

Magnetic Fields of Coils

EQUIPMENT

INCLUDED:

1	Helmholtz Coil Base	EM-6715
2	Field Coil (2)	EM-6711
1	Patch Cords (set of 5)	SE-9750
1	Patch Cords (set of 5)	SE-9751
1	Optics Bench	OS-8541
2	Optics Bench Rod Clamps (2)	648-06569
1	DC Power Supply	SE-9720
1	Digital Multimeter	SE-9786
1	Magnetic Field Sensor	CI-6520A

INTRODUCTION

The magnetic fields of various coils are plotted versus position as the Magnetic Field Sensor is passed through the coils, guided by a track.

It is particularly interesting to compare the field from Helmholtz coils at the proper separation of the coil radius to the field from coils separated at less than or more than the coil radius. The magnetic field inside a solenoid can be examined in both the radial and axial directions.

THEORY

Single Coil

For a coil of wire having radius R and N turns of wire, the magnetic field along the perpendicular axis through the center of the coil is given by

$$B = \frac{\mu_0 N I R^2}{2(x^2 + R^2)^{3/2}} \quad (1)$$

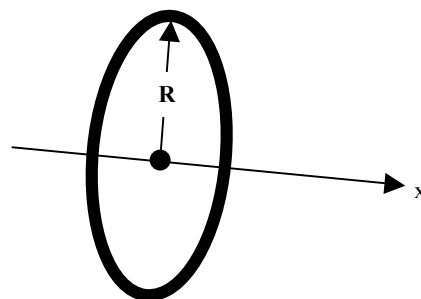
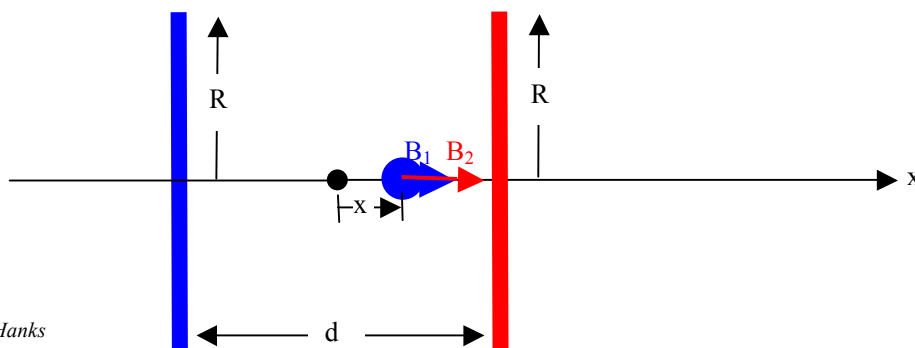


Figure 1: Single Coil

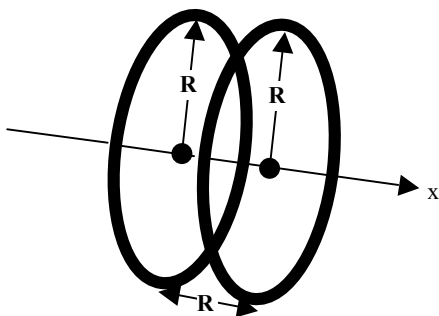
Two Coils

Figure 2: Two Coils with Arbitrary Separation

For two coils, the total magnetic field is the sum of the magnetic fields from each of the coils.



$$\vec{B} = \vec{B}_1 + \vec{B}_2 = \frac{\mu_o N I R^2}{\left(\left[\frac{d}{2} - x \right]^2 + R^2 \right)^{\frac{3}{2}}} \hat{x} + \frac{\mu_o N I R^2}{\left(\left[\frac{d}{2} + x \right]^2 + R^2 \right)^{\frac{3}{2}}} \hat{x} \quad (2)$$



For Helmholtz coils, the coil separation (d) equals the radius (R) of the coils. This coil separation gives a uniform magnetic field between the coils. Plugging in $x = 0$ gives the magnetic field at a point on the x -axis centered between the two coils:

$$\vec{B} = \frac{8\mu_o N I}{\sqrt{125}R} \hat{x} \quad (3)$$

Figure 3: Helmholtz Coils

SET UP

1. Attach a single coil to the Helmholtz Base. Connect the DC power supply directly across the coil (not across the coil's internal resistor). To measure the current through the coil, connect the digital ammeter in series with the power supply and the coil. See Figure 5.

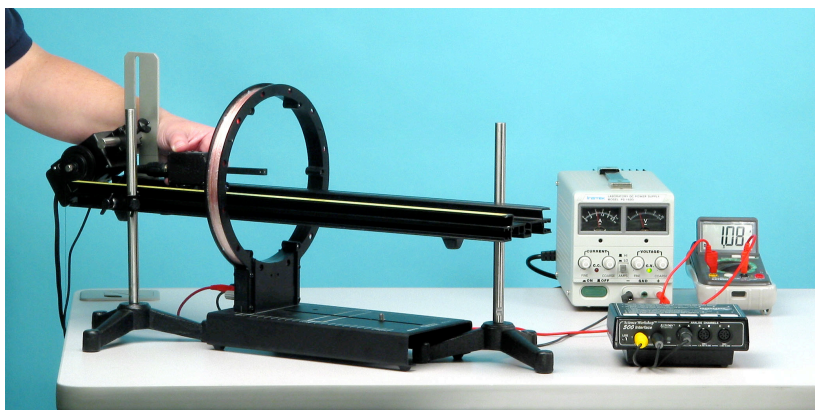


Figure 5: Single Coil Setup

2. Pass the optics track through the coil and support the two ends of the track with the support rods. Level the track and adjust the height so the Magnetic Field Sensor probe will pass through the center of the coil when it is pushed along the surface of the track. (Note: The Vernier magnetic sensor has to be at right angle to the axis of the coil.)
4. Plug the Magnetic Field Sensor into Channel 1 of Logger pro.

5. Turn on the DC power supply and adjust the voltage so about 1 Amp flows through the coil. Turn the DC power supply off at the switch.
6. Open the program called "Magnetic Field in a Coil".

SINGLE COIL PROCEDURE

1. Find the radius of the coil by measuring the diameter from the center of the windings on one side across to the center of the windings on the other side. Record the number of turns in the coil.
2. Set the Magnetic Field Sensor switch high gain. With the DC power supply off, set the Magnetic Field Sensor in the middle of the track about 15 cm from the coil. Zero the sensor.
3. Turn on the DC power supply. Starting 10 cm from the center of coil, click on START and measure the magnetic field along the center of the track, keeping the probe perpendicular to the track. Then click on STOP.
4. Record the value in the magnetic field and the distance from the center in the data table in Excel. Write an equation in Excel to calculate the theoretical value of the magnetic field. Repeat the measurement every centimeter from $x = +10$ cm to $x = -10$ cm.
5. On the graph, plot the experimental magnetic field vs. distance and the theoretical magnetic field vs. distance.
6. Does the theoretical equation fit everywhere? If not, why not?

HELMHOLTZ COILS PROCEDURE

1. Attach a second coil to the Helmholtz Base at a distance from the other coil equal to the radius of the coil. Make sure the coils are parallel to each other. See Figure 6.

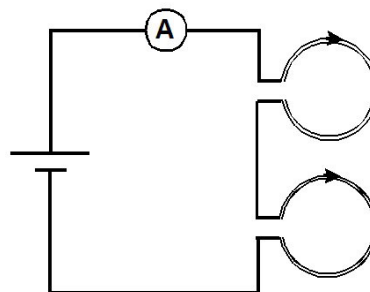
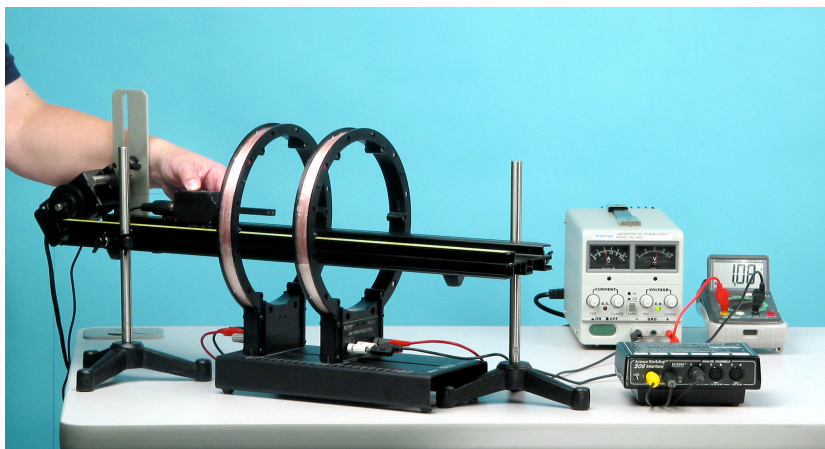


Figure 6: Helmholtz Coils

2. Connect the second coil in series with the first coil.
See Figure 7.
3. Repeat the measurements. Starting at 5 cm outside the first coil and continue to 5 cm outside the second coil.
7. Calculate the theoretical value for the magnetic field between the coils and compare it to the measured value on the graph.