FORCE ON A CURRENT IN A MAGNETIC FIELD

PURPOSE: To study the force exerted on an electric current by a magnetic field.

BACKGROUND: When an electric charge moves with a velocity \( v \) in a magnetic field \( B \), it experiences a magnetic force, called the Lorentz force,

\[
F = qvB \sin \theta,
\]

which results in motion along a curved path. If the charge is an electron confined in a conducting wire, it travels only a short distance before colliding with the metallic ions making up the metal. Thus the motion of the electron is a series of slightly curved arcs along the wire. As a result of the repeated collisions of the electrons with the ions, the wire itself experiences a magnetic force due to the interaction of the current it is carrying with the magnetic field. For a wire of length \( l \) that carries a current \( I \) in an external magnetic field \( B \), the force on the wire is:

\[
F = IBl \sin \theta
\]

The figure illustrates a wire of length, \( l \), in a magnetic field, \( B \). The wire lies at an angle, \( \theta \), with respect to the magnetic field.

To determine the direction of the force use the right hand rule: If your fingers are the field lines and your thumb is the current direction, then your palm pushes in the direction of the force. For the diagram, the force \( F \) is perpendicularly downward into the page. Note that the force is at its maximum when the wire is perpendicular, \( \theta = 90^\circ \), to the magnetic field.

The SI unit for the magnetic field, \( B \), is the tesla (T) which has the units of N/A·m. Another common magnetic field unit is the gauss (G); \( 1 \text{ G} = 10^{-4} \text{ T} \). The geomagnetic field at the surface of the Earth is about \( 0.5 \text{ G} \) or \( 0.5 \times 10^{-4} \text{ T} \).

PROCEDURE: The schematic diagram on the next page shows the Current Balance apparatus. A quadruple beam balance (5) measures the magnetic force from the current loop (3) that is suspended in the magnetic field of magnet assembly (4). The apparent "weight" of the magnet assembly is increased or decreased by the force from the current loop. The size of the force depends upon the current, \( I \), and the length, \( l \), of the loop.

Study the top view of the base unit (2). A current from the power supply travels down one of the unit's arms to the current loop (3) (see arrows on the arms). The other arm returns the current to an ammeter (or multimeter) to measure the current.
The front view of the current loop (3) shows a thick (foil) wire is connected to the base unit's arms. The magnetic force from the vertical parts cancel; only the horizontal part contributes to a vertical force that changes the apparent "weight" of the magnet assembly (4) that sits on the plate of electronic balance (5). In this setup the angle between the magnetic field and the wire is always fixed at 90°.

Note: (5) shown as a quadruple beam balance is replaced by an electronic balance. Ammeter is replaced by the current reading on the power supply.

We will now give the procedure for three different experiments using this apparatus:

**FORCE VERSUS CURRENT:**

- Select one current loop (3) and record its model number that might be something such as "SF 40". Measure the length of its horizontal foil (wire) and record this value. Attach the current loop to the end of the base unit (2) with the foil (wire) end extending down.
• Put the magnet assembly (4) marked "A" on the pan of the quadruple beam balance (5). Move the lab stand (1) and base unit (2) so the horizontal position of the conductive foil (wire) on the current loop passes between the pole region of the magnets. The current loop must not touch the magnet or balance.

• Connect the power supply and ammeter as shown in the above figure.

• Record the mass of the magnet assembly before turning on the power. Convert this into weight, namely force. Remember the balance measures mass, not force.

• Do not use the zeroing feature of the electronic balance, as this causes unstable reading. Instead, record the initial balance reading with no current.

• Measure the force for 10 different (evenly spaced) currents. First use the lowest current the supply delivers, then the highest. Select 8 other currents.

• Repeat the measurement, but reverse the current by exchanging the + and - power supply cables.

• Plot your results: Force vs Current. Use OriginPro and fit a straight line to each of your data sets. Calculate the B field from Eq. (2).

FORCE VERSUS WIRE LENGTH

• Select one current loop and record its model number that might be something such as "SF 40". Measure the length of its horizontal foil (wire) and record this value. Attach the current loop to the end of the base unit with the foil (wire) end extending down.

• Put the magnet assembly on the pan of the quadruple beam balance. Move the lab stand and base unit so the horizontal position of the conductive foil (wire) on the current loop passes between the pole region of the magnets. The current loop must not touch the magnets or balance.

• Connect the power supply and ammeter as shown in the above figure.

• Record the weight of the magnet assembly before turning on the power. Convert this into weight (force).

• Adjust the current to, say, 3.0 A. Then measure the force. Always make sure the current does not change as you repeat these steps.

• Turn off the current and change the current loop.

• Repeat the measurement, but reverse the current by exchanging the + and - power supply cables. Repeat the above steps for a minimum of 5 current loops.
• Plot your results: Force vs Wire Length. Use OriginPro and fit a straight line to each of your data sets. Calculate the B field from Eq. (2) and compare with your previous value.
FORCE VERSUS ANGLE

In the above experiments the angle between the magnetic field direction and the wire length was fixed at 90°. Now, you will vary the angle and see how the force changes. The next illustration shows how we replaced the wire foil by a rotating coil unit (6).

- Replace the current loop with the rotating coil unit that plugs into the base unit.
- Rotate the unit coil until the dial reads 0°.
- Use a magnetic assembly marked "B"; it is different than the one used in the previous experiment. Align the magnetic assembly on the pan of the quadruple beam balance so that the magnetic field is approximately parallel with the wires in the coil.
- Before turning on the current, measure the weight of the magnetic assembly.
- Set the current to a little less than 2 amps. Record the effective weight for \( \theta = 0° \). **Never exceed 2 amps current, or you will damage the apparatus.**
- Rotate the dial clockwise in increments of +10°, taking new readings at each angle up to and including 90°. Then go back to \( \theta = -10° \) and make measurements at -10° increments down to -90°. Make sure that the arrangement of your apparatus (base unit, balance, and especially the current) do not change while you make these measurements. **DO NOT MOVE ANYTHING ELSE OR YOUR BASELINE WILL CHANGE.**
- Plot your data as Force versus Angle using OriginPro (You do not have to make a fit for this graph). Also make a second plot of Force versus Sine Angle and make a linear fit to determine B.
MAGNETIC FIELDS FROM ELECTRIC CURRENTS

Name: ____________________________________________ Section: ______________________

Partners: _________________________________________ Date: ______________

Loop Lengths: SF40= 1.2 cm; SF37= 2.2 cm; SF39= 3.2 cm; SF38= 4.2 cm; SF41= 6.4 cm; SF42= 8.4 cm.

FORCE VERSUS CURRENT

Current Loop #: ________ Loop Length: ________

Initial Balance mass with no current = __________; Initial Force $F_{I=0} =$ __________

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<th>Current ( )</th>
<th>Balance Mass ( )</th>
<th>Net Force $F - F_{I=0}$ ( )</th>
<th>Current ( )</th>
<th>Balance Mass ( )</th>
<th>Net Force $F - F_{I=0}$ ( )</th>
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Attach your graph of Force vs. Current. Use the value of the slope and the Loop Length to calculate the magnetic field $B$ (Hint: Use eqn 2). Show calculations.

$B = __________$ Compare this to the geomagnetic field: $B/B_{earth} = __________$
Equation (2) gives the force on a wire carrying a current in a magnetic field. In the experiment you measured the change in apparent weight of the magnet producing the magnetic field. These are different forces. Give the reasoning that allows you to conclude that your data should be described by Eq. (2).

**FORCE VERSUS WIRE LENGTH**

Initial Balance mass with no current = __________; Initial Force $F_{I=0} = __________$

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<tr>
<th>Current Loop #</th>
<th>Length ( )</th>
<th>Balance Mass ( )</th>
<th>Net Force $F - F_{I=0}$ ( )</th>
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Attach your plot of Force vs. Wire Length.

Graph slope = __________. From Eq. (2) calculate the magnetic field, B. Show work.

Compare this field strength with the previous value. If they are different, why?
FORCE VERSUS ANGLE

Initial Balance mass with no current = _________; Initial Force \( F_{I=0} \) = _________

DO NOT MOVE ANY APPARATUS WHEN TAKING DATA!

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<thead>
<tr>
<th>Angle (°)</th>
<th>Balance Mass ( )</th>
<th>Net Force ( F - F_{I=0} ) ( )</th>
<th>Angle (°)</th>
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Attach your plots of Force versus Sine of Angle.

Determine the slope of linear fit: \( g = \) _________

length of one wire segment from which measured magnetic force arises
\( s = \) _______________

no. of the wire segments = \( N = \) _______________

Write a formula relating the slope \( g \) to \( s\), \( N \) and \( B \).

Find the magnetic field \( B \).