

Lab 1: Stationery Magnetic Fields

Goal

You will apply the Biot-Savart law to determine magnetic field due to current-carrying wire then compare with experimental data for verification.

Objectives

1. Become familiar with PASCO Scientific workshop software to acquire data
2. Measure the free space magnetic permeability μ_o .
3. Compare measured static magnetic field using exact Biot-Savart law formula and numerical approximations

Expectations

1. You are expected to take detailed notes during each step outlined in the procedure that can be used during the lab report write-up.
2. You are expected to provide a neat table of the data that you measured where you clearly label what each data set is and include units for all measured quantities.
3. You are expected to clearly record the measured values of any components that you use.
4. You are expected to clearly record the detail related to images captured by the oscilloscope.
5. You are expected to make your final plots in a program such as Excel. Make sure that your data points appear clearly on the plots, that all axes are clearly labeled and have units.
6. If it is possible to compare your measurements with an expectation or a prediction, you are expected to do so in your lab report
7. You are expected to answer the questions encountered in this manual as well as discuss exercises given during the lectures in your lab write up.

Introduction to Concepts

The magnetic field generated due to a current element is given by the Biot-Savart law (Figure 1). For simplicity, the axial magnetic field due to a current carrying loop will be studied in the lab. The axial component of the magnetic field from a current carrying loop is given by,

$$B_z = N \cdot \frac{\mu_o I}{2} \frac{R^2}{(z^2 + R^2)^{3/2}} \quad (1)$$

Where free space magnetic permeability is μ_0 , I is the current in the loop, R is the radius of the loop, z is the distance from center of coil to axial location where the axial magnetic field, B_z is measured, and N is no.of turns of the coil. See Figure 2

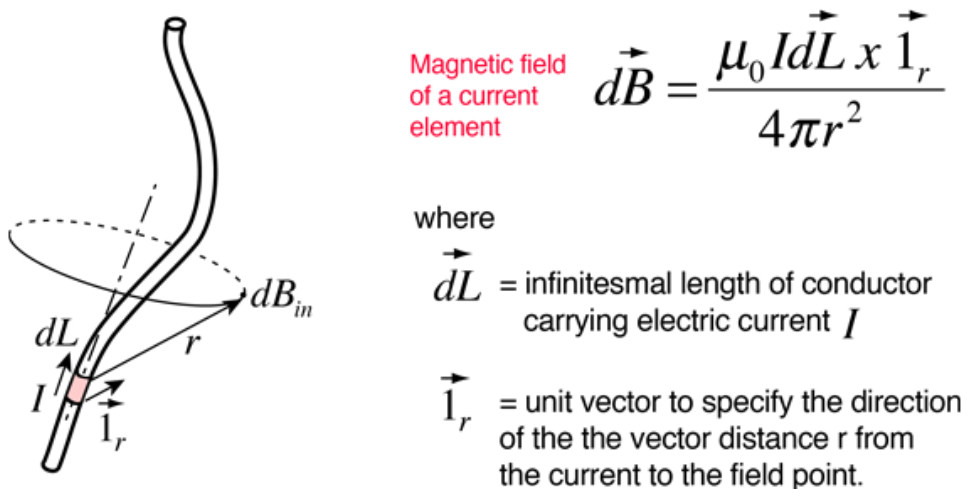


Figure 1: Magnetic field at a given location due to a current element.

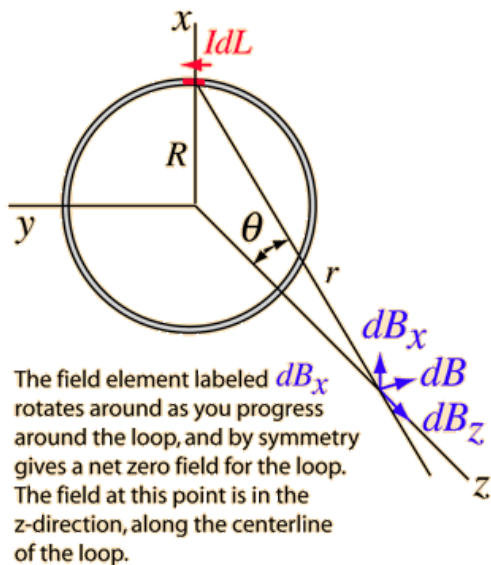


Figure 2: Axial magnetic field at a given location along the axis of a current carrying loop.

Preliminary Lab Questions

1. What the magnetic field at the center of the current carrying loop?
2. Find an approximate formula for magnetic field at $z \ll R$ showing up-to second order term. Exact formula is given in equation 1

3. Find an approximate formula for magnetic field at $R \ll z$ showing up-to second order term. Exact formula is given in equation 1

Equipment and Parts

1. Multimeter
2. Magnetic field sensor (Hall probe) to measure magnetic field,
3. A stand and clamp to hold the magnetic field sensor
4. A 200 turns current coil with a maximum allowed current of 2A.
5. Meter scale for length measurements
6. Power supply (EXTEC 18 V DC power supply) for powering the current loop (coil)
7. Science workshop interface to control the power amplifier II from computer and
8. A Laptop.

Procedure

Setup PASCO Software Suite

- Connect the magnetic field sensor to Science workshop interface
- Connect the USB cable from Science workshop interface to the laptop
- Open the PASCO software suite in the laptop
- Add the magnetic field sensor to current work environment
- Using the settings icon, make sure sampling rate is set to 1 Hz and gain is set to $1 \times$
- Set the sensor to measure “axial” magnetic field by using selector switch on the sensor
- Check the magnetic field sensor to have gain is set to $1 \times$
- Add a measurement tab to PASCO software suite work environment to read the magnetic field sensor
- Click “Record” button in the PASCO software suite
- The magnetic field sensor values should be visible in the PASCO software suite

Magnetic Field due to a Current Loop: Part I

- Measure the resistance of the current coil using a multimeter
- Measure the average diameter of the coil winding (see Figure 3)
- Measure the thickness of the coil (see Figure 3)
- The maximum rated current on the coil is 2 A, therefore, calculate the voltage that will give $I \sim 1.9$ A
- Set the power supply to above calculated voltage
- **Read the current reading shown in the power supply display and compare with expected $I \sim 1.9$ A.**
- Set the current coil on the table and note down the position. Do not move the coil once measurements are started
- Connect the magnetic sensor into the stand using a clamp.
- Position the stand near the current coil to have magnetic sensor approximately located at the center of the coil.
- Move down the magnetic sensor to $z \sim 0$. Note that coil is about 2 cm thick (see Figure 3), therefore carefully align the sensor to be at the vertical center location of the coil.
- Press “Tare” button on the sensor to reset.
- Connect the power supply to the current coil. Using the multimeter measure the voltage across the coil
- Align the magnetic sensor to center of the coil. **Note that , the magnetic field straight is minimum at the center of the coil, $z = 0$**
- Note down the position of the coil and do not move the coil.
- Measure the magnetic field strength by using the “Record” button in the PASCO software suite
- Measure the voltage drop across the coil using the multimeter
- Reduce the current through the coil by ~ 0.1 A.
- Measure the magnetic field strength by using the “Record” button in the PASCO software suite
- Repeat it until the current through the coil reaches zero
- Plot magnetic field vs. the current for the data set. **Note: Use SI units ★**

- Calculate the free space magnetic permeability μ_o using the slope of the plot ★
- Plot magnetic field vs. the current using the Biot-Savart equation in the same graph ★

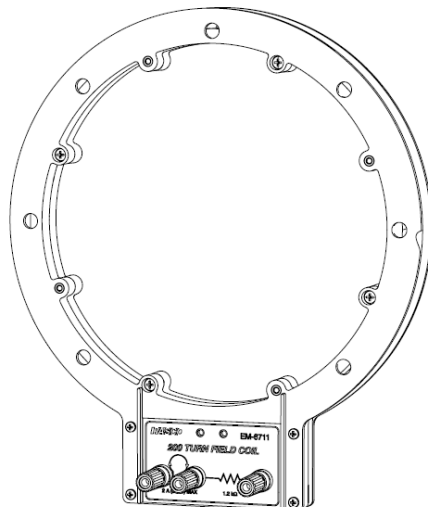


Figure 3: PASCO coil used in the lab. Measure the outer and inner diameter of the coil winding to calculate the radius R of the coil. Measure the thickness of the coil to determine the mid-point along the axis.

Magnetic Field due to a Current Loop: Part II

- Set the current coil on the table and note down the position. Do not move the coil once measurements are started
- Connect the magnetic sensor into the stand using a clamp.
- Position the stand near the current coil to have magnetic sensor approximately located at the center of the coil. You will be moving the sensor up and down to measure the axial magnetic field
- Move down the magnetic sensor to $z \sim 0$. Note that coil is about 2 cm thick (see Figure 3), therefore carefully align the sensor to be at the vertical center location of the coil.
- Press “Tare” button on the sensor to reset.
- Connect the power supply to the current coil.
- The maximum current rated current on the coil is 2 A, therefore, adjust the voltage that will give $I \sim 1.9$ A
- Align the magnetic sensor to center of the coil. **Note that , the magnetic field straight is minimum at the center of the coil, $z = 0$**

- Note down the position of the coil and do not move the coil.
- Measure the magnetic field strength by using the “Record” button in the PASCO software suite
- Slowly move the magnetic sensor up by $z \sim 2 - 3 \text{ cm}$. Use the measuring stick to measure the distance from **mid-point of the coil to the tip of the sensor**.
- Measure the magnetic field strength
- Repeat this until about $z \sim 50 \text{ cm}$
- Calculate the magnetic field strength at each axial distance z using the exact equation.
Note: Use SI units
- Plot magnetic field strength vs. axial distance z . **Note: Use SI units★**
- Estimate the free space magnetic permeability μ_o using measured magnetic field. Use a fit to the measured magnetic field.
- Plot magnetic field strength from equation 1 vs. axial distance z on the same graph ★
- Use the first order approximation equation for for $R \ll z$ to calculate magnetic field strength at axial distances. ★
- Plot the first order approximation equation with measurements in the same plot ★
- Use the approximation equation with first and second order terms for $R \ll z$ to calculate magnetic field strength at axial distances. ★
- Plot the first and second order approximation equation with measurements in the same plot ★
- Compare the accuracy of the approximation with and without the second order term when compared to the exact equation. You can use a graph of magnetic field vs. axial distance (Z) to make the comparison.