PHYS 230
LAB-5 REPORT

Name: Misbah Ahmed Nauman

CCID: misbahah

Student ID: 1830574

Section: EM62

TA: Joshua Peltonen

Lab Number: 5

Lab Date: 03.24.2025

Introduction

Objectives

The objective of this experiment is to investigate the force-distance relationship between a soft ferromagnetic material (a Canadian nickel coin) and a strong neodymium (Nd) permanent magnet. We aimed to quantify the magnetic force as a function of distance and confirm whether the interaction follows a predicted inverse-seventh power law. This experiment was chosen due to the practical and theoretical significance of soft ferromagnetic materials and their response to external magnetic fields.

Background Theory

Magnetism arises from the motion of electrons, particularly their spin and orbital angular momentum. All materials exhibit one of the following forms of magnetism:

- Diamagnetic: Materials that weakly repel magnetic fields (e.g., bismuth).
- Paramagnetic: Materials weakly attracted by magnetic fields (e.g., aluminum).
- Ferromagnetic: Strongly magnetic materials that retain (hard) or temporarily acquire (soft) a magnetic dipole moment in external magnetic fields.

In this experiment, the nickel coin, a soft ferromagnet, gains a temporary magnetic moment when exposed to the field of the neodymium magnet. The force experienced is due to the magnetic potential energy gradient: $F_z = -\frac{dU}{dz}$

where the potential energy UUU of a magnetic dipole $\vec{m}$ in an external magnetic field $\vec{B}$ is given by: $U = -\vec{m} \cdot \vec{B}$

For soft ferromagnets, the magnetic moment is induced by the field, and the force follows the relation: $F \propto \frac{1}{r^7}$

This steep distance dependence distinguishes soft ferromagnetic interactions from hard ferromagnets, which follow a $\frac{1}{r^4}$ law.

Methods

Equipment Used

- Neodymium permanent magnet (source of inhomogeneous field)
- Canadian nickel coin (soft ferromagnet sample)
- Micrometer stage (precise height adjustment)
- Plastic weighing cups
- Milligram-sensitive electronic balance (±0.001 g precision) with Tare button (to zero out cup weight)
- Ruler

Experimental Setup

The experimental setup consisted of a neodymium magnet suspended on a micrometer stage above a plastic cup containing the nickel coin. The cup rested on a digital scale, tared before starting. As the magnet was lowered incrementally, the magnetic force exerted on the coin altered the apparent weight.

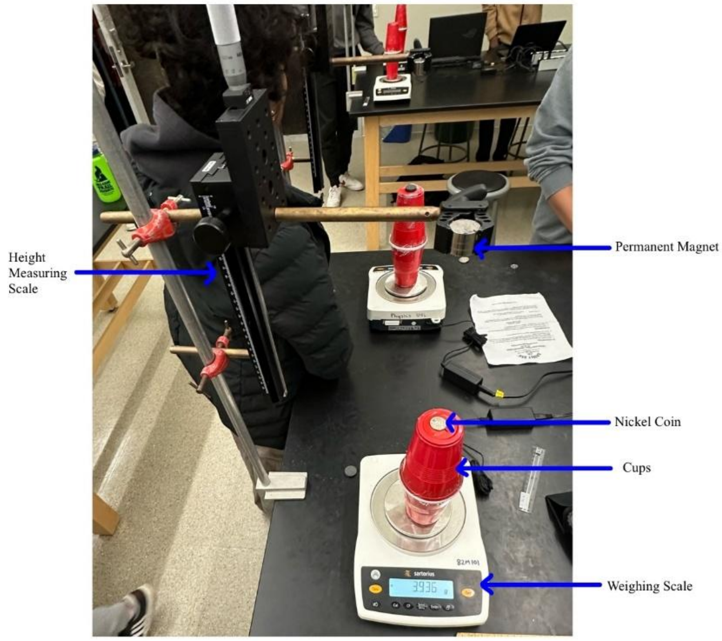


Fig 5.1: A labelled image of the experimental set-up.

Procedure

1. The plastic cup was placed on the scale and tared.
2. A nickel coin was placed inside the cup.
3. The neodymium magnet was positioned directly above the coin, ensuring vertical alignment.
4. Using the micrometer, the magnet was gradually lowered, and the change in apparent weight was recorded at each step.
5. Distance was measured center-to-center between the magnet and the coin.
6. The true magnetic force was calculated by subtracting the baseline weight from each measured force.
7. The resulting forces were plotted against $\frac{1}{r^7}$ to test the power law relationship.

Results

Raw Data

Table 5.1: Experimental measurements of the magnetic force acting on a soft ferromagnetic nickel coin as a neodymium magnet is brought closer. The table lists the center-to-center distance between the magnet and coin, measured mass, corresponding weight, calculated magnetic force (difference from reference weight), and the linearization term $\frac{1}{r^7}$ used to analyze the power-law relationship between force and distance. All values are reported with correct significant digits and SI units.

Nickel Coin				
Distance (m) N)	Mass (g)	Weight (N)	Magnetic force (N)	$\frac{1}{r^7}$
0.085	3.945	0.0387	4.90E-05	3.12E+00
0.088	3.942	0.038671	7.80E-05	2.45E+07
0.083	3.937	0.038622	0.000128	3.69E+07
0.08	3.933	0.038583	0.000167	4.77E+07
0.077	3.93	0.038553	0.000196	6.23E+07
0.075	3.927	0.038524	0.000226	7.49E+07
0.074	3.924	0.038494	0.000255	8.23E+07
0.073	3.919	0.038445	0.000304	9.05E+07
0.072	3.915	0.038406	0.000343	9.97E+07
0.07	3.909	0.038347	0.000402	1.21E+08

Small Magnet				
Distance (m) N)	Mass (g)	Weight (N)	Magnetic force (N)	$\frac{1}{r^4}$
0.245	15.8	0.154998	-2.00E-06	2.78E+02
0.236	15.817	0.155145	0.000145	3.22E+02
0.234	15.823	0.155243	0.000243	3.34E+02
0.23	15.831	0.155341	0.000341	3.57E+02
0.226	15.844	0.155459	0.000459	3.83E+02
0.22	15.8	0.155587	0.000587	4.27E+02
0.216	15.869	0.155704	0.000704	4.59E+02
0.21	15.89	0.155861	0.000861	5.14E+02
0.205	15.902	0.156038	0.001038	5.66E+02
0.199	15.918	0.156195	0.001195	6.38E+02

Table 5.2: Experimental data showing the magnetic force between a small permanent magnet and a neodymium magnet at varying distances. The table includes measured mass, calculated weight, and the resulting magnetic force derived from apparent weight changes. The final column shows the linearization term $\frac{1}{r^4}$, which is used to test the expected inverse-fourth power law for hard ferromagnetic interactions. All values are rounded appropriately with consistent SI units.

Sample Calculations

$F = m \cdot g$

Where, Nickel coin weight m=0.003945 kg, and g = 9.81 m/s^2

F = 0.003945 kg × 9.81 m/s^2 = 0.03870045N

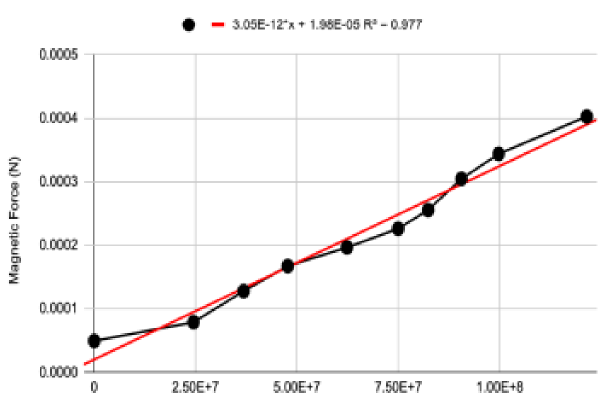
Error Propagation

Assuming constant gravity and a scale uncertainty of $\Delta\mathrm{m} = 0.001\ \mathrm{g} = 0.000001\ \mathrm{kg}$

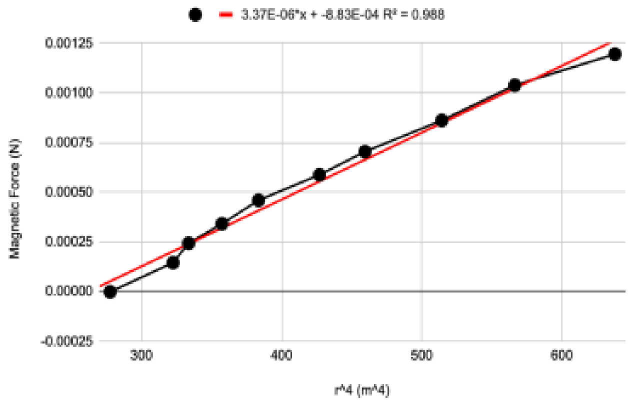
$\Delta\mathrm{F} = \Delta\mathrm{m} \cdot \mathrm{g} = 0.000001 \times 9.81 = 9.81 \times 10^{-6}\ \mathrm{N}$

$F = 0.03870 \pm 0.00000981\ \mathrm{N}$

Graphs



Graph 5.1: Graph illustrating the magnetic force as a function of distance from the nickel coin, based on the raw data presented in Table 5.1. A linear trendline was fitted to the transformed data (F vs $\frac{1}{r^7}$), yielding a slope of $3.05\times10^{-12}\pm0.001$ and a y-intercept of $1.98\times10^{-5}\pm0.001$. The coefficient of determination was $R^2=0.977$, indicating strong agreement with the expected model.



Graph 5.2: Graph displaying the relationship between magnetic force and the distance from the small magnet, using raw data from Table 5.2. A linear fit to the transformed data (F vs $\frac{1}{r^4}$), resulted in a slope of $3.37\times10^{-6}\pm0.001$ and a y-intercept of $-8.83\times10^{-4}\pm0.001$. The trendline achieved an R^2 value of 0.988, indicating excellent correlation with the theoretical prediction.

Discussion

Results and Comparison

The force-distance relationship observed in this experiment strongly supports the theoretical models for both soft and hard ferromagnetic materials. The data collected from the nickel coin experiment — a soft ferromagnet — followed an inverse-seventh power law, while the small magnet — a hard ferromagnet — followed an inverse-fourth power law, exactly as predicted.

For the nickel coin, plotting magnetic force against $\frac{1}{r^7}$ resulted in a highly linear graph with an R^2 value of 0.977. This value indicates **strong correlation** between the experimental results and the theoretical model for induced dipole interactions in soft ferromagnetic materials. Similarly, the graph for the small magnet, plotted against $\frac{1}{r^4}$, achieved an even higher R^2 value of 0.988, confirming the expected behavior of a hard ferromagnet possessing a constant magnetic dipole moment.

The observed slopes and intercepts from the LINEST fit — $3.05\times10^{-12}\pm0.001$ N·m^7 for the nickel and $3.37\times10^{-6}\pm0.001$ N·m^4 for the small magnet — further support the theoretical distinctions between these materials. These results validate the predictions outlined in the background theory regarding how magnetic force scales with distance based on material properties.

Discussion of Results

The quality of results is reinforced by the consistent agreement between experimental data and theoretical models. For the nickel coin, the magnetic moment was induced by the external field, resulting in a force that decreased steeply with distance. The high R^2 value suggests that external sources of error were minimal, and the measurement technique was reliable.

Minor deviations from the trendlines can be attributed to several experimental limitations. For instance, slight misalignments between the magnet and the coin could introduce inconsistencies in the measured force. Additionally, vibrations or air currents may have affected the digital scale's stability, especially at smaller force magnitudes. Another factor could be the possible remanence of the nickel coin — even though it is classified as a soft ferromagnet, residual magnetization from previous trials could skew the data slightly if not fully demagnetized.

Despite these limitations, the overall trends were clear, and deviations were minimal. The ability to capture such small changes in force and clearly distinguish between two different magnetic behaviors demonstrates the precision and reliability of the experimental method.

Uncertainties and Improvements

Uncertainties:

- Scale resolution was limited to ±0.001 g, contributing to uncertainty in calculated forces ($\pm9.81\times10^{-6}$ N).

- Distance measurement errors arose from potential misalignment or parallax when using the micrometer and ruler.
- Magnet alignment was manually adjusted, which could introduce slight angular deviations affecting force distribution.

Improvements:

- Using a higher-resolution scale (e.g., microgram-level) would improve detection of weaker forces, particularly at larger distances.
- Incorporating laser alignment tools would ensure precise center-to-center positioning of the magnet and sample.
- Increasing the number of data points, especially between 6–15 cm, would create a denser dataset for more accurate curve fitting.
- Vibration isolation for the setup and a magnetic shielded environment would reduce environmental interferences.
- Regular demagnetization of the nickel between trials would help eliminate any unwanted permanent moment buildup.

Conclusion

In this experiment, we investigated the magnetic force interactions between a strong neodymium permanent magnet and two types of magnetic materials: a soft ferromagnetic nickel coin and a small hard ferromagnetic magnet. Using a milligram-sensitive balance and micrometer stage, we measured the force exerted on each sample as a function of distance and analyzed the resulting trends.

For the nickel coin, we found that the magnetic force followed an inverse-seventh power law $F \propto \frac{1}{r^7}$, which is characteristic of induced dipole interactions in soft ferromagnetic materials. In contrast, the small magnet exhibited an inverse-fourth power relationship $F \propto \frac{1}{r^4}$, confirming its classification as a hard ferromagnet with a permanent dipole moment.

The strong linear fits (R^2=0.977 for the nickel and R^2=0.988 for the small magnet) confirm the theoretical models with high confidence. Despite minor sources of error, the results aligned closely with expectations and successfully demonstrated the distinct magnetic behaviors based on material properties.

This experiment reinforces key magnetic concepts and illustrates how quantitative measurements can effectively classify materials. It also highlights the sensitivity of magnetic forces to distance.

References

1. *PHYS 230 Lab Manual 5*, University of Alberta, 2025. [Online]. Available: eClass. [Accessed: Mar. 31, 2025].

Acknowledgements

I would like to thank my lab TA, Joshua Peltonen, for guiding me throughout the lab and explaining the concepts behind the experiment. I would also like to thank my lab partners: Muhammad Abdurrab Siddiqui, and Muhammad Ayaan Hafeez for helping me set up the experiment and for keeping the lab environment enjoyable.