Magnetic Fields of Coils

EQUIPMENT

INCLUDED:

1	Helmholtz Coil Base	EM-6715
2	Field Coil (2)	EM-6711
1	Primary and Secondary Coils	SE-8653
1	Patch Cords (set of 5)	SE-9750
1	Patch Cords (set of 5)	SE-9751
1	60 cm Optics Bench	OS-8541
1	Dynamics Track Mount	CI-6692
1	20 g hooked mass (Hooked Mass Set)	SE-8759
2	Small Base and Support Rod (2)	SE-9451
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
1	Rotary Motion Sensor	CI-6538

NOT INCLUDED, BUT REQUIRED:

1	ScienceWorkshop 500 or 750 Interface	CI-6400
1	DataStudio Software	CI-6870

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. The position is recorded by a string attached to the Magnetic Field Sensor that passes over the Rotary Motion Sensor pulley to a hanging mass.

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

$$B = \frac{\mu_o N I R^2}{2\left(x^2 + R^2\right)^{\frac{3}{2}}} \qquad (1)$$

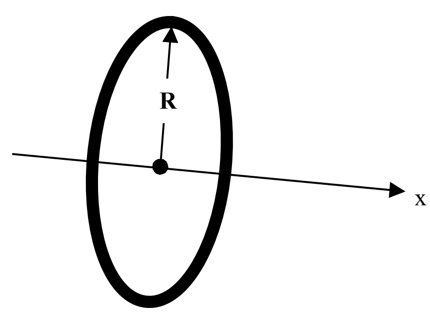


Figure 1: Single Coil

Two Coils

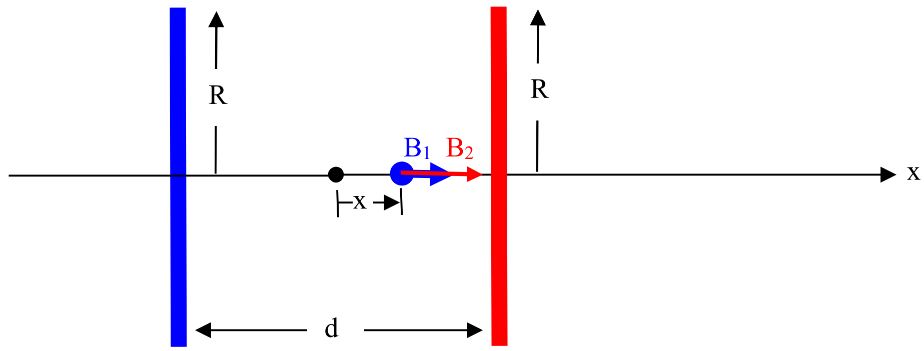


Figure 2: Two Coils with Arbitrary Separation

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

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

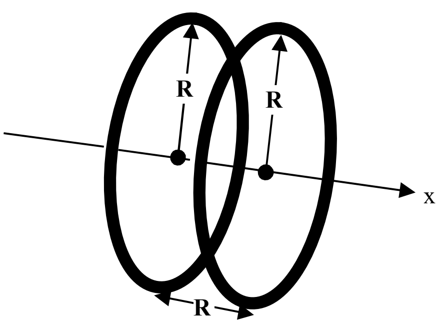


Figure 3: Helmholtz Coils

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:

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

Solenoid

For a solenoid with n turns per unit length, the magnetic field is $B = \mu_o n I$.   (4)
The direction of the field is straight down the axis of the solenoid.

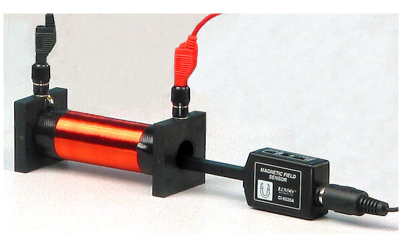


Figure 4: Solenoid

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.

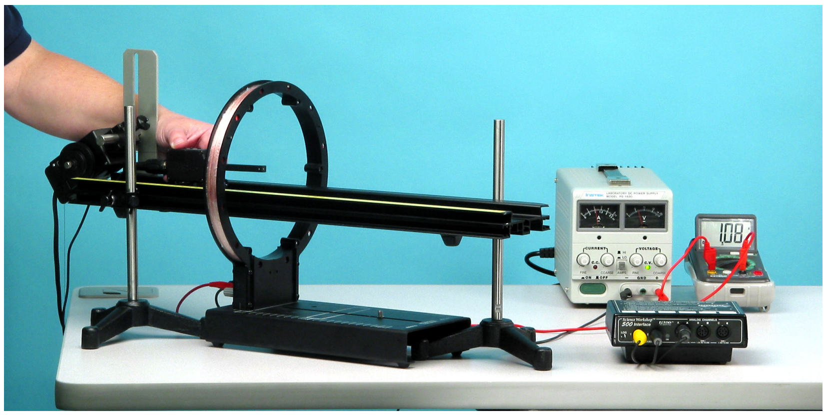


Figure 5: Single Coil Setup

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.

3. Attach the Rotary Motion Sensor to the track using the bracket. Cut a piece of thread long enough to reach from the floor to the track. Tape one end of the thread to the side of the Magnetic Field Sensor and pass the other end of the thread over the middle step of the Rotary Motion Sensor pulley and attach the 20-g mass. Place the Magnetic Field Sensor in the center of the track and adjust the position of the Rotary Motion Sensor so the thread is aligned with the middle step pulley.

4. Plug the Magnetic Field Sensor into Channel A of the ScienceWorkshop 500 interface. Plug the Rotary Motion Sensor into Channels 1 and 2. Note that the Rotary Motion Sensor plugs can be reversed in Channels 1 and 2 to change which direction of rotation is positive.

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 DataStudio program called "Mag Field Coils".

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.

2. Set the Magnetic Field Sensor switch on Axial and x10 gain. With the DC power supply off, set the Magnetic Field Sensor in the middle of the track about 15 cm from the coil. Press the tare button.

3. Turn on the DC power supply. Click on START in DataStudio and slowly move the Magnetic Field Sensor along the center of the track, keeping the probe parallel to the track, until the end of the sensor is about 15 cm past the coil. Then click on STOP.

4. Use the Smart Cursor on the graph to measure the position of the peak. Click on the DataStudio calculator and enter the peak position in for the constant (c) in the equation for the distance. This will center the peak on zero on the graph.

5. Click on FIT at the top of the graph and choose User Fit. Type in the theoretical equation for the magnetic field and enter in the current, the coil radius, and number of turns in the coil.

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.

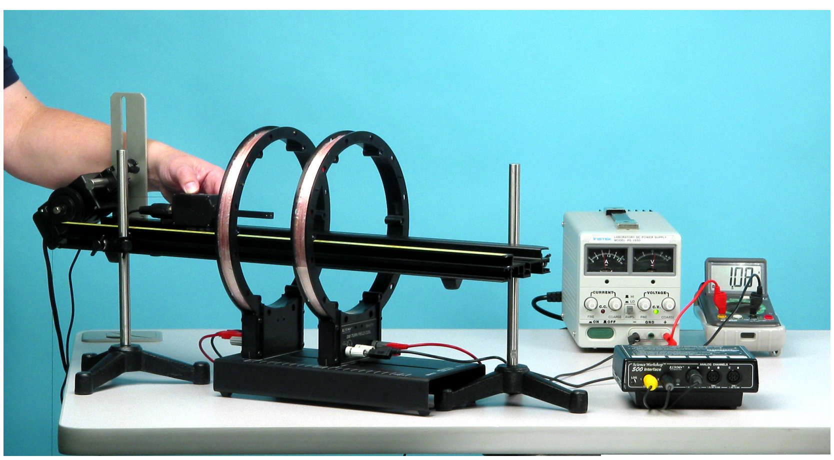
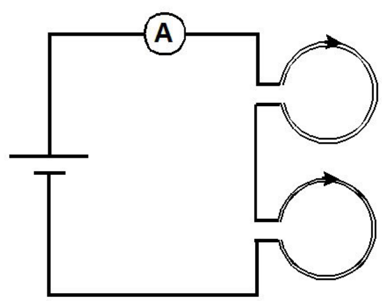


Figure 6: Helmholtz Coils



2. Connect the second coil in series with the first coil. See Figure 7.

Figure 7: Helmholtz Wiring

3. Set the Magnetic Field Sensor switch on Axial and x10 gain. With the DC power supply off, set the Magnetic Field Sensor in the middle of the track about 5 cm from the first coil. Press the tare button.

4. Turn on the DC power supply. Click on START in DataStudio and slowly move the Magnetic Field Sensor along the center of the track, keeping the probe parallel to the track, until the end of the sensor is about 5 cm past the second coil. Then click on STOP.

5. Use the Smart Cursor on the graph to measure the position of the center of the peak. Click on the DataStudio calculator and enter the peak position in for the constant (c) in the equation for the distance. This will center the peak on zero on the graph.

6. Click on the annotation button at the top of the graph and put a note showing the position of each coil on the graph. Is the magnetic field strength constant between the coils?

7. Calculate the theoretical value for the magnetic field between the coils and compare it to the measured value on the graph.

8. Now change the separation between the coils to 1.5 times the radius of the coils. Repeat steps 3 through 6.

9. Now change the separation between the coils to half the radius of the coils. Repeat steps 3 through 6.

SOLENOID PROCEDURE

1. Connect the DC power supply in series with the digital ammeter and the solenoid.

2. Set the Magnetic Field Sensor switch on Axial and x10 gain. With the DC power supply off, put the Magnetic Field Sensor inside the solenoid (see Figure 4). Press the tare button.

3. Turn on the DC power supply and adjust it until the ammeter reads about 100 mA.

4. Click on START and measure the magnetic field at various points all over the inside of the solenoid, keeping the sensor probe parallel to the long axis of the solenoid.

5. Is the field inside the solenoid constant? What happens near the end of the solenoid?

6. Measure the length of the coil and using the given number of winds in the coil, calculate the theoretical value of the magnetic field. Compare this value to the value at the center at the coil.

7. Set the Magnetic Field Sensor switch on Radial and x10 gain. With the DC power

switched off, put the Magnetic Field Sensor inside the solenoid. Press the tare button.

8. Turn on the DC power supply with the same current as before.

9. Click on START and measure the magnetic field at various points all over the inside of the solenoid, keeping the sensor probe parallel to the long axis of the solenoid.

10. Is the field inside the solenoid constant? What happens near the end of the solenoid?