

EXPERIMENT 10: MAGNETIC FIELDS

Introduction: In this lab, you will use compasses and iron filings to investigate the magnetic field of a bar magnet and the magnetic field of a long straight current.

The magnetic field is our way of describing the condition of space around a bar magnet or around any moving charge, such as the moving charges in a current. If a magnetic field exists at a certain point in space, any point charge q moving through that point in space will experience a magnetic force which is perpendicular both to the direction of the magnetic field and to the direction of the velocity of the moving charge.

The direction of the magnetic field at any point in space can be measured by placing a small compass at that point; the N pole of the compass will point in the direction of the magnetic field. Pictorial representations of magnetic fields are usually produced by drawing magnetic field lines. The field line passing through any point in space must be parallel to the magnetic field at that point. Small arrowheads are usually drawn on the field lines to indicate the field direction. Since the field can only point in one direction at one point in space, field lines can never cross. Magnetic field lines always make complete loops, and field lines are closest together where the magnetic field strength is largest.

Magnetic field strength is measured in units of $(N/C)/(m/s)$. This combination of units is called a tesla (T) to honor Nikola Tesla, a 20th century physicist famous for his work on electromagnetic induction. The Earth's magnetic field at the location of Tempe points roughly towards geographic North with a strength of about 20-50 μT . Inside a modern steel-frame building, the ambient field can vary significantly from the Earth's field at that location. The field strength near the end of a common bar magnet is typically hundreds of times larger than the field of the Earth.

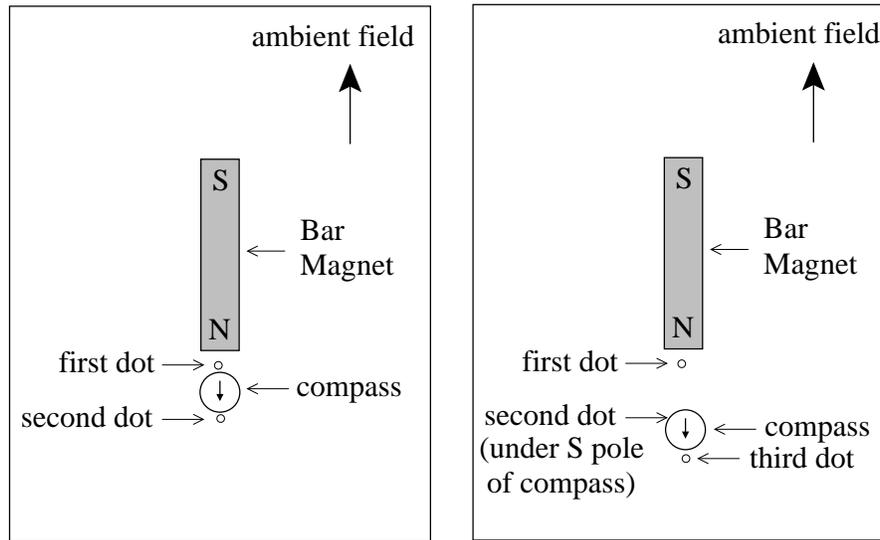
Part One

You will first use a small compass, and then iron filings, to trace the magnetic field lines of a bar magnet.

Procedure

1. Tape a sheet of paper to your lab table with the long edge of the paper parallel to the ambient field direction at your location. When using the compass to determine the ambient field direction, make sure that all bar magnets are far away.
2. Center a bar magnet on the paper with its south-seeking pole pointing in the direction of the ambient field at your location. Trace the bar magnet on the paper, then remove the magnet so that you can indicate on the paper the S and N pole locations of the magnet, and finally replace the magnet.

- Use a small compass to trace a magnetic field line for the bar magnet. The procedure for line tracing is described in steps 4-7 and indicated in the figure below.



- Place the compass close to the north-seeking pole of the bar magnet (not directly on the centerline). Make two dots on the paper, one on either side of the compass and aligned with the compass needle.
- Move the compass so that the south-seeking pole of the needle is directly over the second dot. Make a new dot exactly in front of the north-seeking pole of the needle.
- Repeat step #5, moving the compass so that the south-seeking pole is over the most recently drawn dot, then making a new dot just beyond the north-seeking pole. Stop when you get back to the bar magnet or when you hit the edge of the paper.
- Draw a smooth curve through the dots. Use several arrowheads along the curve to show the direction of the magnetic field. You have now completed one magnetic field line outside of the bar magnet; inside of the bar magnet, the field line continues to form a complete loop.
- Repeat steps 4-7 until you have completed enough field lines to form a reasonable map of the magnetic field of the bar magnet. Four lines on each side of the magnet is a good choice; two of the four lines should stay relatively near to the side of the magnet and two should venture relatively far from the side of the magnet.
- Finally, cover the bar magnet with a sheet of glass, and cover that with a second sheet of paper. There is a low cardboard stand in which to place the magnet so that it is nearly touching the glass. Sprinkle a thin, even layer of iron filings over the paper, tapping lightly as you sprinkle. Use a pencil to sketch the magnetic field lines on the paper as shown by the iron filings (a pencil is more convenient than a pen for tracing through the filings).

Part Two

The magnetic field lines due to a long straight current make circles around the current, with the current at the center of those circles. The direction of the magnetic field due to the current is given by a right-hand rule. Grab the current with your right hand and with your thumb in the current direction; the curled fingers of your hand indicate the field direction. The magnetic field strength B due to the current I is proportional to the current, but inversely proportional to the distance r from the current. In symbols,

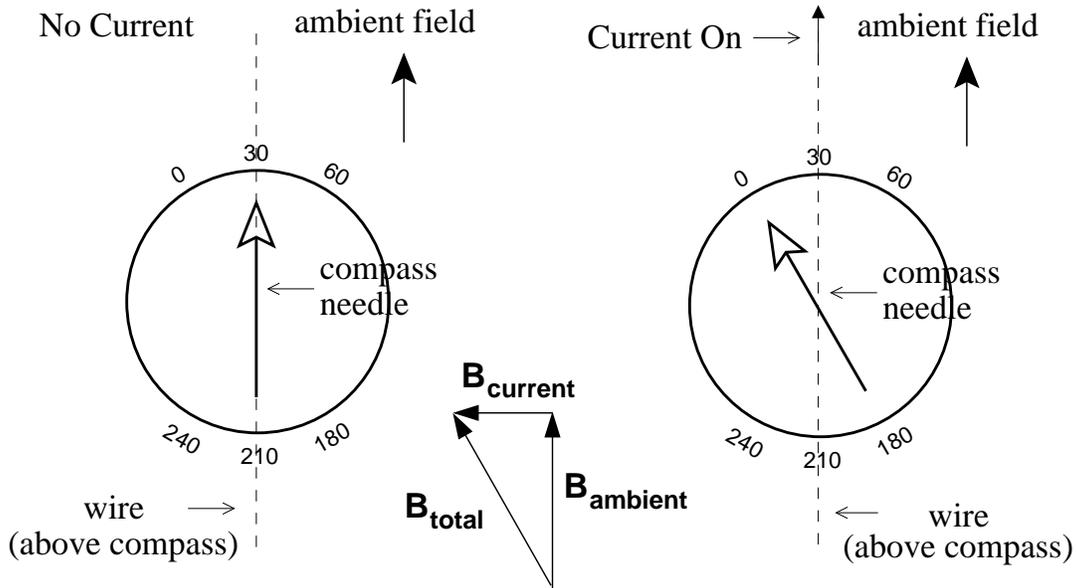
$$B \propto \frac{I}{r}.$$

You will measure the current I required to give a constant value of B at three different values of r . You will determine B relative to the ambient field strength. We will arrange that the field due to the current is perpendicular to the ambient field. In this way, if the field due to the current is equally as strong as the ambient field, then a compass needle will point at 45° (the direction of the total field will be halfway between the directions of the two component fields). Doing so would require large currents which would cause the wires to get dangerously hot, so instead we will adjust the current until the compass needle points only 30° away from the ambient field direction.

Procedure

1. Remove all bar magnets from your lab table. Place a medium-sized compass on your table, far from any power supply. For the compasses provided, the compass needle is then 4 mm above the table. With no nearby currents or magnets, the compass indicates the direction of the ambient field. Adjust the dial of the compass so that, when the compass is pointing in the ambient field direction, the needle is aligned with the 30° - 210° direction of the dial. In this way, when we use a current to deflect the needle by 30° , it will point exactly in the N-S alley of the compass dial (making the 30° deflection easy to see). THE REST OF THIS EXPERIMENT MUST NOW BE PERFORMED WITHOUT TOUCHING OR MOVING THE COMPASS IN ANY WAY.
2. Tape a wire, a part of a long circuit, to the center of a plastic ruler. For the provided wires, this makes the center of the wire 7 mm above the bottom of the ruler.
3. You will be supplied with some one cubic centimeter blocks, which you can use to construct stable supports of heights 1 cm, 2 cm, and 3 cm. Use two 1 cm supports to place the ruler, with the wire taped to its center, directly over the compass; the distance between the center of the wire and the compass needle should now be 1.3 cm. The wire direction must be exactly in the ambient field direction. The wire connections

should be made so that, when the current is turned on, the current will flow in the ambient field direction. You should be able to clearly see the compass by looking down through the clear plastic ruler. The compass should be at the midpoint of the ruler and the wire should be directly over the compass needle. See the left side of the figure below.



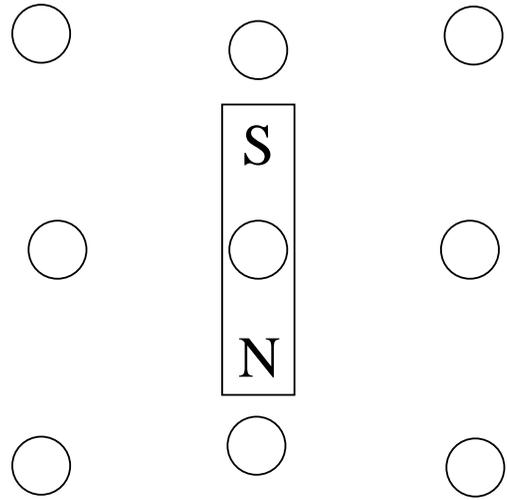
With the current on, the ambient field plus the field due to the current equals the total field. The needle always points in the direction of the total field.

4. With the power supply at its lowest setting, turn on the power switch. Your circuit will have been set up with a digital multimeter with which you can read the current I in the wire. Slowly and gently increase the power supply voltage until the needle has been deflected by 30° . See the right side of the figure above. Record the resulting current in Data Table 10.1. Decrease the power supply voltage to zero. Turn off the power switch.
5. Repeat steps #3 and #4 with 2 cm supports and with then with 3 cm supports. In these two cases, the distances between the needle and the wire center should be 2.3 and 3.3 cm, respectively.
6. To test the repeatability of your measurements, now take an additional set of readings with each set of supports. Record this second set of readings in Data Table 10.1. Your two sets of readings should be reasonably similar. Average the two readings for each support height and record those three average values in Data Table 10.1.

Results

1. Draw a compass needle in each of the empty circles to represent the approximate direction of the magnetic field at each of those locations. The circle at the center represents INSIDE the magnet. The field at that location can only be deduced; it cannot be measured.

2. In your drawings for the field of the bar magnet, where are the field lines closest together? Where are they farthest apart? What is the significance of a concentration of field lines?



3. Make a graph of the average I 's versus the distances from Data Table 10.1. Draw a straight "line of best fit" which, as nearly as possible, passes through the three points on your graph. Use your line to determine the three values of I which you would have measured at our three selected distances had the proportionality between distance and current been exact in your experiment. Record these three values of I in Data Table 10.1.

4. Find the percent differences between the three I values from the line in your graph and the three average values of I . Write these three percent differences in Data Table 10.1 and show a sample calculation in the space below.

5. Are you able to conclude, from your data and analysis, that in order to produce a constant value of magnetic field strength at various distances from a long straight current, the required current is proportional to the distance from the wire? Why or why not?

Guide to Symbols in the Table

I_1 = first set of current measurements I_2 = second set current measurements
 I_{avg} = average of I_1 and I_2 $I_{from\ line}$ = I 's taken from line on graph
 % difference = $100\% \times |I_{avg} - I_{from\ line}| / (\text{average value of } I_{avg} \text{ and } I_{from\ line})$

Data Table 10.1

supports	distance (cm)	I_1 (A)	I_2 (A)	I_{avg} (A)	$I_{from\ line}$ (A)	% difference
1 cm	1.3					
2 cm	2.3					
3 cm	3.3					

