

PHY 4210-01 Senior Lab
Lab M-1: Magnetic Field Mapping

Sarah Arends
Jacquelyne Miksanek
Ryan Wojtyla

Instructor: Jerry Collins II

February 7, 2019

Abstract

In this experiment the magnetic field inside a Helmholtz coil was measured and compared to theoretical calculations determined from the Smythe derivation of the Biot-Sarvat Law for a plane displaced from the central axis, with coordinates z , ρ , and ϕ . When determining the magnetic field inside a Helmholtz coil, a Hall probe is used to obtain the magnitude of the magnetic field at varying positions inside the coil. Theoretically the magnetic field that is produced axially inside of the Helmholtz coil is of uniform magnitude.

Contents

1	Objective of the Experiment	3
2	Theory of the Experiment	3
3	Equipment Utilized	3
4	Procedure	4
4.1	Data Analysis	4
5	Results	4
5.1	Comparing the directions of the Magnetic Field	4
6	Conclusion	5

1 Objective of the Experiment

During this lab, the number of turns of wire inside a Helmholtz coil was determined for use in theoretical calculations. Then a 3-dimensional and 2-dimensional mapping of the magnetic field inside the Helmholtz coil was created in order to investigate the presence of a uniform field, running along its axial direction.

2 Theory of the Experiment

Recall for a straight current-carrying wire, circular magnetic field lines are generated around the wire in accordance with the curling right-hand rule. The Helmholtz coil contains two regions of circularly wound wires. Due to the the circular symmetry, all components of each infinitesimal segment of the wire will cancel *except* for that in the axial direction. In summary, a circular current produces a linear magnetic field. The field point of the system has before been typically placed along the axis of the direction of the magnetic field, we will call this the z-direction. This was due to the ease of solving the Biot-Savart Law under these simple conditions, as the direction and strength of the magnetic field will follow along the z-axis of the system, which is where the field point is placed. When this is applied to the co-axial coils of the Helmholtz apparatus the evaluation of the Biot-Savart Law becomes too trivial. One then chooses the field point to be placed off of the z-axis as more information about the magnetic field of the coils can be determined. This is the more general scenario and thus more complex. The off axis form can be used for any point that is off of the z-axis, while the on axis is a specific and simplified form of the general case. The general form is best represented by Smythe's derivation of the Biot-Savart Law.

$$B_z = \frac{\mu_0 IN}{2\pi} \left[\frac{1}{\sqrt{(a+\rho)^2 + (a-z)^2}} \left[K_1 + \left(\frac{a^2 - \rho^2 - (a-z)^2}{(a-\rho)^2 + (a-z)^2} \right) E_1 \right] \right. \\ \left. + \frac{1}{\sqrt{(a+\rho)^2 + z^2}} \left[K_2 + \left(\frac{a^2 - \rho^2 - z^2}{(a-\rho)^2 + z^2} \right) E_2 \right] \right]$$

3 Equipment Utilized

A DC Gaussmeter (AlphaLab Model GM-1-HS) was connected to a Hall Effect Probe in order to measure the field strength inside the Helmholtz coil. The Hall Effect Probe contains a semiconductor junction that, when exposed to a magnetic field, produces a voltage proportional to the field strength.

The position of the Hall Effect Probe can be modified in the ρ direction by sliding the ruler bar through the acrylic cube shown in figure ???. The position can be modified in the ϕ direction by rotation the ruler bar about the central pole. However, for the sake of this experiment, this did not have to be modified because measurements were taken in a single ρ, z plane. The z coordinate was modified by sliding the acrylic cube and ruler bar up and down the central pole.

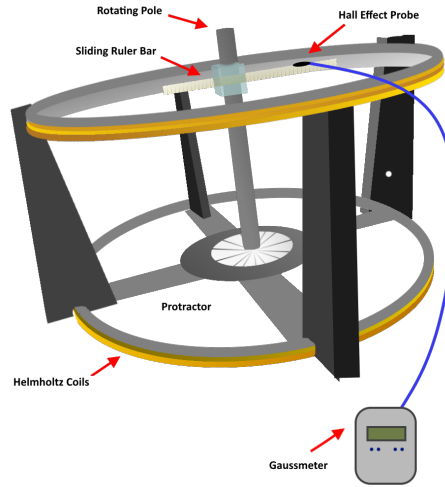


Figure 1: Two concentric Helmholtz coils separated by a distance equal to their radius. Rotating pole and sliding ruler allow for modification of the probe's position.

4 Procedure

Note that, per suggestion of the laboratory manual, the procedural steps of this experiment have been omitted. The discussion section provides sufficient detail on what actions were taken.

4.1 Data Analysis

5 Results

5.1 Comparing the directions of the Magnetic Field

When measuring at a probe height of $a/2$ (16cm), where 'a' is the separation distance between the coils, the strength of the magnetic field in the 'z' direction was measured to be -3.13 Gauss. When measuring the magnetic field in the 'z' direction at a probe height of 5cm, the magnetic field strength was measured to be -3.28 Gauss. These results follow with the theory as it is expected that the magnetic field is propagated in the 'z' direction. The measured magnetic field strength for the ρ direction was -0.46 and -0.05 Gauss for a probe height of 16cm and 5cm respectively. The measured magnetic field strength for the ϕ direction was -0.51 and -0.31 Gauss for a probe height of 16cm and 5cm respectively. For a probe height of 16cm the percentage for the magnitude of the magnetic field that is measured to be in the ρ direction is 14% while the percentage for the magnitude of the magnetic field that is measured to be in the ϕ direction is 16%. For a probe height of 5cm the percentage for the magnitude of the magnetic field that is measured to be in the ρ direction is 1% while the percentage for the magnitude of the magnetic field that is measured to be in the ϕ direction is 9%. The magnetic field produced by the Helmholtz coils should be directed along the 'z' axis. These small measured values follow the

aforementioned theory and we can determine that the magnetic field produced by the Helmholtz coil is indeed axial. Furthermore, we can determine that the magnetic field is axial along the 'z' direction.

6 Conclusion