Lab 210: Magnetic Field of Helmholtz Coils - Biot-Savart Law

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1. **INTRODUCTION**

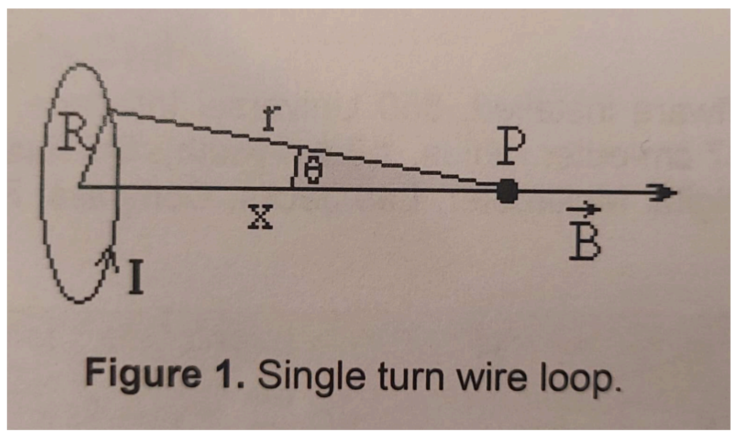
1.1 **OBJECTIVES**

The objective of this lab is to verify Biot-Savart law and its equations by using a circular current loop(coil). Measuring the magnitude of a magnetic field of a single coil and a pair of coils as a function of radial distance from the center.

1.2 **THEORETICAL BACKGROUND**

As seen in Figure 1. The point *P* is on the axis of a coil at a distance *x*. According to the Biot-Savart Law, the magnitude of the magnetic field, *B*, at *P* created by the coil with current, *I*, is given by the equation:

(1) $$B = \frac{\mu_0 IR\sin(\theta)}{2r^2}$$



, I being the current going through the coil, μ_0 is the permeability of free space, and r, R, and θ are defined like in Figure 1.

The magnitude of the magnetic field, B, at P created by the coil with N turns with a current of I is given by the following equation (2):

(2) $$B(x) = \frac{\mu_0 NIR^2}{2(R^2+x^2)^{\frac{3}{2}}}$$

Direction of the B vector is along the x-axis if I is in the direction like in Figure 1. R is written as a function of x, hence why r = $\sqrt{R^2 + x^2}$. For this lab we are only finding the magnetic field at different distances from the center of the coil while I is constant.

When there are two coils with separation, *D*, each with *N* turns with the same current running through both (connected through series) running in the same direction, B_{Net} at point P on the axis is the sum of the two B vectors.

$$(3) \quad \vec{B}_{Net} = \vec{B}_1\left(\frac{D}{2} + x\right) + \vec{B}_2\left(\frac{D}{2} - x\right) = \frac{\mu_0 NIR^2}{2[R^2 + (\frac{D}{2}+x)^2]^{3/2}} + \frac{\mu_0 NIR^2}{2[R^2 + (\frac{D}{2}-x)^2]^{3/2}}$$

The argument of B_1 is $\frac{D}{2} + x$ since P is at a distance of $(\frac{D}{2} + x)$ from coil 1 and vice versa for the second coil being at a distance $(\frac{D}{2} - x)$ from P.

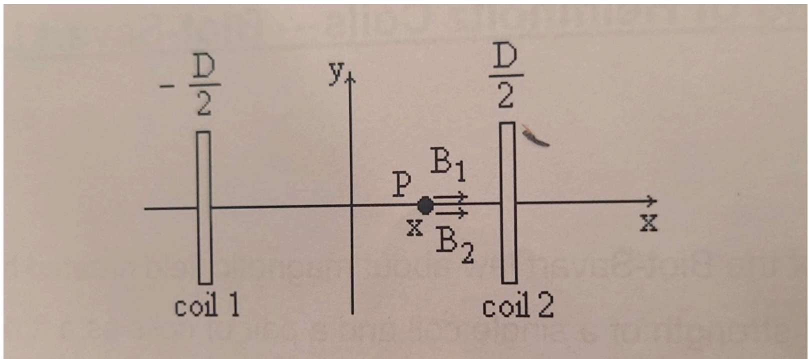


Figure 2. Schematic diagram of Helmholtz coils.

Essentially, there will be two parts of this lab. Part I, we explore and measure the magnetic field produced by a singular coil. We will also be observing the relationship in direction and magnitude between the electrical current in a coil and the magnetic field generated by it. Additionally, we map the magnetic field to the radial distance as a function. Part II we will be measuring the magnetic field produced by two coils with a specific separation with a function of radial distance. Since both coils have the same current running through them, they'll have a magnetic field equal to each other.

2. EXPERIMENTAL PROCEDURE

Setup:

- Jacks were used to suspend a wooden track between two Helmholtz coils.
- The magnetic field sensor was attached to a rotary motion sensor.
- An AC current was connected to one coil, with an ammeter in series.

Procedure:

- We adjusted the sensor so it goes through the coil's center.
- This was recorded on the computer for a couple currents.
- The second Helmholtz coil was connected in series with the first.
- In part two, we kept the current at 0.6A.

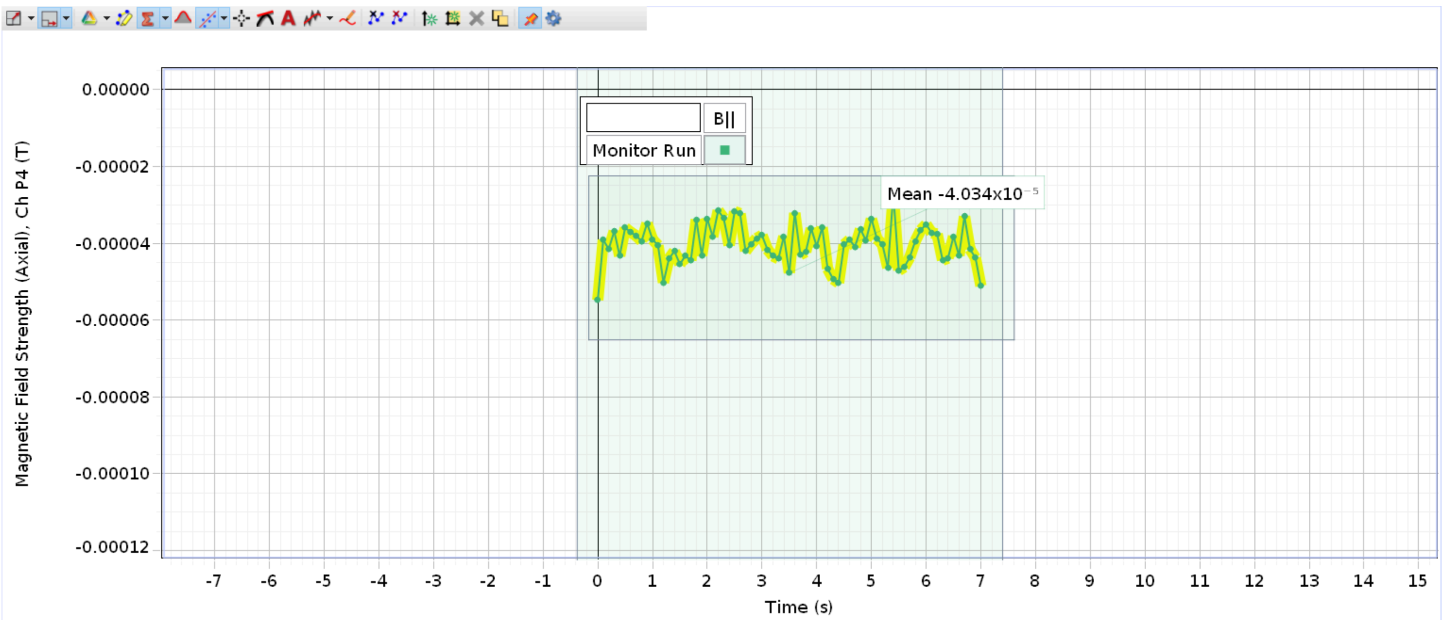
3. **RESULTS**

3.1 **EXPERIMENTAL DATA**

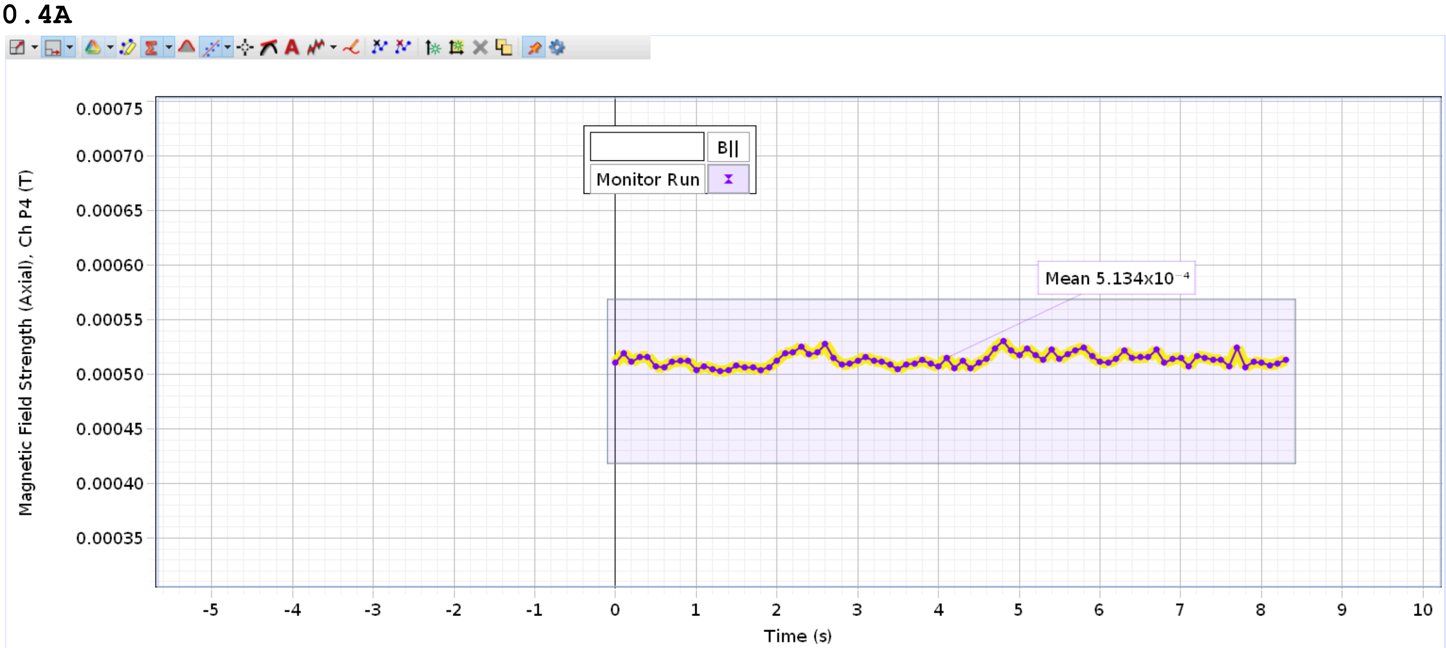
Part 1 A:

Case 1 Current (A)	0.2 A	0.4A	0.6A
Magnetic Field Strength (T)	4.03x10^-5	5.134x10^-4	1.086x10^-3

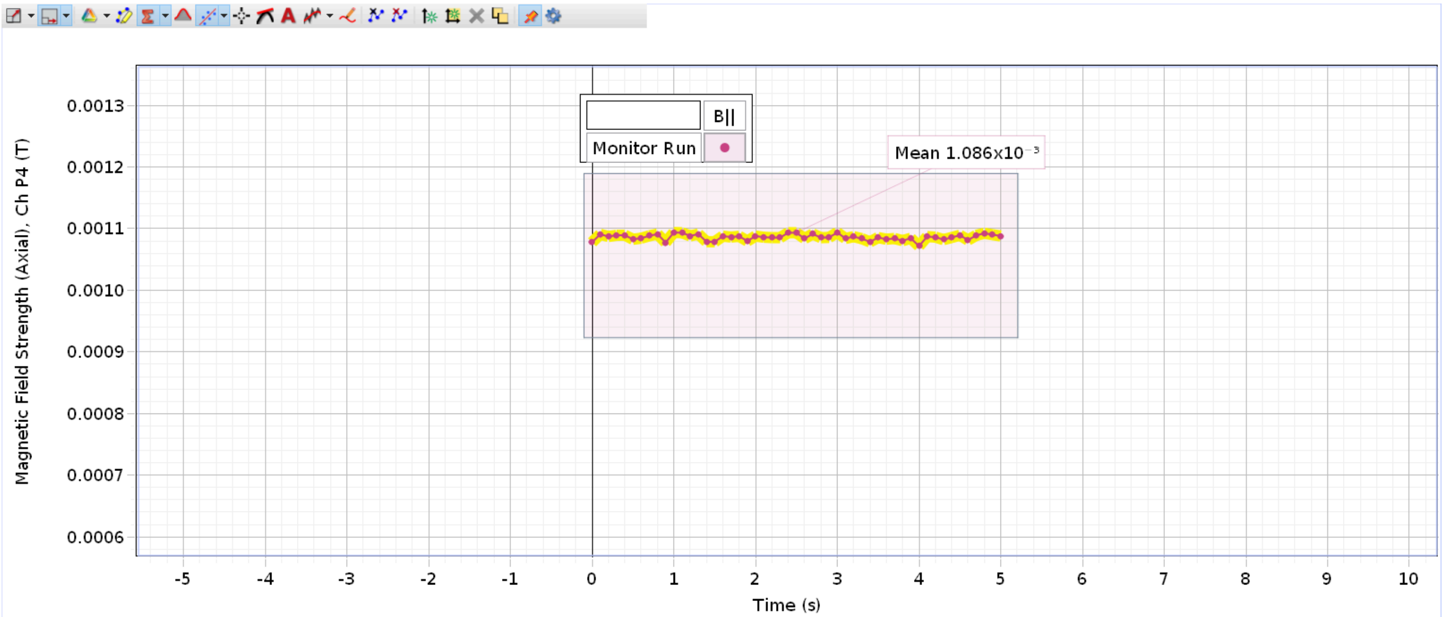
0.2A



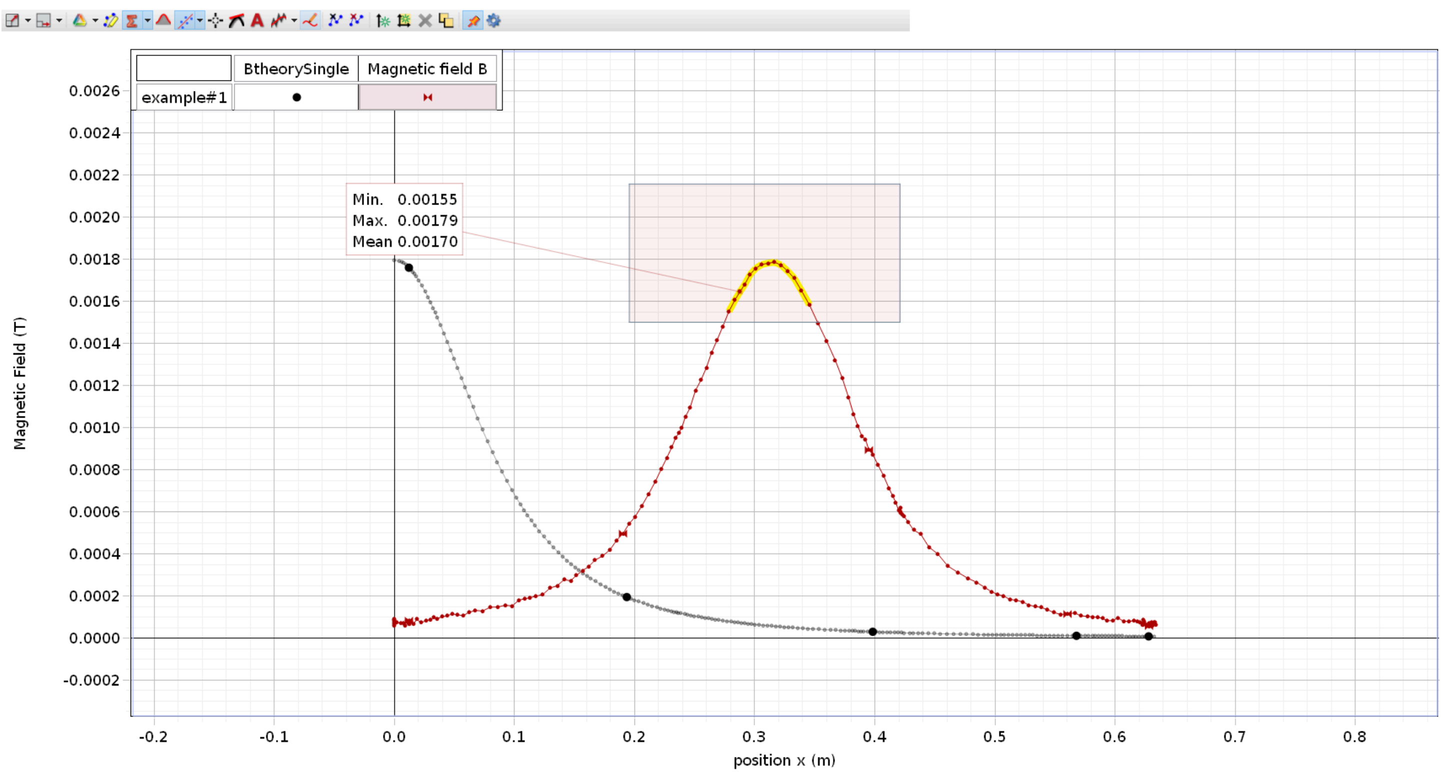
0.4A



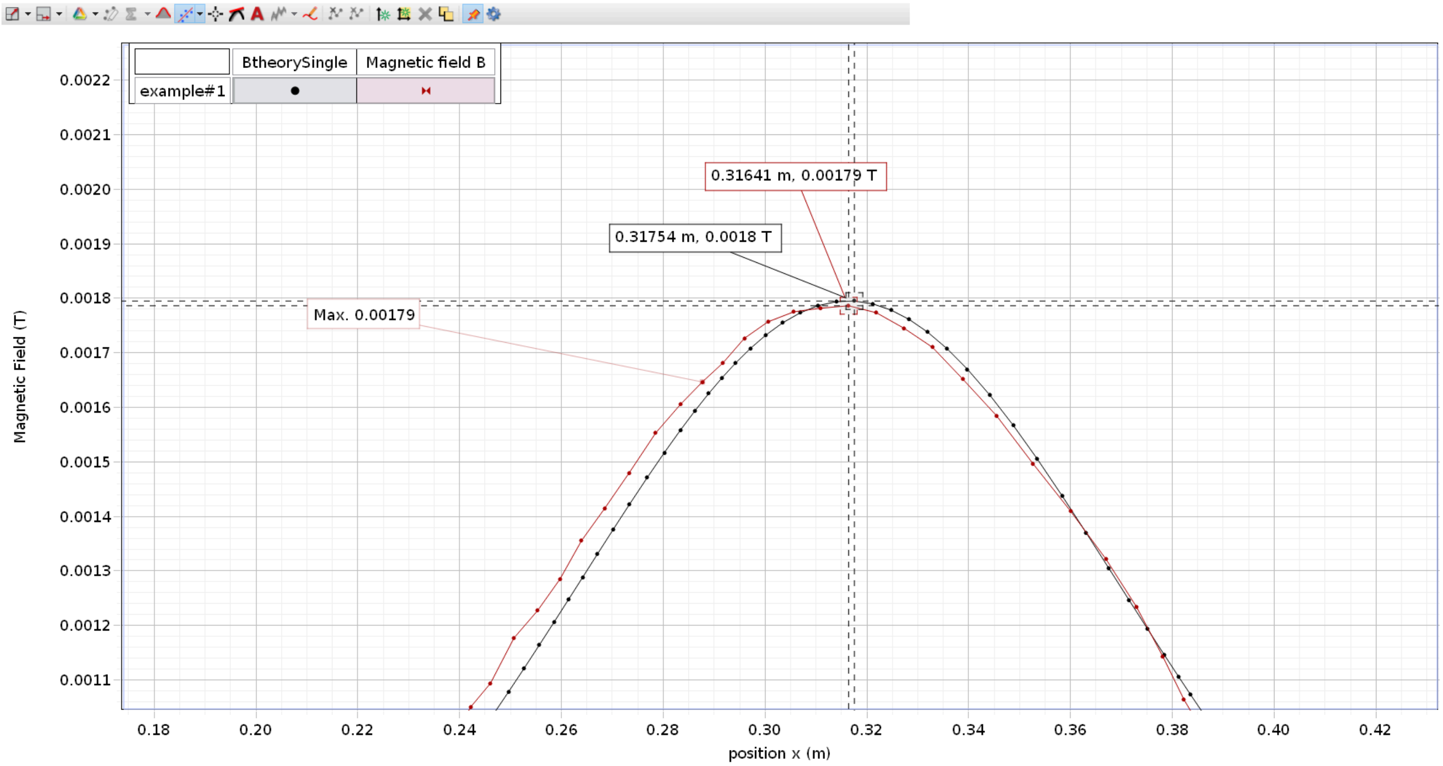
0.6A



Part 1 B:



Max : 0.00179



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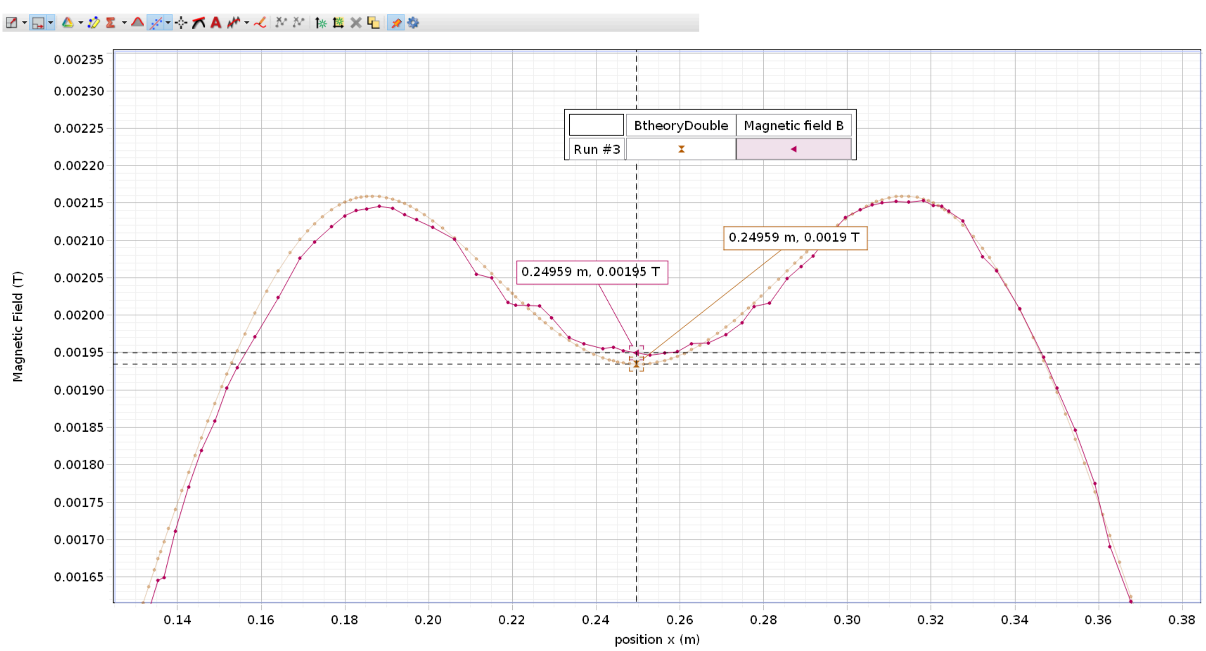
Maximum Position of Magnetic Field:

Red is what we observe

Blue is what software gave us

Part 2:

d > r (d =0.15m)



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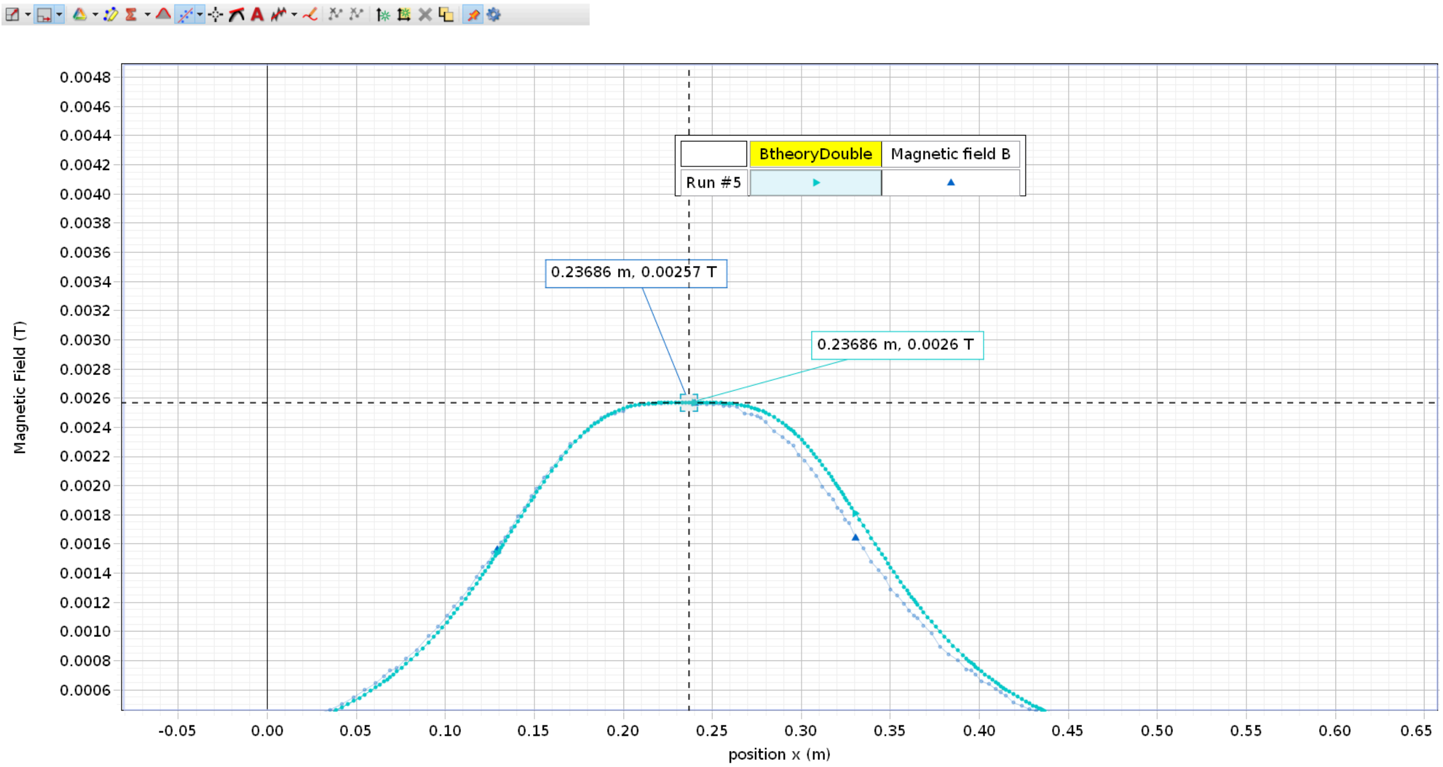
D = r   (d = 0.015m)



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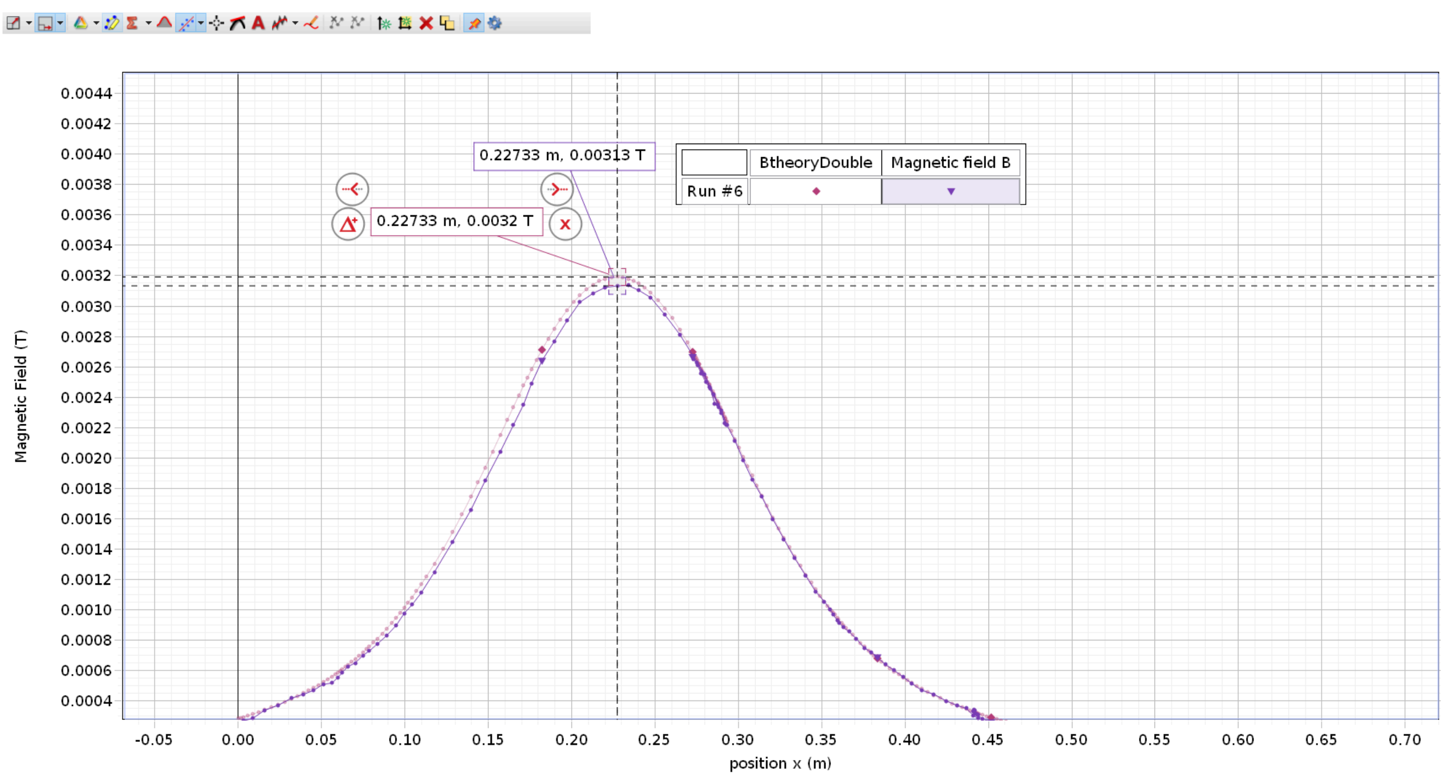
D < r   d=0.06m



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3.2 CALCULATION

No calculations were conducted during this experiment. There was also no Matlab code.

4. **ANALYSIS and DISCUSSION**

Consistent with the theoretical prediction, the experimental data show that the magnetic field intensity diminishes with increasing distance from the center of the Helmholtz coils. The theoretical and experimental values, however, differ in a few ways. Various variables, including non-uniformity in the current distribution inside the coils and external magnetic interference, might be responsible for these disparities.

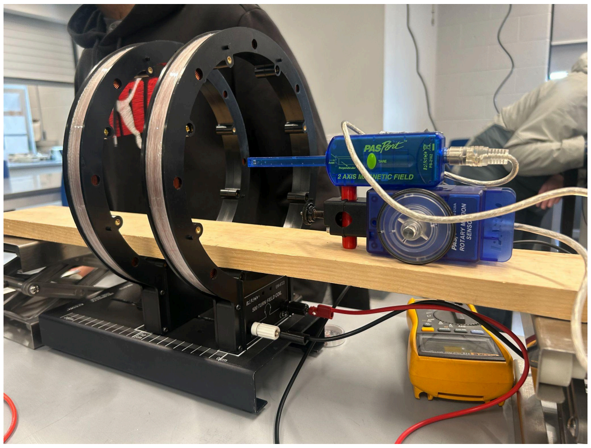
The magnetic field strength grows in tandem with the current. There is a clear proportionality between them. The theoretical plot and the experimental plot resemble each other a lot. Although it fits differently in certain places, ultimately, the form is the same. The magnetic field grows as the distance between the coils gets more, but it gets less when it is between the coils. For instance, as the D=1.5 R graph illustrates, the magnetic field rises but falls between the two coils. The form of D=R resembles an inverted hyperbola. This resulted from the coils being closer to one another, which extended the length of the homogeneous magnetic field. D=0.5R is substantially thinner, yet it has the same form. Therefore, the most consistent magnetic field between two coils is produced by the D=R (Helmholtz arrangement).

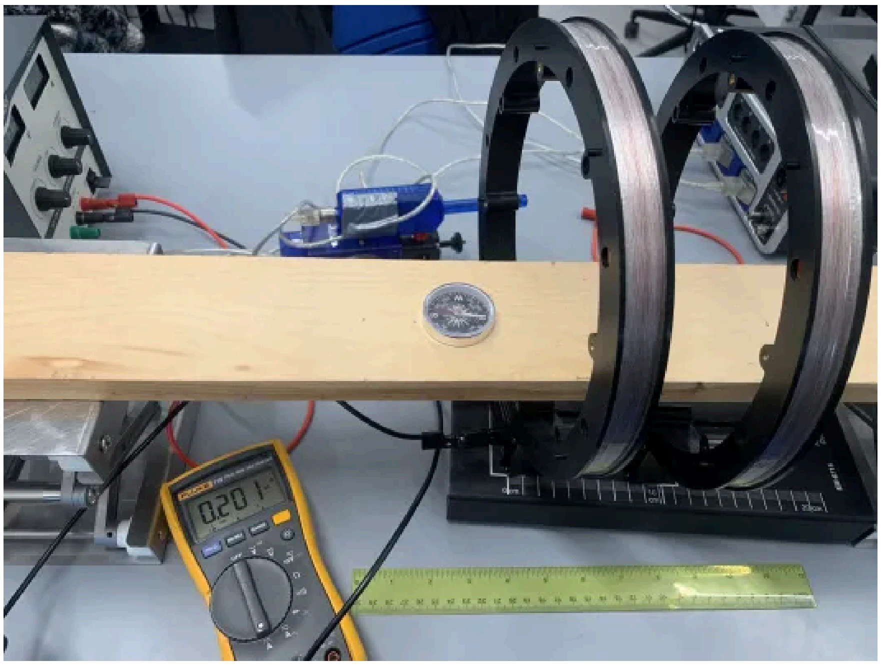
5. **CONCLUSIONS**

In conclusion, this experiment effectively illustrated how to use Helmholtz coils to create a consistent magnetic field. Although there were occasional differences, the measured magnetic field intensity along the center axis between the coils and theoretical predictions generally agreed. To find the reasons behind these differences and raise the measurement accuracy, more research might be done. We discovered that a longer and more consistent magnetic field is produced when the coils are closer to one another and overlap. I also comprehended the equations pertaining to the magnetic fields generated by coils in the Biot-Savart Law. In this experiment, Pasco Capstone and MATLAB were utilized. The goals were validated by the data analysis. No questions were raised by the experiment. Overall, this experiment enhanced our understanding of fundamental electrical principles and also demonstrated the relationship between magnetic field and current in a real-world scenario.

6. **RAW DATA**

Part 1





Part 2