University Physics 2: PHYS222

Lab 8: Magnetic Fields at the Center of a Loop

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1 Introduction

One delusion that came out of nuclear physics during the 1920's and slowly up to 1990's is the idea of *cold fusion*, a hypothesized type of nuclear reaction that could occur at or close to room temperature around $22°C$ (for reference, nuclear fusion occurs at around 100 million $°C$ inside the sun). One method was to use the element Palladium. Experiments were done on Palladium by analyzing the inner-structure of Palladium. The inner structure consists of *aliging atomic spin* by passing Palladium through a *loop of wire with a current running through it.* What they needed to know was the required strength of the magnetic field to *align* the atoms of Palladium.

?| What is the magnetic field at the center of a loop?

Equipment:

- Loop of wire
- Power supply
- Smartphone to measure magnetic field using the *Physics Toolbox Sensor Suite* app

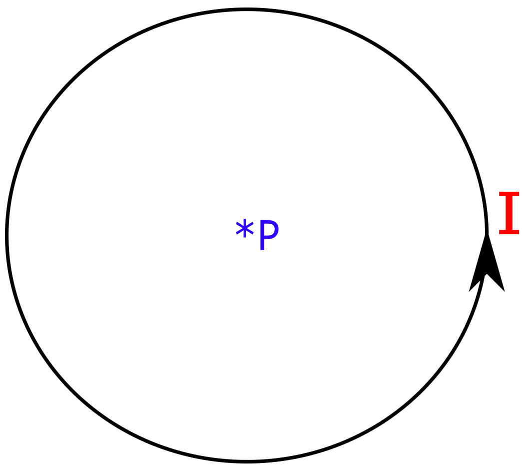


Figure 1: Some loop of wire with current I around a point P.

2 Prediction

This week's lab will be a different form of prediction then previous weeks. We will not be working from first principles such as $F = ma$ or $E = \int kq/r^2 dq$ to find an equation. Instead, we will be using dimensional analysis. The units that are important for the magnetic field B are the following four pieces:

- B is measured in units of Tesla.

- Whenever we send some current I through a wire, the wire produces a magnetic field B. So, current matters.
- Each time we calculated electric fields, there was an associated fundamental constant being, $k = 9.0 \times 10^9 Nm^2/C^2$. For magnetic fields, there is another fundamental constant *always* associated with B,

$$\mu_0 = 4\pi \times 10^{-7} \left(\frac{T \cdot m}{A}\right)$$

  which is read as, "Tesla-meter per amp."
- Finally, just like electric fields, magnetic fields depend upon distance... What is the associated distance in our situation?

Prediction

Please answer these questions before lab:

Question 1: Use dimensional analysis (see example below) to find a relation between B and the relevant parameters of the problem: I, R(radius of loop), and μ_0. Or simply, find a proportionality that relates the magnetic field to the three quantities above,

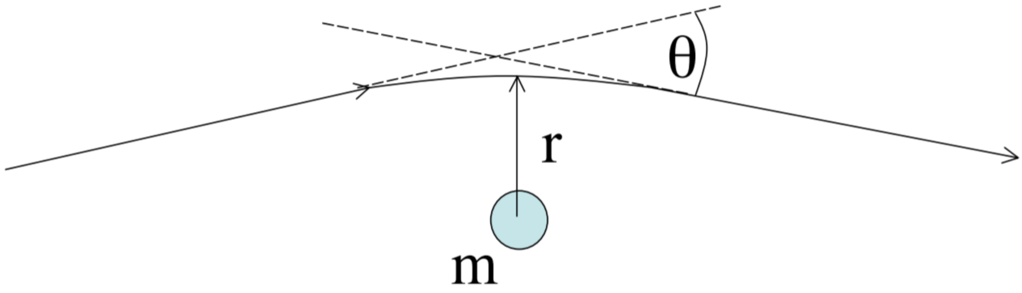
$$B \sim ? \tag{1}$$

Question 2: Make a graph of B *vs* R. It this a logarithmic relationship? If not, what kind is it? A $1/R^p$ for some power p? Use question one to help answer this.

Example of dimensional analysis:

Consider for example the idea of the deflection of light around a large planet, star, or *something* of mass m depicted in the figure below,

Figure 2: Deflection/bending of a single light ray by some distance r at angle θ.



We know that since θ is an angle, it must be dimensionless. So far, we have two quantities, $r \sim meters(m)$ and $m \sim (kilograms)kg$ for distance and mass. But, since we are in *space*, there are two fundamental constants we can use, G and c being Newton's gravitational constant, and the speed of light. G has units $G \sim m^2/(kg \cdot s^2)$ and $c \sim m/s$. For these, we can try to multiple two constants together, and then slowly build up to see what needs to be canceled,

$$\begin{aligned} \theta \rightarrow_{units} G \cdot m &\sim \left(\frac{m^3}{kg \cdot s^2}\right)(kg) \sim \frac{m^3}{s^2} \\ \theta \sim \frac{G \cdot m}{c^2 \cdot r} &\rightarrow_{units} \left(\frac{m^3}{s^2}\right)\left(\frac{s}{m}\right)^2 \cdot \left(\frac{1}{m}\right) = dimensionless. \end{aligned} \tag{2}$$

The first line is simply seeing what the multiple of G and m is, and then with our remaining two quantities, r and c, the second line is placing them where we need them to cancel the above. Thus our final equation is,

$$\theta \sim \left(\frac{mG}{rc^2}\right) \rightarrow \theta = \beta \left(\frac{mG}{rc^2}\right), \tag{3}$$

where β is some constant that is figured out via experiment.

3 Exploration

Explore your equipment. Install the *Physics Toolbox Sensor Suite* app on your phone (it is free). Choose the "Magnetometer". It measures the magnetic field which is a vector and has x, y, and z components.

Use a bar magnet to determine where the magnetic sensor is located in your smartphone. You'll have to devise a technique to do this but the magnetic field for a bar magnet typically looks like this (with a North and South pole).

You are given 4 different wire loops each with 10 wire wraps. You can send current thru one of them with the power supply. Dial the current up to about 1 amp. Practice measuring the magnetic field at the center of the loop. Put your sensor in the center of the loop and turn the current on and off. Does the measurement change?

→ If you double the current:

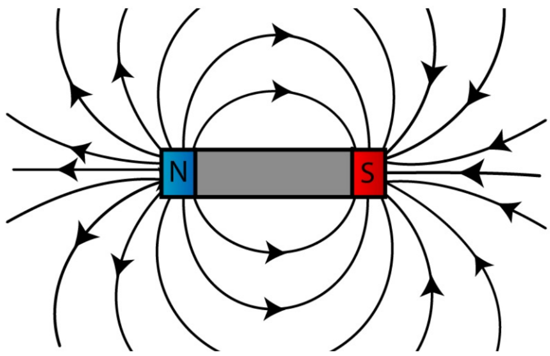


Figure 3: Magnetic field lines of a bar magnet.

- based upon your equation, what should happen/change about the field?
- Try this with your equipment. Does it work?

Finally, to confirm that you are doing things correctly, use a Hall Probe/Magnetic Field probe with Logger Pro. Your instructor will explain.

4 Data, Results, and Analysis

Use your experience from the Exploration section and measurement plan to determine the field at the center of the loops.

Make a plot and add a trendline. Does it match the *shape* of your prediction?

Your prediction was just a proportion. Plug in the values of I and μ_0, and see if you can find the constant that makes the proportion an equality based on your trendline. Don't forget it has 10 loops.

5 Conslusions/Summary

Where you able find a reasonable equation for your magnetic field?

6 Check Your Understanding

Unless otherwise indicated, the only way to receive full credit for an answer is 1) If it is correct and 2) You have correctly justified your answer using BASIC principles of physics (those principles that are represented by the equations on the reference sheet).

1. Compare and contrast magnetic and electric fields:
   (a) What is the electric field a the center of a uniformly charged ring?

   (b) What is the magnetic field at the center of a loop of current?

2. What would be the equation for a magnetic field at the center of a loop, radius R, that has 20 wraps of wire and a current, I?

3. The magnetic field at the center of a loop of wire, radius = 4 cm, is 12 mT (milli-Tesla). What would be the magnetic field at the center of the same loop of wire with the same amount of current but a radius of 10 cm?

4. Compare and contrast: what is E at the center of a uniformly charged ring? What is the B field at the center if the ring has a current of I?