23. MAGNETIC FIELDS DUE TO COILS

Purpose: To find the axial magnetic field produced by current-carrying coils.

Equipment:

- Science Workshop 500 Interface
- Magnetic Field Sensor
- DC Power Supply w/ammeter
- Two 500-turn or 200-turn coils
- Motion Sensor
- Pasco Capstone Software
- Aluminum channel, lab jack, wooded block

Theory:

Single Coil

For a coil of wire having radius $\boldsymbol{R}$ and $\boldsymbol{N}$ turns of wire, and with a current $\boldsymbol{I}$, the magnetic field along the perpendicular axis through the center of the coil is given by

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

$$\mu_o = 4\pi \times 10^{-7}\, T\cdot m/A = 1.26 \times 10^{-6}\, T\cdot m/A$$

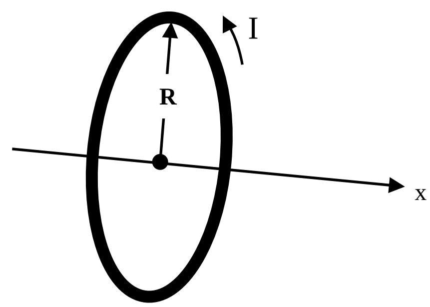

Figure 1: Single Coil
(Courtesy of PASCO Scientific)

Two Coils

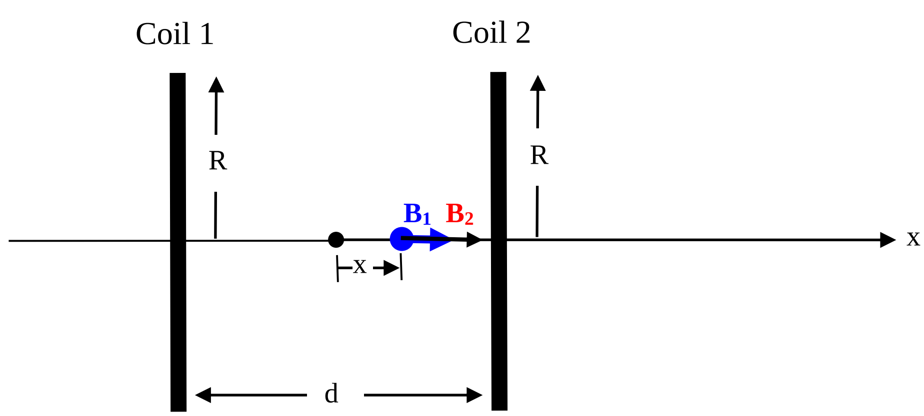

Figure 2: Two Coils with Arbitrary Separation
(Courtesy of PASCO Scientific)

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

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

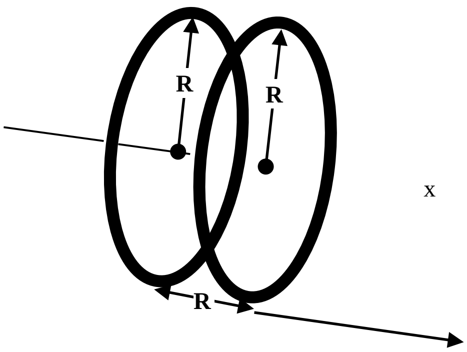

Figure 3: Helmholtz Coils
(Courtesy of PASCO Scientific)

Two coils are called Helmholtz coils when the coil separation (d) equals the radius (R) of the coils. This coil separation gives a highly uniform magnetic field between the coils. Plugging in x = 0 and d = R into Eq. 2 gives the magnetic field at a point on the x-axis centered between the two coils:

$$\vec{B} = \frac{8\mu_0 N I}{\sqrt{125}R} \hat{x} \qquad (3)$$

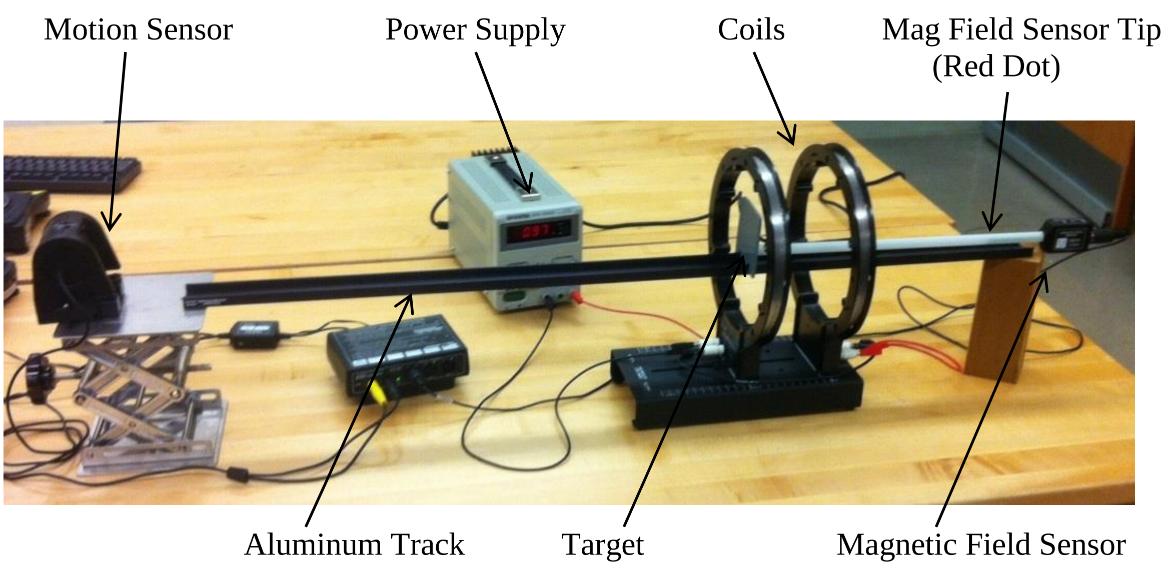

Figure 4

Procedure:

A. Single coil

1. You will use the coil (500 turns) fixed at the zero cm mark. 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. Connect the power supply to the coil and set the meter to measure current.

2. 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. See Fig. 4.
3. Plug the Magnetic Field Sensor into Channel A and the Motion Sensor into Channels 1 and 2 (yellow plug in 1) of the Science Workshop 500 interface.
4. A. Start Pasco Capstone program from the "Physics Applications" folder on the desktop.
   B. Choose "Table and Graph" from the pop-up window.
   C. Click "Hardware Setup" (left side menu). On the Science Workshop 500 icon double click the left most jack (#1) and choose the "Motion Sensor II" from the menu. Click on "Properties" and position the tip of the Magnetic Field Sensor (Marked by a RED DOT on the target tube) directly in the center of the coil; then click "Zero Sensor Now." This creates an offset in the position measurement so that it will display a zero position when the sensor is in the center of the coil.
   D. Double click the A jack, third from the right, and choose "Magnetic Field Sensor" from the menu.
   E. On the graph, click on the "<Select Measurements>" tab for each axis and choose "Magnetic Field Strength (10X)" for the y-axis and "Position (m)" for the x-axis.
5. Set the Magnetic Field Sensor on Axial (↕↕) and ×10 gain. With the DC power supply off, move the Magnetic Field Sensor so that the target is about 15 cm from the motion sensor. Press the tare button on the magnetic field sensor.
6. Turn on the DC power supply and adjust the voltage so about 1 Amp flows through the coil. Click "Record" in Capstone and slowly move the Magnetic Field Sensor away from the motion sensor until the target is flush with the first coil. Then click "Stop."
7. Click on CURVE FIT at the top of the graph, select User-Defined Fit. Type in the right-hand side of the theoretical equation (Eq. 1 above) for the magnetic field and fit for the current, the coil radius, the separation, an x offset, and a B offset.
8. Do the maximum values agree? Can the discrepancies be corrected by modifying some of the parameters in the theoretical equation?

9. Helmholtz Coils

1. Put a second coil on 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 the picture below.

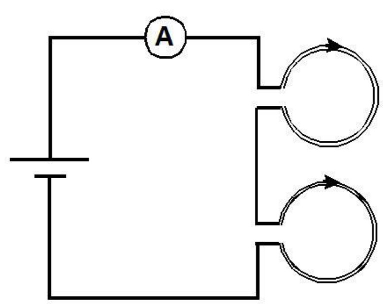

Figure 5
(Courtesy of PASCO Scientific)

2. Connect the second coil in series with the first coil, pay close attention to the direction of the current, as shown in the Fig. 5.
3. Under the Hardware Setup, click on the Motion Sensor and in properties, re-zero with the tip of the magnetic field sensor in the center of the two coils. Tare the field sensor with the power supply off and repeat the procedure above, but use 0.5 amps this time.
4. Now, fit the magnetic field between the coils using Eq. 2. This time fit for the separation, d, between the coils in addition to the other parameters.
5. Now change the separation between the coils to 1.5 times the radius of the coils. Repeat steps 3 and 4.
6. Now change the separation between the coils to half the radius of the coils and repeat again.

Results:

Part A.

R = ____________ N = ___________ I = ___________

Magnetic field at zero position: Theoretical: ______________________(T)

Measured: ______________________ (T)

Part B.

Coil Separation	$B_{theoretical}$ (Tesla)	$B_{measured}$ (Tesla)
R =		
1.5 R =		
0.5 R =		

Conclusions or Summary:

Is the magnetic field strength constant between the coils for the three cases, d = R, d = 1.5·R and d = 0.5·R?

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