Magnetic field of current-carrying wires

Recorder__________________________________ Manager__________________________________

Skeptic__________________________________ Energizer__________________________________

1 Observe a compass deflection due to a magnetic field

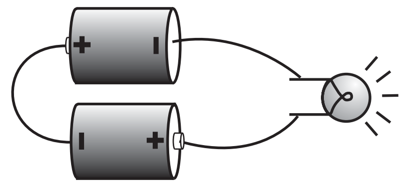


Figure 1 Use 2 batteries and a round bulb

Make a two-battery circuit with a ROUND bulb in a socket, using a battery holder, as shown in Figure 1. Place your magnetic compass on a flat surface under one of the wires (Figure 2). Keep the compass away from steel objects, such as the steel-jacketed batteries, and the alligator clips on the ends of your wires. If you are working on a steel table, you may need to put the compass on a thick book. (For flexibility in placement, you may find it useful to make a long wire by connecting two of your wires together.)

Align the compass so the arrow on the plastic case is aligned with the needle, which is pointing North.

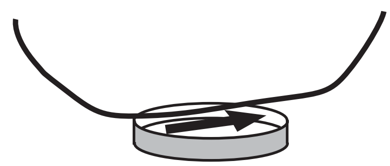


Figure 2 Wire aligned parallel to North

Connect the circuit so that the bulb glows, and do the following:
- Lift the wire up above the compass.
- Orient a section of the wire to be horizontal and lined up with the compass needle. (Using a long wire may make it easier to do this.)
- Bring the aligned wire down onto the compass (Figure 2).

(1.a) What is the effect on the compass needle as you bring the wire down onto the top of the compass? As you move the wire up and away?

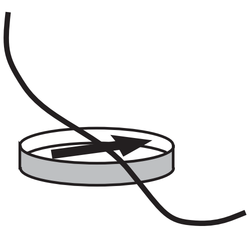


Figure 3 Wire aligned perpendicular

(1.b) Turn the wire $180°$, so the current flows in the opposite direction over the compass. What do you observe? How is this different from (a)?

(1.c) What happens if you put the wire parallel to the needle, but under the compass instead of on top? What does this imply about the pattern of magnetic field around the wire? (Look at the cover of the textbook.....)

(1.d) What happens when the wire is aligned perpendicular instead of parallel to the needle (Figure 3)?

(1.e) Break the circuit, so the light bulb is not glowing, and repeat measurement (1.a). What happens?

2 Quantitative measurement of magnetic field made by moving electrons in a wire

A compass points in the direction of the net magnetic field at the location of the compass. A compass placed under a current-carrying wire is affected by magnetic fields from two sources: (1) the Earth, and (2) the moving electrons in the wire.

(2.a) Move all wires and batteries far from the compass, so the compass points North. Continue using two batteries and one round bulb. Make sure the bulb lights, then disconnect the circuit. Align one wire carefully with the compass needle, then connect the circuit. Don't move the compass! Carefully measure the compass deflection (to the nearest $2°$) when current is flowing through the circuit.

Show in detail your calculation of the magnetic field made by the current in this circuit. Include a clear vector diagram. At this latitude, the horizontal component of the Earth's magnetic field is approximately 2×10^{-5} T.

vector diagram (show and label 3 vectors)

calculation of magnetic field due to current

Check with a neighboring group, then both groups check with instructor.

3 Distance dependence of the magnetic field of a long, straight current-carrying wire

You will need *one* *battery, two clip leads, a compass, a meter stick and a ruler, and a long wire (~ 1 m).*

(3.a) As accurately as you can, measure the distance dependence of the magnetic field due to a current in a long straight wire. Make sure that the straight segment of the long wire is ***at least* 60 cm long and tape it to a meter stick**. ***Using one battery and no bulb, first find a distance ABOVE the compass that produces a 40 degree deflection.*** We will call this distance r_{40}. Make and break the connection to the battery, to be sure you are observing a genuine deflection each time. Make and record 3 measurements of the distance. ***Don't leave the circuit connected for a long time, or you will run down the battery!***

Next, make three measurements at 1.5 times the average value of r_{40}, and three more at 1.75 times the average value of r_{40}, and three more at 2 times the average value of r_{40}. At each distance, compute an average value for the magnetic field.

Distance above compass (m)	Compass deflection	calculated $\lvert\vec{B}\rvert$	average $\lvert\vec{B}\rvert$
r_{40} =	40°		
r_{40} =	40°		
r_{40} =	40°		
$r_{40,\text{ average}}$ =			
$1.5(r_{40,\text{ average}})$ =			
$1.5(r_{40,\text{ average}})$ =			
$1.5(r_{40,\text{ average}})$ =			
$1.75(r_{40,\text{ average}})$ =			
$1.75(r_{40,\text{ average}})$ =			
$1.75(r_{40,\text{ average}})$ =			
$2(r_{40,\text{ average}})$ =			
$2(r_{40,\text{ average}})$ =			
$2(r_{40,\text{ average}})$ =			

What was the length of the straight section of the wire you used to make these measurements? ______________________

(3.b) A simple and useful approach to extracting a distance dependence from your experimental data involves making a logarithmic plot of your observations. Here is why:

Assume that the magnitude of the magnetic field due to the current in the wire is proportional to some constant times some power of the distance. We can write this dependence as $|\vec{B}| = Kr^n$. We expect the magnitude of the magnetic field to decrease with distance, so n should be a negative number. For example, if $|\vec{B}| = K(1/r^2)$, then $n = -2$, and so on. You may already know what the theoretical prediction for n is for a long straight wire.

From a plot of $|\vec{B}|$ vs. r, it is difficult to tell exactly what your experimental value of n is, unless you use curve-fitting software. However, if we take the logarithm of both sides of the initial equation, we get:

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

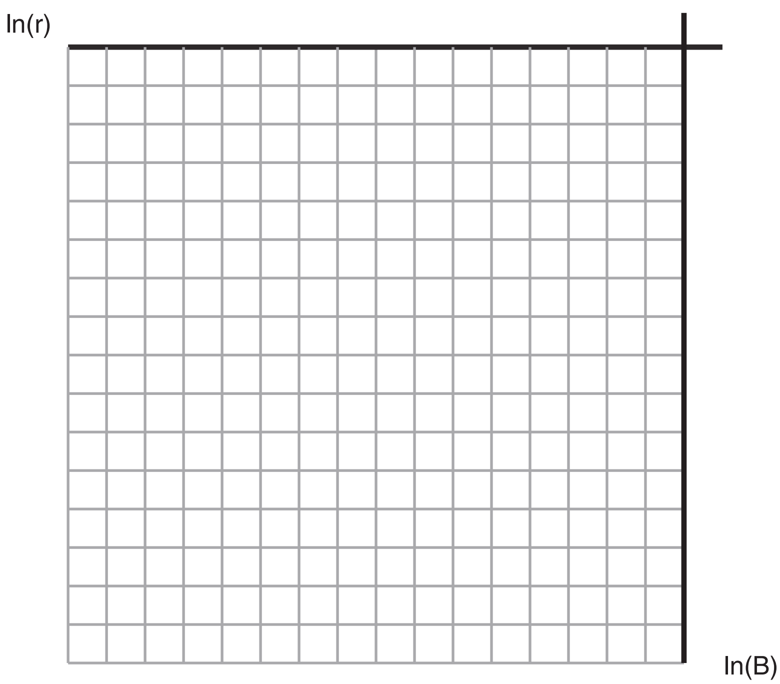
Since $\ln(|\vec{B}|)$ and $\ln(r)$ vary, but n is a constant (and K is also constant), this plot will give a straight line with slope n (and intercept $\ln(K)$).

You could of course also use the base 10 logarithm, but on most calculators it is easier to use the natural log.

Enter your data here, using average values for B and r:

r	$\ln(r)$	$\lvert\vec{B}\rvert$	$\ln(\lvert\vec{B}\rvert)$

Plot your data CLEARLY here. Use as much of the graph as possible (don't jam all the data into a corner):



label axes (need not start at zero)

On the graph use a straightedge to draw the best straight line you can through all your data points. Show in detail how you calculated the slope:

Your finding: $|\vec{B}| \propto r^n$, where n = ____________________

Make sure that everyone in the group agrees on the results.
Check with another group, then give to instructor to grade.