Experiment 47: Zeeman Effect

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Abstract

The experimental finding for the Zeeman effect was a value for the Bohr-Magneton, which was $1.17 \times 10^{-23} JT^{-1} \pm 22.4\%$*, which had a percentage error of 20.74% with the given accepted value.*

The value for the Bohr-Magneton was determined by using a lamp to help produce a 585.2nm spectral line and determine the change in wavelength of the by measuring splits in the fringes then finding the change in frequency to calculate the value.

1 Introduction

The Zeeman effect experiment examines the effects of a strong magnetic field on spectral lines. It was discovered by Dutch physicist P. Zeeman, in 1896 that an external magnetic field would split the spectral lines into components which were polarized. The "normal Zeeman effect" studied in this experiment shows the spectral line of a source placed in a magnetic field is split into two or three components depending on the angle the splitting is observed. If viewed in the direction of the magnetic field then two components are visible, but if viewed at right angles to the magnetic field there's three observed components. This experiment focuses on the split into two satellites as the observation is in the direction of the magnetic field. A lummer plate image used in the experiment will show the chief fringes if no magnetic field is applied, and these relatively larger fringes will split into two fringes, one going top and another bottom, as the magnetic field is applied and the amount of separation is dependent on the strength of the magnetic field. We have to be careful not to apply too large of a magnetic field, since the satellites might become largely separated and mistaken for the satellites of the chief fringe above of below it. This splitting can be used to determine the change in wavelength caused by the magnetic field that's applied to the fringes. From the change in wavelength, the change in frequency can be easily calculated using $v_0 = \frac{c}{y_0}$ for Δv, which is needed to calculate an experimental value for the Bohr-Magneton.

1.1 Equations

$$\Delta v = \pm \mu_B \frac{B}{h} \tag{1}$$

This is the equation used to calculate the Bohr-Magneton μ_B, in units of JT^{-1}, which has a theoretical value of $0.9273 \times 10^{-23} JT^{-1}$. Where B in the magnetic field in Tesla and Δv is the frequency in Hertz, and h is Planck's constant $6.626 \times 10^{-34} Js$.

$$\Delta v = c(\frac{1}{\Delta\lambda + \lambda_0} - \frac{1}{\lambda_0}) \tag{2}$$

Using the average of the $\Delta\lambda$ that are acquired from the data, the Δv value can be calculated along with $\lambda_0 = 585.2nm$.

$$R = \frac{\lambda^2 (n^2 - 1)^{\frac{1}{2}}}{2d(n^2 - 1 - n\lambda)\frac{\delta n}{\delta \lambda}} \tag{3}$$

The "useful range" R, is calculated using the constants $\lambda, nandd$, which are the wavelength, index of refraction of the plate, and the thickness of the plate, respectively. As well as, $\frac{\delta n}{\delta \lambda}$. The values for these are given to be $\lambda = 585.2nm, n = 1.51, d = 4.62mm, \delta n = 0.00338, \delta\lambda = 102.8nm$.

$$\Delta\lambda = \frac{2s'}{c + c'} R \tag{4}$$

The change in wavelength is calculated using the distances $2s', c, c'$, which are the distances between the satellite and the chief fringe, a pair of chief fringes, and a pair of satellites, respectively.

2 Data and Calculations

2.1 Data

Table 1: Lengths measured in pixels and resulting $\Delta\lambda$ values

	$\Delta\lambda_1$	$\Delta\lambda_2$,	$\Delta\lambda_3$
$2s'$	$21px$	$17px$	$14px$
c	$48px$	$46px$	$37px$
c'	$46px$	$45px$	$41px$
$\Delta\lambda$	7.49×10^{-12} m	6.26×10^{-12} m	6.01×10^{-12} m

2.2 Sample Calculations

$$R = \frac{\lambda^2(n^2-1)^{\frac{1}{2}}}{2d(n^2-1-n\lambda)} \\ = 3.352 \times 10^{-11} \tag{5}$$

$$\Delta\lambda_1 = \frac{21px \pm 2px}{(48px + 46px) \pm 2px} 3.352 \times 10^{-11} \\ = 7.49 \times 10^-12m \pm 10\% \tag{6}$$

$$Average\Delta\lambda = \frac{(\Delta\lambda_1)(\Delta\lambda_2)(\Delta\lambda_3)}{3} \\ = \frac{(7.49 \times 10^-12m \pm 10\%)(6.26 \times 10^-12m \pm 10\%)(6.01 \times 10^-12m \pm 10\%)}{3} \\ = 6.59 \times 10^{-12} \pm 10\% \tag{7}$$

$$\Delta v = c(\frac{1}{\Delta\lambda + \lambda_0} - \frac{1}{\lambda_0}) \\ = 3 \times 10^8 m/s(\frac{1}{6.59 \times 10^{-12} \pm 10\% + 585.2 \times 10^{-9}m} - \frac{1}{585.2 \times 10^{-9}m}) \\ = 5.77 \times 10^9 Hz \pm 10\% \tag{8}$$

$$\mu_B = \frac{\Delta vh}{B} \\ = \frac{(5.77 \times 10^9 Hz \pm 10\%)(6.626 \times 10^{-34})}{0.328T \pm 20\%} \\ = 1.17 \times 10^{-23} JT^{-1} \pm 22.4\% \tag{9}$$

$$\%error = \frac{|actual - expected|}{expected} * 100 \\ = \frac{0.9273 \times 10^{-23} JT^{-1} - 1.17 \times 10^{-23} JT^{-1}}{1.17 \times 10^{-23}} * 100 \qquad = 20.74\% \tag{10}$$

3 Experimental Procedure and Design

The setup for the experiment consisted of a Ne spectral lamp, Variac, Magnet, an eyepiece, and a computer recording software. The magnet is used to produce the electric field which splits the chief fringes into its satellite components. The lamp produces the pattern of Ne that can be observed through the eyepiece and on the camera recording connected to it and the computer.

1. The first step was to setup the computer to view the Lummer plate pattern through the eyepiece after turning on the lamp.

2. The Variac was turned on to produce a current of 1.6A, which made the magnet split the fringes on all spectral lines including on the particular line ($\lambda = 585.2nm$) measured into this experiment into its satellites.

3. Three measurements were to be taken for three different splits of the fringes. First, a picture of the pattern appearing in the eyepiece of the split was taken via screenshot and measured using paint software.

4. The first measurement was of the length $2s'$, which is the distance between the satellite and the chief fringe. This was measured using the paint software to measure the length in units of pixels. The units of measurement will not matter because to calculate equation 4 all that matters in the units are the same for the numerator and denominator.

5. Next, the length of c was measured, which is the distance between a pair of chief fringes using the same method as stated above, this was measured from midpoint to midpoint of the satellites.

6. Finally, the length c' was measured, which is the distance between a pair of satellites that are next to each other. This was measured from the top satellite to the top satellite of the fringe below.

7. The last three steps were repeated for more 2 more splits at different locations on the picture. Since there's more or less amount of splitting depending on where you're measuring on the line (y-axis for this case).

8. Using the average of the three $\Delta\lambda$ values, Δv was calculated using equation 2. That was then used to calculate the value of the Bohr-Magneton, μ_B.

4 Results

The final results for the $\Delta\lambda$ values were 7.49×10^{-12} m, 6.26×10^{-12} m, 6.01×10^{-12} m, which produced an average of $6.59 \times 10^{-12} m \pm 10\%$. This average was used to get a value

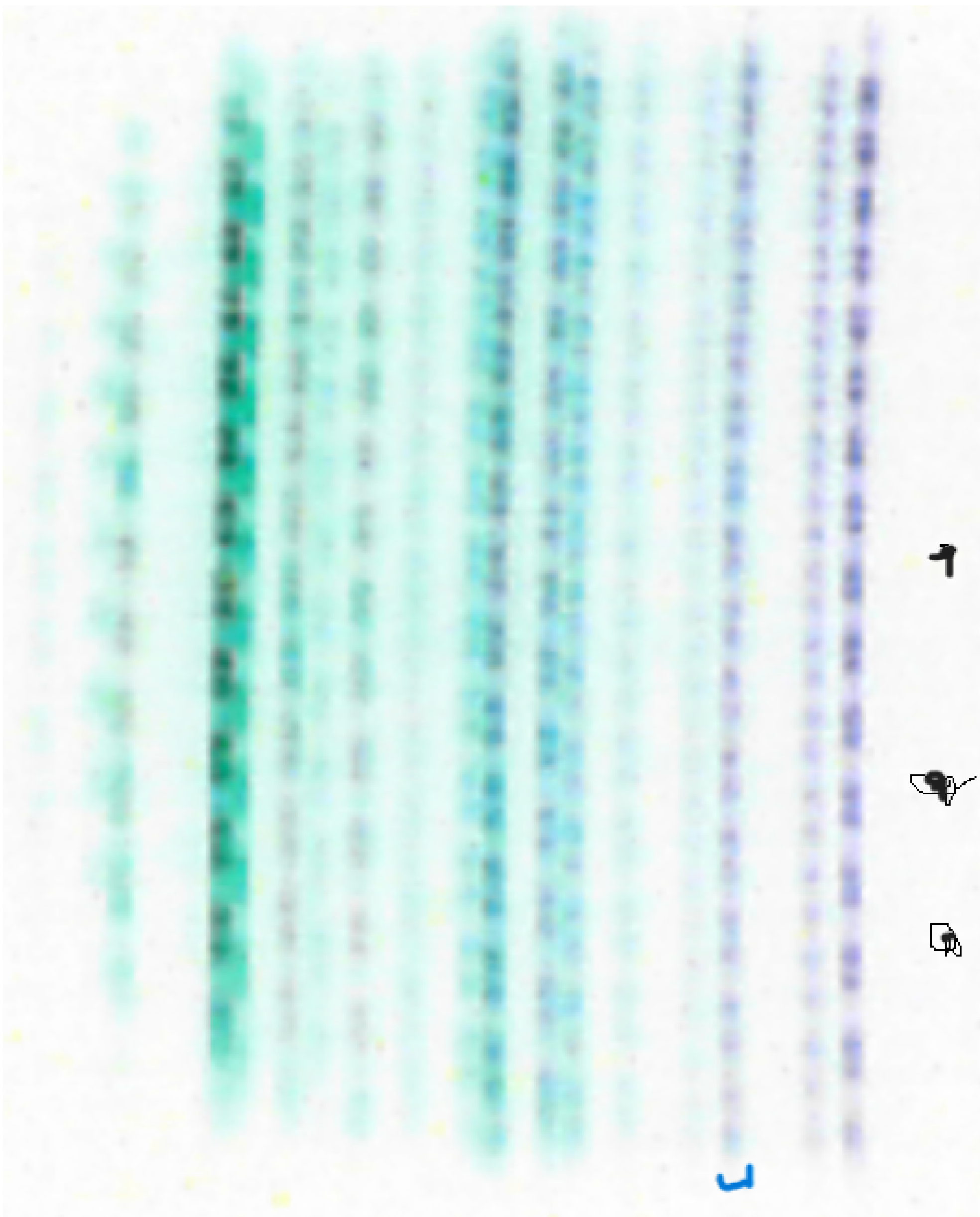

Figure 1: This is the picture taken from the camera on the eyepiece and used to take the measurements that were required to calculate the change in wavelength in equation 4. The oddly shaped markings on the right of the picture in black as well as the blue marker show which splits the three measurements were taken from.

for the change in frequency, which was $5.77 \times 10^9 Hz \pm 10\%$. Finally, the experimental value for the Bohr-Magneton was determined to be $1.17 \times 10^{-23} JT^{-1} \pm 22.4\%$ with a percent error with the accepted value of 20.74%.

5 Discussion

The experiment produced consistent results for the $\Delta\lambda$ values, which were used for the change in frequency and the calculation of the Bohr-Magneton. The result for the Bohr-Magneton had a 20.74% error, and the reasons for this difference can be largely due to the measurement of the magnetic field and partly due to the measurement of the three length units $(2s', c, c')$. The reason that the measurement of the magnetic field would have the largest effect on the result is because the measurement of it using a Gauss meter produced largely varying data in a certain range and so determining the maximum value for the field was an exercise in observing the largest magnetic field value before it changed. The reason why the measurement of the three lengths partly effected the result is because only the vertical axis used to record the distances in paint, so if the lines were slightly off-axis then the measurement would be slightly smaller than it should be. The results still reasonable given the errors presented and so the experiment was successful in its intended purpose.

6 Conclusion

The experiment produced fairly accurate results in comparison to the given accepted value for the Bohr-Magneton within a reasonable uncertainty given the large error caused by the magnetic field reading.

References

[1] Physics 323, Laboratory Manual. University of Victoria, 2022.