Lab 8. Current Balance

Goals

- To explore and verify the right-hand rule governing the force on a current-carrying wire immersed in a magnetic field.
- To determine how the force on a current-carrying wire depends on its length, the strength of the magnetic field, and the magnitude of the current flowing in the wire, and to display the relationships graphically.

Introduction

Electric charges can experience a force when they move through a region of nonzero magnetic field. Stationary charges experience no force. Since currents are just electric charges in motion, current carrying wires can also experience forces when immersed in magnetic fields. The magnitude of the force F on a straight wire of length L carrying a current I in the presence of a uniform magnetic field of strength B is given by

$$F = ILB\sin\theta \tag{8.1}$$

where θ is the angle between the direction of positive current flow and the magnetic field. The direction of the resulting force is determined by applying the "right-hand rule" as shown in your textbook. In this experiment the angle *theta* between the wire and the magnetic field is always 90° so that $\sin\theta = 1$.

The purpose of this experiment is to measure the force on a current carrying wire in the presence of a magnetic field and to determine how this force depends on magnetic field strength, current, and wire length. You should also be able to apply the right hand rule to predict the direction of the force on a current carrying wire in a magnetic field.

Caution: The load limit for these electronic balances is 200 grams. Use appropriate care to ensure that this limit is not exceeded.

Force versus wire length

Equipment set up

1. Using all six of the small magnets, place the magnets and magnet holder on the electronic balance and tare the balance. The “red ends” of the small magnets are N poles. The “white ends” are S poles. It is a good idea to check the direction of the magnetic field just above the gap with a compass. Make certain that all the magnets are oriented with the same polarity so that the magnetic field is maximized.

2. Plug circuit sf37 into the ends of the shiny metal bars of the current balance apparatus mounted on the stand. (sf37 is the manufacturer’s designation and has no other purpose than to identify it.)

3. With the power supply off, connect the red and black jacks on the front of the power supply to the current balance apparatus using the holes provided on the tops of the metal bars of the apparatus.

4. Before turning on the power supply, adjust the “Coarse” voltage knob and the “Current” knob to their full counter-clockwise positions. Adjust the “Fine” voltage knob to the middle of its range, with the white mark pointing vertically upward. Set the current switch to the “Hi” position. In this position, the ammeter on the front of the power supply reads on the 0–3 A scale.

Analysis of forces on wire and balance

1. Draw a free-body diagram of the magnets and magnet holder in equilibrium on the balance with no current flowing through the circuit.

2. Draw another free-body diagram of the magnets and magnet holder in equilibrium when current is present in the wire that is between the poles of the magnet. You must apply the right-hand rule in conjunction with the magnetic force equation given earlier to determine the direction of the magnetic force on the wire. Make sure that your diagram and explanation are very clear here. Remember that, by convention, the magnetic field outside the magnet itself points from the N pole to the S pole. Also recall that current flows out of the red (+) terminal of the power supply and into the black (–) terminal.

3. On the basis of your free-body diagrams predict whether the electronic balance will read a positive value or a negative value.

Force measurements

1. Position the bottom of the U-shaped “wire” on sf37 so that it is centered between the poles of the magnet sitting on the electronic balance. Align sf37 carefully so that it is not touching the magnet holder anywhere. You may need to tare the balance again at this point before turning on the power supply.

2. Turn on the power supply and adjust the current knob clockwise until the ammeter reads 2 A. Check this from time to time during the rest of this exercise since the current sometimes can drift small amounts as the power supply warms up.

3. Compare and comment on the sign of the reading on the balance. If you didn't get it right the first time, go back and rethink it. Explain in your report how you went wrong and give a corrected explanation.

4. Record the balance readings for sf37, sf38, sf41, and sf42 keeping the current set at 2 A.

5. For sf42 only, reverse the direction of the current by switching the connections to the black and red terminals on the power supply. What happens to the reading given by the electronic balance? What did you expect to happen? Explain.

Data analysis

Convert all the balance readings from mass units to forces in newtons. For each of the circuits, sf37, sf38, sf41, and sf42, measure the effective length of the wire that was immersed in the magnetic field and produced a net force on the magnet. Plot the force on the magnet as a function of the length of the wire immersed in the magnetic field. If appropriate, fit a straight line to the data and calculate the magnetic field in tesla (T) for all six magnets. Refer back to the force law described above for help here.

Force versus strength of magnetic field

Equipment set up

1. Plug circuit sf41 into the ends of the current balance apparatus.

2. The manufacturer assures us that the magnetic field between the poles of the magnet is directly proportional to the number of small magnets used. You have already made a measurement with sf41 and six small magnets. Now remove one of the small magnets, leaving five. Center the five magnets relative to the magnet poles.

3. Align the wire of sf41 relative to the magnet poles as done previously.

Force measurements

1. Set the power supply current to 2 A.

2. Record the balance reading when current is passed through the wire. Be sure to tare the electronic balance appropriately.

3. Remove one magnet at a time and repeat the measurement. You should have six data points counting the one already done in Section 2.

Data analysis

Make a graph of the magnetic force as a function of the number of magnets. Based on your graph what can you say about the relationship between the force and the value of the magnetic field? If it is linear, find the slope of the graph and calculate the magnetic field of all six magnets again. Remember that the field of all six magnets is simply six times greater than the field of a single magnet.

Force versus current

Equipment set up

1. Replace all the magnets, making sure that all the red poles and white poles are aligned correctly.
2. Plug sf42 into the ends of the current balance apparatus.
3. Set the current from the power supply at 3 A.

Force measurements

1. Record the balance reading when current is passed through the wire between the poles of the magnet.
2. Lower the current to 2.5 A and repeat the measurement.
3. Continue reducing the current in 0.5 A increments until you reach 0.5 A. Record the balance reading in each case.

Data Analysis

Plot the magnetic force on sf42 as a function of the current. What can you say about the relationship between force and current? From this analysis you should be able to calculate the magnetic field with all the small magnets present. This calculated magnetic field should agree with the magnetic field value calculated from your measurements of force versus wire length and force versus magnetic field strength. Does it? Compare, discuss, and explain.

Conclusion

The fundamental magnetic force law for current carrying wires in magnetic fields given in the Introduction makes certain predictions about the dependence of the force on the current, wire length, and the magnetic field. Are your findings in harmony with the force law as formulated? Be very specific here and speak to the results of each set of measurements. If not in harmony, explain specifically in what way your results differ.

It is important to remember that the force law as formulated actually was induced from experiments like those you have done today. Thus the law as stated just characterizes how nature behaves; it doesn't prescribe beforehand how nature must behave. Nature behaves however she wishes, and we can only hope to characterize that behavior in simple ways from time to time. Of course, we often express these characterizations in mathematical terms, the shorthand of science.

Before you leave the lab please:

- Turn off the power to all the equipment.
- Disconnect the power supply.
- Make sure that all six of the small magnets are accounted for.
- Straighten up your lab station.
- Report any problems or suggest improvements to your TA.