Magnetic Fields and Magnetic Forces

Objective

Become familiar with the action of a magnetic field on electric currents.

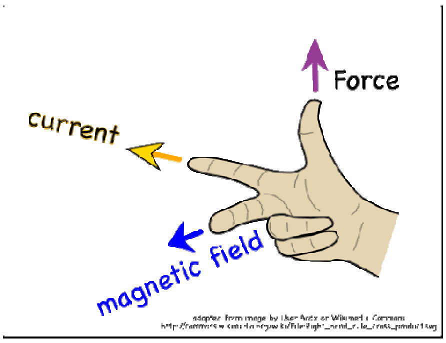
Theory

An electric charge q moving in a magnetic field B with speed v feels a force applied to it in the direction perpendicular to the velocity and the magnetic field, so called Lorentz force.

$$F = qvBsin\ \theta$$

where the angle θ is the angle between the magnetic field and charge's speed. The unit for the magnetic field is Tesla, 1 Tesla=1 Newton/(1 Coulomb*1 m/s).

While we said that the force is perpendicular to both B and v, there are two suitable possibilities for this definition, such as to the right and to the left in the figure below. Whether the magnetic force points to the left or to the right is determined by the so called "Right-Hand Rule" (RHR) below.



Here, the motion of charge is represented with the arrow "current"; for positive charge, it is the same with the direction of the motion of the charge and, for negative charge, it is the opposite, as we learned in class.

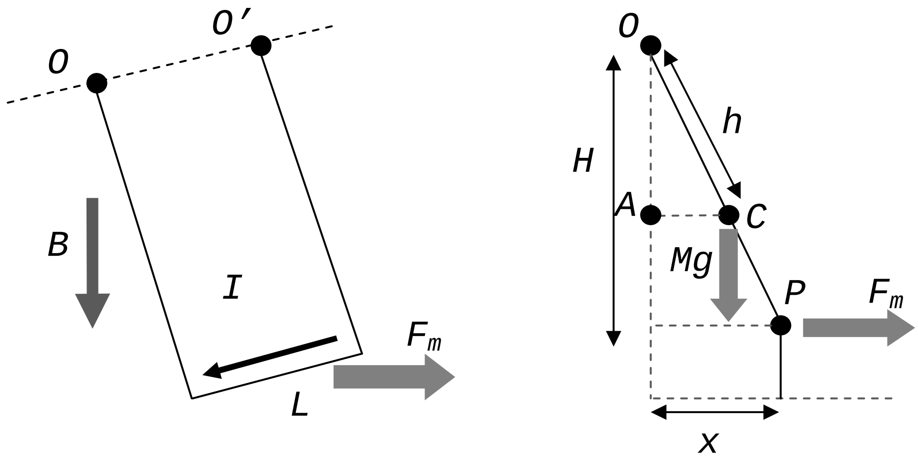
Electric current is produced by the motion of charged particles inside conductors. Therefore, a wire carrying electric current in a magnetic field likewise experiences a magnetic force, as result of magnetic force acting on all of the moving charges inside it. The strength of that force can be written as

$$F = IBL \sin \theta$$

Where I is the strength of the current and L is the length of the wire. The direction of this force is again determined by RHR as shown in the figure above.

In this experiment you will observe the effect of magnetic field on a current-carrying metal frame, suspended between the poles of a strong permanent magnet.

When electric current flows through the frame, the frame experiences a magnetic force in RHR direction, and moves until this magnetic force is compensated by out-of-equilibrium gravity force.



The equilibrium position of the frame can be found from the equality of magnetic and gravity forces' torques, relative to the frames pivot point O (Figure 2). The magnetic force is applied in horizontal direction at the lowest part of the frame, P, and the gravity force is applied straight downward at the center of mass of the frame, C. Therefore,

$$l_{Mg} = Mgx\frac{h}{H} = F_m H = l_M$$

Here the distance from the pivot O to the center of mass C is OC=h and the total length of the frame is OP=H. Note here that the arm of gravity force is $l_{Mg} = x\frac{h}{H}$, if the position of the frame is *x* (from triangle OAC). We also assumed here that $x \ll H$, so that the arm of the torque for the magnetic force remains approximately $l_m = \sqrt{H^2 - x^2} \approx H$.

In the experiment, you will observe position of the frame *x* for different values of the electric current I, by comparing frame's position to the millimeter paper attached to the magnet below. From *x* the strength of the magnetic field can be found. Considering that

$$F_m = IBL$$

we calculate the strength of the magnetic field between the poles of the magnet *B*,

$$B = K \cdot \frac{x}{I}$$

where $K = \frac{Mgh}{LH^2}$.

Equipment

- Adjustable current source.
- Magnet frame and rails apparatus (MFRA).

Procedures

1. Make sure that the current supply is off. Connect the current supply with the red and black connectors on the MFRA near the metal frame (on top face of the apparatus).
2. Use the millimeter paper on the apparatus and take note of the position of the frame when there is no current. This will be your x=0 position.
3. Take note of the frame's parameters such as length H, horizontal part's length L, center of mass position h, and the total mass M. These are written on the millimeter paper. Write these down in your data-sheet – you will need these for the calculations in your report.
4. Turn on the current supply on. Using the current regulator slowly increase the current to 1A, 2A, 3A, 4A, and 5A. At each of these values, compare the position of the frame against the millimeter paper by carefully looking at the frame from above, and take notes of the displacement of the frame, x, for I=1A, 2A, 3A, 4A, 5A. BE CAREFUL NOT TO TOUCH ANY METAL PARTS OF THE APPARATUS WHILE DOING THAT.
5. Repeat part 4 at least two times.
6. Turn the current regulator all way to zero and turn the current supply off.

ALYSIS (TO BE PERFORMED IN THE REPORT)

7. Use your measurements in (4) and (5), and the formula for the magnetic field *B* in the Theory section to calculate the values for *B* for I=1A, 2A, 3A, 4A, and 5A. Calculate the average value for *B* using <u>all measurements</u> as well as the standard deviation for *B*. PAY SPECIAL ATTENTION TO THE UNITS OF DIFFERENT CONSTANTS YOU USE TO CALCULATE *K* IN THE FORMULA FOR *B*, <u>YOUR RESULT FOR *B* SHOULD BE IN TESLA</u>.