

Lab 6. 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

$$F = ILB \sin \theta \quad (6.1)$$

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 θ 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 make sure 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 your measurement with sf41 during your study of force versus wire length.

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.

Grading Rubric

	No Effort	Progressing	Expectation	Exemplary
AA Is able to extract the information from representation correctly Labs: 1-12	No visible attempt is made to extract information from the experimental setup.	Information that is extracted contains errors such as labeling quantities incorrectly, mixing up initial and final states, choosing a wrong system, etc. Physical quantities have no subscripts (when those are needed).	Most of the information is extracted correctly, but not all of the information. For example physical quantities are represented with numbers and there are no units. Or directions are missing. Subscripts for physical quantities are either missing or inconsistent.	All necessary information has been extracted correctly, and written in a comprehensible way. Objects, systems, physical quantities, initial and final states, etc. are identified correctly and units are correct. Physical quantities have consistent and informative subscripts.
AB Is able to construct new representations from previous representations Labs: 1-12	No attempt is made to construct a different representation.	Representations are attempted, but omits or uses incorrect information (i.e. labels, variables) or the representation does not agree with the information used.	Representations are constructed with all given (or understood) information and contain no major flaws.	Representations are constructed with all given (or understood) information and offer deeper insight due to choices made in how to represent the information.
AC Is able to evaluate the consistency of different representations and modify them when necessary Labs: 3-8, 10-12	No representation is made to evaluate the consistency.	At least one representation is made but there are major discrepancies between the constructed representation and the given experimental setup. There is no attempt to explain consistency.	Representations created agree with each other but may have slight discrepancies with the given experimental representation. Or there is inadequate explanation of the consistency.	All representations, both created and given, are in agreement with each other and the explanations of the consistency are provided.
AF Sketch Labs: 1, 2, 4-7, 11	No representation is constructed.	Sketch is drawn but it is incomplete with no physical quantities labeled, or important information is missing, or it contains wrong information, or coordinate axes are missing.	Sketch has no incorrect information but has either a few missing labels of given quantities. Subscripts are missing or inconsistent. Majority of key items are drawn.	Sketch contains all key items with correct labeling of all physical quantities have consistent subscripts; axes are drawn and labeled correctly.

	No Effort	Progressing	Expectation	Exemplary
AG Mathematical Labs: 3, 6, 8, 10-12	No representation is constructed.	Mathematical representation lacks the algebraic part (the student plugged the numbers right away) has the wrong concepts being applied, signs are incorrect, or progression is unclear.	No error is found in the reasoning, however they may not have fully completed steps to solve problem or one needs effort to comprehend the progression.	Mathematical representation contains no errors and it is easy to see progression of the first step to the last step in solving the equation. The solver evaluated the mathematical representation with comparison to physical reality.
AI Graph Labs: 3, 6, 8, 12	No graph is present.	A graph is present but the axes are not labeled. There is no scale on the axes. The data points are connected.	The graph is present and axes are labeled but the axes do not correspond to the independent and dependent variable or the scale is not accurate. The data points are not connected but there is no trend-line.	The graph has correctly labeled axes, independent variable is along the horizontal axis and the scale is accurate. The trend-line is correct, with formula clearly indicated.
CA Is able to identify the hypothesis to be tested Labs: 4-6, 9	No mention is made of a hypothesis.	An attempt is made to identify the hypothesis to be tested but is described in a confusing manner.	The hypothesis to be tested is described but there are minor omissions or vague details.	The hypothesis is clearly stated.
CC Is able to make a reasonable prediction based on a hypothesis Labs: 4-6, 9	No prediction is made. The experiment is not treated as a testing experiment.	<ul style="list-style-type: none"> A prediction is made but it is identical to the hypothesis OR Prediction is made based on a source unrelated to hypothesis being tested OR is completely inconsistent with hypothesis being tested OR Prediction is unrelated to the context of the designed experiment. 	Prediction follows from hypothesis but is flawed because <ul style="list-style-type: none"> relevant experimental assumptions are not considered and/or prediction is incomplete or somewhat inconsistent with hypothesis and/or prediction is somewhat inconsistent with the experiment. 	A prediction is made that <ul style="list-style-type: none"> follows from hypothesis, is distinct from the hypothesis, accurately describes the expected outcome of the designed experiment, incorporates relevant assumptions if needed.
CD Is able to identify the assumptions made in making the prediction Labs: 4-6, 9	No attempt is made to identify any assumptions.	An attempt is made to identify assumptions, but the assumptions are irrelevant or are confused with the hypothesis.	Relevant assumptions are identified but are not properly evaluated for significance in making the prediction.	Sufficient assumptions are correctly identified, and are noted to indicate significance to the prediction that is made.

	No Effort	Progressing	Expectation	Exemplary
CE Is able to determine specifically the way in which assumptions might affect the prediction Labs: 4-6, 9	No attempt is made to determine the effects of assumptions.	The effects of assumptions are mentioned but are described vaguely.	The effects of assumptions are determined, but no attempt is made to validate them.	The effects of the assumptions are determined and the assumptions are validated.
CF Is able to decide whether the prediction and the outcome agree/disagree Labs: 4-6, 9	No mention of whether the prediction and outcome agree/disagree.	A decision about the agreement/disagreement is made but is not consistent with the outcome of the experiment.	A reasonable decision about the agreement/disagreement is made but experimental uncertainty is not properly taken into account.	A reasonable decision about the agreement/disagreement is made and experimental uncertainty is taken into account.
CG Is able to make a reasonable judgment about the hypothesis Labs: 4-6, 9	No judgment is made about the hypothesis.	A judgment is made but is not consistent with the outcome of the experiment.	A judgment is made, is consistent with the outcome of the experiment, but assumptions are not taken into account.	A judgment is made, consistent with the experimental outcome, and assumptions are taken into account.
GA Is able to identify sources of experimental uncertainty Labs: 4-6, 11	No attempt is made to identify experimental uncertainties.	An attempt is made to identify experimental uncertainties, but most are missing, described vaguely, or incorrect.	Most experimental uncertainties are correctly identified. But there is no distinction between random and experimental uncertainty.	All experimental uncertainties are correctly identified. There is a distinction between experimental uncertainty and random uncertainty.
GB Is able to evaluate specifically how identified experimental uncertainties may affect the data Labs: 1, 2, 5, 6, 11	No attempt is made to evaluate experimental uncertainties.	An attempt is made to evaluate experimental uncertainties, but most are missing, described vaguely, or incorrect. Or only absolute uncertainties are mentioned. Or the final result does not take the uncertainty into account.	The final result does take the identified uncertainties into account but is not correctly evaluated. The weakest link rule is not used or is used incorrectly.	The experimental uncertainty of the final result is correctly evaluated. The weakest link rule is used appropriately and the choice of the biggest source of uncertainty is justified.
GC Is able to describe how to minimize experimental uncertainty and actually do it Labs: 2, 5, 6, 11	No attempt is made to describe how to minimize experimental uncertainty and no attempt to minimize is present.	A description of how to minimize experimental uncertainty is present, but there is no attempt to actually minimize it.	An attempt is made to minimize the uncertainty in the final result is made but the method is not the most effective.	The uncertainty is minimized in an effective way.

	No Effort	Progressing	Expectation	Exemplary
GD Is able to record and represent data in a meaningful way Labs: 1-12	Data are either absent or incomprehensible.	Some important data are absent or incomprehensible. They are not organized in tables or the tables are not labeled properly.	All important data are present, but recorded in a way that requires some effort to comprehend. The tables are labeled but labels are confusing.	All important data are present, organized, and recorded clearly. The tables are labeled and placed in a logical order.
GE Is able to analyze data appropriately Labs: 1-12	No attempt is made to analyze the data.	An attempt is made to analyze the data, but it is either seriously flawed or inappropriate.	The analysis is appropriate but it contains minor errors or omissions.	The analysis is appropriate, complete, and correct.
IA Is able to conduct a unit analysis to test the self-consistency of an equation Labs: 2-6, 8-12	No meaningful attempt is made to identify the units of each quantity in an equation.	An attempt is made to identify the units of each quantity, but the student does not compare the units of each term to test for self-consistency of the equation.	An attempt is made to check the units of each term in the equation, but the student either mis-remembered a quantity's unit, and/or made an algebraic error in the analysis.	The student correctly conducts a unit analysis to test the self-consistency of the equation.

EXIT TICKET:

- ☐ Turn off the power to all the equipment.
- ☐ Disconnect the power supply.
- ☐ Make sure that all six of the small magnets are accounted for.
- ☐ Quit any software you have been using.
- ☐ Straighten up your lab station. Put all equipment where it was at start of lab.
- ☐ Report any problems or suggest improvements to your TA.
- ☐ Have TA validate Exit Ticket Complete.