Performance: Report: Total:

Physics 212-5

Solenoids and Wires

NAME: ______________________________ ☐

STUDENT ID ______________________________ ☐

LAB PARTNER(S): ______________________________ ☐

______________________________ ☐

______________________________ ☐

Check the box next to the name of the person to whose report your group's data will be attached.

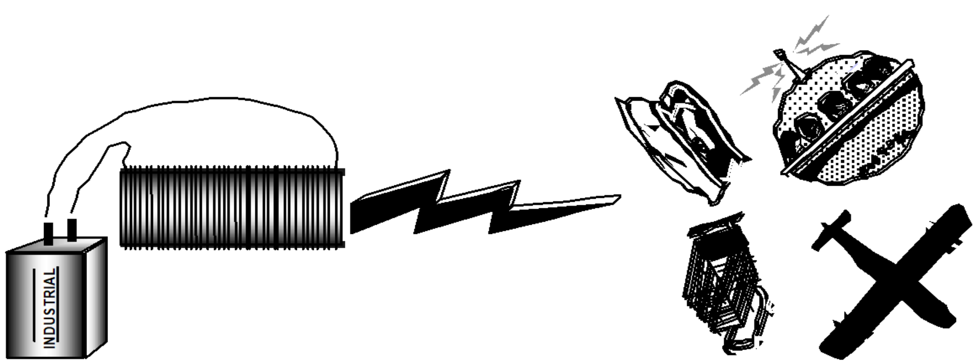
LAB SECTION: ___________________________

INSTRUCTOR: ___________________________

DATE: ___________________________

TABLE: ___________________________

(YOU WILL BE TAKEN 3 POINTS IF TABLE IS VACANT.)



Physics Lab 212-5

Equipment List
Magnetic field sensor
DC Power Supply
5 m long wire with banana ends
Rods and clamps for supporting wire for Oersted experiment (3 rods—one 5' vertical, two 2' horizontal and 3 clamps- 1 table clamp and 2 right angle clamps)
Compass

Vacuum hose with groove, approx. 10 cm, with hole in its side
Steel tube

At the front of each room set up a CRT.

Computer File List
Capstone file "212-05 I vs. B Measure"
Capstone file "212-05 Table 2"

Physics Lab 212-5

Solenoids and Wires

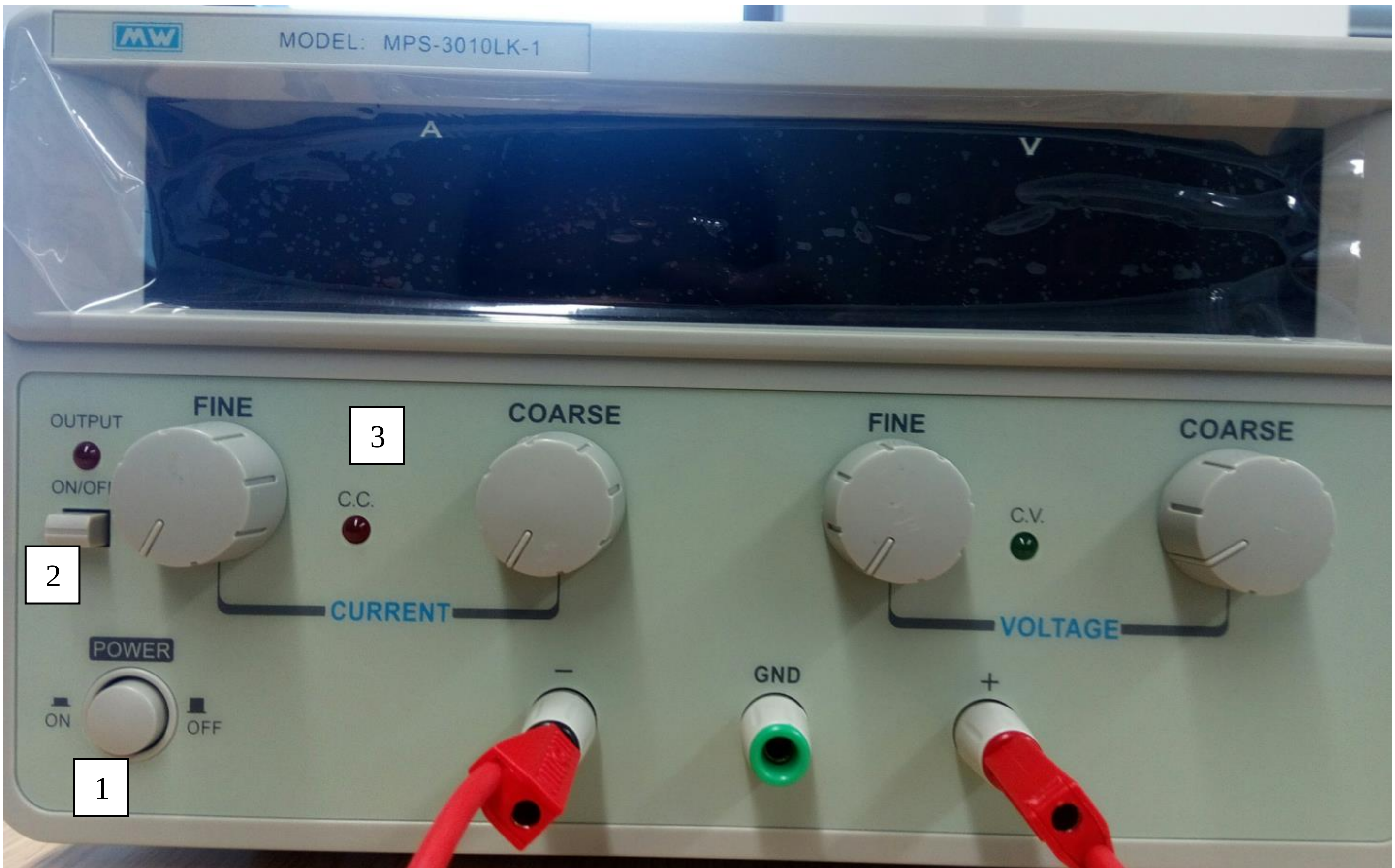
Please Note:
Since there are a limited number of people who can do Investigation 2 at one time, your group might want to get it started now. If there is nobody else working on Investigation 2 at the front of the room you may start with Investigation 2 and return to Investigation 1 afterwards.

Investigation 1: Magnetic Fields of Current-Carrying Wires

To find out
- How electric currents produce magnetic fields
- The qualitative relationship of field strength versus distance from a current-carrying wire

Preview
- Probe the field near a current-carrying wire with a compass and field probe to determine field direction and strength

Activity 1 Oersted's Experiment



DC power supply

1. **Power button; 2. Output button, click it, the power supply will output current &/ voltage. 3. Knobs to tune the current, FINE means fine tuning, COARSE means coarse tuning.**

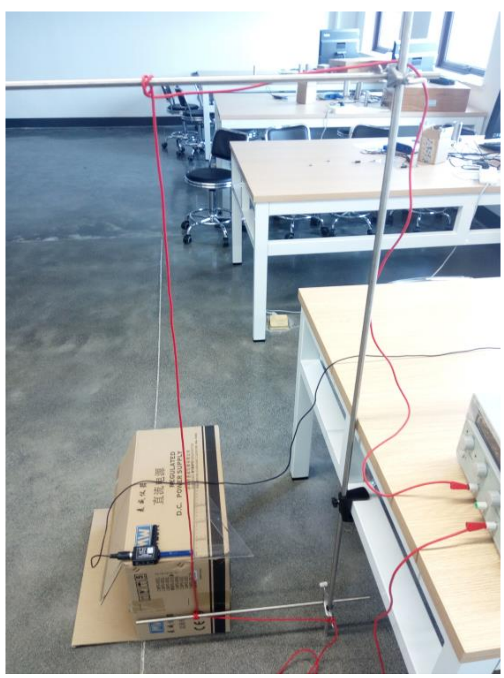
Never set current larger than 6.4 A!!!

Never set current larger than 6.4 A!!!
Tune knobs of power supply carefully!

You will now explore the creation of magnetic fields by moving charges in a wire.

1. Set up the hardware.
    - Find the very long, thin, insulated wire with banana plugs on both ends. Assemble or check this wire as it looks like Picture 1. The wire should be vertical, keeping away from the edge of the table and straight. Make sure the ends leading back to the power supply are not close to the vertical run. **Notice:** the vertical wire should be keeping away from any kinds of ferromagnetic material, as the ferromagnetic material may be magnetized. Then it will affect your data.
    - Plug the two banana ends into the power supply into the "+" and "–" connections in such a way that the current through the vertical stretch of wire is **downward** (toward the floor).

Prediction	Discuss with your group the rules for determining the shapes and strengths of magnetic fields near current carrying wires that you have learned in lecture and in your text. Draw on Picture 1 at the spot where the straight vertical wire touches the paper box what you expect the direction of the magnetic field lines due to the downward current in the wire will be. Will the lines be parallel with the wire upward? Will they be parallel downward? Or will they be clockwise (looking downward) around the wire? Or will they be counter-clockwise (looking downward)?



Picture 1. Top view and side view of setup

2. Test your predictions for the field direction using a compass.
   - The DC power supplies should be set by turning up the voltage a little and adjusting carefully the current (after turning the power supply on) to **6.3** Amps.
   - Place your compass at a variety of positions near the wire and observe the direction of the field.

Q1 How well do your observations agree with your predictions? Is there any difference? If yes, why?

____

____

Q2 What is the "right-hand" rule used to predict the field direction?

____

____

3. Change the current.
   - Reverse the leads (i.e., reverse the '+' and '-' connections).
   - Make sure the power supply is set to 6.3 Amps and use your compass to find the direction of the field again. Verify what you just stated concerning the right-hand rule.

The expression

$$B(r) = \frac{\mu_o I}{2\pi\, r} \qquad \text{(Eq. 1)}$$

gives the magnitude of the magnetic field B for an infinite straight wire. Here, I is the current measured in amperes, and r is the perpendicular distance from the wire, in meters. The constant of proportionality μ_o is called the *permeability of free space*. Its value is $\mu_o = 4\pi \cdot 10^{-3}$ G·m/A or $\mu_o = 4\pi \cdot 10^{-7}$ T·m/A.

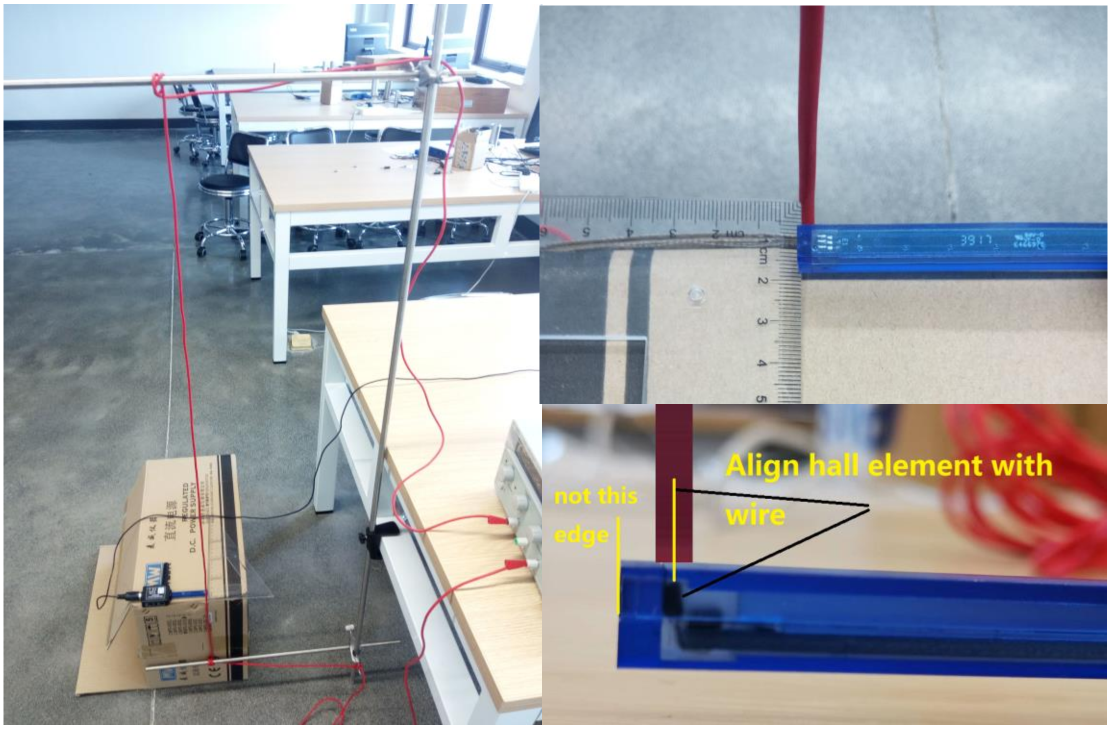
Theory Calculation

What is the magnitude of the field 0.7 cm away from the wire if the current is 6.3 Amps?

B(r=0.7 cm) = __________ [G] = __________ [T]

The magnetic field probe and the computer's curve fitting ability will allow you to test your theory calculation and verify the structure of Equation 1. **Remember that the field probe measures the magnitude of the field along the direction perpendicular to the <u>white dotted</u> surface at the tip of the probe.** The probe will measure a positive quantity for a magnetic field if the perpendicular component of the field is pointed in the white dotted surface. For room E416/E417, note too that the probe used in this lab is meant to have a measuring range from -10 G to +10 G (100X).

4. Set up the hardware and software.
   - Open “212-05 Oersted” from the "212 Lab Files" on the desktop.
   - Prepare to measure field versus distance from the wire. Your aim is to arrange your setup like Picture 2 below. This is the axial mode. If you choose the perpendicular mode, you should use different placement.



Picture 2. Probe and ruler placement (for **axial mode** of probe)
The paper box could be replaced as plastic stool or something nonmagnetic

- Hold the probe parallel to the edge of the table with the side of the probe near the end of the probe barely touching the vertical wire as shown above. **Exactly speaking, you should find the hall element you are using, and hold the probe that the hall element plane is along radial direction of the circle centered at the vertical wire.**
- Turn up the current to 6.3 amps and observe the readout of the field on the computer.
- Now find the location of the Hall Effect element in your probe. (It’s not exactly at the extreme end of the probe.) Observe the readout of the field on the computer and look for a maximum reading while sliding the probe back and forth in the direction parallel with the edge of the table while keeping lightly in contact with vertical wire. When you are satisfied you’ve found the location where the field measurement is a maximum, hold the probe steady and have one of your lab partners secure a ruler as shown in Picture 2 above.
- The ruler should be perpendicular to the edge of the table, its zero mark on its metric scale should line up with the vertical wire, and its metric scale side should be touching the end of the probe. The center of the end of the end of the probe should be approximately lined up with the 0.7cm mark on the ruler.

- **Keep holding the probe in place. Have a partner turn off the current and then hit the zero button TARE to zero the probe. Now when you turn the current on, the magnetic field reading will be due only to the current in the wire. <u>For E521/E519 room,</u> to get the real magnetic field of current you should make <u>the reading minus the offset! (so your offset: ________ G.) # the reading after zero is offset.</u>**

5. Measure the field generated by the current carrying wire.
   - Turn the current back up to 6.30 Amps while still holding the probe in place at the 0.7cm mark. Note: if you have moved the probe, you'd better zero it again before the current is on.
   - Click on **Record** and take about 10 seconds of data and then click on **Stop** and turn the current off (press the on/off button).
   - Find the average field reading by selecting a good portion of your data with the mouse and choosing **Statistics** under the **Analyze** menu.

   Average field = __________ [G]

Q3 How well did your result for the final field compare with your prediction? Calculate the percentage difference.

____

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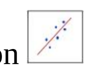
6. Measure the field versus radius.
   - Turn the current in the wire back up to 6.30 Amps.
   - Prepare to graph the dependence of the field versus distance. The plan is to start taking data with the probe at the 0.7 cm radius (<u>i.e., with the side of the end of the probe just **touching** the wire and the tip touching ruler's edge.</u> Why?). You should take about 7 seconds of data, and then abruptly move the probe **0.5** centimeters along the ruler's edge away from the wire so the center of the dotted end of the probe is then lined up with the 1.2 cm mark on the ruler and make sure the probe is still perpendicular to the ruler. **Take an additional 7 seconds of data, move another 0.5 centimeters, and so on. You do not have to stop the program between points.** Just hold the probe steady and move it quickly and precisely to the next radius at the appropriate time. It's best if the person holding and moving the probe is told when to move to the next point by the person operating the computer.
   - Start taking data by clicking on **Record**. Take data from 0.7cm out to 3.7cm in steps of 0.5cm.
   - **<u>Turn the current down to zero when you are finished taking data.</u>**

7. Analyze the results.
   - Highlight the region of flat response in your data for r= 0.7 cm and then select **Statistics** under the **Analyze** menu to obtain and record in Table 1 below a good mean value of the field strength and the standard deviation.
   - Complete Table 1 by repeating the above step for each value of *r*. What does the standard deviation tell you about how many digits you should record for the field strength?

Radius [m]	Field [G]	Std. Dev. [G]
Offset (E521)		
0.007		
0.012		
0.017		
0.022		
0.027		
0.032		
0.037		

Table 1. Magnetic field strength versus distance from a long straight wire

9. Enter the results.
   - Make sure you have completed Table 1 and printed out your data. In the next task your data on the computer will be lost!
   - **Open…** the file "212-05 Table 1" from the "212 Lab Files" folder.
   - Manually enter the data you have recorded in Table 1 in the data table displayed by clicking on and typing in the appropriate boxes. The graph will automatically be drawn as you enter your data.

10. Fit the results on the graph.
    - Click on the curve fit button  on the toolbar.
    - Because there may still be a small offset to your data, you need to fit the data to a form

$$B = \frac{A_1}{r} + B_1$$

      where A_1 is equal to $\frac{\mu_0 I}{2\pi}$ and B_1 **is the offset**. You can do this by choosing the "Inverse" from the list of fitting formula.
    - Copy the expression given by the computer, substituting in the parameters *B* and *r* if you want.

      Formula: $B =$ ______________________________

11. Print and annotate your graph.
    - Adjust your graph if necessary to get a good display.
    - Give your graph a title with your names or initials on it and print a copy of your results.

Q4 Does the curve fit the data well? How do you know?

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____

Q5 Determine the theoretical value for $\frac{\mu_o I}{2\pi}$. Compare this value to the A_1 obtained by your curve fit. Calculate a percentage difference.

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Investigation 2: Electrons and magnetic fields

To find out

- How a magnetic field affects charged particles

Preview

- Use bar magnets to alter the path of a beam of electrons

WARNING: This Investigation Utilizes Some Relatively Strong Magnetic Fields That Can Be Hazardous to Your Possessions. Be Sure To Keep Computer Monitors, Watches, Credit Cards, And Student IDs Away From The Magnets.

Activity 2 Messin' with the TV

In this investigation, you will examine how a magnetic field can affect a beam of electrons. The force on a moving charged object due to a magnetic field is given by

$$\boldsymbol{F} = q\boldsymbol{v}\text{x}\boldsymbol{B} \qquad \text{(Eq. 2)}$$

where q is the charge, $\boldsymbol{v}$ is the velocity of the object and $\boldsymbol{B}$ is the magnetic field.

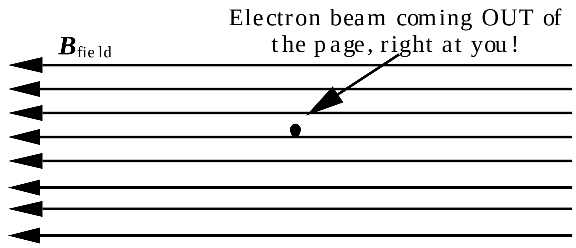

Figure 1. Electron beam and magnetic field

Q6 Which way would a beam of *electrons* be deflected by the magnetic field as shown in Figure 1? Draw this direction on the diagram.

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Magnetic fields are commonly used to change the direction of a beam of charged particles. You will now explore your understanding of how a magnetic field affects charged particles by considering a common source of such particle beams: a cathode ray tube.

Prediction	A cathode ray tube (CRT) uses a voltage (potential difference) to accelerate electrons to a high velocity. The electrons are accelerated at the back of the tube and then collide with a phosphorescent coating on the face of the tube. Images in most TVs and computer monitors are produced in this manner. Examine the diagram of the CRT in Figure 2 and your answer to Question 6. If you place the north end of the magnet at positions *a*, *b*, *c*, or *d*, which way will the dot move from the center of the screen? What if you use the south end of the magnet?

North end at *a*: __________________ ☐   South end at *a*: __________________ ☐

North end at *b*: __________________ ☐   South end at *b*: __________________ ☐

North end at *c*: __________________ ☐   South end at *c*: __________________ ☐

North end at *d*: __________________ ☐   South end at *d*: __________________ ☐

1. Test your prediction.
   - Lead your group up to the front of the room where there are two CRTs. *If the CRT's in use by other groups, go ahead and work on the other Investigations ... you can come back to this part later.*
   - For each of the eight magnet orientations specified in the prediction, place a single magnet at the side of the CRT with one end touching the box, as shown in Figure 2. (Be sure to keep the other magnets away from the CRT.)
   - Test each magnet orientation while placing a "√" in the box by each correct prediction, and an "X" by each incorrect prediction.

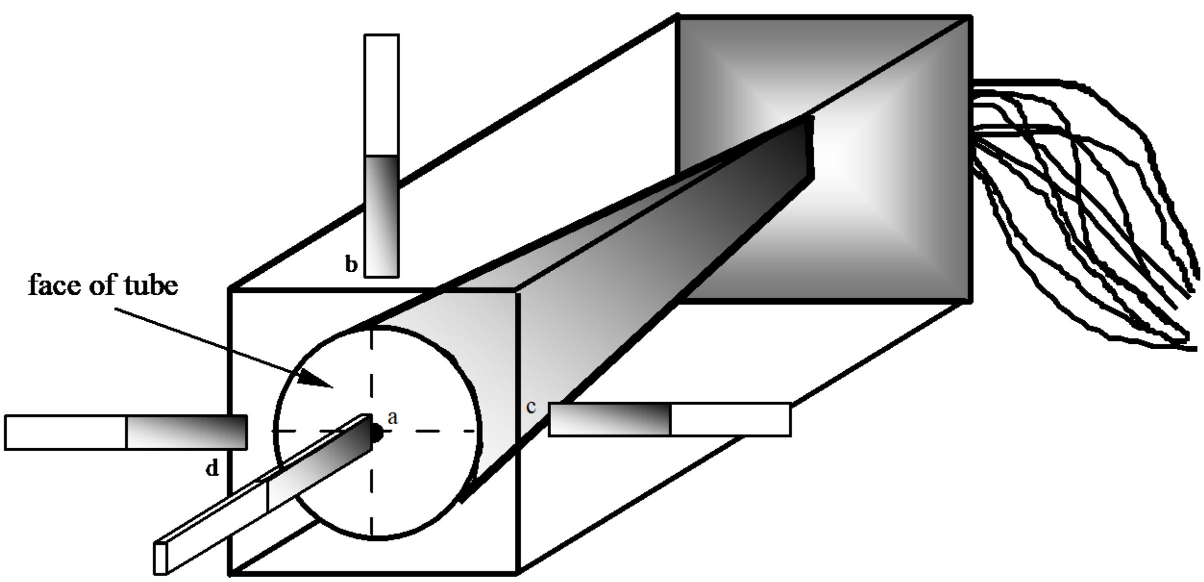

Figure 2. CRT and magnet

Q7 Did your predictions agree with the experimental results? Discuss.

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2. Change the field.
    - Put two magnets together close to the CRT tube, both pointed in the same direction (i.e., north touching north and south touching south) and place them at position *b*.
    - Now remove one of the magnets, while still keeping the other at *b*.

Q8 Describe the difference in the amount of deflection using one magnet versus two.

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Investigation 3: Magnetic Fields of Current-Carrying Coils

To find out
- The nature of the magnetic field generated by current in a coil of wire
- The relationship between current, geometry, and magnetic field strength in a coil

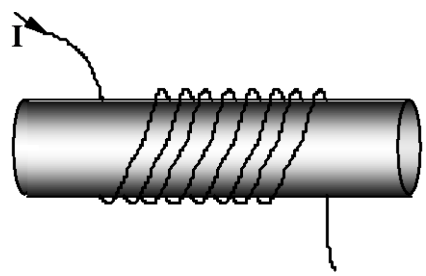
Preview
- Create two different types of coils by winding a long piece of wire around a tube, and explore the magnetic field inside each coil using a magnetic field probe

Activity 3 Coil-o-rama

In the first activity, you discovered that a long, straight, current-carrying wire can generate a magnetic field. The magnetic field lines surrounding that wire took the form of concentric circles. You also verified that the magnetic field became weaker with increasing distance from the wire.

Now, you will again use a current-carrying wire to create a magnetic field. However, you will find that the geometry of the wire plays a major role in the final strength and direction of the associated magnetic field.

Prediction Suppose you made a single-wrap coil as shown below, and sent a current through the wire. Which way will the field *inside* the cylinder point?



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1. Prepare your measuring equipment.
   - Insure that the current control dial on your DC power supply is turned down to zero. Use the long banana wire (**not** the one in activity1) to make a single-wrap coil on the vacuum hose or steel tube as shown above. **Be careful to wind the wire as evenly as possible. Keep the side hole uncovered.**
   - Plug the two banana ends of the wire into the "+" and "–" connections of the DC power supply.

2. Load the proper software.
   - Open the "212-05 I vs. B Measure" file from the “212 lab files” folder on your desktop.

3. Build the single-wrap coil (solenoid) with the probe inserted in the side hole.
    - Straighten out the wire, removing any kinks in it.
    - Insert the field probe into the side hole of the vacuum hose (the one with the grooves) as shown in Figure 3 below.
    - Wind the coil *into* the groove on the ~10 cm long vacuum hose. Although the probe is in your way, work around it but do not skip any of the grooves. You should have about the same number of turns on either side of the probe.
    - Place the coil and the probe carefully on the table, so they will not be disturbed.

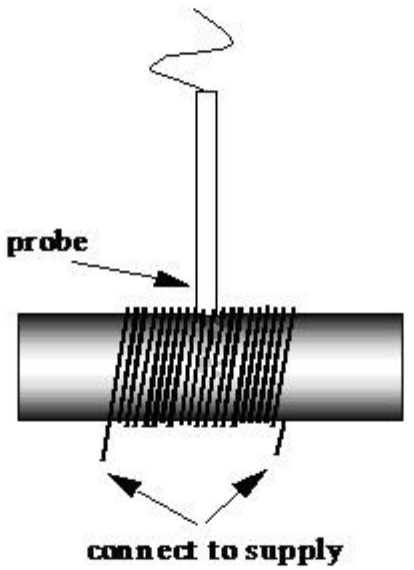

Figure 3. Measuring radial field

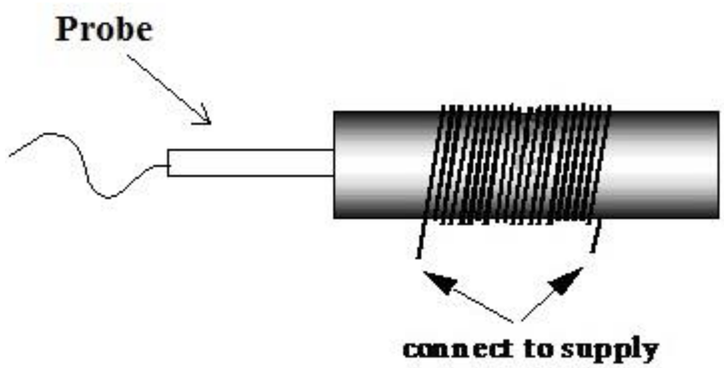

Figure 4. Measuring axial field

4. Test your prediction (<u>choose the axial mode of the field probe</u>)
    - Turn the power supply current up to 3 A.
    - Observe the readout of the magnetic field on the computer for a measure of the radial field inside the coil. Turn the current down to zero.
    - To test for a field along the axis of the coil, remove the probe from the side hole and insert it into one of the ends of the tube far enough that you see the end of the probe through the hole in the side of the tube. See Figure 4 above.
    - With no current in the coil, zero the probe again using the zero button on the toolbar.
    - Turn the power supply current up to 3 A as before.
    - Observe the readout of the magnetic field on the computer for a measure of the axial field inside the coil.
    - When you have convinced yourself of the orientation of the field, turn the current down to zero. Leave the probe as it is for the next activity.

Q9 Did your observations agree with your prediction? Discuss any differences.

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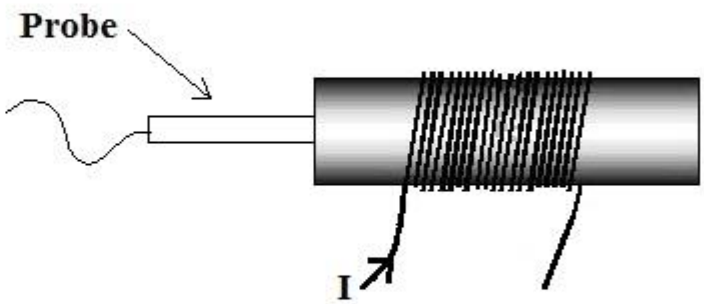
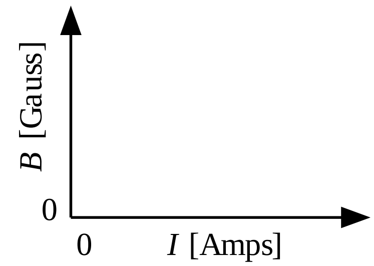
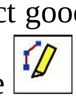
Prediction How would you expect the field strength to change as the current flowing through the coil is increased? Plot what you expect would happen.





5. Make measurements of the magnetic field inside the coil.

- You learned earlier in this lab approximately where the Hall Effect element is with respect to the end of the probe. Look through the hole in the side of the tube and adjust the probe position so that the Hall Effect element is at the center point of your coil. Hold it steady at this position.
- Record the readout with the current at 0.0 Amps (The real readout should be modified by this value.) and don't move the coil or probe for the rest of your readings. Note: the best way is lay the tube perpendicular to the direction of the earth's magnetic field so that the readout at current is 0 A is 0.
- Click on **Record** and take data for about 5 seconds for each of the current settings in Table 2 below. Select good data for each of the current settings with the mouse and then choose  and Σ to complete Table 2.

- After taking measurements, turn the current down to zero.

Current [A]	Field [G]	Std. Dev. [G]
0.00		
0.50		
1.50		
2.00		
2.50		
3.00		

Table 2. Current and magnetic field data for a single-wrap coil

At this point, you have seen that the magnetic field inside your single-wrap coil is related to the current; in fact, the more current flowing through the wire, the stronger the magnetic field inside. For a long straight coil, theory predicts that the magnetic field follows the relation

$$B = \mu_o n I \qquad \text{(Eq. 3)}$$

where B is measured in gauss, I is measured in amps and n is the number of turns per unit length of the coil.

Theory Calculation

For a long straight coil (solenoid), the proportionality constant between B and I is equal to $\mu_o n$, as shown by Equation 3. Calculate this value, but first measure n, the number of turns per meter. [Note: If you count N loops, and the distance from the first to the last is L, then n=(N-1)/L; e.g., if the distance between adjacent loops is 1m, you have one turn per meter, not two!]

n = __________ [turns/m] $\mu_o n$ = __________ [G/A]

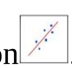
What will be the field inside the coil for the following currents?

If I = 1.5 A, B = __________ [G]

If I = 3.0 A, B = __________ [G]

You will now use the *capstone* software again to perform a *regression* (another name for curve-fitting) on your data.

6. Enter the current and magnetic field data into the computer.
   - Open "212-05 Table 2" from the “212 lab files” folder on your desktop and enter your data from Table 2 in the appropriate column. Enter your data by clicking in the box and typing it in.
   - When all your data has been entered, adjust the scale of the graph if necessary.

7. Fit a curve to the data.
   - Click on the Curve Fit button . You may need the “user defined: f(x)” to define your function.
   - Choose “Linear Fit”. You should now see a line on top of your points and the formula of the fit.
   - Copy the formula given by the computer, substituting in the parameters B and I.

   Formula: B = _b + mI, m=$\mu_o n$______

8. Print your graph.
    - Adjust your graph if necessary to get a good display.
    - Print a copy for you report.
    - Use the standard deviation information you recorded in Table 2 to draw vertical uncertainty bars around each data point on your graph. If they are less than the size of the data point, simply write, "error bars contained within the size of the data points" on the graph.

Q10 Do your measurements agree with your predictions? What does the constant *b* in your fit tell you? From where might this contribution come?

____

____

____

Q11 Does a line fit the data well?

____

____

Q12 Compare the slope of your fitted line, given by the constant *m* with the theoretical value $\mu_o n$ you found in your theory calculation. Calculate a percentage difference.

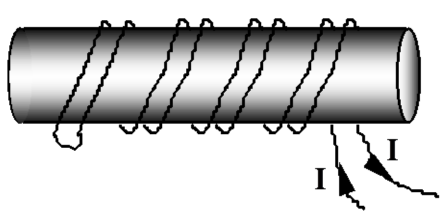
____

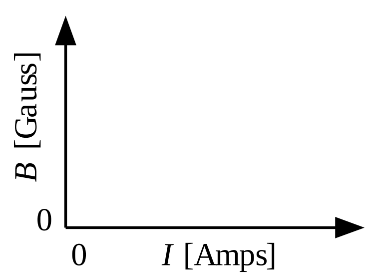
____

Activity 4 Curses! Coiled again!

Let us try another way of winding the coil. This time, we will make a double-wrap coil by laying down a *pair* of wires per wrap.

Prediction Suppose you wrap a wire around a tube and allow current to flow through the wire, as shown below. Now suppose you increase the current while monitoring the magnetic field inside the coil. Predict and plot what will happen.





1. Test your prediction by building this coil.

   - Stretch out the long wire, removing any kinks or bends. Then find the midpoint of this wire, and mark this point by gently folding the wire into a small hairpin (or "U") shape.
   - Build the double-wrap coil around the vacuum hose (if you think the wire is too short, use the steel tube) as shown in Figure 4. Notice that there are five "wraps" on either side of the probe, but since each wrap consists of two wire loops, you will actually see ten wire loops on either side of the probe.

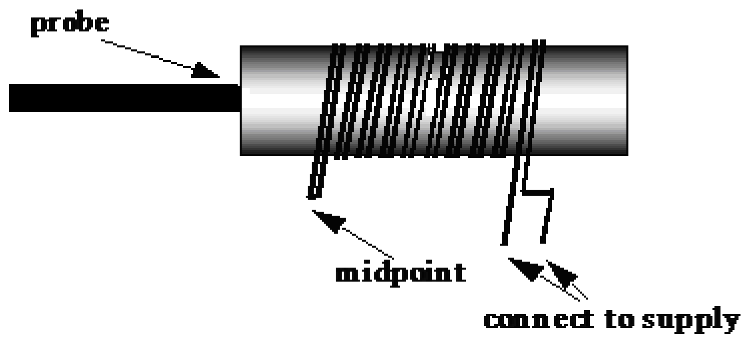


Figure 4. Wiring the double-wrap coil

2. Test out the double-wrap coil.

   - Insert the magnetic field probe into the end of the vacuum hose as in the previous activity.
   - As before, look through the hole in the side of the tube and adjust the probe position so that the Hall Effect element is at the center point of your coil. Hold it steady at this position.
   - Record the readout with no current in the coil, and then don't move the coil or probe until you are done with this activity.
   - Adjust the current to various levels and examine the magnetic field.
   - When you have completed your data collection, set the current to zero amps and turn off the power supply.

Q13 Did your prediction agree with your measurements?

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Q14 what's the advantage of this double-wrap approach?

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____

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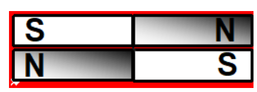
CLEAN UP CHECKLIST

☐ Turn down the current knob, turn off your power supply, and disconnect the wire. Quit any computer programs and do not save the data or calibration. Turn off any other pieces of equipment.

☐ Collect the paper onto which data was taken (and annotated) and attach them to one of the lab reports.

☐ Make your setup look neat for the next group. So as not to ruin the magnets, store them two together, as shown below:



☐ Staple everything together, make sure you have answered all the questions and done all the activities, make sure the first page is completed with lab partners' names and check boxes. Hand in your work before you leave.