University Physics 2: PHYS222

Lab 10: Magnetic Fields at the Center of a Loop

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October 26^{th}, 2021

1 Introduction

A question that was posed in the 1990's was whether or not intense magnetic fields can cause harmful affects to the body (a question that is still around today being tested). This question arose due to people noticing all the different kinds of work environments the human body is not subjected to. A few years after the industrial revolution (1760's), people began to question what affect does the loud noise and working conditions have on the human body. From this, they made regulations, and so on. (If you are reading this, the assignment is a Group Lab report).[1] So, one team decided to test the affect of strong-magnetic fields that simulate working conditions (such as at *Intel*). They decided to produce a magnetic field that was created by a coil of N loops, and measure the magnetic field $\mathbf{B}$ at some point P a distance $\mathbf{r_p}$ away[2].

?| What is the magnetic field produced by one coil of wire along its axis?

Equipment:

- Coil (of wire)
- Power supply
- Compass
- Field Probe, Logger Pro and Computer
- Field Probe Holder

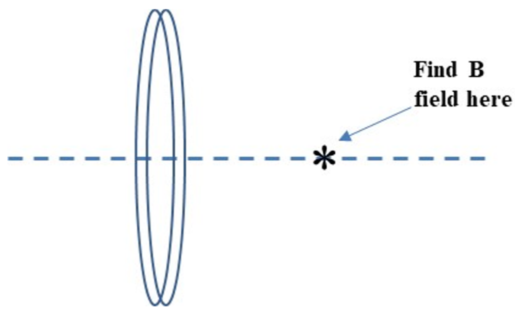


Figure 1: Some loop of wire with current I around a point P.

2 Prediction

Given the number of loops, N, the current in each loop, I, and the radius of each loop, R, calculate the magnetic field at some position on the axis of the loop (see diagram above). Your answer can also depend on a

[1] This is to see who read through the entire lab.

[2] If you would like to learn more, the link is: https://pubmed.ncbi.nlm.nih.gov/10207957/.

symbol which indicates the position along the axis (as measured from some place that you get to choose).

Make a rough graph of the field versus position along the axis.

3 Pre-Lab Questions

1. Draw a diagram of the problem and label all of the known quantities.

   (a) Identify the position, p, where you are going to calculate the magnetic field.

2. Make an educated guess. Should **B** get bigger or smaller with R? What about with the number of loops N?

3. Not really a question; just some background info that you may have seen before: To find the magnetic field produced by a steady current in one loop, along the loop's axis, use the Biot-Savart law,

$$\mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi} \int_S \frac{I d\ell \times \hat{\mathbf{r_p}}}{\mathbf{r_p}^2}. \tag{1}$$

4. Set up your integral:

   (a) Identify and label $d\ell$ and $\hat{\mathbf{r}}_p$ on your diagram, and then find/calculate *symbolically* what $d\ell \times \hat{\mathbf{r}}_p$ is for this situation. Remember that it has a direction and a magnitude. You must find both.

   (b) What will your integration variable be?

   (c) Replace r_p with those relevant quantities in your diagram.

(d) Determine if there is a symmetry which cancels out the x or y component of the total field.

5. Perform the integration:

   (a) Pull out the things in the integral (constants) which do not depend on your variable of integration. (*Hint: what changes as you go from on piece of current $d\ell$ to another? Is the distance constant or the angle?*)

   (b) Perform the integral after determining the limits. The limits are determined by the configuration of the current.

6. Evaluate your answer"

   (a) Do the units work?

   (b) Does your equation give the correct behavior for **B** compared to your educated guess? (*Hint: recall last weeks lab CYU question one.*)

4 Exploration

Set up your coil. Hook up (but do not turn on) the power supply. Use the ± outputs from the power supply, and hook them into the inputs of the coils.

On the power supply, turn the "current" dials all the way down (counter clockwise) and turn the voltage all the way up (clockwise). This will allow you to use the power supply as a "current supply" – you turn up the current to a desired amount. Don't touch the voltage dial....the voltage will adjust automatically to respond to your request.

Now, turn on the power supply. You can use the current dials to increase or decrease the current to the coils. You may want to hook up the ammeter to measure the current going through the coil because the ammeter on the power supply may not be accurate. Please also note that you should **NOT EXCEED** about three Amps in the coils.

Before using the Magnetic Field Probe to measure the field, explore the direction of the field by using the **compass**. Which way does the field point on the inside of the coils? Which way does the field point on the outside of the coils? Based on your results, which of the following is the BEST summary:

- the magnetic field points away from the current
- the magnetic field points toward the current
- the magnetic field wraps around currents; not pointing toward the wire or away.

Next, setup your magnetic field probe. Plug the magnetic field probe into the *LabPro* if it is not already.

You may occasionally have to "zero" the probe. If there is no current in the coils then the probe should be reading zero (unless there is a source of magnetic fields somewhere nearby). If it does not read zero, "zero" it.

Leaving the magnetic field probe at one spot, find the magnetic field (magnitude and direction). Then, reverse the current (but leave it at the same magnitude) in the coils. What happens to the reading on the field probe? Explain why the field probe's reading changes the way it does.

5 Data, Results, and Analysis

Now, keeping the above facts in mind, take measurements of the magnetic field at various positions along the axis of the coils. To improve accuracy, I suggest that you use the clamps and supports and attach the magnetic field probe to them. This way you can easily adjust the probe's distance from the center and (1) keep the orientation of the probe fixed as well as (2) on axis.

From time to time, you may need to re-zero the probe.

Make a graph of measured magnetic field versus position and compare it to your prediction (You should use Microsoft Excel to graph your data points). If your predicted graph does not resemble the measured graph, you will need to redo your prediction or check your measurements.

In your prediction, you chose the position p to be either (1) on the right side of coil, or (2) on the left side of coil. Is the field symmetric? Do those each give the same value?

6 Conclusions/Summary

Can you predict the magnetic field produced by one coil of wire on its axis?

Make a sketch of the coil as shown on page 1 of this handout. Indicate the direction of the current and sketch the magnetic field lines produced by both coils along the axis of the coils.

7 Check Your Understanding

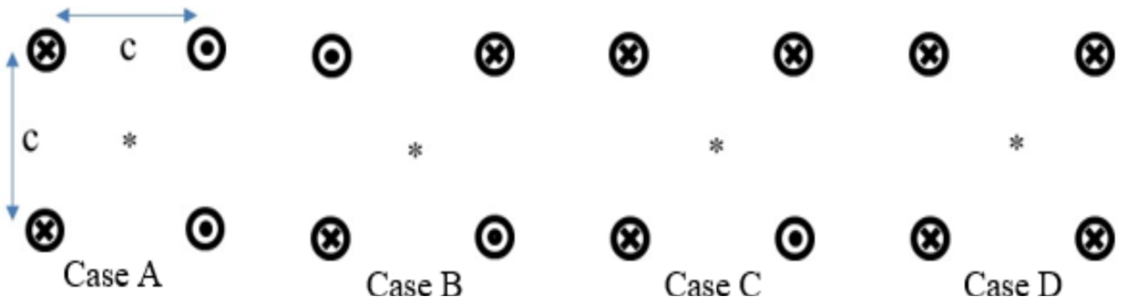
Unless otherwise indicated, the criteria for receiving full credit on each answer is first, is the answer correct, and second, you have convinced me you know how to complete the problem in a manner that utilizes **only** the equation sheet, or reference an equation we have used previously in lecture or lab.

1. (Ferstl Special): Take a charged ring and spin it, draw an **E**-field diagram. Then, on a separate diagram, draw the magnetic field diagram. Compare and contrast the two diagrams.

2. (Alex Special): Find an image of your favorite design for a nuclear fusion reactor (my personal favorite is the *tokamak*). Draw the magnetic field lines created by the reactor. Make sure to specify which reactor you chose, and tell me why it has said magnetic field lines (something like, "since the current runs in a circular direction..."). Also, draw and indicate the current with direction.

3. In the diagrams below, there are four wire arrangements (A, B, C, and D). In each arrangement, there are 4 wires that run into and out of the page with the current indicated by a $\otimes$ or a $\odot$. Each wire is very long and straight (so, each creates a B field of $\mu_0 I/2\pi r$) and carries a current of 0.4 A. The four wires form the corners of a square with side, $c = 4cm$. Rank the magnitude of the magnetic field produced by each foursome at the center of the square. Explain your answer. No calculation needed, but can be helpful.

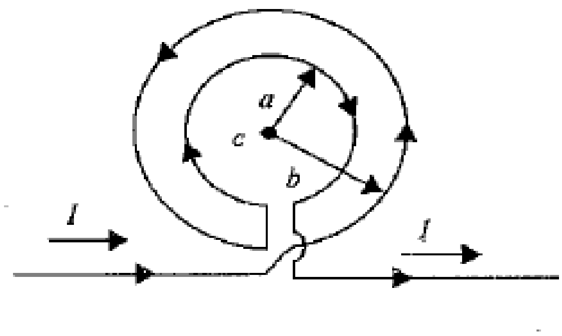
Figure 2: Various setups of magnetic fields into and out of the page.



4. An otherwise infinite, straight, wire has two concentric loops of radii a and b caryying equal currents in opposite direction as shown in the figure below. Show that the magnitude of the magnetic field at the common center of the loops is zero if the radii have the ratio,

$$\frac{a}{b} = \frac{\pi}{\pi + 1} \simeq 0.7585. \tag{2}$$

Figure 3: Curled loop of wire.



5. Remember when taking the cross product of two vectors, you must use the sine function. In other words, $|d\ell \times \hat{\mathbf{r_p}}| = |d\ell| sin(\theta)$.
   (a) What is the angle in this case?

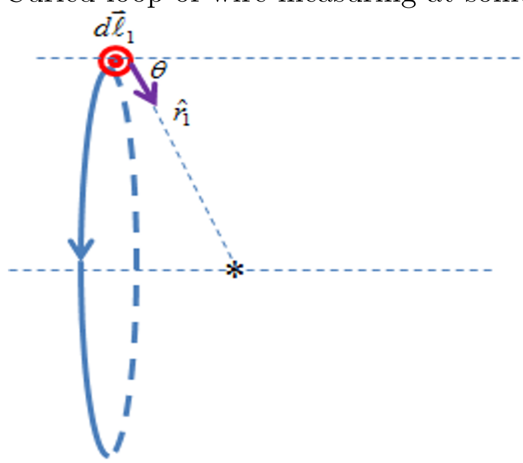
   (b) Explain why, when calculating the field for the coil, the procedure:

$$|d\ell \times \hat{\mathbf{r_p}}| = |\hat{\mathbf{r_p}}||d\ell| sin(\theta) = |d\ell| \frac{R}{\sqrt{R^2 + x^2}}, \tag{3}$$

   is wrong but yet gives the right answer?

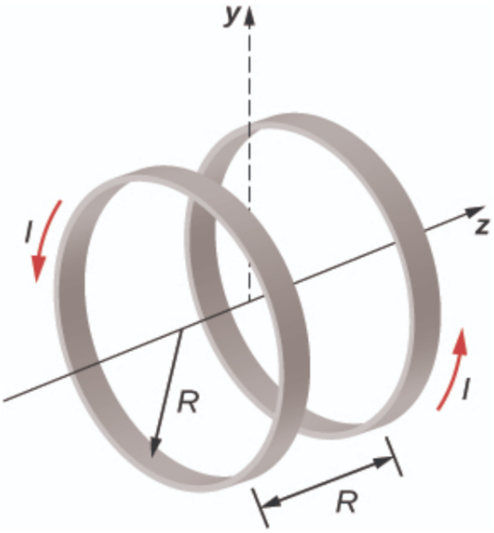
   In other words: explain what happens to the $sin(\theta)$ (from the cross product), and where the $R/\sqrt{R^2 + x^2}$ actually comes from.

Figure 4: Curled loop of wire measuring at some point P.



6. A reasonably uniform magnetic field over a limited region of space can be produced with the Helmholtz coil, which consists of two parallel coils centered on the same axis. The coils are connected so that they carry the same current I. Each coil has N turns and radius R, which is also the distance between the coils.

(a) Find the magnetic field at any point on the z-axis shown in the accompanying figure.



(b) Show that $d\mathbf{B}/dz$ and $d^2\mathbf{B}/dz^2$ are both zero at $z = 0$. (These vanishing derivatives demonstrate that the magnetic field varies only slightly near $z = 0$.)