Magnetic Dipoles and Quadrupoles

Objectives

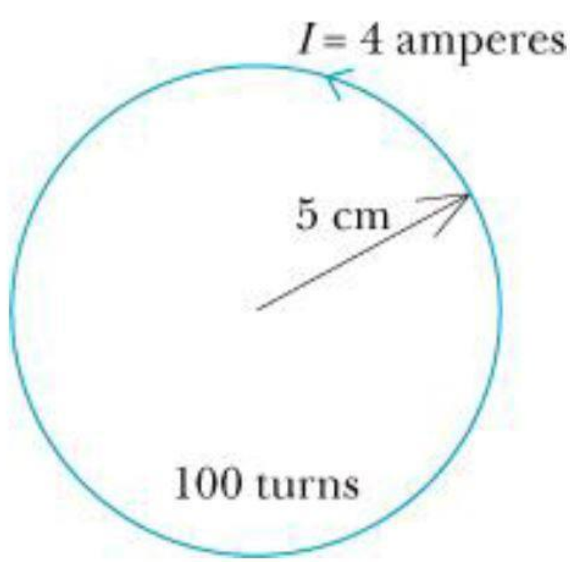
In this lab you will:

- Measure the magnetic field of a circular loop of wire and a bar magnet throughout space.
- Verify the cylindrical symmetry of the fields of both the loop and magnet.
- Measure the distance dependence of the magnitudes of the fields of both the loop and magnet.
- Calculate the dipole moments of both the loop and magnet.

From lecture you are familiar with the magnetic field created by a current loop as well as by a bar magnet. They may seem to be different phenomena, however, after comparing their magnetic fields, you will see that they are in fact very similar. You will then compare these two objects by calculating their dipole moments.

1: Warm-Up Problem

A thin circular coil of wire of radius 5 cm consists of 100 turns of wire, as shown. If the conventional current in the wire is 4 amperes, and runs in the counter clockwise direction, what are the magnitude and direction of the magnetic field at the center of the coil?



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

2: Measuring the Magnetic Field on Axis

You should find a PASCO 850 Universal Interface and PASCO PS-2612 2-axis Magnetic Field Sensor on your lab table. The sensor detects magnetic fields either along the direction of the probe (axially) or perpendicular to the direction of the probe. The precise locations of the sensors are indicated by the white dots. For this lab, you will only need the axial mode. Download the PASCO Capstone workbook "Lab 7" from Blackboard under Lab 7 folder which is set to take data from the magnetic field probe. You will also need the following:

- One red banana plug wire
- One black banana plug wire
- One wire coil
- One bar magnet (don't get the magnet until you are ready for it)
- One meter stick

Make your table neat and clear. Then attach the red and black banana plug wires to the red #1 and black #1 output of the Universal Interface. Plug one of these banana clip wires into the coil, but leave the other unattached. Make sure the axis of the coil is oriented parallel to the table. Put your coil at the end of the meter stick so that the meter stick is along the axis of the coil.

You will take a variety of measurements of the magnetic field of the coil after you complete the circuit. We will walk you through the first measurement in detail. Use the same procedure for all the other measurements.

(a) Place the magnetic field sensor above the meter stick, with its probe aligned with the axis of the coil. Hold it so that the tip of the probe is above the 10 cm mark on the meter stick.

(b) Hold the "Tare" button on the probe down for several seconds. (This will tell the probe to ignore Earth's magnetic field, and only measure deviations from that.)

(c) Make the final connection to complete the circuit.

(d) Click on the "Signal Generator" menu option on the left hand side of your Capstone workbook.

(e) Under "850 Output 1" click "On". Current is now running through your circuit.

(f) Click the "Signal Generator" button again to close the Signal Generation menu.

(g) Hit the "Record" button on the bottom of the workbook. It will turn into the "Stop" button. Make sure that your coil is orientated so that the recorded magnetic field is positive.

(h) Record data for several seconds.

(i) Hit the "Stop" button to stop recording data.

(j) Click the "Signal Generator" button again.

(k) Under "850 Output 1" click "Off".

(l) Disconnect one banana wire from the coil. Current is no longer running through your circuit.

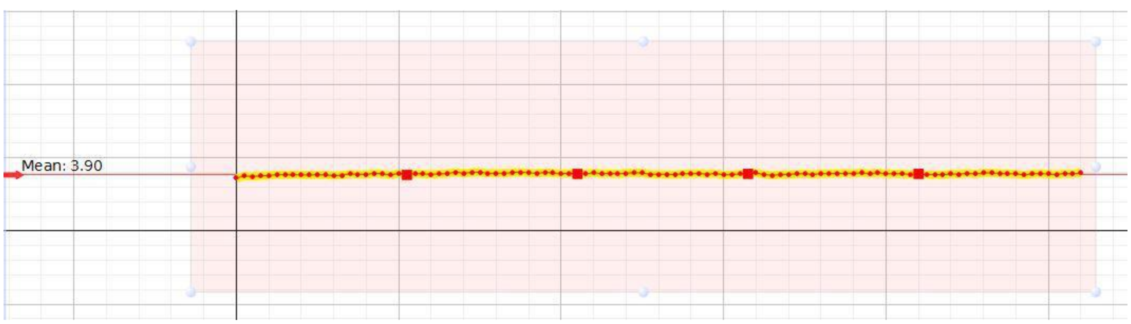
The probe takes measurements several times per second while you are recording. To get your best estimate of the true value of the magnetic field, you will need to average all of the data points. The Capstone workbook can do this for you. We will also walk you through that procedure.

(m) Click the highlighter tool in the graph menu near the top of your workbook. (It is a button with three blue dots and one yellow rectangle.) This will create a transparent colored rectangle.

(n) Drag the rectangle over the data points you want to include in the average. (All of them in this case.)

(o) Click the red statistics tool in the graph menu. (It is a button with a large red capital sigma.) This will cause the mean to appear near your data points.

(p) If needed, drag the data away from where the mean is written so you can read it. Do this by clicking and holding on an empty part of the graph and dragging to the right.



Your averaging process should look something like this

(q) Record the value of the average and the distance of the probe from the center of the coil. Save these values.

(r) His the "Delete Last Run" button to reset your graph.

The tools you need to average data

You will use this same procedure on all future measurements. You don't need to turn the signal off and disconnect the circuit between measurements that you take immediately one after the other. But make sure you do once you stop taking measurements. Ask your instructor for assistance, if required.

3: Finding the Distance Dependence of On-Axis Magnetic Field

Now, you will use the Capstone workbook to determine the distance dependence of the magnetic field on the axis of the coil and the bar magnet and simultaneously measure their magnetic dipole moments.

A) Current-Carrying Coil

(a) With the procedure of the previous section, take other measurements of the magnetic field at whatever distances from the coil you want. It is up to you to decide how many measurements and at which distances they should be measured at, but you should think about both and decide what is justified.

(b) Fill in the table on workbook page #2 with the distances and corresponding magnetic field values you measure.

(c) Also measure the field at a few points on the opposite side of the coil to verify that the magnitude of the magnetic field is symmetric about the coil. (You'll have to reposition the meter stick to accomplish this.) Do not include these values in the fitting later on. The fitting will assume a positive value of the magnetic field and a positive distance.

(d) Turn off the signal and disconnect the circuit.

(e) On "Page #2", you should now have all the distances and magnetic field values you measured on one side of the coil.

(f) Highlight the data points that that you wish to fit to the inverse power law.

(g) Press the arrow next to the curve fitting tool. (It looks like a red line surrounded by blue dots.) In the menu, select **"Inverse Power"**. Make sure that your magnetic field and distances are positive, and think about which regions the fitting function is valid over.

(h) Record the values of the parameters of the fit.

As you know from lecture, a current-carrying coil can be approximated as a dipole whose on-axis magnetic field is given by:

$$B_{axis} = \frac{\mu_0}{4\pi}\frac{2\mu}{r^3} \tag{1}$$

μ is called the magnetic dipole moment of the dipole

The "Inverse Power" fitted parameters are n, A, B and x_0. Comparing the fitting equation with equation (1), what is A? what are the units of A from the fitting equation? Convert A into SI units.

Using the value of A from the fitting equation (with the correct units) and $\frac{\mu_0}{4\pi} = 10^{-7}$, calculate the magnetic dipole moment of the coil.

Using the value of μ from above, estimate the current running through the coil. Does your estimate seem reasonable? (Hint: think about the relationship between the magnetic dipole moment of a coil of a given cross sectional area and turns and current running through it.)

What values do you expect for n, B and x_0? Do the values of the fitting parameters match with what you expect?

Theory would tell us that n should be 3, as long as the distance from the coil is much larger than its radius.

Do you get better agreement if you leave the data taken near the coil out of the fit (by adjusting the transparent rectangle)? If so, why?

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

B) Bar Magnet

(a) Get the bar magnet

(b) Repeat all your measurements for the magnetic field at the same distances as the coil. Record your data in the same way again on page #2.

(c) Make sure to "Tare" the magnetic field sensor after each measurement while keeping the bar magnet away.

(d) Perform a best fit for "Inverse power" as before.

Compute the magnetic dipole moment of the bar magnet. How does the result for the bar magnet compare to that for the coil?

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

4: Magnetic Field Off Axis

(a) Hold the meter stick up vertically behind the magnet.

(b) Hold the probe horizontally above the center of the magnet. At a height equal to the distance from one of your measurements. (Keep in mind that the center of the magnet is no longer at the 0 of the meter stick. The distances are offset by the radius of the magnet.)

(c) Take data and average it.

How does the magnitude of the magnetic field here compare to the value on the axis of the magnet, the same distance away? How about the direction?

Checkpoint 4: Ask an instructor to check your work for credit. You may proceed while you wait to be checked off.

5: Magnetic Field of a Magnetic Quadrupole

(a) Make a magnetic quadrupole by placing two bar magnets together with their long sides touching, but N and S poles reversed (so one bar magnet's south pole is adjacent to the other's north pole and vice versa). You may have to share magnets with other groups, if you do, go ahead and work on the final problem first and do this section afterwards.

(b) Repeat the distance measurements of the magnitude of the magnetic field at various distances away from, but along the central axis, and record them on page #3 of the capstone workbook.

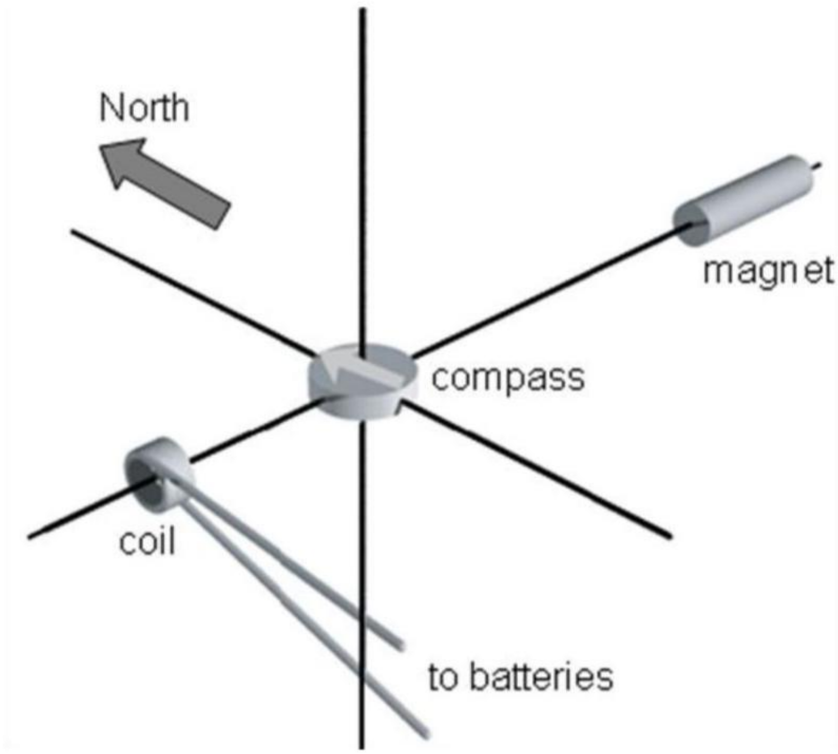
(c) Fit it with the same inverse power law.

Before you fit, think for a moment - should the quadrupole fall more or less rapidly with distance compared to the dipole? Does the result of the fit match your physical intuition?

Checkpoint 5: Ask an instructor to check your work for credit. You may proceed while you wait to be checked off.

6: Final Problem

A coil of wire with 12 turns of radius 0.01m is connected to a battery. Conventional current of 6A runs through the coil. The coil is 0.11m away from a compass (see diagram below). A bar magnet lies along the opposite axis with its center 0.25m from the compass. The compass needle points North. What is the magnetic dipole moment of the bar magnet?



Checkpoint 6: Ask an instructor to check your work for credit.