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

$$F = ILB\sin\theta \tag{6.1}$$

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.

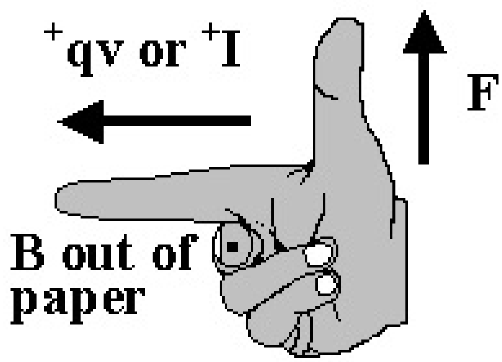
Caution: The load limit for these electronic balances is 200 grams. Use appropriate care to make sure that this limit is not exceeded.

Right Hand Rule

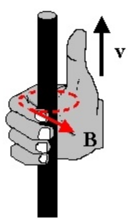
For the right hand rule, it is vital to use the appropriate hand. Or to remember that your result is reversed if you must use your left. There are two versions of the right hand rule which are useful in electromagnetic interactions. (Descriptions and images via Buffalo State)

Right Hand Rule 1

Right-Hand Rule 1 determines the directions of magnetic force, conventional current and the magnetic field. Given any two of these, the third can be found.
Using your right-hand: point your index finger in the direction of the charge's velocity, v, (recall conventional current).
Point your middle finger in the direction of the magnetic field, B.
Your thumb now points in the direction of the magnetic force, $F_{m}agnetic$.



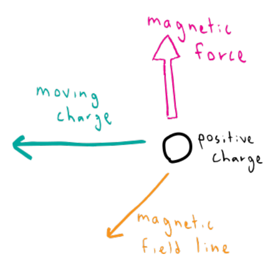
You can change which vector is represented by each finger, so long as you keep them in the same order (So it can be F->I->B, or I->B->F, or B->F->I).



Right Hand Rule 2

Right-Hand Rule 2 determines the direction of the magnetic field around a current-carrying wire and vice-versa.
Using your right hand: Curl your fingers into a half-circle around the wire, they point in the direction of the magnetic field, **B**.
Point your thumb in the direction of the conventional current.

Application this week



For each charge flowing through your wire, the Right Hand Rule applies as shown (Image via Khan Academy)

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.
    - If your power supply does not have a digital display: 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.

	No Effort	Progressing	Expectation	Scientific
SL.A.b Is able to identify the hypothesis for the experiment proposed Labs: 4-6, 9	No deliberately identified hypothesis is present in the first half page or so of notes	An attempt is made to state a hypothesis, but no clearly defined dependent and independent variable, or lacking a statement of relationship between the two variables	A statement is made as a hypothesis, it contains a dependent and independent variable along with a statement of relationship between the two variables. This statement appears to be testable, but there are some minor omissions or vague details.	The hypothesis is clearly stated and the direct link to the experiment at hand is apparent to any reasonably informed reader.

	No Effort	Progressing	Expectation	Scientific
SL.A.c Is able to determine hypothesis validity Labs: 4-6, 9	No deliberately identified attempt to use experimental results to validate hypothesis is present in the sections following data collection.	A statement about the hypothesis validity is made, but it is not consistent with the data analysis completed in the experiment	A statement about the hypothesis validity is made which is consistent with the data analysis completed in the experiment. Assumptions which informed the hypothesis and assumptions not validated during experimentation are not taken into account.	A statement about the hypothesis validity is made which is consistent with the data analysis and all assumptions are taken into account.
SL.B.c Is able to explain steps taken to minimize uncertainties and demonstrate understanding through performance where able. Labs: 2, 6	No explicitly identified attempt to minimize uncertainties and no attempt to describe how to minimize uncertainties present	No explicitly identified attempt to minimize uncertainties is present, but there is a description of how to minimize experimental uncertainty.	An attempt is made and explicitly identified for minimizing uncertainty in the final lab results, but the method is not the most effective.	The uncertainties are minimized in an effective way.
CT.A.a Is able to compare recorded information and sketches with reality of experiment Labs: 3, 4, 6, 7	No sketches present and no descriptive text to explain what was observed in experiment	Sketch or descriptive text is present to inform reader what was observed in the experiment, but there is no attempt to explain what details of the experiment are not accurately delivered through either representation.	Sketch and descriptive text are both present. The sketch and description supplement one another to attempt to make up for the failures of each to convey all observations from the experiment. There are minor inconsistencies between the two representations and the known reality of the experiment from the week, but no major details are absent.	Sketch and description address the shortcomings of one another to convey an accurate and detailed record of experimental observations adequate to permit a reader to place all data in context.
CT.A.b Is able to identify assumptions used to make predictions Labs: 4-6, 9	No attempt is made to identify any assumptions necessary for making predictions	An attempt is made to identify assumptions, but the assumptions stated are irrelevant to the specific predicted values or apply to the broader hypothesis instead of the specific prediction	Relevant assumptions are identified regarding the specific predictions, 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	Scientific
CT.A.c Is able to make predictions for each trial during experiment Labs: 4-6, 9	Multiple experimental trials lack predictions specific to those individual trial runs.	Predictions made are too general and could be taken to apply to more than one trial run. OR Predictions are made without connection to the hypothesis identified for the experiment. OR Predictions are made in a manner inconsistent with the hypothesis being tested. OR Prediction is unrelated to the context of the experiment.	Predictions follow from hypothesis, but are flawed because relevant experimental assumptions are not considered and/or prediction is incomplete or somewhat inconsistent with hypothesis or experiment.	A prediction is made for each trial set in the experiment which follows from the hypothesis but is hyper-specific to the individual trial runs. The prediction accurately describes the expected outcome of the experiment and incorporates relevant assumptions.
CT.A.d "Is able to identify sources of uncertainty " Labs: 4, 6 No attempt is made to identify experimental uncertainties.	descworst	An attempt is made to identify experimental uncertainties, but many sources of uncertainty are not addressed, 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.
QR.A Is able to perform algebraic steps in mathematical work. Labs: 3, 6, 8, 10-12	No equations are presented in algebraic form with known values isolated on the right and unknown values on the left.	Some equations are recorded in algebraic form, but not all equations needed for the experiment.	All the required equations for the experiment are written in algebraic form with unknown values on the left and known values on the right. Some algebraic manipulation is not recorded, but most is.	All equations required for the experiment are presented in standard form and full steps are shown to derive final form with unknown values on the left and known values on the right. Substitutions are made to place all unknown values in terms of measured values and constants.
QR.C Is able to analyze data appropriately Labs: 1-4, 6-12	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 for the data gathered, but contains minor errors or omissions	The analysis is appropriate, complete, and correct.
IL.A Is able to record data and observations from the experiment Labs: 1-12	"Some data required for the lab is not present at all, or cannot be found easily due to poor organization of notes. "	"Data recorded contains errors such as labeling quantities incorrectly, mixing up initial and final states, units are not mentioned, etc. "	Most of the data is recorded, but not all of it. For example measurements are recorded as numbers without units. Or data is not assigned an identifying variable for ease of reference.	All necessary data has been recorded throughout the the lab and recorded in a comprehensible way. Initial and final states are identified correctly. Units are indicated throughout the recording of data. All quantities are identified with standard variable identification and identifying subscripts where needed.

	No Effort	Progressing	Expectation	Scientific
WC.A Is able to create a sketch of important experimental setups Labs: 1, 2, 4-7	No sketch 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, or subscripts are missing/inconsistent. Majority of key items are drawn with indication of important measurements/locations.	Sketch contains all key items with correct labeling of all physical quantities and has consistent subscripts. Axes are drawn and labeled correctly. Further drawings are made where needed to indicate precise details not possible in the scale of initial sketch.
WC.B Is able to draw a graph Labs: 3, 6, 8, 12	No graph is present.	A graph is present, but the axes are not labeled. OR there is no scale on the axes. OR the data points are connected.	"A graph is present and the axes are labeled, but the axes do not correspond to the independent (X-axis) and dependent (Y-axis) variables 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.

Print this page. Tear in half. Each lab partner should submit their half along with the lab report and then retain until the end of semester when returned with evaluations indicated by TA.

Lab 6 Current Balance:

Name: ______________________ Lab Partner: ______________________

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.
- ☐ Return all circuits to the box.
- ☐ Quit any software you have been using.
- ☐ Straighten up your lab station. Put all equipment where it was at start of lab.
- ☐ Required Level of Effort.
  - ☐ Complete the pre-lab assignment
  - ☐ Arrive on time
  - ☐ Work well with your partner
  - ☐ Complete the lab or run out of time

SL.A.b		CT.A.b		QR.C	
SL.A.c		CT.A.c		IL.A	
SL.B.c		CT.A.d		WC.A	
CT.A.a		QR.A		WC.B	

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SL.A.b		CT.A.b		QR.C	
SL.A.c		CT.A.c		IL.A	
SL.B.c		CT.A.d		WC.A	
CT.A.a		QR.A		WC.B	