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Experiment 5: Magnetic Field

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Section 221-006
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Statement of Objectives

The objective of the lab was to study the effects of magnetic fields, namely the interactions between magnetic fields and electric current. These interactions include the force on a wire with current and the magnetic field created by a current. We also studied the relationship between the charge and mass of an electron.

Theory

Magnetic fields can be created by current loops. The magnitude of the magnetic field along the axis of a loop can be expressed by:

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

Where B = magnetic field
I= current
z = axis
N = number of turns in loop
R = radius

When you plot B versus $\frac{1}{(R^2 + z^2)^{3/2}}$ using equation (1) the slope corresponds to $\frac{\mu_o I R^2 N}{2}$. A stronger more uniform magnetic field can be created by aligning two identical current loops. The magnetic field of a Helmholtz coil, a special configuration of two current loops, is:

$$B = \frac{8}{5\sqrt{5}} \frac{\mu_o I N}{R} \qquad (2)$$

When a plot of B versus I is made the slope corresponds to:

$$\frac{8}{5\sqrt{5}} \frac{\mu_o N}{R}$$

The magnetic force on a wire of length *l* is described by the following equation.

$$F = I l \times B \qquad (3)$$

Where I = current vector
l= length of wire
B = magnetic field

Equipment List

- Hall Effect Probe
- DC Power Source
- Ammeter
- Helmholtz coil
- Balance
- Prefab current loops

Procedure

Part A: The Hall Effect Probe

The Hall probe was calibrated using a permanent magnet of known induction of 750 Gauss.

Part B: Magnetic Field Strength of a Current Loop

A coil of wire was connected to a DC power source. A current of 1A was flowed through the coil. The magnetic field along the axis of the coil was measured using the Hall probe. The number of turns in the coil was recorded along with the radius of the coil. The magnitude of the magnetic field was recorded along various distances in the plane of the coil.

Part C: Magnetic Field at the Center of a Helmholtz Coil

The radius of the Helmholtz coil and the number of turns were recorded. The coil was then connected to the DC power supply. Using the Hall probe, the field at the center of the coil was determined from currents ranging from 0A to 1A in 0.1A increments.

Part D-1: Current Balance – Magnetic Force with Varying Current

The current loop with the longest 3-4 section was selected and its length recorded. The loop was then plugged into the main unit with the 3-4 section passing through the pole region of the magnet assembly. The mass of the magnet was then recorded with no current flowing through the loop, and then at each .5A increment up to a 4.0A maximum.

Part D-2: Current Balance – Magnetic Force with Varying Length

The setup in Part D-1 was used with the current set to 3.0A. The mass was then recorded and the current reduced to naught. The current loop was then replaced with another loop with a different 3-4 length. The current was again set to 3.0A and the mass recorded. This procedure was repeated until all of the available current loops were measured.

Data

Part B: Magnetic Field Strength of a Current Loop

Coil Data

Loops (N)	Radius (m)
104	.0625

Table 1-A

Magnetic Field Measurements

z (m)	B (Gauss)
.025	19.30
.040	17.25
.053	15.10
.065	13.60
.073	11.90
.087	10.50
.126	8.40
.139	8.00
.153	7.70
.165	7.50
.185	7.30

Table 1-B

Part C: Magnetic Field at the Center of a Helmholtz Coil

Coil Data

Loops (N)	Radius (m)
104	.0625

Table 2-A

Magnetic Field Measurements	
Current (A)	B (Gauss)
0.0	7.70
0.1	9.0
0.2	10.40
0.3	12.00
0.4	13.30
0.5	14.80
0.6	16.30
0.7	17.80
0.8	19.20
0.9	20.60
1.0	22.10

Table 2-B

Part D-1: Current Balance – Magnetic Force with Varying Current

Current Loop	
Length of Segment	0.084 m

Table 3-A

Current (A)	Mass (kg)
0.0	0.1608
0.5	0.1612
1.0	0.1615
1.5	0.1619
2.0	0.1622
2.5	0.1626
3.0	0.1629
3.5	0.1632
4.0	0.1636

Table 3-B

Part D-2: Current Balance – Magnetic Force with Varying Length

Current Loop

Current	3.0A

Table 4-A

Length (m)	Mass (kg)
0.012	0.1611
0.022	0.1614
0.032	0.1616
0.042	0.1619
0.064	0.1623
0.084	0.1629

Table 4-B

Analysis

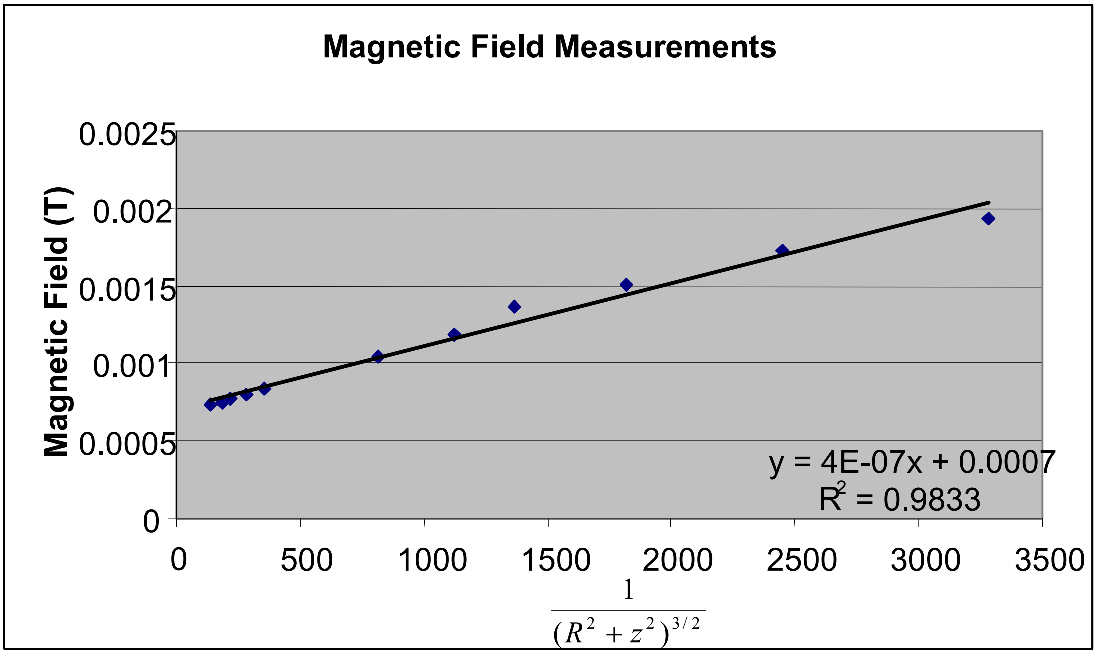
Part B: Magnetic Field Strength of a Current Loop

Using equation (1), we can check our value of B by making a graph of B (in Teslas) v. $\frac{1}{(R^2+z^2)^{3/2}}$ as shown in Table 5 and Graph 1.

Magnetic Field Measurements

z (m)	B (Gauss)	B (T)	$\frac{1}{(R^2+z^2)^{3/2}}$
.025	19.30	.001930	3278.48
.040	17.25	.001725	2447.46
.053	15.10	.001510	1817.22
.065	13.60	.001360	1363.84
.073	11.90	.001190	1126.75
.087	10.50	.001050	813.499
.126	8.40	.000840	359.407
.139	8.00	.000800	282.490
.153	7.70	.000770	221.509
.165	7.50	.000750	182.056
.185	7.30	.000730	134.301

Table 5



Graph 1

The slope of the best-fit line corresponds to $\frac{\mu_o I R^2 N}{2}$ with an experimental value of $4.0 * 10^{-7}$ and a theoretical value of $2.55 * 10^{-7}$.

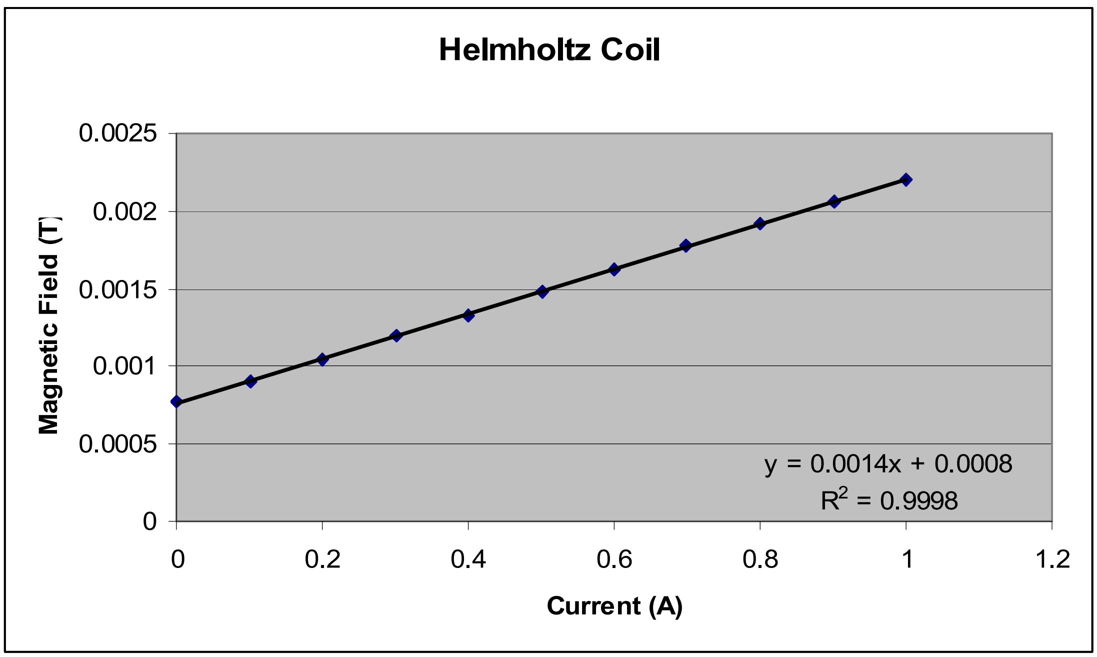
Part C: Magnetic Field at the Center of a Helmholtz Coil

Using equation (2), the magnetic field in the center of a Helmohltz coil, we are able to plot the magnetic field (in Telsas) v. the current. By doing so, we can compare our value of the field to the theoretical value. The conversion is shown in Table 6 and plot in Graph 2.

Magnetic Field Measurements

Current (A)	B (Gauss)	B (T)
0.0	7.70	.000770
0.1	9.0	.000900
0.2	10.40	.001040
0.3	12.00	.001200
0.4	13.30	.001330
0.5	14.80	.001480
0.6	16.30	.001630
0.7	17.80	.001780
0.8	19.20	.001920
0.9	20.60	.002060
1.0	22.10	.002210

Table 6



Graph 2

The slope of the best-fit line corresponds to $\frac{8}{5\sqrt{5}}\frac{\mu_o N}{R}$ with an experimental value of $.0014\frac{T}{A}$ and a theoretical value of $.0015\frac{T}{A}$.

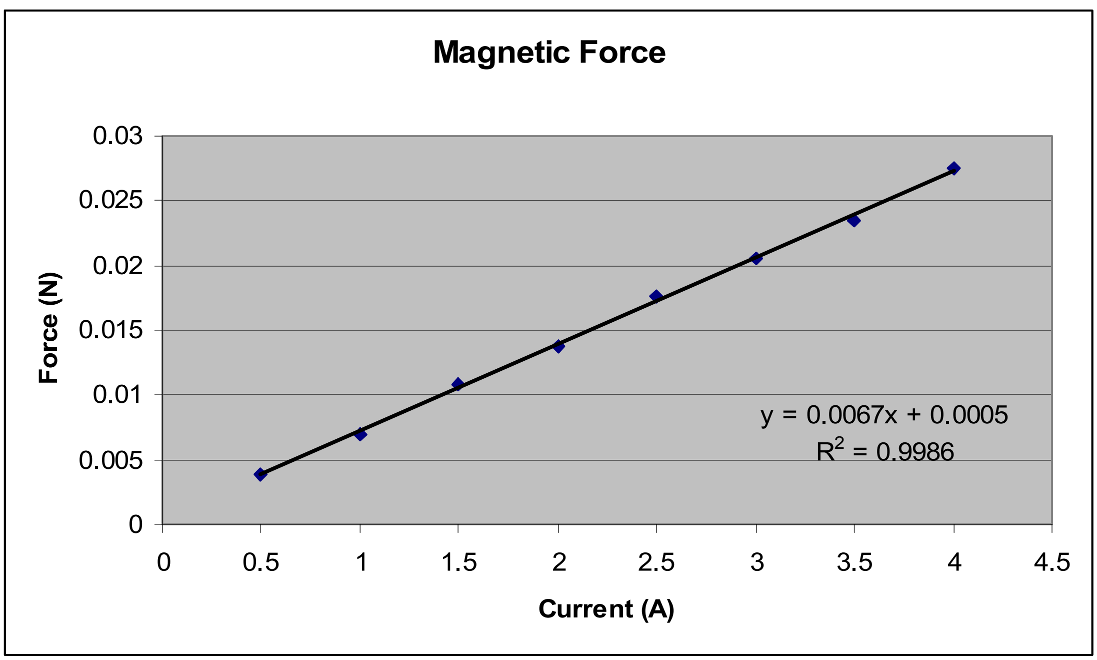
Part D-1: Current Balance – Magnetic Force with Varying Current

The net change in mass is determined by subtracting the initial mass value with the mass value associated with each current. The net mass is then multiplied by g to find the force. Table 3-B shows the initial mass and mass associated with the current. Table 7 shows the net mass and force.

Current Balance (Initial Mass = 0.1608kg)

Current (A)	Net Mass (kg)	Force (N)
0.5	.0004	.0039
1.0	.0007	.0069
1.5	.0011	.0108
2.0	.0014	.0137
2.5	.0018	.0177
3.0	.0021	.0206
3.5	.0024	.0235
4.0	.0028	.0275

Table 7



Graph 3

The force caused by the magnetic field can be calculated using equation (3). The slope of the best-fit line, when the force is plotted against the current is equal to lB, where l = .084m. Graph 3 has a slope of .0067, while the theoretical value is .0063. This gives us a magnetic field strength of .0798 Teslas.

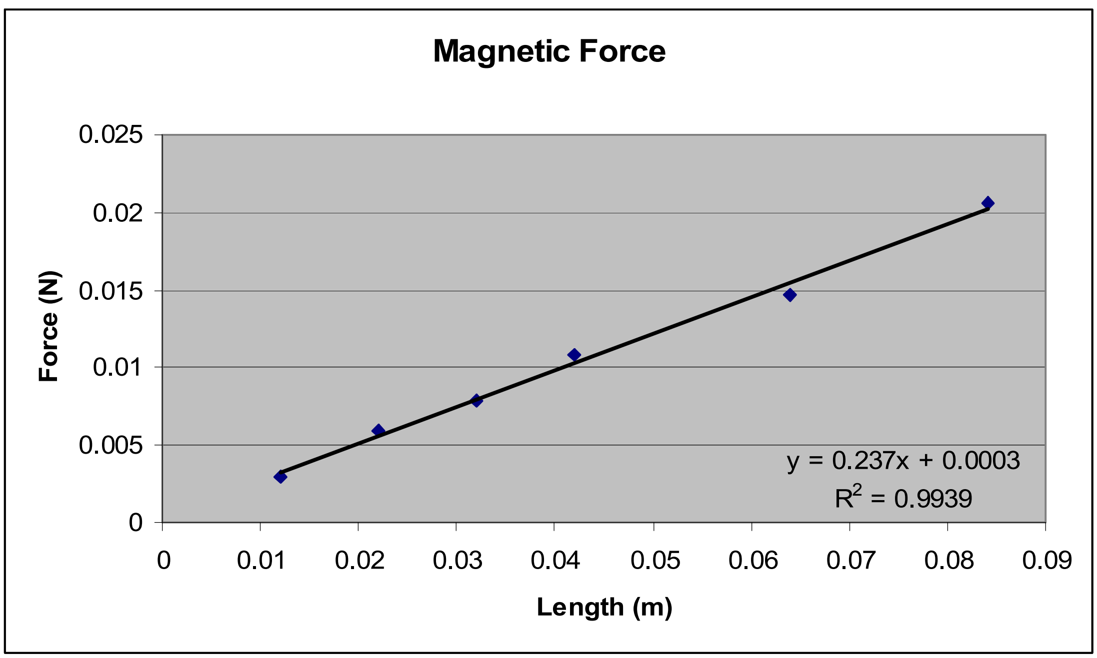
Part D-2: Current Balance – Magnetic Force with Varying Length

The net mass and force are found again, this time for each varying length. These values are stored in Table 8 below. The force v. length is plotted below in Graph 4.

Current Balance (Initial Mass = 0.1608kg)

Length (m)	Net Mass (kg)	Force (N)
0.012	.0003	.0029
0.022	.0006	.0059
0.032	.0008	.0078
0.042	.0011	.0108
0.064	.0015	.0147
0.084	.0021	.0206

Table 8



Graph 4

Dividing the slope of the line of best-fit, .237, by the current, 3A, we get the experimental value of the magnetic field, .079 Teslas.

Question

Why are we justified in ignoring the force acting on segments 2-3 and 4-5?

The forces in these two segments do not act downwards and thus do not affect the balance. These forces will also cancel each other out.

Discussion of Results

Part B: Magnetic Field Strength of a Current Loop

With an experimental value of $4.0*10^{-7}\frac{\mu_o IR^2 N}{2}$ and a theoretical value of $2.55*10^{-7}\frac{\mu_o IR^2 N}{2}$ the computed error value is 36.25%, a very large error. The most likely cause of error is in the calibration of the magnetic probe.

Part C: Magnetic Field at the Center of a Helmholtz Coil

With the experimental value of $.0014\frac{T}{A}$ and a theoretical value of $.0015\frac{T}{A}$, we achieve a 7.14% error.

Part D-1: Current Balance – Magnetic Force with Varying Current

The experimental value of the magnetic field was .0798T. Comparing this to our theoretical magnetic field value of .075T, we get a 6.02% error reading.

Part D-2: Current Balance – Magnetic Force with Varying Length

The experimental value of the magnetic field was .079T. Comparing this to our theoretical magnetic field value of .075T, we get a 5.06% error reading.

Conclusion

We can conclude that Magnetic Field caused by a coil does indeed follow equation (1). The magnetic Field does indeed decrease as the distance from the center of the coil increases. Part C shows us that the magnetic field depends on the current through the coil, and furthermore goes to explain the relationship between the two. Part D shows that a magnetic field creates a force which acts upon moving charges. In this instance, the moving charges happened to be a current running through a circuit board, however moving point charges are affected as well.