Magnetic Force on Charged Objects Moving in Magnetic Field

PHYS 296

Your name____________________ **Lab section**____________________

PRE-LAB QUIZZES

1. What will we investigate in this lab?

2. What is the magnetic force exerted on a charged particle at rest in a magnetic field?

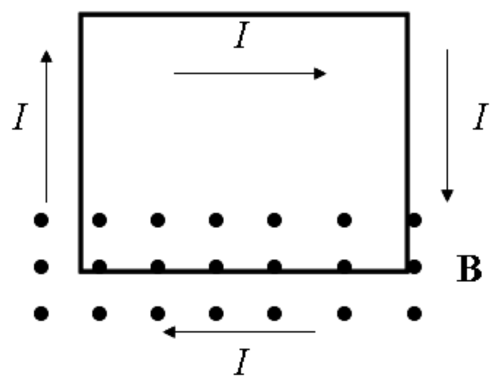
3. A *25-cm* wire carrying *1-A* current is placed in a magnetic field of *0.5 T*. For the following two cases, calculate the magnetic force exerted on the wire and draw a diagram marking the directions of the wire, the magnetic field, and the magnetic force.

(a) The wire is parallel to the magnetic field.

(b) The wire is perpendicular to the magnetic field.

4. Discuss the forces acting on the four sides of the rectangular coil in Figure 1. The magnetic field points out the paper and is non-zero only in the lower part of the coil.

Figure 1



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PHYS 296

Name______________________________ **Lab section**____________________

Lab partner's name(s)____

Objective

Investigate the magnetic force exerted on charged objects moving in a magnetic field.

Background

Moving in a magnetic field $\boldsymbol{B}$ with velocity of $\boldsymbol{v}$, a particle with charge q experiences a magnetic force ($\boldsymbol{F}$) described by

$$\boldsymbol{F} = q(\boldsymbol{v} \times \boldsymbol{B}). \tag{1}$$

Because the force is proportional to the cross product of the two vectors, $\boldsymbol{v}$ and $\boldsymbol{B}$, the direction of the force is perpendicular to the direction of $\boldsymbol{v}$ and the direction of $\boldsymbol{B}$. Denoting θ as the angle between $\boldsymbol{v}$ and $\boldsymbol{B}$, the magnitude of the magnetic force is

$$F = qvB \sin\theta. \tag{2}$$

Thus, the magnetic force is zero when $\boldsymbol{v}$ is parallel to $\boldsymbol{B}$. The magnetic force reaches maximum magnitude when $\boldsymbol{v}$ is perpendicular to $\boldsymbol{B}$.

Current-Carrying Wire in Magnetic Field

When a current-carrying wire is placed in a magnetic field, all the conducting charges moving within the wire experience tiny magnetic forces which together exert a net magnetic force on the wire. For instance, consider a straight wire carrying current I and assume simply that the conducting charges move along the wire with velocity $\boldsymbol{v}$. The sum of $q\boldsymbol{v}$, where q is the charge, over all the conducting charges in the wire equals $I\boldsymbol{L}$. $\boldsymbol{L}$ is a vector whose magnitude is the length of the section of the wire immersed in the magnetic field and with the direction parallel to the current. $\boldsymbol{v}$ and $\boldsymbol{L}$ are thus both parallel to the wire. When the wire is placed in a magnetic field $\boldsymbol{B}$, the sum of the forces on all the conducting charges, namely, the net force on the wire is

$$\boldsymbol{F} = (\text{the sum of } q\boldsymbol{v}) \times \boldsymbol{B} = I\,(\boldsymbol{L} \times \boldsymbol{B}). \tag{3}$$

The magnitude of the force obtained from Equation (3) is

$$F = ILB \sin\theta, \tag{4}$$

where θ is the angle between $\boldsymbol{L}$ and $\boldsymbol{B}$. We will demonstrate in part II that the magnitude of the force is $F = ILB$ when $\boldsymbol{L}$ and $\boldsymbol{B}$ are perpendicular to each other.

PART I: Motion of Electrons in a Magnetic Field

In part I, we investigate the trajectory of an electron beam in a magnetic field and study how it varies with the angle between the electron beam and the magnetic field. You must observe carefully when the TA is demonstrating the experiment. You should sketch in the lab report the trajectories of the electron beam under different experimental conditions.

Data Analysis

1. Sketch the observed trajectory of the electron beam when the angle between the electron beam and the magnetic field is *0°*, *45°*, and *90°*.

2. Use Equation (1) and the right hand rule to explain the observed trajectories for the cases of *0°* and *90°*.

PART II Magnetic Force on the Current-Carrying Wire

In part II, we use the electromagnetic balance as shown in Figure 2 to study the force acting on a current-carrying wire in a magnetic field. Schematically shown in Figure 2 for the electromagnetic balance, *100* turns of copper wires are wound around a rectangular aluminum plate to form a rectangular coil. The width of the plate is *1.5* cm and the length is *5.7* cm. The top part of the aluminum plate is a circular pan used to hold weights. The aluminum plate hangs from the vertical spring through a hook. Adjust the vertical position of the aluminum plate such that the bottom part of the coil is inside the permanent magnet and is thus placed in the magnetic field. When a current flows through the coil, a net magnetic force is induced on the coil and it points along the vertical direction. This force can point upward or downward, depending on the direction of the current. For this experiment, you connect the positive end of the power output to the red banana plug and the negative end to the black plug, which should produce an upward net magnetic force. Two additional forces, the elastic force exerted by the spring and the gravitational forces on the coil-plate assembly and the added masses, are also acting on the coil-plate assembly.

To calculate the magnetic force on the coil, note that the total effective length of the coil in the magnetic field is: $L = NW$, with N as the number of turns and W as the width of the plate. Thus, following Equation (4) the magnetic force exerted on the coil in the magnetic field is

$$F_{Magnetic} = INWB. \qquad (5)$$

When a mass of m is placed in the pan, an extra gravitational force exerted on the system is

$$F_{Gravitational} = mg. \qquad (6)$$

When the two forces are balanced, the plate returns to the original vertical position. The condition for such a balance is

$$mg = INWB. \qquad (7)$$

In Equation (7), when B, N, and W are kept constant, I is linearly proportional to m. Equation (7) can thus be used to calculate B.

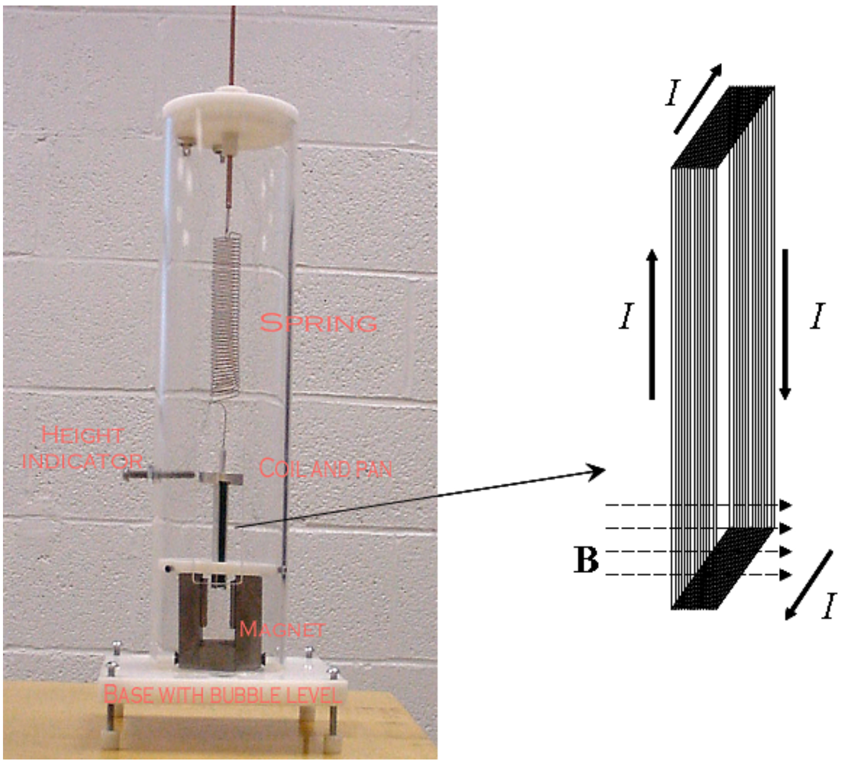

Figure 2. The electromagnetic spring balance.

QUESTIONS

1. Should we include the vertical sections and the top horizontal section of the rectangular coil to calculate the magnetic force exerted on the wire by the magnetic field? Why?

PROCEDURES

1. Level the spring balance by adjusting the four supporting screws. When the balance is level, the bubble should be near the center of the eye of the bubble level.
2. Make sure the vertical position of the aluminum plate is initially set correctly, such that the vertical position of the circular pan should match the height marker. Make sure that the aluminum plate is not clogged and can move freely up and down through the rectangular hole.
3. Connect Output to the coil, and in series with Current Sensor which is connected to *channel A*. Follow the color code: connect red plug to red plug and black plug to black plug.
4. Open ***Data Studio***, select *DC voltage* for Output and first set it to *0* V. Select current sensor for *channel A*. Open a `Digits` display and set it to display *channel A*.
5. Place a *1.5-g* mass in the weight pan. This stretches the spring and the pan is below the height marker.
6. Gradually increase the output voltage in small increment (typically *0.1 V*) until the pan returns to the original position marked by the height marker. When this condition is met, the weight of the mass placed in the pan equals the magnetic force exerted on the coil. Record in Table 1 the mass and the current shown in the Digital Meter.
7. Repeat steps 5 and 6 for mass of *0.5*, *1*, *2*, *2.5*, *3*, *3.5*, *4*, *4.5*, and *5 g*. Record the corresponding mass and current values in Table 1.
8. Use ***Excel*** to plot *current (A)-versus-mass (kg)*. Fit the curve using linear fit and obtain the slope of the fitting. Print the graph and attach it to the lab report.

TABLE 1

Mass (g)	**Current (A)**
0.5	
1	
1.5	
2	
2.5	
3	
3.5	
4	
4.5	
5	

QUESTIONS

1. Is the *current-versus-mass* curve a straight line? Why?

2. Record the formula of the linear fit for the *current-versus-mass* curve. Identify the slope of the fit with proper units. Use the obtained slope and Equation (7) to calculate the magnitude of ***B***.