire be attracted or repelled by the permanent magnet, or will it feel no force?

![Figure 9.4 A circular coil placed above the magnet](image)

**Question 2:** Which of the two field figurations (A or B) shown just above represents the TOTAL magnetic field configuration in this case? __________________________

**EXPERIMENTAL VERIFICATION**

**Question 3:** Now do the actual measurements. If any of your predictions were incorrect, briefly explain why.