Magnetic Field of Current-Carrying Wires

OBJECTIVES

In this lab you will
- Measure the deflection of a compass needle due to a magnetic field of a wire
- Test the relation between current and magnetic field strength
- Calculate the distance dependence of the magnetic field from a wire

You have seen in class how a moving charge will create a microscopic magnetic field. You have also seen how a large number of moving charges (current) will create a macroscopic magnetic field given by:

$$\Delta \vec{B} = \frac{\mu_0}{4\pi} \frac{I\Delta\vec{l} \times \hat{r}}{r^2}$$

You can measure the macroscopic field that comes a long chunk of wire with a compass.

1) Warm Up Problem

Problem 1) What is the direction of the magnetic field at the indicated locations inside and outside this current carrying rectangular coil of wire shown? Explain briefly.

CHECKPOINT 1: Ask an instructor to check your work for credit. You may proceed while you wait to be checked off

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2) Measuring a Magnetic Field with a Compass

a) Get out the following items for this lab:
- A resistor (bulb)
- 3 batteries with holder (you may need to temporarily borrow the third battery)
- 4 alligator clips
- 1 compass

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b) Put away everything else (except your lab manual), so your table is neat and clear.

c) Make a circuit with two-batteries, a resistor and the four alligator clips (Fig. 1). Leave one end of one of the alligator clips unconnected.
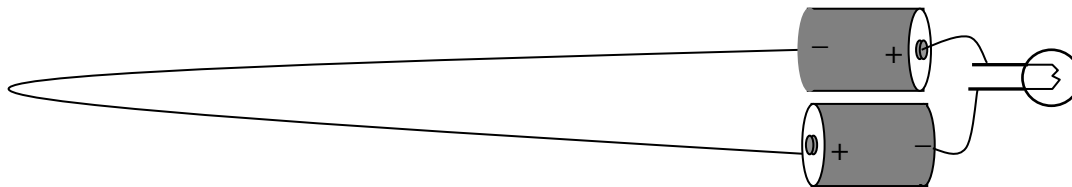

Figure 1. Two battery, short bulb circuit

d) Place your magnetic compass on a flat surface

Make sure the compass is not near steel objects, such as the circuit you just made, and the computer.

e) Once the compass needle settles, align the north marker with the red end of the compass needle.

f) Continue aligning the compass until, at rest, the red end of the needle is aligned with the north marker.

g) Stretch the alligator clip wire out straight, running north-south.

h) Make the last connection.

i) Lift the wire up above the compass. Keeping it stretched out north-south.
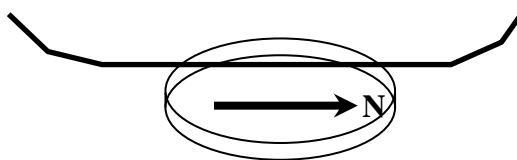
j) Bring the aligned wire down onto the compass (Fig. 2)

Figure 2. Wire parallel to north-south

i. *What is the effect on the compass needle as you bring the wire down on top of the compass?*

ii. *What do you observe if you turn the wire so the current flows in the opposite direction over the compass?*

  iii. What happens when the wire is initially aligned perpendicular instead of parallel to the needle (Fig. 3)?
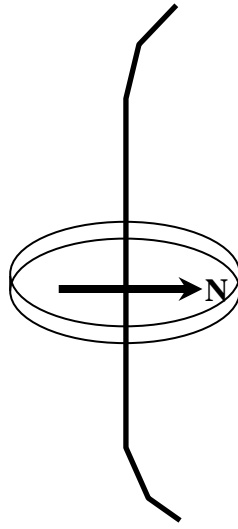
Figure 3. Wire perpendicular to north

  iv. What happens to the compass needle if you disconnect the circuit?

As discussed in the textbook, a compass points in the direction of the net magnetic field at its location. When a current flows through a wire, the moving electrons create a magnetic field everywhere in space. Magnetic fields from the Earth and the current in the wire affect the compass.

 k) Move all wires and batteries far from the compass.

 l) Align your compass with the north marker.

 m) Assemble a circuit consisting of one battery, one resistor and three alligator clips, keeping one connection undone so as not to discharge the battery.

 n) Align the wire carefully with the compass needle then make the connection.

 o) When current is flowing through the circuit, carefully measure the compass deflection (to the nearest 2 degrees).

 p) Show in detail your calculation of the magnetic field from the current in the circuit. Include a clear vector diagram.

Note: At this latitude, the horizontal component of *the Earth's magnetic field is approximately 2 x 10^{-5} T.* If you cannot remember the physics behind this calculation, page 675 (4th edition) of your book has the details.

CHECKPOINT 2: Ask an instructor to check your work for credit. You may proceed while you wait to be checked off

3) The Current Dependence of the Magnetic Field from a Long Wire

In order to test the effect of the size of the current on the magnetic field, you will need to construct three circuits, each with a different amount of current. The current flowing in the circuit can be read off from the multimeter which will be used as an ammeter connected in series. The more batteries you use in a circuit the more current will flow. **The three circuits you construct will have one resistor, the necessary number of alligator clips, a multimeter connected in series, and one, two or three batteries.** You will make comparisons between measurements, so it is crucial that you keep things consistent for each measurement.
- Always align the compass before each measurement.
- Always make sure circuit elements, other than the long wire, are away from the compass.
- When reading your measurement, always look directly down on the compass.
- Always place the long wire directly on the face of the compass.
- For a set number of batteries, always make two measurements disconnecting the circuit and aligning the compass between each measurement.

Record your observed values in the table below. In your work space clearly show all your work.

Circuit	Deflection (degrees)	Deflection (degrees)	Average Deflection (degrees)	Average $\|\vec{B}\|$ (Tesla)	Current (mA)	Current (mA)	Average Current I (mA)
1. One battery							
2. Two batteries							
3. Three batteries							

i. Plot a graph of Magnetic Field (B) versus Current (I). What does the relation look like?

CHECKPOINT 3: Ask an instructor to check your work for credit. You may proceed while you wait to be checked off

4) The Distance Dependence of the Magnetic Field from a Long Wire

You just saw how the magnetic field depends on the current in a wire. The strength of the magnetic field also depends on the distance from the wire. In the following experiment you will not only attempt to observe the dependence but also find the exact form of the magnetic field's distance dependence.

To find this dependence you will hold the wire, running north-south, above the compass at varying heights. You will measure the height when the compass deflects by a specific amount (40, 30, 20, and 10 degrees). These deflections correspond to specific magnetic field strengths. You will measure the distance between the wire and the compass needle several times for each specific deflection. You will average those distances and thus have a data set of field strength at a given distance. Even more so than in your last experiment, consistency is crucial.

- Always align the compass before each measurement.
- Always make sure circuit elements, other than the long wire, are away from the compass.
- When reading your deflection measurement, always look directly down on the compass.
- When finding your distance measurement, always measure from the height of the compass needle
- For a set deflection, always make three measurements disconnecting the circuit and aligning the compass between each measurement.

a) **Assemble a circuit with just one battery and the alligator clip wires (no resistor). Do not make the connection until you are ready to take a measurement. DISCONNECT THE BATTERY IMMEDIATELY AFTER EACH MEASUREMENT, AND DO NOT RECONNECT IT UNTIL YOU ARE READY FOR THE NEXT MEASUREMENT.**

There is a blank table for your data on the next page.

b) Record your data here.

Compass Deflection (degrees)	Calculated $\left|\vec{B}\right|$ (T)	Distance From Wire (m)
40		.
40		
40		
40		
30		
30		
30		
30		
20		
20		
20		
20		
10		
10		
10		
10		

c) Put the averages of your measurements in this table.

Average Distance From Wire (m)	Calculated $\left|\vec{B}\right|$ (T)

You will use a logarithmic plot of your observations to extract the distance-dependence.

It is a reasonable assumption that the magnitude of the magnetic field due to the current in the wire is proportional to a constant times distance raised to an unknown power.

$$\left|\vec{B}\right| = Kr^n$$

Here K and n are both constants. You are trying to find n. n determines the distance dependence.

$$\text{If } n=-1/2 \text{ then the distance dependence is } \frac{1}{\sqrt{r}}$$

$$\text{If } n=-2 \text{ then the distance dependence is } \frac{1}{r^2}$$

$$\text{etc.}$$

One would expect, and you should have observed, the magnitude of the magnetic field decreases with distance, so *n* should be a negative number.

From a plot of B vs. r, it is difficult to find your experimental value of n, unless you use curve-fitting software. However, if you take the logarithm of both sides of the assumed equation, you'll get:

$$\ln\left|\vec{B}\right| = \ln(Kr^n)$$

$$\ln\left|\vec{B}\right| = \ln(K) + \ln(r^n)$$

$$\ln\left|\vec{B}\right| = \ln(K) + n\,\ln(r)$$

ln(B) and ln(r) both vary, but ln(K) and n are constant. If you think of ln(B) as the y variable, ln(r) as the x variable, and ln(K) as a constant, this equation becomes an simple linear equation with n as the slope.

$$\ln\left|\vec{B}\right| = \ln(K) + n\,\ln(r)$$

$$y = C + n\,x$$

If you plot of ln(B) vs. ln(r) you should get a straight line with slope n and ln(K) intercept.

d) Use Excel to make this plot and find n.

e) Record the value of n you calculate.

   i. To what type of distance relation does your value of n correspond?

  ii. You may already know what the theoretical prediction for n is for a long straight wire. Do your experiments agree?

f) The y-intercept depends on which two physical parameters? Does the value of the y-intercept agree reasonably well with what these two values should be?

CHECKPOINT 4: Ask an instructor to check your work for credit.