LABORATORY VI
MAGNETIC FIELDS AND FORCES

Magnetism plays a large role in our world's modern technology. Some uses of magnets today are imaging parts of the body, exploring the mysteries of the human brain, and storing information in computers. Magnetism also allows us to explore the structure of the universe, the atomic structure of materials, and the quark structure of elementary particles.

Magnetic interactions can best be described using the concept of a field. For this reason, your experiences exploring the electric field concept in the first lab are also applicable in this lab dealing with magnets. There are similar activities in both labs so you can experience the universality of the field concept. Although the magnetic force is related to the electric force, the two are not the same. You should watch for the differences as you go through the problems in this lab.

In this set of laboratory problems, you will map magnetic fields from different sources and will use the magnetic force to deflect electrons.

OBJECTIVES:

After successfully completing this laboratory, you should be able to:

- Explain the differences and similarities between magnetic fields and electric fields;
- Describe the pattern of magnetic fields near various sources, such as permanent "bar" magnets, straight current-carrying wires, and coils of wire;
- Calculate the magnetic force on a charged particle moving in a uniform magnetic field and describe its motion.

PREPARATION:

Before coming to lab you should be able to:

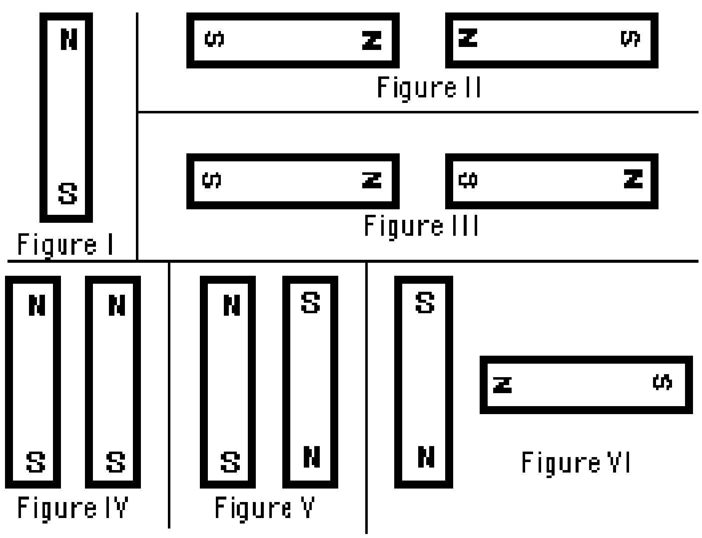
- Add fields using vector properties.
- Calculate the motion of a particle with a constant acceleration.
- Calculate the motion of a particle with an acceleration of constant magnitude perpendicular to its velocity.
- Write down the magnetic force on an object in terms of its charge, velocity, and the magnetic field through which it is passing.

PROBLEM #1:
PERMANENT MAGNETS

You have a job working a company that designs magnetic resonance imaging (MRI) machines. The ability to get a clear image of the inside of the body depends on having precisely the correct magnetic field at each that position. In a new model of the machine, the magnetic fields are produced by configurations of permanent magnets. You need to know the pattern of the magnetic field from each magnet and how to combine magnets to change that pattern.

EQUIPMENT

You will have two permanent magnets and a clear plate filled with small pieces of Taconite (an iron rich ore) immersed in a viscous liquid. When a magnet is placed on top of one of these plates, the Taconite pieces align themselves with the magnetic field. You will also have a compass. Some possible magnet configurations are as follows:



PREDICTION

Sketch a map of the magnetic field for each magnet configuration in the figures above. Assume that the different magnet configurations in each figure do not interact with the magnets in the other figures.

WARM-UP

Read Serway & Vuille, Chapter 19, Section 19.1 (or Cutnell & Johnson 20.1)

Before you start, you should review the Warm-up questions for Problem #1 in the Laboratory on Electrical Fields and Forces.

1. Make a sketch of all magnet configurations shown. Be sure to label the poles of the magnets.

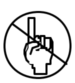
2. Choose a point near the pole of a magnet. At that point draw a vector representing the magnetic field. The length of the vector should give an indication of the strength of the field. Move a short distance away in the direction of the vector and choose another point. At that point draw another magnetic field vector. Continue this process until you reach another magnetic pole. Choose another point near a pole and start the process again. Continue until you can see the pattern of the magnetic field for all parts of the configuration. Remember:

-The field can have only one value and direction at any point.

-The direction of the magnetic field is from the north pole to the south pole.

-The field at a point is the vector sum of the fields from all sources.

EXPLORATION



WARNING: The viscous liquid (glycerin) in the Taconite plate may cause skin irritation. **If a plate is leaking, please notify your lab instructor immediately.**

Check to make sure your plate is not leaking. Gently shake the plate until the Taconite is distributed uniformly. Properties of magnets can change with handling. Check the poles of the magnet with your compass. Inform your lab instructor if the magnet does not seem to behave as you would expect.

Place a permanent magnet on the plate. How long do you need to wait to see the effect of the magnetic field? Is it what you expected? Try some small vibrations of the Taconite plate. Try different configurations of magnets and determine how to get the clearest pattern in the Taconite.

What influence does the field have on the Taconite pieces? Does the field cause a net force? What did you observe to show that? Does the field cause a net torque? What did you observe that shows that? What can you do to show that the poles of a magnet are not electric charges? Try it.

MEASUREMENT AND ANALYSIS

Lay one bar magnet on the plate. In your journal, draw the shape of the magnetic field produced. Repeat for each figure in the predictions.

CONCLUSION

How did your predictions of the magnetic field pattern for each configuration of magnets compare with your results?

PROBLEM #2:
CURRENT CARRYING WIRE

Your friend's parents live on a dairy farm where high-voltage power lines cross the property. They are concerned about the effect that the magnetic field from the power lines might have on the health of their dairy cows grazing nearby. They bought a device to measure the magnetic field. The instructions for the device state that it must be oriented perpendicular to the magnetic field. To measure the magnetic field correctly, they need to know its shape near a current carrying wire. They know you have taken physics, so they ask you for help. You decide to check your prediction about the pattern of the field with a magnetic compass *before* you make the trip to your friend's farm.

EQUIPMENT

You will have a magnetic compass, a length of wire, a meter stick, a power supply, and the EM Field computer application.

PREDICTIONS

Sketch your best guess of the pattern of the magnetic field near a current carrying wire when the wire is (a) stretched straight, and (b) formed into a loop.

Read Serway & Vuille, Chapter 19, Sections 19.1, 19.2, 19.6 and 19.8 (or Cutnell & Johnson 21.7)

EXPLORATION

To open the EM Field application, just double click on the EM Field icon on your lab computer desktop. Click anywhere for instructions.

To study magnetic fields of current carrying wires, you will want to choose the *2D Line Currents* option in the *Sources* menu. At the bottom of the window, there will be a list of various line currents of different magnitudes. Choose one by clicking and dragging it into the screen. Under the *Field and Potential* menu, you should choose the *Field Vector* option. This option for magnetic fields behaves exactly like that for electric fields. Hence, it is useful to review the EM Field instructions from labs 1 and 2. Once you have a clear picture of what the direction of the field is, print it out using the *Print* command under *File*. You might also find it useful to play around with different sizes of current to note any changes.

Once you are finished with EM Field, it is time to move to the physical apparatus. Keep in mind that a compass needle, because it is a small magnet, aligns itself parallel to the local magnet field.

Attach several wires together to give a total length of at least a meter. Stretch the wire vertically and move your compass around the wire. Is there any evidence of a magnetic field from a wire with no current? Does the compass always point in the same direction?

WARNING: You will be working with a power supply that can generate large electric currents. Improper use can cause painful burns. **To avoid danger, the power should be turned OFF and you should WAIT at least one minute before any wires are disconnected from or connected to the power supply. NEVER GRASP A WIRE BY ITS METAL ENDS!**

Connect the wire across the 5V terminals of the power supply and turn the power supply on. The circuit breaker built into the power supply minimizes the hazard of this short circuit.

Stretch the wire vertically and move your compass around the wire. Start where you expect the magnetic field to be largest. Is there any evidence of a magnetic field from a current carrying wire? Watch the compass as you turn the current on and off. Does the compass always point in the same direction? How far from the wire can the compass be and still show a deflection? Develop a measurement plan.

Now make a single loop in the wire large enough to easily move the compass through. Move the compass around the loop. How far away from the loop can you see a deflection? Is this distance larger along the axis of the loop or somewhere else?

MEASUREMENT

Use your measurement plan to create a map of the magnetic field around the stretched wire and the looped wire.

ANALYSIS

The direction of the magnetic field around a current carrying wire can be found by using the "right-hand rule" described in your text. How does the "right-hand rule" compare to your measurements?

CONCLUSION

How did your predictions of the map of the magnetic field near current-carrying wires compare with both physical and simulated results? How do they compare with the "right-hand rule"?

PROBLEM #3:
THE MAGNETIC FIELD FROM A CURRENT CARRYING WIRE

You are working for a car company designing electronics for next year's models. A source of concern is interference from the magnetic fields from the power lines that so often run parallel to roads. You have been assigned to find out the how the size of these magnetic fields vary with the distance the car is from the power lines so they can determine if their new technology will work. You decide to model the situation to test your measurement technique before going out in the field.

EQUIPMENT

You will have a Hall probe (see *Appendix A*), a computer data acquisition system (HallPROBE2+, see *Appendix E*), a length of wire, and a 18V5A power supply.

PREDICTIONS

Calculate the size of the magnetic field as it depends on the distance from the center of the wire and the electric current running through the wire

Use this expression to graph the magnetic field strength as a function of position.

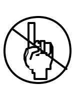
WARM-UP

Read Serway & Vuille, Chapter 19, Sections 19.1, 19.2, 19.6 and 19.8 (or Cutnell & Johnson 21.7)

Draw a picture of a long wire with current running through it. On your drawing choose any place some distance from the wire and away from its ends. Draw all of the other points that have the same size magnetic field as your original point. Explain how you chose these points.

Give a relationship between the current through a wire and the magnetic field at each point in space. Explain all of the quantities in that equation in terms of your drawing. Under what conditions is this equation true? Under what conditions is this equation useful?

EXPLORATION



WARNING: You will be working with a power supply that can generate large electric currents. Improper use can cause painful burns. **To avoid danger, the power should be turned OFF and you should WAIT at least one minute before any wires are disconnected from or connected to the power supply. NEVER GRASP A WIRE BY ITS METAL ENDS!**

To put current through your wire you will need a circuit. Draw this circuit and explain how different parts of the circuit will affect your measurement. How can you minimize this effect so your situation is most like a long straight wire?

Choose a current setting on your power supply so that its maximum current goes through your wire. WARNING; Make sure that the maximum current is around 5 amps, if it is significantly higher (by one or more amps) it may damage equipment and increases the risk of shock and injury.

Set up your circuit so that the magnetic field in some region of space most closely approximates that of a long straight wire with current running through it. Put your Hall probe some distance from the wire and measure the magnetic field. **Don't forget to calibrate the probe first!** What orientation does the Hall probe have to be in to measure the size of the magnetic field at that point? Keeping the position the same, change the orientation of the probe and see where the measured magnetic field is largest. When is it the smallest? Do those agree with what you thought? Leave the Hall probe in the same position and lower the current. What happens to the size of the magnetic field? Is that what you expected? Note what happens when you move the probe away from the wire. How far away from the wire can you still measure the magnetic field?

Now move the Hall probe slowly along a path that you have determined has the same size of magnetic field. Does it? How will you orient the probe on the path? Try a path closer to the wire. Try one further away.

Now keep the Hall probe in one place and change the shape of the circuit. How does that affect the magnetic field? Is it what you expected?

Create a measurement plan using information collected above.

MEASUREMENT

Use your measurement plan to measure how the size of the magnetic field depends on the distance from a long current carrying wire. Use the smallest distances possible while still remaining accurate. The more data points you have the more recognizable your graph's pattern will be. If you move the probe away too quickly you will end up with a flat line.

ANALYSIS

Make a graph of your measurements and compare them to your predictions.

CONCLUSION

How did your prediction of the magnitude of the magnetic field caused by a current-carrying wire compare with your measurements? In what situation is the method you used to calculate the magnetic field from a current not useful even though it is still correct?

PROBLEM #4:
MAGNETS AND MOVING CHARGE

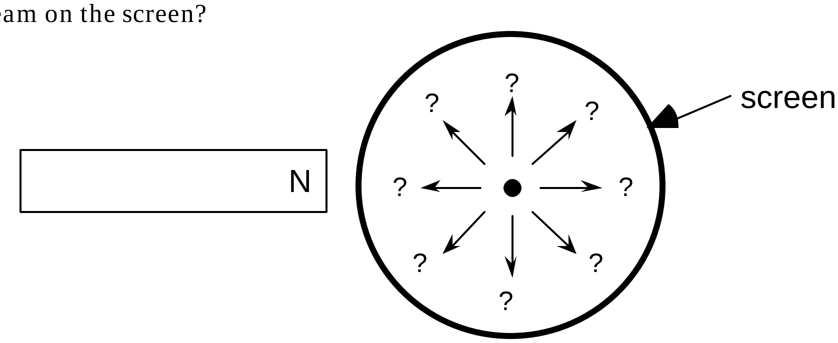
You are leading a technical team at a company that is redesigning the cathode ray tubes (CRTs) used for computer monitors. To introduce this project to a group of stockholders, you need to demonstrate how an electron beam can be moved across a screen by a magnetic field. You decide to use an ordinary bar magnet held outside of the CRT to deflect the electrons. Before you do the demonstration, you should determine the qualitative effect of bringing a bar magnet up to a CRT.

EQUIPMENT

For this problem you will need a cathode ray tube (CRT) , several banana cables, a Cenco power supply, a bar magnet, and a compass. Review the information from Laboratory 4 and *Appendix A* regarding the design of the CRT and the proper way to use it.

PREDICTION

If you bring the north end of a magnet near the side of the CRT, which arrow represents the deflection of the electron beam on the screen?



Does the size of the deflection increase or decrease, as the magnet gets closer to the CRT? Does the size of the deflection increase or decrease, as you increase the size of the magnetic field? Does the size of the deflection depend on the speed of the electrons? Explain your reasoning.

Read Serway & Vuille, Chapter 19, Sections 19.1, 19.2, and 19.5. Review Chapter 3, Section 3.4 to refresh your knowledge of projectile motion. (or Cutnell & Johnson 21.2, 21.3, and Chapter 3)

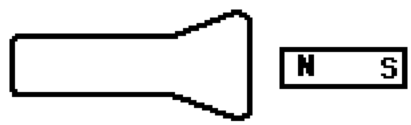
EXPLORATION

WARNING: You will be working with equipment that generates large electric voltages. Improper use can cause painful burns. **To avoid danger, the power should be turned OFF and you should WAIT at least one minute before any wires are disconnected from or connected to the power supply. NEVER GRASP A WIRE BY ITS METAL ENDS!**

Connect the CRT according to the directions in *Appendix A* and your lab journal from Lab 4. Select the accelerating voltage that gave the largest deflection for the smallest electric field based on your explorations from Lab I. Record the location of the undeflected beam spot.

Determine which pole on your bar magnet is the north magnetic pole. Describe the magnetic field at the end of the magnet? Place the magnet near the side of the CRT. Did the deflection match your prediction? Why or why not? Repeat this procedure for the south pole. Should there be any difference? In what direction did the beam deflect?

If you placed the bar magnet perpendicular to the screen of the CRT, should you see a deflection? Try this experiment with both poles of the magnet. Record your results. Were they what you expected?



Can you orient the bar magnet so that it attracts or repels the electron beam?

Place the north pole of your magnet a fixed distance away from the side of the CRT near the screen. Record the deflection. Increase the speed of the electrons by increasing the accelerating voltage as much as possible. Calculate the increase in speed. How does deflection change? Try this with both poles of the magnet. Record your results. Were your results what you anticipated?

Place the north pole of your magnet a fixed distance away from the side of the CRT near the screen. Record the deflection. Increase the magnetic field adding more magnets. How does deflection change? Try this with both poles of the magnet. Record your results. Were your results what you anticipated?

What effect does the Earth's magnetic field have on the electron beam of a CRT? What is the direction of the Earth's magnetic field in your laboratory room? Arrange the CRT to see the maximum effect. Do the same for the minimum effect. What is the effect of the Earth's magnetic field on the electron beam relative to the Earth's gravitational field? How did this affect your results from Lab 4, Problem #3?

Devise your own exploration of the CRT with the bar magnets. What variables can you control with the magnets and the CRT? Record your questions that will guide your exploration and check it with your lab instructor for safety before starting.

ANALYSIS

Draw a picture showing the directions of the three vectors representing the velocity of the electron, the magnetic field, and the force on the electron that is consistent with your results.

CONCLUSION

Did the electron beam deflection in the presence of a magnetic field agree with your prediction? Why or why not? What was the most interesting thing you learned from this exploration?

☑ CHECK YOUR UNDERSTANDING

1. For each of the configurations of magnets below, sketch the magnetic field map. Assume that the figures do not interact with each other.

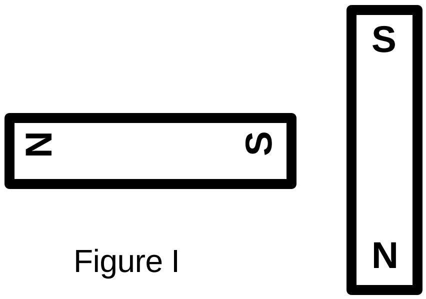


Figure I

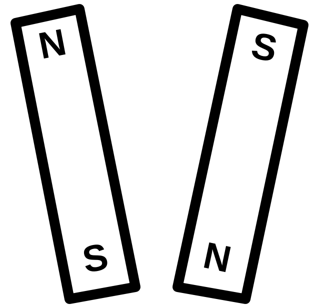


Figure III

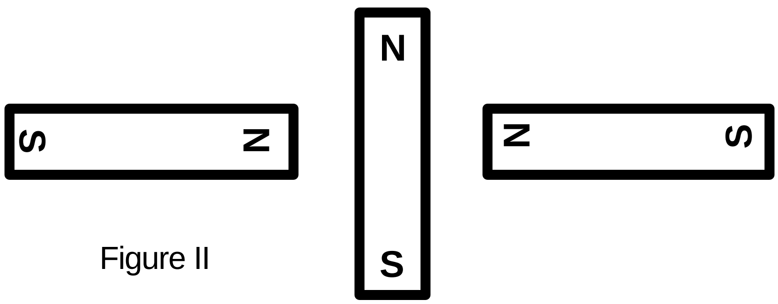


Figure II

2. You and your friends are flipping through the cable channels on the TV when you come across an old Godzilla movie. In one poorly dubbed scene, a scientist broke a magnet in half because he needed a monopole for his experiment. You cringe and start laughing, but your friends don't understand what you found so funny. Explain it to your friends.

3. Two parallel wires have an equal current flowing through them in the same direction. What is the direction of the magnetic field half way between them? How does the size of this field compare to that of a single wire? What would happen to the magnetic field at that point if one of the currents were reversed?

TA Name:____________________________

PHYSICS 1102 LABORATORY REPORT

Laboratory VI

Name and ID#: ____

Date performed: ______________ Day/Time section meets: ________________________

Lab Partners' Names: ____

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Problem # and Title: ____

Lab Instructor's Initials: __________

Grading Checklist	Points
LABORATORY JOURNAL:	
PREDICTIONS (individual predictions and warm-up completed in journal before each lab session)	
LAB PROCEDURE (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
PROBLEM REPORT:*	
ORGANIZATION (clear and readable; logical progression from problem statement through conclusions; pictures provided where necessary; correct grammar and spelling; section headings provided; physics stated correctly)	
DATA AND DATA TABLES (clear and readable; units and assigned uncertainties clearly stated)	
RESULTS (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
CONCLUSIONS (comparison to prediction & theory discussed with physics stated correctly ; possible sources of uncertainties identified; attention called to experimental problems)	
TOTAL(incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
BONUS POINTS FOR TEAMWORK (as specified by course policy)	

* An "R" in the points column means to rewrite that section only and return it to your lab instructor within two days of the return of the report to you.