Objectives

These lab activities will focus on the concepts of magnetic forces and how they interact with moving charges in an external magnetic field. You should read all the steps in each part before you start. Work in your assigned groups and maintain a collaborative and communicative team.

For the following activities you will be using a simulation from Colorado PhET simulations. Visit: https://uglabs.physics.ucr.edu/ for lab downloads and links.

Introduction

A wire carrying a current in a magnetic field experiences a force

\[ \vec{F} = iL \times \vec{B} \quad \text{or} \quad F = iLB \sin \theta \]

where \( \vec{F} \) is the force, \( i \) is the current, \( L \) is the wire length, \( \vec{B} \) is the magnetic field, and \( \theta \) is the angle between the field and the wire.

The force will be directly measured in the lab. The values of \( i, L, \) and \( B \) will be varied, so that the dependence of \( F \) on them can be studied. An important note is that you can choose whatever coordinate system you want, as long as it obeys the right-hand rule – so feel free to define your directions in whichever way makes solving the problems simple (e.g. up == negative-y direction).

The Physics

The force on a moving charge in a magnetic field is:

\[ \vec{F}_q = q \vec{v} \times \vec{B} \]
Magnetic Force on a Current

This force was our first introduction to the magnetic field, and forms, in some sense, the definition of a magnetic field.

If a current-carrying wire is placed in a magnetic field, a force will be exerted on the wire. The total current consists of individual charge carriers, so that for a length \( \vec{L} \) of wire we get:

\[
i = n q v A
\]

where \( n \) is the number density of carriers, and \( A \) is the cross sectional area of the wire. Multiplying by the length of the wire gives:

\[
iL = n(AL)qv \quad \text{or} \quad iL = Nqv
\]

where \( N = nAL \) is the total number of charge carriers (density \( \times \) volume). Since the wire length \( L \) is in the same direction as the average charge motion, \( v \), we can write this as a vector equation:

\[
i\vec{L} = Nq\vec{v}
\]

The total force on the length of wire is equal to the total magnetic force on all the charge carriers, so:

\[
\vec{F} = N\vec{F}_q = Nq\vec{v} \times \vec{B} = i\vec{L} \times \vec{B}
\]

In today’s lab, \( \vec{B} \) and \( \vec{L} \) will be perpendicular, so we can simply use:

\[
F = iLB \quad \text{(1)}
\]

Where the magnetic field is:

\[
B = \frac{\mu_0 i}{2\pi r} \quad \text{(2)}
\]
Magnetic Force on a Current

1. Practicing the Right-Hand Rule

For this activity we will use the standard convention that a vector coming out of the plane of the page straight toward you is written as a circle with a dot in it, and a vector going into the plane of the page is written as a circle with an “X” in it.

In the arrangements shown below, assume a positive electrical charge is moving with velocity \( \vec{v} \) through a magnetic field \( \vec{B} \).

1.1: Find the direction of the force, \( \vec{F} \), for the figure to the right.

1.2 Find the direction of the force, \( \vec{F} \), for the figure to the right.
1.3 Find the direction of the magnetic field, B, for the figure to the right.

2. Measuring the Magnetic Force on a Current

2.1: Open Simulation 1. You will see the page shown below.
Magnetic Force on a Current

Wire A feels the effects of the magnetic field generated by the current in Wire B. Likewise, Wire B is affected by the field produced by the current in Wire A. We can quantify this relationship by combining Eq. 1 and Eq. 2.

\[
F = i_B \Delta L B_A = \frac{\mu_0 i_A i_B}{2\pi r} \Delta L
\]  

(3)

2.2: Make a drawing of the parallel wire setup in your notebook, including labels for the current and magnetic field. Using the right-hand rule, determine the direction of the magnetic force exerted on Wire A by Wire B as well as the magnetic force exerted on Wire B by Wire A. Add the force vectors to your drawing. Change the current in Wire B to be -3 A. Make another drawing for this new setup. Once again, use the right-hand rule to determine the direction of the magnetic force exerted on both wires and add the force vectors to your drawing. Describe the general relationship between direction of current in two parallel wires and their force vectors.

2.3: What do you get when you plug in \(i_a, i_b, \) and \(r\) from the simulation and solve for \(\Delta L\)? What does this result mean?

2.4: Your TA will assign you a radius \(r\), the distance between wires (the simulation denotes this as \(m\)). Set the current through both wires to -5 A and record the force on Wire A. Note that force is a vector. The sign of \(F_{BA}\) (i.e. The force Wire B exerts on Wire A) will depend on the coordinate system you choose to use. In your lab report, make sure you indicate your coordinate system (i.e. is positive left or right?). Increase the current through Wire B to -4 A and record the force on Wire A. Keep repeating this until the current on Wire B is 5 A. Produce a table like the one shown below:

<table>
<thead>
<tr>
<th>Current (A)</th>
<th>Force (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5</td>
<td></td>
</tr>
<tr>
<td>-4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>
**Magnetic Force on a Current**

2.5: Plot your data as $F$ versus $i$ using Excel. Plot your force values on the y-axis and your current values on the x-axis. Based on $F = i\Delta LB$, we would expect $F$ vs. $i$ to be linear. What is the slope of this line? Is the value of the slope consistent with the equation?

2.6: Repeat step 2.4, but instead, set the current through Wire A to -5 A and record the force on Wire B. Increase the current through Wire A until you get to 5 A. Compare your data to the table you created in step 2.4 and comment on any relationships you see.

2.7: Say we start off with 1 A of current through both Wire A and Wire B. If we increased the current through Wire A, which wire feels a greater magnitude of force: A on B, B on A, or are they the same?
3.1: Open Simulation 2 and you should see the page below. This simulation shows a loop of wire connected to a battery between the poles of two magnets.

3.2: Press “Run” to start the simulation. What happens to the wire loop? Explore how each of the three sliders (Magnetic Field, Battery Voltage, and Number of Loops) affect the behavior of the simulation. Using words, equations, and/or drawings, explain why you think the wire loop is rotating.

3.3: What is the force on the segment of wire that’s parallel with the magnetic field? Why?
1. Consider the rigid wire shown above with current flowing as indicated. There is a uniform magnetic field perpendicular to the wire into the paper. Use the right-hand rule to determine the direction of the force on the horizontal segment of the wire.

   (a) Parallel to the paper and down
   (b) Parallel to the paper and up
   (c) Parallel to the paper to the left
   (d) Parallel to the paper to the right
   (e) There is no force

2. Why can we ignore the current in the vertical segments of the wire?

   (a) The current flowing in the vertical segments is significantly less than in the horizontal segment
   (b) The magnetic field does not interact with the current in the vertical segments
   (c) The forces on the vertical segments cancel each other out
   (d) None of the above