Force on a Wire

PY 212

Introduction and Purpose

One of the fundamental facts of physics is that magnetic fields exert forces on wires that carry an electric current. In fact, the only direct means that we have to measure the current in a wire is to measure the force that a known magnetic field exerts on the wire.

In this experiment a rectangular circuit loop will be partially inserted between the north and south poles of a permanent magnet. As a result the apparent mass of the magnet, which is sitting on a balance, will change.

In this lab we will determine the relationship between the length of a current carrying wire and the force experienced by that wire in a magnetic field. We will also determine the relationship between the current in the wire and the force. By using known values (or values measured directly) for both length and current, we will be able to determine the magnetic field associated with the permanent magnet.

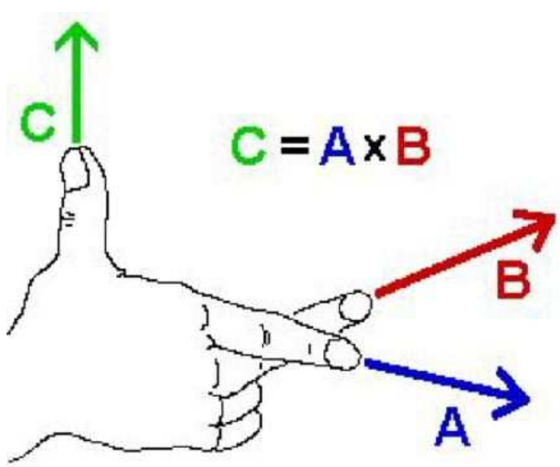

Figure 1: The right-hand rule.

Discussion of Principles

The force of exerted by a magnetic field $\vec{B}$ on a short, straight wire of length ℓ that carries a current I, is given by the vector equation

$$\vec{F} = I\left(\vec{\ell} \times \vec{B}\right) \tag{1}$$

where $\vec{\ell}$ is a vector whose magnitude is equal to the length of the wire and whose direction is the same as the direction of the current.

The magnitude of the force is given by

$$|\vec{F}| = I|\vec{\ell}||\vec{B}|sin\left(\theta\right) \tag{2}$$

where θ is the angle between $\vec{\ell}$ and $\vec{B}$. In this experiment, the angle between $\vec{\ell}$ and $\vec{B}$ will always be 90°, so $|\vec{F}| = I\ell B$. The direction of the force is given by the right hand rule, shown in Figure 1.

In this lab, we'll be measuring the force on the wire loop by measuring the changes in mass of our magnet as it sits on an electronic balance. While the theory discussed above deals with force on the *wire*, we can consider both the wire and the magnet and the wire as a closed system which allows us to conclude that any force on the wire by the magnet will lead to an "equal and opposite" force on the magnet by the wire.

With the equation for force in the form $|\vec{F}| = I\ell B$, we can see that two different linear relationships can be brought about. If we first consider the force on the wire as the y-axis variable and the length of the wire as the x-axis variable, we see that the above equation takes on the familiar linear form of $y = mx + b$ (where we're not concerned with the intercept). If this is the approach we use, what parameters make up the slope? If we then consider (as in the second part of our lab today) the force as the y-axis variable and the current in the wire as the x-axis variable, what parameters will make up the slope now? If we understand what parameters make up the slope in each case, it will be easy to determine the magnitude of the magnetic field in each part.

Procedure

1. Turn on the digital balance and wait for the display to read zero. Carefully place the magnet assembly on the measuring pan. Dropping the magnet on the measuring pan will permanently damage the scale.

2. Measure the mass of the magnet and record this in the Data section on the last page.

3. Attach the main unit to the ring stand so that the lever arm can swing upward from horizontal.

4. Attach a current loop to the end of the main unit.

5. Position the equipment so that the current loop extends into the top notch of the magnet assembly **without touching the sides or the bottom of the magnet**, as shown in Figure 2.

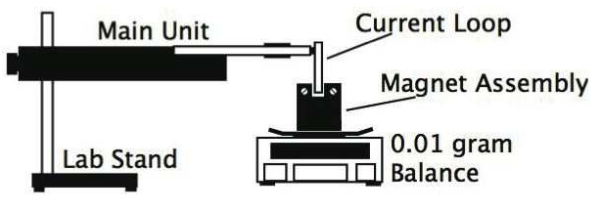

Figure 2: A side view of the apparatus

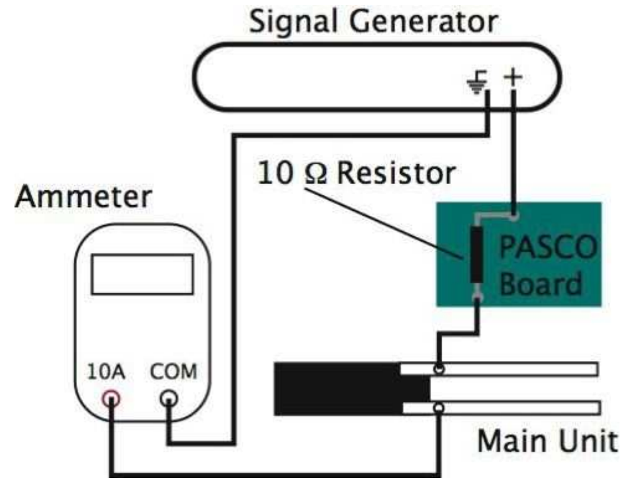

Figure 3: Connections between the signal generator output, PASCO circuit board, main unit, and ammeter

6. Make the following electrical connections (use Figure 3 as a guide for your connections):
   - Make a connection from the positive terminal of the signal generator output to the 10Ω resistor on the PASCO circuit board.
   - Make a connection from the other resistor terminal to one arm on the main unit.
   - Connect the remaining arm to the high current (10A or 2A, depending on the model you're using) socket of an ammeter.
   - Connect the COM terminal of the ammeter back to the negative/ground terminal of the signal generator output.

Force v. Length

You will be using current loops #37, #38, #39, and #40 for this part of the experiment.

1. Measure and record the length of each wire. *Think about what part of the current loop you measure.* Record this length on the last page.

2. Open the "Force on a wire" DataStudio file from the course webpage.

3. Make sure that the **AUTO** button is active in the signal generator window, ***not the ON button***. Current will begin flowing when the "Start" button is pressed and stop flowing after 10 seconds or when the "Stop" button is pressed. **This will ensure that the resistor does not overheat in between measurements.**

4. Attach one of the current loops to the main unit. Lower the main unit arm so that the edge of the current loop is lowered into the magnet assembly. Supply a current of about 0.3 A to the circuit by increasing the voltage to 5 Volts in the signal generator window.

5. Press the "Start" button and measure the current and the new value for the mass of the magnet. Record these values in the Force v. Length data table on the last page. The new magnet mass will be recorded in the "Mass, absolute" column.

Be sure to include the Data Table in your final report.

6. Repeat with a different current loop until all current loops have been used.
7. Calculate the remaining columns of the table on the last page. Also calculate the average current applied to the loops.

   Be sure to include sample calculations in your final report.

8. Plot Force (y-variable) v. Length (x-variable) in Excel. User a linear line of best fit and find the slope of this line. Record this value on the last page.

   Be sure to include the plot in your final report. Any values determined from the plot and discussion about these values should also be included.

9. Recalling $|\vec{F}| = I\ell B$, we see that the slope of a Force(F) v. Length graph(ℓ) is $I|\vec{B}|$. Since you've recorded the current, you can now calculate the strength of the magnetic field B.

Force v. Current

Use the current loop labeled sf 38

1. Vary the current to five different values between -0.3A and 0.3A by adjusting the voltage to five different values between -5 V and 5 V in the signal generator window.
2. Make measurements of current and absolute mass when the "Start" button is pressed. Complete the appropriate table on the last page. *Be careful to use the correct sign with the force on the wire.*
3. Plot Force v. Current in Excel and use a linear line of best fit to determine the slope.

   Again, be sure to include a complete Data Table, sample calculations, and the plot in your final report.

4. From the slope calculate a value for the magnitude of the magnetic field $|\vec{B}|$ and record this value.
5. Determine the percent difference between the values for $|\vec{B}|$ that you obtained.

   Include the percent difference in your final report and comment on its significance.

Things to consider when writing your final report

- In the Force v. Length part of the lab, did the current vary when you used different wire loop segments? If so, explain any variance you saw.
- In the Force v. Length part of the lab, what in the experiment determines whether the slope is positive or negative? What would you change to get the slope to be the opposite sign?

- In the Force v. Current part of the lab, how would the slope change if we used a different current loop that was either longer or shorter than loop #38?
- During any part of the experiment, was there any force exerted on the sides of the loop? If so, did this affect the apparent mass as measured by the electronic balance?
- What would happen to the apparent change in mass if the direction of the current is reversed? What would happen if the poles of the magnet were switched?

Force v. Length

Mass of magnet = ______________________ kg

L (m)	Current (A)	Mass, absolute (kg)	Change in mass (kg)	Force on Wire (N)

$I_{average}$ = ______________________ A

Slope = $|\vec{B}|I$ = ________________ T A

$|\vec{B}|$ = ________________ T

Force v. Current

Current (A)	Mass, absolute (kg)	Change in mass (kg)	Force on Wire (N)

Slope = $|\vec{B}|L$ = ________________ T m

$|\vec{B}|$ = ________________ T

Percent difference in $|\vec{B}|$ = ____________________ %