Lab. 04. Magnetic Fields by Coils

INTRODUCTION

The magnetic fields of the Helmholt coils for e/m Apparatus 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

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

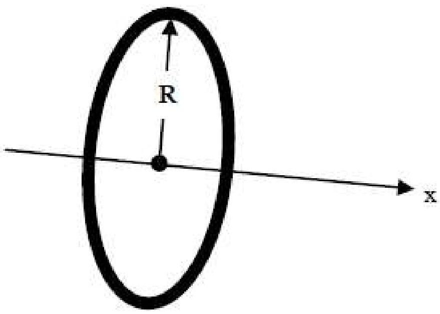

Figure 1. Single Coil

Twin Coils

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

$$\vec{B} = \vec{B}_1 + \vec{B}_2 = \frac{\mu_0 N I R^2}{\left(\left[\frac{d}{2} - x\right]^2 + R^2\right)^{3/2}}\hat{x} + \frac{\mu_0 N I R^2}{\left(\left[\frac{d}{2} + x\right]^2 + R^2\right)^{3/2}}\hat{x}$$

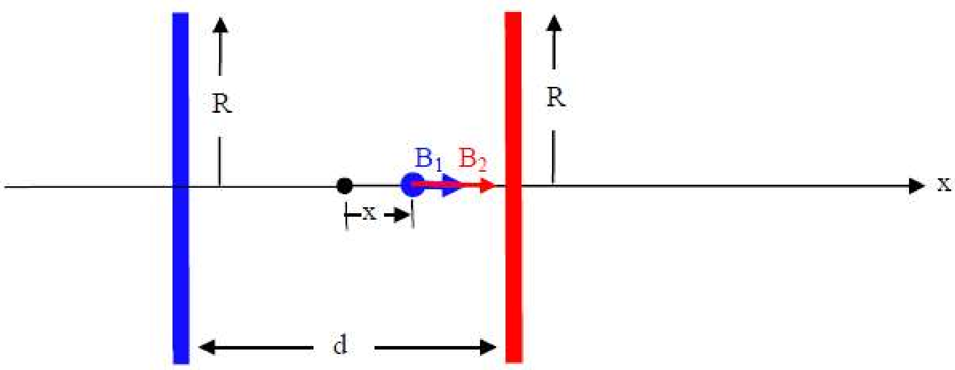

Figure 2. Twin Coils with Arbitrary Separation

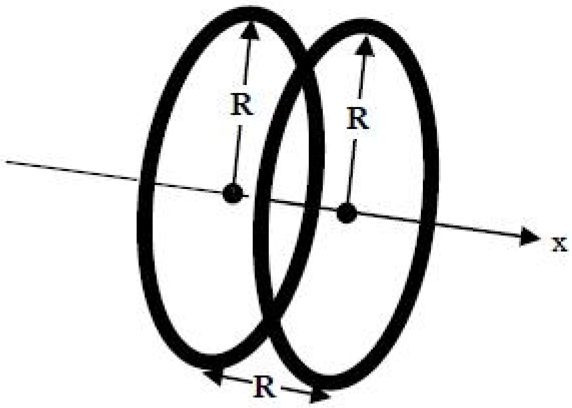

Figure 3. Helmholtz Coil

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:

$$\vec{B} = \frac{8\mu_0 NI}{\sqrt{125}\,R}\hat{x}.$$

Solenoid

For a solenoid with n turns per unit length, the magnetic field is

$$B = \mu_0 nI.$$

The direction of the field is straight down the axis of the solenoid.

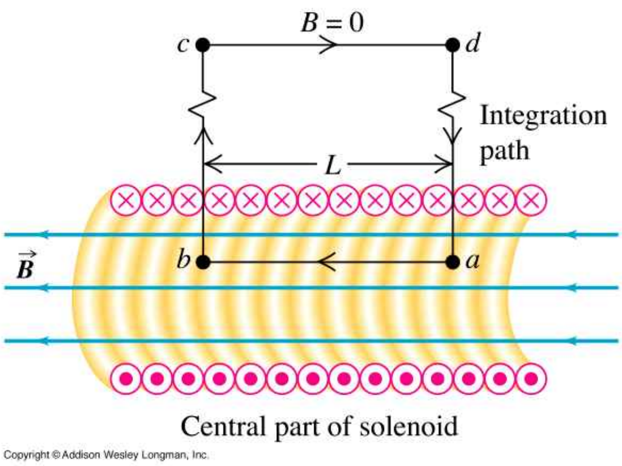

Figure 4. Magnetic field caused by long current carrying solenoid.

EQUIPMENT

INCLUDED:

Helmholtz Coil Base EM-6715	1
500-Turn Field Coil EM-6723	1
Patch Cords (Red, set of 5) SE-9750	1
Patch Cords (Black, set of 5) SE-9751	1
Primary and Secondary Coils SE-8653	1
Dynamics Track Mount	1
Vernier Caliper	1
Small Base and Support Rod (2) ME-9355	1
Optics Bench Rod Clamps (2)	1
Resistor, 100ohm	1
Digital Multimeter (Digital ammeter) MY68	1
Magnetic Field Sensor CI-6520	1
Rotary Motion Sensor CI-6538	1
DC Power Supply GP-4303DU/TP	1

NOT INCLUDED, BUT REQUIRED:

850 Universal Interface UI-5000	1
Capstone Software	1

SET UP

① Connect the DC power supply directly across the Helmholt coil (500turn, Φ0.64mm). To measure the current through the coil, connect the digital ammeter in series with the power supply and the coil. See Figure 4.

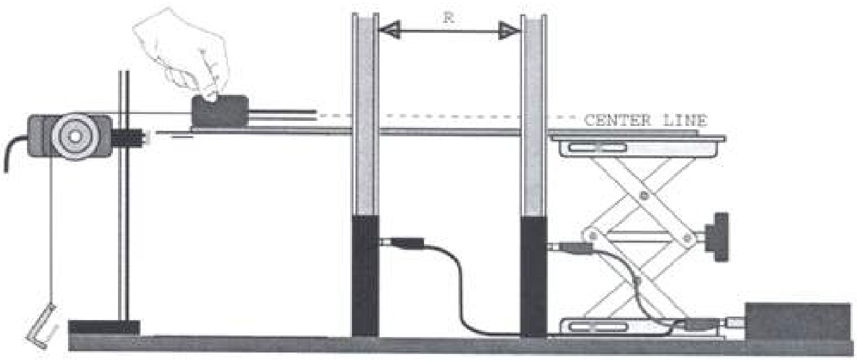

Figure 4. Experimental setup for the Helmholtz coil.

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 first coil** when it is pushed along the surface of the track.

③ 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 to the hanger and* put the Magnetic Field Sensor on the track.

④ Plug the Magnetic Field Sensor into Channel A of the Science 850 Universal 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 100 mili Ampere flows through the coil. Turn the DC power supply off at the switch.

⑥ Open the Capstone program and Drag & Drop the Rotary motion sensor into Channel 1 and 2 of 850 Universal Interface on the Screen. Drag & Drop the Magnetic Field Sensor into Channel A. Open a Graph window and Drag & Drop the x-position to the horizontal axis, and Drag & Drop the Magnetic Field Intensity to the vertical axis.

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 Make sure the Helmholtz coils are parallel to each other. See Figure 4.

③ Connect the second coil in series with the first coil. See Figure 5.

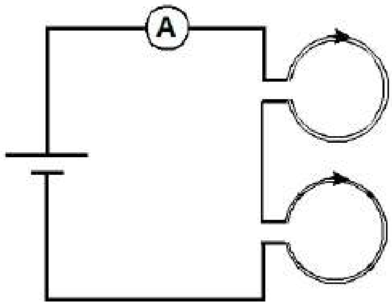

Figure 5. Helmholtz wiring

④ Set the Magnetic Field Sensor switch on Axial and x10 gain. *With the power amplifier off,* set the Magnetic Field Sensor in the middle of the track and the center of the first coil. Press the tare button.

⑤ *Turn on the power amplifier and adjust it until the current reads about 100 mA.* Click on START in Capstone 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.

⑥ Use the Smart Cursor on the graph to measure the position of the center of the peak. *Click on the Capstone 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.

⑦ 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?

⑧ Calculate the theoretical value for the magnetic field between the coils and compare it to the measured value on the graph.

⑨ Now change the y-positions from center of the Helmholtz coils with increasing the y-positions by 1.0 cm above the midway. Repeat steps 3 through 6. See Figure 6.

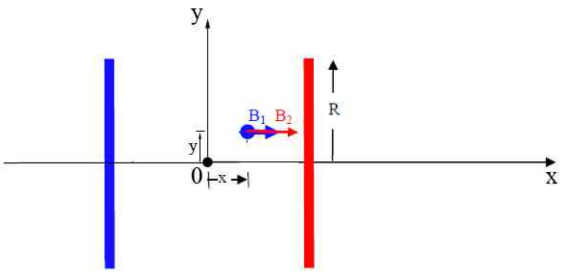

Figure 6. scanning the Magnetic field due to the Helmholtz coils with varying positions of the probe along x- and y-axes.

⑩ Now change the separation between the coils to half the radius of the coils.

⑪ Repeat steps 3 through 6.
⑫ Now change the separation between the coils to three halves the radius of the coils.
⑬ Repeat steps 3 through 6.

SOLENOID PROCEDURE

① Connect the power amplifier in series with the digital ammeter and the solenoid.
② Set the Magnetic Field Sensor switch on Axial and x10 gain. With the power amplifier off, put the Magnetic Field Sensor inside the solenoid (see Figure 7). Press the tare button.
③ Turn on the power amplifier and adjust it until the current 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 longitudinal direction of the solenoid.

Figure 7. Experimental setup for the measurement 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 power amplifier off, put the Magnetic Field Sensor inside the solenoid. Press the tare button.
⑧ Turn on the power amplifier 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 longitudinal direction of the solenoid.
⑩ Is the field inside the solenoid constant? What happens near the end of the solenoid?

Worksheet 04. Magnetic Field by Coils

요약문 (Abstract)

Fill this area as you done.

실험 분반	( ) 학년 ( ) 분반	
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( ) 조	학번	이름
제출자		
공동 실험자		

Results

1. Draw magnetic fields parallel to the *x*-axis by the single coil with varying the current.

2. Draw magnetic fields perpendicular to the x-axis by the single coil with varying the current.

3. Draw magnetic fields parallel to the *x*-axis by the double coil with varying the spacing between the coils.

4. Draw magnetic fields perpendicular to the x-axis by the double coil with varying the spacing between the coils.

5. Draw magnetic fields parallel to the x-axis in the inside and the outside of the solenoid with varying the current.

6. Draw magnetic fields perpendicular to the x-axis in the inside and the outside of the solenoid with varying the current.

QUESTIONS

1. Did the axial reading change when the sensor was moved radially outward from the center toward the windings on the single coil?

2. Was the axial reading different from the reading in the middle of the single coil when the sensor was center of the single coil?

3. How uniform is the magnetic field between the two coils as the sensor was moved radially outward from the center toward the windings of the two coils?

4. Compare the theoretical value to the axial value using a percent difference. What are some factors that could account for this percent difference?

5. Based on your graph for the solenoid, over what distance along the x-axis can the magnetic field be considered a constant?

6. How did the measured value of magnetic field strength inside a solenoid compared to the theoretical value? What factors may have caused the difference, if any?

7. By comparing the axial and radial readings, what can you conclude about the direction of the magnetic field lines outside of the solenoid?