Experiment # 5

MAGNETIC FIELD OF COILS

OBJECTIVE
To measure the magnetic field at the center of wire loops and along the axis of a coil and verify the analytical expressions.

EQUIPMENT REQUIRED
1. Ammeter l*A*/5*A DC*.
2. Universal power supply.
3. Teslameter with an axial probe.
4. Induction coils.
5. Digital meter.
6. Conducting circular loops.
7. Meter scale.

INTRODUCTION
The magnetic flux density ***B*** at a point on the axis of a circular loop of radius *b* that carries a direct current *I* (see Figure 1) is given by:

$$\left|\overline{B}\right| = \frac{\mu_o I b^2}{2(z^2 + b^2)^{3/2}} \quad \text{.......... (1)}$$

If there is a number of identical loops close together, the magnetic flux density is obtained by multiplying by the number of turns *N*. At the center of the loop (*z*=0), equation (1) becomes:

$$\left|\overline{B}(0)\right| = \frac{\mu_o N I}{2b} \quad \text{.......... (2)}$$

To calculate the magnetic flux density of a uniformly wound coil of length *L* and *N* turns (see figure 2), we multiply the magnetic flux density of one loop by the density of turns, *N/L* and integrate over the length of the coil. The resulting magnetic flux density is given by

$$\left|\overline{B}(z)\right| = \frac{\mu_o N I}{2L}\left(\frac{a}{\sqrt{b^2 + a^2}} - \frac{c}{\sqrt{b^2 + c^2}}\right) \quad \text{.......... (3)}$$

where $a = z + L/2$ and $c = z - L/2$.
If the length of the coil is much larger than its radius, the magnetic flux density near the center of the coil axis can be obtained by approximating equation (3), yielding:

$$\left|\overline{B}(z)\right| \cong \frac{\mu_o N I}{L} \quad \text{.......... (4)}$$

(provided that $b << L$ and z is smaller than $L/2$).

PROCEDURE

Calibration and measurement of the teslameter

The calibration steps are as follows

a) *Adjust the multimeter knob to the 3V position (choose AC).*
b) *Push the DC button of the teslameter.*
c) *Push the "Eichen" button of the teslameter.*
d) *Turn the "Eichen" knob unth the multimeter reads exactly 3 volts.*
e) *Release the "Eichen" button. The teslameter is now calibrated.*

Note: Because part *A* of this experiment involves the measurement of relatively weak *DC* magnetic fields, a procedure must be followed to cancel out the contribution to measurement from the naturally occurring magnetic fields.

1. Set the digital multimeter to read *AC* voltage and choose the 20 *V* setting.
2. Set the knob of the teslameter to 0.3*mT* (i.e., 0.3*mT* = 3*V* or 0.l*mT* = 1*V*).
3. Push the *DC* button of the teslameter.
4. Place the tip of the axial probe in the location where the magnetic field is to be evaluated (at the center of the coil) and leave it there. The magnetic field must be parallel to the axis of the axial probe.
5. Switch the current *I* to zero.
6. Turn the "*O* adjust" knob until the multimeter gives minimum reading (for the purpose of this experiment, the reading of the multimeter should be < 0.4 *V*).
7. Switch the current *I* on to +5 *A*. Record the multimeter's reading, call it V_1.
8. Reverse the direction of the current *I* (i.e., *I* = -5*A*), record the multimeter's reading and call it V_2. To reverse the direction of *I* without moving the probe, turn off the power supply, interchange the leads at the output of the power supply, and turn on the power supply again.
9. Take the average of the voltage readings in steps (7) and (8). The average voltage $V=(V_1+ V_2)/2$ is the voltage due only to the magnetic field to be measured.
10. Finally, multiply *V* by the appropriate factor to obtain the value of ***B***.

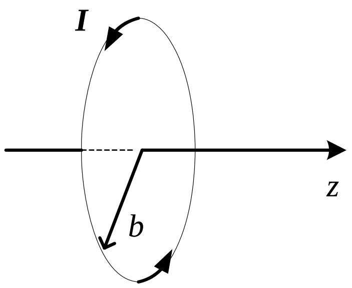

Figure 1: A circular loop of radius *b*.

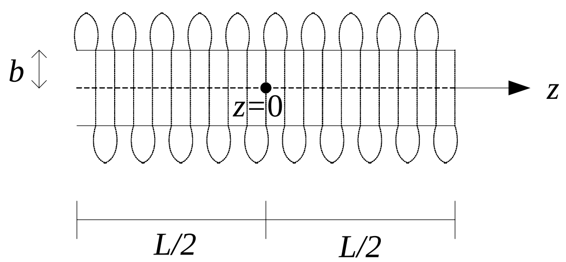

Figure 2: A coil

PART A: Magnetic Field at the Center of a Circular Conductor

1. Connect the *DC* output of the power supply to the single-turn circular conductor of diameter 2*b*=12 *cm*. Connect the ammeter to measure the current in the conductor. Adjust the current to 5 *A*. Using the Teslameter, measure the resulting *DC* magnetic field ***B*** at the center of the circular conductor.

2. Repeat step (1) for the circular conductor of diameter 2*b*=12 *cm* and *N*=2 and *N*=3 turns.

Table 1: Magnetic Field Measurement at the Center of Conductor.

No. of Turns '*N*'	**V_1 (Volt)**	**V_2 (Volt)**	**$V = (V_1+V_2)/2$ (Volt)**	**$B_{(experimental)}$ (mT)**	**$B_{(Theoretical)}$ (mT)**
1					
2					
3					

PART B: Magnetic Field inside a Coil

1. Connect the coil of length *L*=160 *mm*, diameter 2*b*=33 *mm* and *N*=300 turns to the *DC* output of the power supply. Adjust the current *I* to 1*A*. Measure ***B*** inside the coil at several distances along the axis of the coil.

Table 2: Magnetic Field Measurement inside a Coil.

Distance 'z' cm	**V (Volt)**	**$B_{(experimental)}$ (mT)**	**$B_{(Theoretical)}$ (mT)**
0			
2			
4			
6			
8			
10			
12			
14			
16			

QUESTIONS FOR DISCUSSION

1. Plot the relation between the magnitude of the magnetic field and the number of turns and compare it with the theoretical result based on equation (2). (Note: plot both results on top of each other).
2. Why did we need to eliminate the field of the surrounding in part *A* of the experiment but not in part *B*?
3. Plot the magnetic field inside the coil as a function of distance. Compare it with the theoretical graph based on equation (3). (Note: plot both results on top of each other).
4. Plot a curve representing equation (4) on top of the two curves in step (3). Do you think equation (4) is a valid approximation of equation (3) in this case'? Why or why not?

