LABORATORY V
MAGNETIC FIELDS AND FORCES

Magnetism plays a large part in our modern world's technology. Magnets are used today to image parts of the body, to explore the mysteries of the human brain, and to store data for computers. Magnetism also allows us to explore the structure of the Universe, the atomic structure of materials, and the quark structure of elementary particles.

The magnetic interaction can best be described using the concept of a field. For this reason, your experiences exploring the electric field concept are also applicable in this lab. There are similar activities in both labs; so you can experience the universality of the field concept. Although they are related, the magnetic force is not the same as the electric force. 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 use the magnetic force to deflect electrons. The activities are very similar to the first lab of this semester dealing with electric fields and forces.

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:

Read Serway & Jewett: Chapter 22, sections 1-4. Review your notes from Lab III (Electric Field and Potential).

Before coming to lab you should be able to:

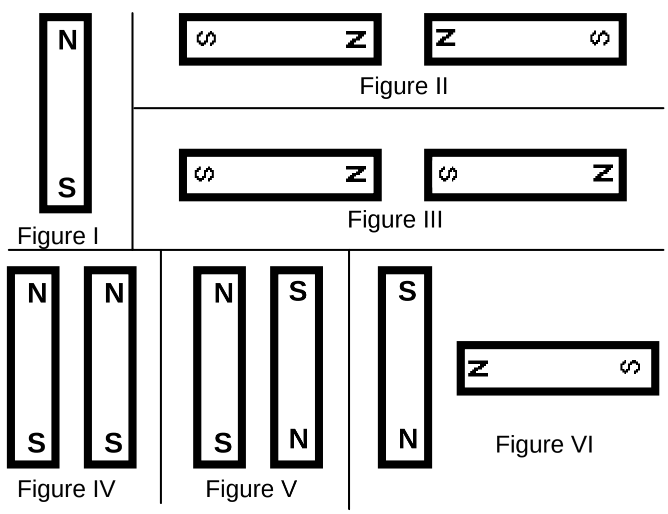
- Add fields using vector properties.
- Use the vector cross product.
- Calculate the motion of a particle with a constant acceleration.
- Calculate the motion of a particle with an acceleration of constant magnitude perpendicular to its velocity.
- Write down the magnetic force on an object in terms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

PROBLEM #1:
PERMANENT MAGENTS

You have a job working with 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 that position. In a new model of the machine, the magnetic fields are produced by configurations of permanent magnets. You need to know the map of the magnetic field from each magnet and how to combine magnets to change the magnetic field at any point. You must determine the map of the magnetic field created by each of the distributions of permanent magnets shown below.

EQUIPMENT

You will have two permanent magnets and a clear plate filled with a viscous liquid along with small pieces of Taconite, an iron-rich ore found in northern Minnesota. 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. The magnet configurations you need to consider 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 & Jewett: sections 22.1, 22.2.

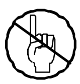
1. Make a sketch of all the magnets in each figure. Be sure to label the poles of the magnets.

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. Keep in mind that:

- The field can have only one value and direction at any point.
- The direction of the magnetic field points away from a North pole, and towards a South pole.
- The field at a point is the vector sum of the fields from all sources.

3. 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.

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 Taconite plate is not leaking. Gently shake the plate until the Taconite is distributed uniformly (the transparent bar inside the plate will help redistribute the flecks when moved).

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 behave as you would expect.

Place a permanent magnet on the Taconite plate. If the flecks are difficult to see, put a piece of white paper behind the plate. How long must you wait to see the effect of the magnetic field? Is it what you expected? Try some small vibrations of the Taconite plate. How does the pattern in the Taconite relate to the direction that a compass needle points when it is directly on top of the Taconite sheet?

Try different configurations of magnets and determine how to get the clearest pattern in the Taconite. 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 Taconite plate. In your journal, draw the pattern of the magnetic field produced. Repeat for each figure in the predictions.

CONCLUSION

How did your predictions of the shape of the magnetic field for each configuration of magnets compare with your results? What influence does the field have on the Taconite filings? Does the field cause a net force? Does the field cause a net torque? If so, in what direction?

PROBLEM #2:
CURRENT CARRYING WIRE

Your friend's parents, who run an organic dairy farm, have high-voltage power lines across their property. They are concerned about the effect that the magnetic field from the power lines might have on the health of their dairy cows. 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 direction at points near a current carrying wire. They know you have taken physics, so they ask you for help. First, you decide to check a simulation of the magnetic field of a current carrying wire. Next, to confirm your prediction and simulation, you decide to use a compass along with a current carrying wire to determine the map of the magnetic field caused by the current carrying wire.

EQUIPMENT

You will have a magnetic compass, a length of wire, a meter stick, a power supply, and the EMField application. Make sure to use the correct power supply – **do not** use the Cenco CRT power supplies!

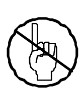
PREDICTIONS

Read Serway & Jewett: sections 22.1, 22.2, 22.7. Sketch your best guess of the map of the magnetic field near a current carrying wire when the wire is (a) stretched straight, and (b) formed into a loop.

EXPLORATION

To open the EMField application, just click on the EMField icon on your 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 EMField 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 EMField, 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 enough wires together to give a total length of at least half a meter. Is there any evidence of a magnetic field from a non current-carrying wire? To check this, stretch the wire vertically and move your compass around the center of the wire. Does the compass always point in the same direction?



WARNING: You will be working with a power supply that can generate 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 wire to the power supply and turn the power supply on (**do not use the Cenco CRT power source**). 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 through which you can easily move the compass. Move the compass around the loop. In which direction is the compass pointing? How far away from the loop can you see a deflection? Is this distance larger along the axis of the loop or somewhere else?
Set up your Hall probe as explained in Appendices D and E. Before you push any buttons on the computer, locate the magnetic field strength window. You will notice that even when the probe is held away from obvious sources of magnetic fields, such as your bar magnets, you see a non-zero reading. From its behavior determine if this is caused by a real magnetic field or is an electronics artifact or both? If you notice an ambient field, can you determine its cause?

Go through the Hall probe calibration procedure outlined in *Appendix E*. Be sure the sensor amplification switch on the Hall probe is set to the correct range. **The Hall Probe application detects the setting of the probe when started, in order to switch settings you must restart Hall Probe.** Why do you rotate the probe 180 degrees for the calibration process? Does the Hall probe ever read a zero field?

Hold the Hall probe next to the wire; how can you use the information from your compass to decide how to orient the probe? Read the value displayed by the Hall probe program. What will happen when you move the probe further from the wire? Will you have to change the orientation of the probe? How will you measure the distance of the probe from the wire?

MEASUREMENT

Use your measurement plan to create a map of the magnetic field around the stretched wire and the looped wire. Include the magnitude and direction of the magnetic field for each distance.

ANALYSIS

The direction of the magnetic field at a point near a current-carrying wire can be found by using the "right-hand rule" that is 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:
MEASURING THE MAGNETIC FIELD OF PERMANENT MAGENTS

Still working on retainer for your friend's parents, the organic dairy farmers, you are now ready to measure the magnetic field near high-voltage power lines. Before making this measurement, you decide to practice by using your Hall probe on a bar magnet. Since you already know the map of the magnetic field of a bar magnet, you decide to use the Hall probe to determine how the magnitude of the magnetic field varies as you move away from the magnet along each of its axes. While thinking about this measurement you wonder if a bar magnet's magnetic field might be the result of the sum of the magnetic field of each pole. Although, to date, no isolated magnetic monopoles have ever been discovered, you wonder if you can model the situation as two magnetic monopoles, one at each end of the magnet. Is it possible that the magnetic field from a single magnetic pole, a monopole, if they exist, has the same behavior as the electric field from a point charge? You decide to check it out by studying how the magnitude of the magnetic field from a bar magnet along each of its axes depends on the distance from the magnet. Is the behavior of the magnetic fields with respect to the distance from a magnetic pole similar to the behavior of an electric field with respect to the distance from a point charge?

EQUIPMENT

You will have a bar magnet, a meter stick, a Hall probe (see *Appendix D*), and a computer data acquisition system (see *Appendix E*). You will also have a Taconite plate and a compass.

PREDICTION

Calculate the magnetic field strength as a function of distance along each axis of a bar magnet. Make a graph of this function for each axis. How do you expect these graphs to compare to similar graphs of the electric field along each axis of an electric dipole?

WARM-UP

Read Serway & Jewett: sections 19.4, 22.1, 22.2

1. Draw a bar magnet as a magnetic dipole consisting of two magnetic monopoles of equal strength but opposite sign, separated by some distance. Label each monopole with its strength and sign. Label the distance. Choose a convenient coordinate system.

2. Select a point along one of the coordinate axes, outside the magnet, at which you will calculate the magnetic field. Determine the position of that point with respect to your coordinate system. Determine the distance of your point to each pole of the magnet, using your coordinate system.

3. Assume that the magnetic field from a magnetic monopole is analogous to the electric field from a point charge, i.e. the magnetic field is proportional to g/r^2 where g is a measure of the strength of the monopole. Determine the direction of the magnetic field from each pole at the point of interest.

4. Calculate the magnitude of the each component of the magnetic field from each pole at the point of interest. Add the magnetic field (remember it is a vector) from each pole at that point to get the magnetic field at that point.

5. Graph your resulting equation for the magnetic field strength along that axis as a function of position along the axis.

6. Repeat the above steps for the other axis.

EXPLORATION

Using either a Taconite plate or a compass check that the magnetic field of the bar magnet appears to be a dipole. Start the Hall probe program and go through the Hall probe calibration procedure outlined in *Appendix E*. **The Hall Probe application detects the setting of the probe when started, in order to switch settings you must restart Hall Probe**

Take one of the bar magnets and use the probe to check out the variation of the magnetic field. Based on your previous determination of the magnetic field map, be sure to orient the Hall probe correctly. Where is the field the strongest? The weakest? How far away from the bar magnet can you still measure the field with the probe? Write down a measurement plan.

MEASUREMENT

Based on your exploration, choose a scale for your graph of magnetic field strength against position that will include all of the points you will measure. Decide whether you should set the amplifier to high or low sensitivity.

Choose an axis of the bar magnet and take measurements of the magnetic field strength in a straight line along the axis of the magnet. Be sure that the field is always perpendicular to the probe. Make sure a point appears on the graph of magnetic field strength versus position each time you enter a data point. Use this graph to determine where you should take your next data point to map out the function in the most efficient manner. Repeat for each axis of the magnet.

ANALYSIS

Compare the graph of your calculated magnetic field to that which you measured for each axis of symmetry of your bar magnet. Can you fit your prediction equation to your measurements by adjusting the constants?

CONCLUSION

Along which axis of the bar magnet does the magnetic field fall off faster? Did your measured graph agree with your predicted graph? If not, why? State your results in the most general terms supported by your analysis.

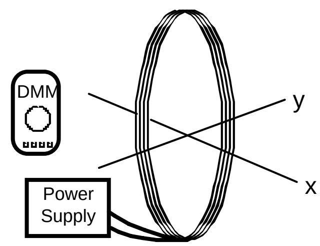
How would the shape of the graph of magnetic field strength versus distance for the magnetic dipole compare to the shape of the graph of electric field strength versus distance for an electric dipole? Is it reasonable to assume that the functional form of the magnetic field of a monopole is the same as that of an electric charge? Explain your reasoning.

PROBLEM #4:
THE MAGNETIC FIELD OF ONE COIL

You read in your text that a coil of wire carrying a current gives the same magnetic field as a bar magnet: a magnetic dipole field. This seems strange, so you decide to check it using a large coil of wire and a Hall probe, as well as a simulation. You decide to measure the strength of the magnetic field as a function of position along the central axis of the coil and compare it to the measurements you have for a bar magnet. As a qualitative check you also use the Hall probe to make a map of the magnetic field everywhere near the current carrying coil, and compare that to what the simulation predicts.

EQUIPMENT

You will have a Pasco coil of 200 turns of wire, a power supply, a compass, a meter stick, a digital multimeter (DMM), a Hall probe, and a computer data acquisition system. You will also have the EMField application. Do not use the Cenco CRT power supply for this problem.



PREDICTION

Compare the magnitude of the magnetic field as a function of distance along central axis of a coil of known radius and carrying a known electric current to that of a bar magnet.

Also compare the field map of the current carrying coil with that of a bar magnet.

WARM-UP

Read Serway & Jewett: 21.1, 21.2, 22.7 (and see example 22.6.)

If you have done Problem #3, you already have the equation that describes the magnetic field strength of a magnetic dipole along an axis of symmetry. If not, answer the warm-up questions in Problem #3.

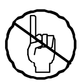
Draw the coil and label the current through it. Using the right hand rule, determine the direction of the magnetic field along the central axis of the coil. Using this information, which symmetry axis of a magnetic dipole corresponds to this central axis?

EXPLORATION

First, see what the simulation gives you. If you do not remember how to use EMField, review lab 5, or the second problem of this lab.

Once you are in the *2D Line Currents* mode, you will need to figure out how to model a coil. You should think of the fact that a coil and its field are symmetric about the coil's central axis and the simulation plots fields in a plane perpendicular to the current flow. Once you have your model of a simple coil input into the program, use the *Field Vectors* option in the *Field and Potential* menu to study the field. You should pick points both inside and outside the coil for a complete map of the magnetic field. Once you have done this, print it out, using *Print* under *File*. **Note that you will use this for qualitative comparisons only!**

Now you should start working with the physical apparatus.



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 a large coil to the power supply using the adjustable voltage. Using your compass, make a qualitative map of the magnetic field produced. To get the most obvious effect on the compass, should the central axis of the coil be oriented N-S or E-W?

Using your compass an indicator, adjust the current up and down to determine the sensitivity of the magnetic field to the current. For a reasonable current in the coil, use the compass to determine how far a measurable magnetic field along the axis of the coil extends. Also check out the magnetic field outside the coil. Is it large or small? Compared to what?

Try reversing the current through the coil. What happens to the magnetic field at each point?

Connect the Hall probe according to the directions in Appendices D and E. Explore the strength of the magnetic field in the plane of the coil. Is the field stronger inside or outside the coil? Where is the field the strongest inside the coil? Decide whether you should set the amplifier to high or low sensitivity.

How far from the center of the coil along the axis can you measure the field? Is it the same on both sides of the coil?

How can you tell by your magnetic field reading if you are on the axis? How far from the axis can you move the Hall probe without introducing additional uncertainty in your measurement?

Write down a measurement plan.

MEASUREMENT

Based on your exploration, choose a scale for your graph of magnetic field strength as a function of position that will include all of the points that you will measure.

Use the Hall probe to measure the magnitude and direction of the magnetic field as a function of position along the axis of the coil. Measure the field on both sides of the coil. Be sure your Hall Probe is calibrated and has the correct orientation to accurately measure the magnetic field.

Use the Hall probe to complete the field map for the coil.

Use the DMM to measure the current in the coil. Try measuring the field along the axis at several different currents.

Don't forget to measure the diameter of the coil and record the number of turns. What considerations need to be made when measuring the diameter?

ANALYSIS

Graph the magnetic field of the coil along its axis as a function of position and compare to the magnetic field of the bar magnet along the comparable axis. The graphical comparison is easier if you normalize the function describing the bar magnet's magnetic field to that of the coil. You can do this by dividing the largest magnetic field strength of the coil by the largest magnetic field strength of the bar magnet. Use the resulting number to multiply the function representing the bar magnet's magnetic field strength. You may also need to use the same process on the x-values. You can then put both functions on the same graph.

CONCLUSION

Is the graph of magnetic field strength as a function of position along the central axis similar to that for a bar magnet? Does the magnetic field map for a current-carrying coil have the same pattern as for a bar magnet? Do you believe that this coil gives a magnetic dipole field? Is this true everywhere? Why or why not?

How does the magnetic field strength of a current-carrying coil depend on the current? What measurements justify your statement?

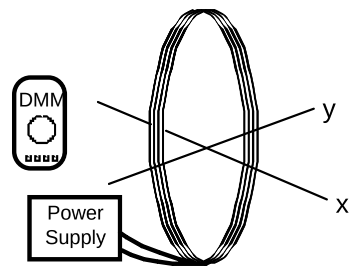
PROBLEM #5:
DETERMINING THE MAGNETIC FIELD OF A COIL

You are a member of a research team studying magnetotactic bacteria. Magnetotactic bacteria from the southern hemisphere preferentially swim to the south along magnetic field lines, while similar bacteria from the northern hemisphere preferentially swim to the north along magnetic field lines. Your team wishes to quantify the behavior of magnetotactic bacteria in closely controlled magnetic fields. You know from your physics class that a coil of wire can be used to produce a magnetic field, which can be varied by changing the current through it. You set yourself the task of calculating the magnetic field along the axis of the coil as a function of its current, number of turns, radius, and the distance along the axis from the center of the coil. To make sure you are correct, you decide to compare your calculation to measurements.

EQUIPMENT

If you have done Problem #4, you can use those measurements for this Problem. If not, you will use the following equipment.

You will have a large, 200 turn coil of wire, a power supply, a digital Multimeter (DMM), a compass, a meter stick, a Hall probe, and a computer data acquisition system.



PREDICTION

Calculate the magnitude of the magnetic field as a function of the position along the central axis of a coil of known radius, the number of turns of wire, and the electric current in the coil.

Use this expression to graph the magnetic field strength as a function of position along the central axis of the coil.

WARM-UP

Read Serway & Jewett: 21.1, 21.2, 22.7 (and see example 22.6.)

1. Make a sketch of a coil of radius R. Define a coordinate axis, label the relevant quantities, and indicate the direction of the current through the coil.

Select a point along the axis at which you will calculate the magnetic field.

2. Select a small element of current along the coil, which will cause a small fraction of this magnetic field. Label the length of that current element. Draw a position vector from that current element to the selected point along the axis of the coil.

Use the Biot-Savart law, (phonetically, “Bee-Oh Saw-Varr”), to draw a vector representing the direction of the small part of the magnetic field from your current element at the position of interest. Determine the components of this vector along the axes of your coordinate system.

Are there any symmetries that rule out one or more components of the magnetic field at the point of interest?

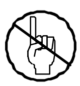
3. Use the Biot-Savart law to calculate the small part of the desired component of the magnetic field, at the selected point, from the small element of current. Now add up (using an integral) all of the small fractions of that component of the magnetic field from all of the small elements of current around the coil.

Determine the magnitude of the magnetic field at that point along the axis for one loop of wire, writing your answer as a function of the distance along the axis of the coil. What will be the effect of N identical loops on the magnitude of the magnetic field?

4. Graph the magnitude of magnetic field strength as a function of the position along the central axis of the coil of wire.

EXPLORATION

If you have the data from Problem #4 you do not need to make any additional measurements. Go directly to the analysis section. If you have not done Problem #4, continue with the 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 a large coil to the power supply using the adjustable voltage. Using your compass, make a qualitative map of the magnetic field produced. To get the most obvious effect on the compass, should the central axis of the coil be oriented N-S or E-W? Decide whether you should set the amplifier to high or low sensitivity.

Using your compass as an indicator, adjust the current up and down to determine the sensitivity of the magnetic field to the current. For a reasonable current in the coil, use the compass to determine how far a measurable magnetic field along the axis of the coil extends. Also check out the magnetic field outside the coil. Is it large or small? Compared to what?

Try reversing the current through the coil. What happens to the magnetic field at each point?

Connect the Hall probe according to the directions in Appendices D and E. Explore the strength of the magnetic field in the plane of the coil. Is the field stronger inside or outside the coil? Where is the field the strongest inside the coil?

How far from the center of the coil along the axis can you measure the field? Is it the same on both sides of the coil?

How can you tell by your magnetic field reading if you are on the axis? How far from the axis can you move the Hall probe without introducing additional uncertainty to your measurement?

Write down a measurement plan.

MEASUREMENT

Based on your exploration, choose a scale for your graph of magnetic field strength against position that will include all of the points you will measure.

Use the Hall probe to measure the magnitude and direction of the magnetic field as a function of position along the axis of the coil. Measure the field on both sides of the coil. Be sure your Hall probe is calibrated and has the correct orientation to accurately measure the magnetic field. Make sure you take at least two measurements for averaging.

Use the Hall probe to complete the field map for the coil.

Use the DMM to measure the current in the coil. Try measuring the field along the axis at several different currents.

Don't forget to measure the diameter of the coil and record the number of turns. What considerations need to be made when measuring the diameter?

ANALYSIS

Graph the measured magnetic field of the coil along its axis as a function of position and compare with your prediction.

CONCLUSION

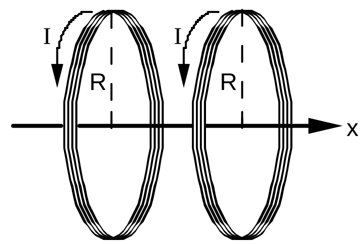
Does the graph of magnetic field strength as a function of distance agree with your prediction? Is this true everywhere? Why or why not?

PROBLEM #6:
MEASURING THE MAGNETIC FIELD OF TWO PARALLEL COILS

As in the previous problem, you are a member of a research team studying magnetotactic bacteria, which preferentially swim along magnetic field lines. Your team now wishes to quantify the behavior of magnetotactic bacteria in magnetic fields which are uniform. However, the magnetic field from one coil varies strongly with position; that configuration is not suitable for the test, and the group needs something that can produce a more uniform field. The laboratory has two nearly identical large coils of wire mounted so that the distance between them equals their radii. You have been asked to determine the magnetic field between them to see if it is suitable for the test.

EQUIPMENT

Connect two large coils to a power supply so that each coil has the same current. Each coil has 200 turns. The coil base has markings showing correct spacing for a uniform field.



You will have a digital Multimeter (DMM), a compass, a meter stick, and a Hall probe. A computer is used for data acquisition with the HallPROBE program.

PREDICTION

Calculate the magnitude of the magnetic field for two coils as a function of the position along their central axis, for the special case where the distance between the coils is the same as the radius of the coils. Use this expression to graph the magnetic field strength versus position along the axis.

WARM-UP

Read Serway & Jewett: 21.1, 21.2, 22.7 (and see example 22.6.), 22.10

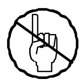
1. Draw a picture of the situation showing the direction of the current through each coil of wire. Establish a single convenient coordinate system for both coils.

Label all of the relevant quantities.

2. Select a point along the axis of the two coils at which you will determine an equation for the magnetic field. In the previous problem, you measured the magnetic field due to one coil as a function of the position along its axis. To solve this problem, add the magnetic field from each coil at the selected point along the axis. Remember to pay attention to the geometry of your drawing. The origin of your coordinate system for this problem cannot be at the center of both coils at once. Also remember that the magnetic field is a vector.

3. Use your equation to graph the magnetic field strength as a function of position from the common origin along the central axis of the coils. Describe the qualitative behavior of the magnetic field between the two coils. What about the region outside the coils?

EXPLORATION



WARNING: You will be working with a power supply that can generate 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 large coils to the power supply with *the current flowing in the opposite direction in both coils*, using the adjustable voltage. Using your compass, explore the magnetic field produced. Be sure to look both between the coils and outside the coils.

Now connect the large coils to the power supply *with the current flowing in the same direction in both coils*, using the adjustable voltage. Using your compass, explore the magnetic field produced. Be sure to look both between the coils and outside the coils.

Based on your observations, should the currents be in the same direction or in opposite directions to give the most uniform magnetic field between the coils?

Connect the Hall probe according to the directions in Appendices D and E. For the current configuration that gives the most uniform magnetic field between the coils, explore the strength of the magnetic field along the axis between the coils. Follow the axis through the coils. Is the field stronger between or outside the coils? Where is the field strongest between the coils? The weakest?

See how the field varies when you are between the two coils but move off the axis. How far from the axis of the coils can you measure the field? Is it the same on both sides of the coils? Decide whether you should set the amplifier to high or low sensitivity.

When using the Hall probe program, consider where you want your zero position to be, so that you can compare to your prediction.

Write down a measurement plan.

MEASUREMENT

Based on your exploration, choose a scale for your graph of magnetic field strength against position that will include all of the points you will measure.

Use the Hall probe to measure the magnitude of the magnetic field along the axis of the coils of wire. Be sure to measure the field on both sides of the coils.

What are the units of your measured magnetic fields? How do these compare to the units of your prediction equations?

Use the DMM to measure the current in the two coils. As a check, repeat these measurements with the other current configuration.

ANALYSIS

Graph the measured magnetic field of the coil along its axis as a function of position and compare to your prediction.

CONCLUSION

For two large, parallel coils, how does the magnetic field on the axis vary as a function of distance along the axis? Did your measured values agree with your predicted values? If not, why not? What are the limitations on the accuracy of your measurements and analysis?

Does this two-coil configuration satisfy the requirement of giving a fairly uniform field? Over how large a region is the field constant to within 20%? This very useful geometric configuration of two coils (distance between them equals their radius) is called a Helmholtz coil.

PROBLEM #7:
MAGNETS AND MOVING CHARGE

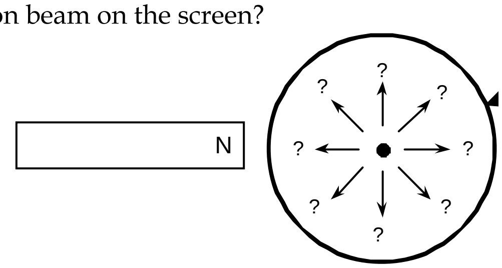
You are leading a technical team at a company that is redesigning the electron linear accelerators used in cancer therapy. Your team is developing a steering mechanism that uses magnetic fields to precisely guide the electrons to their target, where they suddenly slow down and emit high energy photons that can control tumors. To introduce this project to a group of stockholders, you wish to demonstrate how a magnetic field can guide an electron beam across a CRT screen. You decide to use an ordinary bar magnet held outside of the CRT to deflect the electrons. Before you do the demonstration, you need to know the qualitative effect of bringing a bar magnet up to a CRT. In the laboratory you determine how the direction and size of the electron deflection is related to the magnetic field direction, the magnetic field strength, and the velocity of the electron.

EQUIPMENT

For this problem you will need a cathode ray tube (CRT) and accessories, a bar magnet, a meter stick, and a compass. Review the information from Laboratory IV and *Appendix D* regarding the design of the CRT and the proper way to use it.

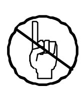
PREDICTION

Read Serway & Jewett: sections 22.1, 22.2, 22.3.
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? 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.

EXPLORATION



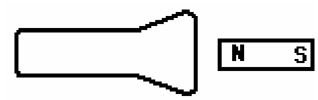
WARNING: You will be working with equipment that generates large electric voltages. Improper use can cause painful burns. **To avoid danger, the power should be turned OFF and you should WAIT at least one minute before any wires are disconnected from or connected to the power supply. Never grasp a wire by its metal ends.**

Connect the CRT according to the directions in *Appendix D* and your lab journal from Lab IV. Select the accelerating voltage that gave the largest deflection for the smallest electric field based on your explorations from Lab IV. Record the location of the non-deflected beam spot.

Determine which pole on your bar magnet is the north magnetic pole. Make a qualitative field map of your magnet to make sure it is a simple dipole. If it is not, ask your instructor to replace it. 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 which direction did the beam spot deflect?

Put the bar magnet perpendicular to the screen of the CRT, do you see a deflection? Try this with both poles of the magnet. Record your results. Were they what you had 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 the deflection change? Try this with both poles of the magnet. Record your results. Were your results what you had 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 by adding more magnets. How does the deflection change? Try this with both poles of the magnet. Record your results. Were your results what you had 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. Arrange it to observe the minimum effect. By measuring the electron deflection, what would you say is the relative strength of the magnet and the Earth's magnetic field in the lab? Remember to take account of the distance that the electron travels through each magnetic field. What is the effect of the Earth's magnetic field on the CRT beam relative to the Earth's gravitational field?

Devise your own exploration of the effect of a magnetic field on electrons using the CRT and 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 relating the three vectors representing the velocity of the electron, the magnetic field, and the force on the electron 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?

PROBLEM #8: MAGNETIC FORCE ON A MOVING CHARGE

You are attempting to design a better electron microscope; in particular, you wish to improve the mechanism that guides the electron beam across a sample. To precisely control the beam of electrons, your research team decides to try a magnetic field. For your study of electron control you decide to use a Cathode Ray Tube (CRT) with a magnetic field perpendicular to its axis. From your work with Helmholtz coils in Problem #5, you know that the magnetic field between these parallel coils is fairly uniform, so you decide to use them for your test. Before you can evaluate the sensitivity of the electron microscope design, you need to determine how the magnitude of a constant magnetic field affects the position of the beam spot.

EQUIPMENT

You will be using the cathode ray tube (CRT) described in *Appendix D*. The magnetic field will be provided by connecting the Helmholtz coils to the power supply and placing the CRT between the coils. You will also have a digital multimeter (DMM), a compass, a meter stick, and a Hall probe connected to a computer data acquisition system.

PREDICTION

Write an equation for the deflection of an electron as a function of the strength of a constant magnetic field and the velocity of the electron when the direction of the magnetic field is such as to give maximum deflection. Use this equation to graph the deflection as a function of magnetic field strength for a typical electron velocity in the CRT.

WARM-UP

Read Serway & Jewett: sections 22.1, 22.2, 22.3.

Review Kinmatics if necessary: Read Serway & Jewett: Chapters 3 and 4.

1. Draw a picture of the CRT in the Helmholtz coils. Since you will not be using electric fields, do not include the deflection plates in your sketch. Be sure you have all the other components in your sketch. Draw a coordinate axis on this sketch and show the magnetic field direction and the region occupied by the magnetic field. Draw the electron trajectory through all regions of the CRT together with its velocity and acceleration. Draw the electron trajectory if there were no magnetic field. The difference between where these two trajectories hit the CRT screen is the deflection.

2. What path does an electron follow while traveling through a constant magnetic field? The magnetic force is always perpendicular to the electron's velocity. Are there any forces other than the magnetic force that need to be considered?

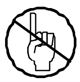
3. Determine the velocity of the electrons as they leave the electron gun in the CRT. (See your notes from Lab 1V, Problem #5.)

4. Determine the position, direction, and velocity of an electron entering the region of constant magnetic field. Determine the position, direction, and velocity of an electron as it leaves the region of constant magnetic field. What type of curve is the electron's trajectory in that region?

5. Determine the path of the electron as it travels after it leaves the magnetic field region until it strikes the screen. Use geometry to determine how far from the center the electron strikes the screen.

EXPLORATION

Review your notes from your exploration in Problem #7.



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 touch the conducting metal of any wire.**

Check to see that the connections from the power supply to the high voltage accelerating plates and the filament heater of the CRT are correct, then turn the power supply on. You should have between 250 and 500 volts between the cathode and anode. After a moment, you should see a spot that you can adjust with the knob labeled “Focus”. If your connections are correct and the spot still does not appear, inform your lab instructor.

Devise a measuring scheme to record the position of the beam spot. Record your zero deflection position and do not move the CRT once you have started taking measurements.

Review the magnetic field map from the Helmholtz Coils. How will you orient the CRT with respect to the coils? Would the deflection be the same if the magnetic field were reversed? Try it. How will you determine the length of the CRT within the magnetic field? Is the field uniform throughout the flight of the electrons?

Write down a measurement plan.

MEASUREMENT

Measure the position of the beam spot as you change the magnetic field. Make at least two measurements for averaging.

Use the Hall Probe to Measure the magnetic field between the Helmholtz coils.

ANALYSIS

Graph your measurements of the deflection of the electron beam for the different values of the magnetic field at a fixed electron speed and compare to your prediction. Repeat for deflection as a function of electron speed for a fixed magnetic field.

CONCLUSION

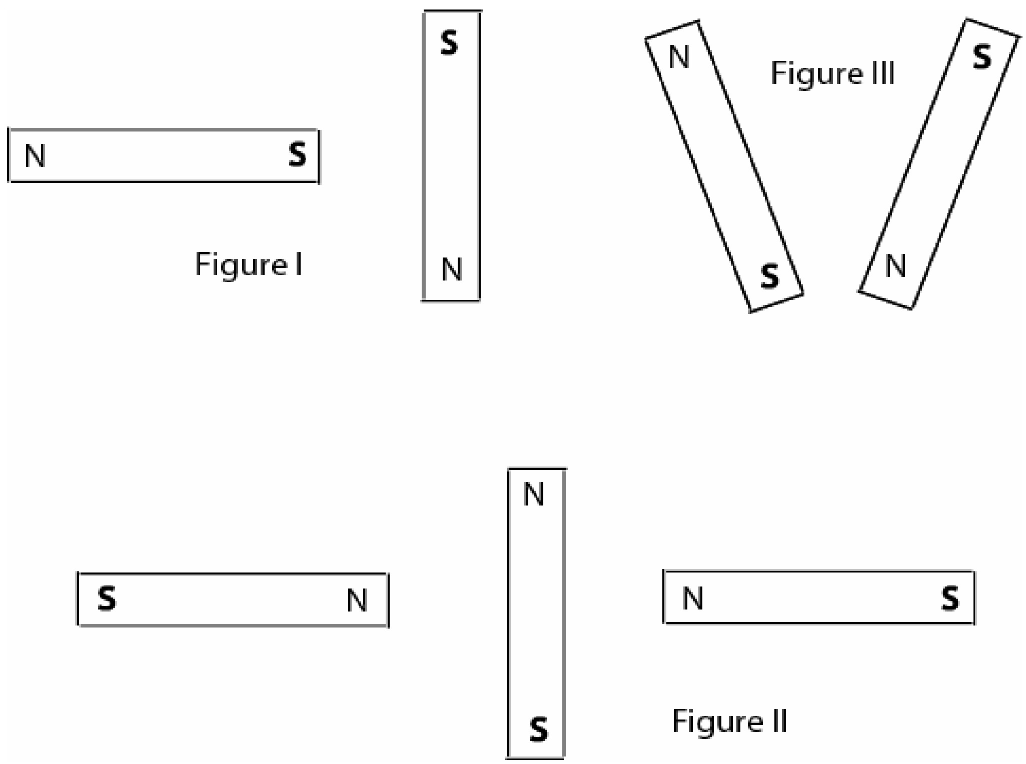
How does the deflection of the electron beam depend on the magnetic field? Did your data agree with your prediction? If not, why? What are the limitations on the accuracy of your measurements and analysis?

How does the deflection of the electron beam depend on the electron speed? Did your data agree with your prediction? If not, why? What are the limitations on the accuracy of your measurements and analysis?

Is controlling the deflection of an electron beam easier with a magnetic field or an electric field? Write down what you mean by easier.

☑ 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.



2. You and your friends are watching an old Godzilla movie. In one 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 the joke.

3. For a cathode ray tube (CRT) with the same electron gun as you used in lab, assume that the distance from the center of the V_X plate to the fluorescent screen is 10 cm, V_{acc} is 500V and V_X = 6V. The CRT is then placed between the large parallel coils (also used in this lab) which have a current of 1 ampere flowing through them. Assume that the CRT is oriented in the large parallel coils such that the electric field between the V_X plates and the magnetic field are <u>in the same direction</u>. What is the displacement of the electron beam on the screen? This is a difficult problem!!

TA Name:______________________________

PHYSICS 1202 LABORATORY REPORT

Laboratory V

Name and ID#: ____

Date performed: _____________ Day/Time section meets: _______________________________

Lab Partners' Names: ____

____

____

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.