Investigation on the Zeeman Effect

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**The objective of this study was to investigate the properties and splitting patterns of the Zeeman effect. The experiment aimed to observe the Zeeman splitting of the red cadmium (Cd) spectral line and to determine Bohr's magneton (μB) and the specific electron charge (e/me).**

1. Introduction

The Zeeman effect describes the splitting of atomic energy levels or spectral lines in the presence of an external magnetic field, it was first predicted by H.A. Lorentz in 1895 and experimentally confirmed by P. Zeeman. The normal Zeeman effect occurs in transitions between atomic states with total spin S = 0, resulting in a line triplet when viewed perpendicular to the magnetic field. This experiment aimed to observe the Zeeman splitting of the red cadmium (Cd) line and to determine the Bohr magneton (μB) and the specific electron charge (e/me) [1] [2]

1. Theory

The Zeeman effect involves the splitting of an atomic energy level into multiple components in the presence of a magnetic field. The magnetic moment 𝜇 of an electron in a magnetic field 𝐵 is given by:

μ = μB/ℏ J

Where μB is the Bohr magneton, J is the total angular momentum and ℏ is the reduced Planck constant.

The energy of the magnetic moment in the magnetic field is:

E = -μ \* B

The splitting of the energy levels can be expressed as:

ΔE = μB

For the red spectral line of cadmium λ = 6.43.8 nm which splits into 5 components resulting in 3 observed spectral lines. [3]

1. Experimental approach

Apperatus

- Cadium Lamp

- Fabry – Perot etalon

- EM Magnet with powersupply

- Camera

- Interference filter

- B sensor

Safety Precautions (Risk Assessment)

1) Electrical Safety:

- It was ensured that all electrical connections were secure and properly insulated this was to avoid electric shocks.

-Live electical connections and components were not touched, especially the high current power supply and EM coils.

-Before making or altering any connections, the power supply was switched off.

2) Magnetic Safety

- All ferromagnetic objects were kept away from the electromagnet to prevent them from being attracted and potentially causing injury or damage.

-Ensured all the pole pieces were securely fastened before switching on the electromagnet.

3) Cadium Lamp Handling

-It was ensured that the cadmium lamp was handled with care, avoiding direct contact with the quartz bulb to prevent contamination and damage from skin oils.

-Protective gloves were used when handling the cadium lamp to avoid damage.

4) Heat Precautions

- The lamp and EM Magnet can become hot during operation. So it was ensured that I did not touch them while they were hot.

-Sufficient cooling time was allowed before handling the equipment.

5) Optical Safety

- Looking directly into the light emitted by the the cadium lamp was avoided to prevent eye damage.

Procedure (Part A of experiment):

- The cadmium lamp was removed, and the magnetic probe (Hall effect probe) was positioned between the center of the pole pieces of the electromagnet.

- The current was set to approximately 2 A, and the magnetic field was measured.

- Measurements of the magnetic field were recorded for currents ranging from 0.5 A to 10 A.

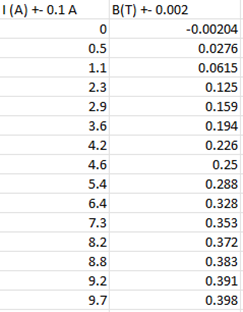
- The data were used to plot the magnetic field (B) as a function of the applied current (I).

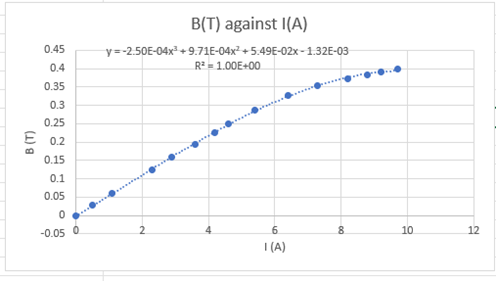
Procedure (Part B of experiment):

In Part B, the cadmium lamp was placed between the electromagnet's pole pieces, and the"VideoComInt" software was used. An intensity-angle graph was first captured without applying a magnetic field, identifying 𝛼1 for the π-component (data can be found in the excel file). Magnetic field values were then used to record angles 𝛼2 for the 𝜎+ and 𝜎- components, applying a polarisation filter to isolate each. Calculations on finding the Bohr’s Magneton and the e/me ratio were then done. These calculations can be found both in this lab report and in the excel file as well as the error/uncertainty calculations.

4. Results and Discussion

Part A:

These were the results from the excel file:



*The magnetic field strength as a function of current.*

Analysis of Part A

The objective of Part A was to measure the magnetic field 𝐵 as a function of the applied current I and to generate a calibration curve. The results are in the table and graph above.

The graph of the magnetic field B against the current I shows a clear relationship between the two variables. The relationship appears to be non-linear, and a polynomial fit has been applied to the data points.

An R^2 value of 1 indicated and that the data points fit very well. This suggested that the polynomial equation accurately described the relationship between the magnetic field and the current. This curve can now be used to predict the magnetic field for any given current within the range measured.

Observations

Linear and Non-Linear Regions:

* At lower currents, the relationship between B and I apeared almost linear.
* As the current increased, the relationship became more non-linear.

Accuracy and Precision

* The magnetic field measurments had an uncertainty of (±0.002 T) .
* The data points have consistent spacing, therefore the measurements were accurate.

Practical Implications:

* The calibration curve can be used to predict the field for any value of current used.

Procedure (Part B of experiment):

1. Setup and Initial Measurement:

- The cadmium lamp was inserted between the pole pieces without changing the distance of the pole pieces.

- The "VideoCommitt" software was started, and the observing optics were adjusted.

- The intensity of the peak was set to around 50%.

- A graph of intensity as a function of angle was captured without applying the magnetic field.

2. Applying the Megnetic Field

- The magnetic field was turned on and the intensity graph was captured again.

- The polarisation filter was reintroduced and set to 90° to observe only the outer components.

- Then the polarisation filter was set to 0° to observe only the π component.

Part B:

A screenshot of a table

Description automatically generatedThe energy interval (ΔE) was plotted as a function of the magnetic field (B):

A screenshot of a computer

Description automatically generated

*From the excel document.*

A graph with numbers and a line

Description automatically generatedA scatter plot of ΔE (µeV) against B (T) (found in the excel document):

Calculation of the Bohr’s Magneton:

There were various anomalies in this graph, which would have contributed to the percentage error which was calculated.

The gradient from the equation is 62.074 µeV/T this is the experimental result for the Bohr’s Magneton.

Calculating the ratio e/me:

e/me = 4πμB/h = 4π \* 62.074 µeV/T / 6.626\*10^-34 = 1.18\*10^30

How does the value we found for the Bohr’s Magneton compare to the real value?

Percentage Error:

Percentage Error = Experimental Value – Accepted Value/Accepted Value \* 100

= (62.074-57.9)/57.9 \* 100

= 7.21%

A screenshot of a data sheet

Description automatically generatedError Calculated found in the excel spreadsheet:

A screenshot of a math problem

Description automatically generatedError of the e/me ratio (from excel file):

Thse are a fairly low values, but the reason for these errors could be due to experimental errors such as alignment issues, calibration inaccuracies, limitations in the detector or in the software used for the data analysis. As well as, the clear outliers in the data which could be seen in the graph.

Conclusion

The calculated Bohr magneton (μB) and the specific electron charge (e/me) were found to be similar to the theoretical values. However, the slight difference in value to the true theoretical value would have been caused by the various anomalies in the data (which could be seen in the graph). The reasons for these errors was discussed above.

References

[1]

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L. H. Davis and R. M. Johnson, "Spectral Line Splitting in Magnetic Fields," in Modern Spectroscopy Methods, 4th Edition, 2016, McGraw-Hill, Chicago, USA. [Online]. Available: https://www.mheducation.com/highered/product.M0078025618.html. [Accessed: 15-Jun-2024].

[3]

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