

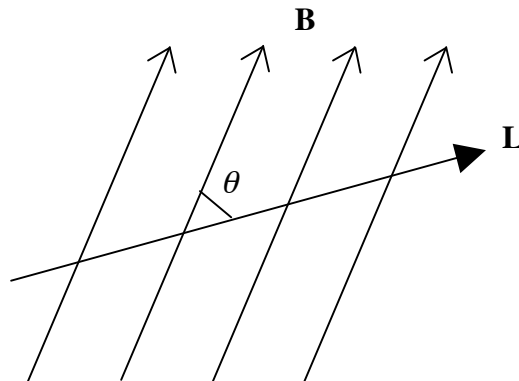
Experiment #8: Magnetic Forces

Purpose: To study the nature of magnetic forces exerted on currents.

Equipment: Magnet Assembly and Stand
Set of Current Loop PC Boards
Triple-Arm Pan Balance
0–15 V dc Variable Power Supply
Handheld Ammeter
Variable Power Resistor

Discussion:

Consider a current carrying wire, a certain straight length L of which lies in a region where there is a uniform magnetic field \mathbf{B} . Let's write \mathbf{L} as a vector whose direction is that of the current in the wire; the magnitude of this vector continues to be the length of the wire in the field. The figure below depicts an arbitrary orientation for both \mathbf{L} and \mathbf{B} , with an angle θ between them.



The force on this wire segment is given by

$$\mathbf{F} = I\mathbf{L} \times \mathbf{B} \quad (1)$$

where I is the current in the wire and “ \times ” denotes the vector (cross) product. The magnitude of this force is

$$F = ILB\sin\theta \quad (2)$$

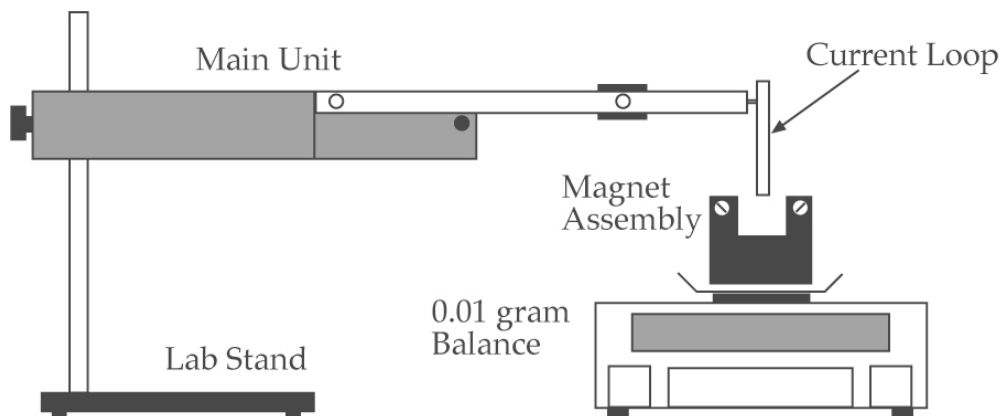
and the direction is perpendicular to both \mathbf{L} and \mathbf{B} , given by the right-hand rule as follows. Extend the fingers of your right hand so that they point along the vector \mathbf{L} . Now sweep your fingers in the direction of \mathbf{B} and while doing so, extend your thumb. Your thumb will then point in the direction of \mathbf{F} . In particular, if \mathbf{L} and \mathbf{B} are perpendicular to each other, then the magnitude of the force takes on its maximum value of

$$F = ILB. \quad (3)$$

We will verify Eq. (3) using a setup known as a current balance. It is shown in the first figure in the procedures section below. Note that in this geometry, the current and the magnetic field are both horizontal but perpendicular to one another. Hence the force on the current loop will be in the vertical direction. Whether it is downward or upward can easily be determined by the right-hand rule. Suppose the force on the current is upward. Then by Newton's third law, there is a downward force of equal magnitude on the magnet. This increases the apparent weight on the pan and by re-zeroing the balance, the magnetic force can be determined. We will measure this force for different currents, different magnetic field strengths, and different lengths of the current loop. Plotting force versus each of these variables in turn with the other two parameters held fixed should yield a straight line given by Eq. (3). From the slope, the strength of the magnetic field can be determined in each case and compared to each other.

Procedure:

1. Set up the apparatus shown in the figure below, using all 6 magnets with their poles aligned. Use the 8-cm current loop, but initially leave it flipped out of the magnet assembly.



2. Connect the power supply in series with a variable power resistor to the current loop through a handheld ammeter in the 10 A mode. Do not switch the power supply on yet. Slide the resistor contact in about a third of the distance from the connection end. Have your circuit checked by your lab instructor.
3. Center the magnet assembly on the pan of the balance so that the pan is level when it is "zeroed" by weighing it. Record this initial mass to the nearest hundredth of a gram.
4. Now flip down the current loop to suspend it between the horseshoe magnets. Adjust the vertical height using the appropriate knob on the stand and the horizontal position of the current loop until it lies neatly centered between the magnetic poles without touching them on their sides or bottom.
5. Turn on the power supply and slowly increase the current to 0.5 A, keeping the scale zeroed by increasing the balancing weights. If you find that the weight is decreasing rather than increasing, reverse the leads on the assembly to flip the current direction. Record the final apparent mass.

6. Repeat step 5, increasing the current in steps of 0.5 A up to a maximum of 4.0 A. This completes the first data set.
7. Turn off the power supply and return the scale to the initial balancing weights. Flip up the current loop and replace it with the 6-cm loop. Flip down the loop and check that it is still aligned. Now turn on the power supply and slowly increase the current to 2.0 A, keeping the scale zeroed by increasing the balancing weights. Record the final apparent mass.
8. Repeat step 7 for the 4-cm loop. This completes the second data set.
9. Turn off the power supply, flip up the current loop, and replace it with the original 8-cm loop. Flip over the second magnet from one end on the assembly (note that the black plastic retainer can be removed); this reduces the net magnetic field to 4 magnets, since 2 cancel each other out. Realign the balance and horizontal position of the stand; you should have the same initial mass as always. Now turn on the power supply and slowly increase the current to 2.0 A, keeping the scale zeroed by increasing the balancing weights. Record the final apparent mass. Clean up your workbench.
10. Repeat step 9 by flipping over the second magnet from the other end of the assembly, thus reducing the net magnetic field to 2 magnets. This completes the third data set. Shut off the power supply and ammeter. Do not leave the magnets misaligned, as this tends to depolarize them.

Analysis:

Type the three data sets into Excel in the format given below. In the Results section of your report, compare the values for the magnetic field per magnet obtained in the three experiments: How good is the agreement? What is the average value of the three and how does that compare to typical magnetic fields listed in your textbook? What are the major error sources in order of importance?

Magnetic Forces Lab

Initial mass M0 (g) <value: if it changed at all during the lab, use the average value>

First Experiment: Force vs. Current

Fixed wire length L	(m)	0.08	
Fixed net number of magnets N		6	
Current (A)	Apparent mass M (g)		Magnetic force (N)
0.5	<value>		=(M-\$M\$0)*9.8/1000

<here \$M\$0 means for example \$B\$4 if the value of M0 above is in cell B4>
 <duplicate the last line 7 more times, incrementing the current in 0.5-A steps up to 4.0 A>

<Now plot force vs current as a scatter plot without grid or line segments joining the points.

Label the axes and graph appropriately. Delete any background color or pattern. Fit a trendline, forcing it through the origin, and display the equation on the graph.>

Magnetic field per magnet (T) = $\text{linest}(\langle y \rangle, \langle x \rangle, 0)/L/N$
 (Here, $\langle y \rangle$ means highlight the force column of data and $\langle x \rangle$ means highlight the current column; the zero forces the fit through the origin.)

Second Experiment: Force vs. Wire length

Fixed current I	(A)	2.0	
Fixed net number of magnets N		6	
Wire length	Apparent mass M		Magnetic force
(m)	(g)		(N)
0.04	<value>		<copy formula from above>
0.06	<value>		<copy formula>
0.08	<value from the first experiment>		<copy formula>

<Now plot force vs wire length as a scatter plot without grid or line segments joining the points. Label the axes and graph appropriately. Delete any background color or pattern. Fit a trendline, forcing it through the origin, and display the equation on the graph.>

Magnetic field per magnet (T) = $\text{linest}(\langle y \rangle, \langle x \rangle, 0)/I/N$
 (Here, $\langle y \rangle$ means highlight the force column of data and $\langle x \rangle$ means highlight the wire length column.)

Third Experiment: Force vs. Net number of magnets

Fixed current I	(A)	2.0	
Fixed wire length L	(m)	0.08	
Net number of magnets	Apparent mass M		Magnetic force
	(g)		(N)
2	<value>		<copy formula>
4	<value>		<copy formula>
6	<value from the first experiment>		<copy formula>

<Now plot force vs net number of magnets as a scatter plot without grid or line segments joining the points. Label the axes and graph appropriately. Delete any background. Fit a trendline, forcing it through the origin, and display the equation on the graph.>

Magnetic field per magnet (T) = $\text{linest}(\langle y \rangle, \langle x \rangle, 0)/I/L$
 (Here, $\langle y \rangle$ means highlight the force column of data and $\langle x \rangle$ means highlight the net number of magnets column.)

Supplemental Problems:

1. A wire of 58.0-cm length and 14.0-g mass crosses a uniform magnetic field of 435 mT. Both the wire and the magnetic field lie in a horizontal plane, making an angle of 60.0° with respect to each other, as depicted in the figure on page 1 of this handout. What is the minimum current (in mA) in the wire required to magnetically levitate the wire, i.e., so that the magnetic force on the wire exactly balances its weight?

2. A metal wire of mass m slides frictionlessly on two horizontal rails spaced a distance d apart, as shown in the following figure. A uniform, vertical magnetic field \mathbf{B} points out of the page. A constant current I flows from the battery along the bottom rail, across the slide wire, and back to the battery along the top rail. Find the speed and direction of motion of the wire after a time t , assuming it starts from rest at $t = 0$. (Hint: Show that the acceleration of the wire is constant, and then use the appropriate equation of 1D kinematics.)

