Physics Lab #5: Magnetic Fields and the Magnetic Dipole

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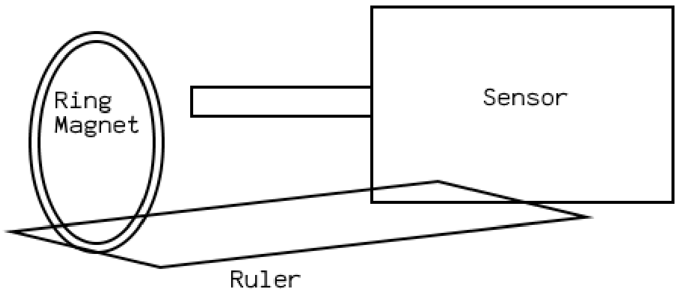
Abstract: The objective of this lab was to measure the magnetic dipole moment with two different methods in order to verify the law. By using the equation for the magnetic field at a distance and the equation for the movement of a magnet in a field, two equations were derived for the magnetic dipole moment. This lab was not a success. Ranges for the moment were found for both parts of the lab, and the lab would be a success if the ranges overlapped. The range for the first part of the lab was 0.4094929 H/m < μ < 0.4206279 H/m. The range for the second part of the lab was 0.298898 H/m < μ < 0.3646308 H/m. These ranges did not overlap at all, and therefore the lab was a failure.

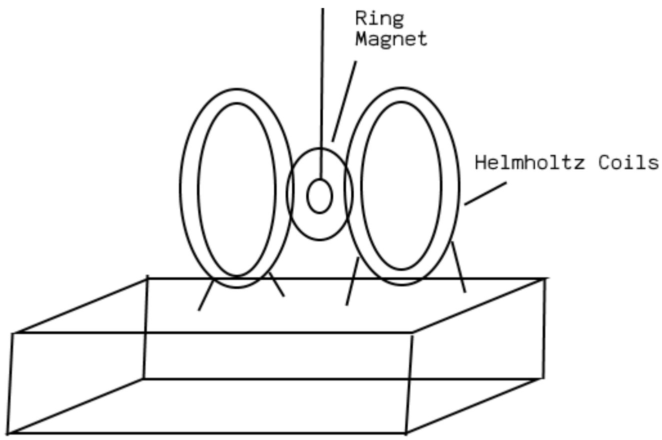
Theory: The electric field created by a magnetic ring is similar to the electric field of a dipole. Contrary to electricity, there is no single 'magnetic charge,' every magnetic charge is coupled with it's opposite. The equation for the field of a magnetic dipole along it's axis is found to be $B_z(z)=\frac{\mu_0}{2\pi}\frac{\mu}{(R^2+z^2)^{\frac{3}{2}}}$ where $R=\frac{R_1+R_2}{2}$. The movement of a magnet in the field is determined by the moment. The torque can be found to be $\vec{\tau}=\vec{\mu}\times\vec{B}_e=-I\alpha$, where I is the moment of inertia, Be is the external field, and alpha is the angular acceleration. At small angles, this equation becomes $\mu B_e\sin\theta\approx\mu B_e\theta=-I\frac{\partial^2\theta}{\partial t^2}$. Solving the differential equation, the equation $\theta=A\sin(\omega t+\delta)$. Through substitution, the equation $\omega=\sqrt{\frac{\mu B_e}{I}}$ is obtained.

Objective: The objective of this lab was to measure the magnetic dipole in two different ways.

Procedure: First, the datastudio program 'dipole2.ds' is run. The magnetic field is measured along the z-axis from 0.07m to 0.17m. Measure the field strength at one distance ten times to obtain an error range. Measure R1 and R2 and m to find the moment of inertia. Hang the ring magnet in between the Helmholtz coils. Use a timer to measure the time of fifty oscillations of the magnet. Measure the magnetic field without the magnet. Repeat for amperages ranging from 0.05A to 0.5A.

Setup:





Data:

Constants	
R1 (m)	0.0165
R2 (m)	0.0222
m (kg)	0.0115
μ0 (H/m)	1.25664E-06

Part one:

Data		Fluctuation
z (m)	Bz (T)	Bz (T)
0.07	0.00027514	0.00034498
0.08	0.00022858	0.00034764
0.09	0.00018069	0.00034764
0.1	0.00015209	0.00034764
0.11	0.00013014	0.00034897
0.12	0.00011418	0.0003483
0.13	9.8214E-05	0.00034564
0.14	9.1562E-05	0.0003483
0.15	8.5576E-05	0.0003483
0.16	0.00007826	

Part Two:

Data		
I (A	B (T)	T50 (s)
0.1	-0.00092	69.05
0.1	-0.00084	52.16
0.2	-0.00074	44.15
0.2	-0.00065	37.4
0.3	-0.00056	34.4
0.3	-0.00046	31.51
0.4	-0.00037	29.69
0.4	-0.00027	25.96
0.5	-0.00018	25.15
0.5	-8.8E-05	24.9
T error (s)		0.1

Calculations:

Part One:

x Coordinates:

$$\frac{1}{\left(\frac{R_1+R_2}{2}^2+z^2\right)^{\frac{3}{2}}}=\frac{1}{\left(\left(\frac{0.165\,m+0.0222\,m}{2}\right)^2+(0.07\,m)^2\right)^{\frac{3}{2}}}=2610.58373\frac{1}{m^3}$$

Worst Line Slope:

$$S_1=\frac{\left(B_{z_f}+\sigma B_z\right)-\left(B_{z_i}-\sigma B_z\right)}{x_f-x_i}$$

$$=\frac{\left(7.826\text{E-}5\,T+1.32\text{E-}6\,T\right)-\left(2.751\text{E-}3\,T-1.32\text{E-}6\,T\right)}{238.880747\frac{1}{m^3}-2610.58373\frac{1}{m^3}}=8.19\text{E-}8\,T\,m^3$$

μ:

$$\mu=\frac{2\pi S}{\mu_0}=\frac{2\pi*8.19\text{E-}8\,T\,m^3}{4\pi E-6\frac{H}{m}}=0.40949\frac{H}{m}$$

Part Two:

Period:

$$T=\frac{T_{50}}{50}=\frac{69.05\,s}{50}=1.381\,s$$

Angular Frequency Squared:

$$\omega^2=\frac{4\pi^2}{T^2}=\frac{4\pi^2}{(1.381\,s)^2}=20.70097\frac{1}{s^2}$$

Error:

$$\sigma\omega=\frac{\sigma t}{\bar{T}}*\bar{\omega}=\frac{0.1\,s}{0.74874\,s}*93.461157\frac{1}{s^2}=12.4825\frac{1}{s^2}$$

Moment:

$$I=\frac{m}{4}\left(R_1^2+R_2^2\right)=\frac{0.0115\,kg}{4}\left((0.0165\,m)^2+(0.0222\,m)^2\right)=2.1996\text{E-}6\,kg*m^2$$

μ:

$$\mu = I * Slope = 2.2E\text{-}6\, kg\, m^2 * 135885.339 \frac{1}{T * s^2} = 0.298898 \frac{H}{m}$$

Qualitative Error Analysis: One error in this lab was the inaccuracy of the time measurements. The reaction times affected the time measured for the 50 oscillation periods, so the angular frequency was lower than actual. Another error is that the magnetic affect of the magnet could not be completely avoided when taring the sensor. This would cause the magnetic field measured to be lower than actual, which would cause the calculated mu to be lower.

Quantitative Error Analysis:

Part One:

StDev B (T)	1.32E-06

Range: 0.4094929 H/m < μ < 0.4206279 H/m

Part Two:

T error: 0.1s

Angular Frequency squared error: 12.48246 1/s^2

Range: 0.298898 H/m < μ < 0.364308 H/m

Results:

Part One:

Calculations
r^-3 (m^-3)
2610.5837294
1793.459533
1281.8429864
946.35504984
717.7435959
556.84487716
440.44805233
354.23270231
289.05121041
238.88074744

	Slope (m^-3)	μ (H/m)
Low	8.189857E-08	0.40949287
High	8.412559E-08	0.42062794

Part Two:

Calculations	
T (s)	ω^2 (s^-2)
1.381	20.700097
1.0432	36.2764332
0.883	50.6335444
0.748	70.55967
0.688	83.4032281
0.6302	99.403789
0.5938	111.964244
0.5192	146.450335
0.503	156.035626
0.498	159.1846

T error (s)	0.1
ω^2 err (s^-2)	12.482458077
I (kg m^2)	2.199634E-06
Low slope	135885.33947
High slope	165768.87051
low μ (s^-2)	0.2988979788
High μ(s^-2)	0.3646308023

Conclusion: In this lab, the magnetic dipole moment of a ring magnet was found with two different methods. In part one, a range for mu of 0.4094929 H/m < μ < 0.4206279 H/m was obtained. The range for part two was 0.298898 H/m < μ < 0.3646308 H/m. These ranges did not overlap, therefore the law was not verified and the experiment was a failure. The failure could be attributed to the errors created by the timing, which could not be perfect as it was based on human reaction times. Another error source could