Zeemann Effect

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1 Abstract

The phenomenon of splitting spectral lines in the presence of a magnetic field was first observed in 1896 by the Dutch physicist Pieter Zeeman as a broadening of the yellow D-lines of sodium in a flame held between strong magnetic poles. One of them is the splitting up of one spectral line into three components called the **'normal Zeeman effect'**. Here cadmium lamp is subjected to various magnetic field intensities and the amount of splitting is measured by the physical distance between the spectral lines. The red cadmium line (643.8nm) is studied using a fabry-perot interferometer. We can calculate a fairly precise value of Bohr magneton from the results.

2 Aim

- Using the Fabry-Perot interferometer, a telescope, a CMOS-camera and measurement software, the splitting up of the central line into two σ-lines is measured in wave numbers as a function of the magnetic flux density.
- From the results of point 1. a value for Bohr's magneton is evaluated.
- The light emitted within the direction of the magnetic field is qualitatively investigated.

3 Theory

Cadmium has the electron structure, $(Kr)4d^{10}5s^2$, i.e. the outer shell taking part in optical transitions is composed of the two $5s^2$ electrons representing a completed electron shell. The transition used to demonstrate the normal Zeeman effect is $3^1D_2 \rightarrow 2^1P_1$ with $643.85nm$ and the transition used to demonstrate anomalous Zeeman effect is $2^3S_1 \rightarrow 2^3P_2$ with $508.58nm$. This has been shown in the Figure 1.

The anomalous Zeeman effect is the more general case where the electron spins do not cancel each other and the energy of an atomic state in a magnetic field depends on both the magnetic moments of electron orbit and electron spin. The spectrum after being filtered out is studied using a Fabry-Perot interferometer. With the magnetic field turned on in the absence of the analyser three lines can be seen simultaneously in the normal Zeeman effect in transversal observation. In the case of the anomalous Zeeman effect, three groups of three lines appear. Inserting the analyser in the normal Zeeman effect two σ lines can be observed if the analyser is in the vertical position, while only the π line appears if the analyser is turned into its horizontal position (transversal Zeeman effect). In the anomalous Zeeman effect, there are two groups of three σ lines in vertical polarization and one group of three π lines in horizontal polarization. Turning the magnetic system by 90° the light coming from the spectral lamp parallel to the direction of the field (longitudinal) can also be studied through the holes in the pole pieces. It can be shown that this light is circularly polarized light (longitudinal Zeeman effect). A $\lambda/4$ plate is generally used to convert linear into elliptically polarized light. In this experiment, the $\lambda/4$ plate is used in the opposite way. With the $\lambda/4$ plate inserted before the analyser, the light of the longitudinal Zeeman effect is investigated. If the optical axis of the $\lambda/4$ plate coincides with the vertical, it is observed that some rings disappear if the analyser 45° is at an angle of with the vertical while other rings disappear for a position of 45°. That means that the light of the longitudinal Zeeman effect is polarized in a circular (opposed way). The π lines are longitudinally not observable.

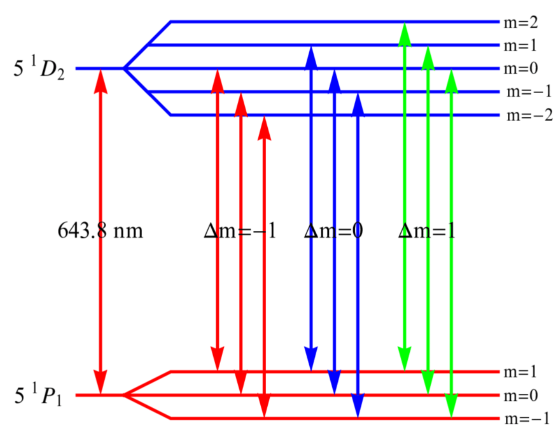

Figure 1: Splitting of lines in cadmium

3.1 Fabry-Perot interferometer

The Fabry-Perot interferometer uses the phenomenon of multiple beam interference that arises when light shines through a cavity bounded by two reflective parallel surfaces. Each time the light encounters one of the surfaces, a portion of it is transmitted out, and the remaining part is reflected back. The net effect is to break a single beam into multiple beams which interfere with each other. If the additional optical path length of the reflected beam (due to multiple reflections) is an integral multiple of the light's wavelength, then the reflected beams will interfere constructively. More is the number of reflection inside the cavity, sharper is the interference maximum.

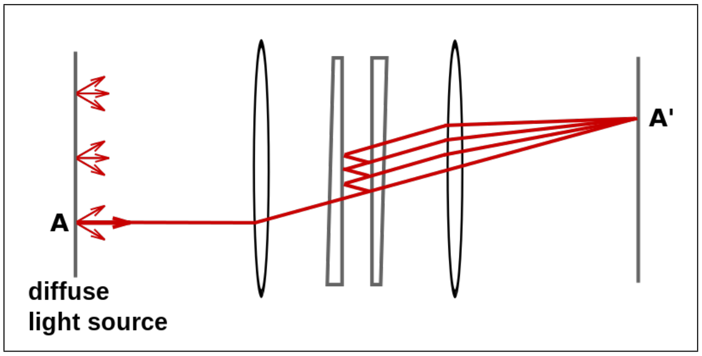

Figure 2: Interferometer working

It makes use of multiple reflections which follow the interference condition for thin films. The net phase change is zero for two adjacent rays, so the relation to find a maxima is:

$$2d\cos\theta = n\lambda \tag{1}$$

Figure 3: Experimental setup

4 Observations and Calculations

With the magnetic field turned on,three lines can be seen simultaneously in the normal Zeeman effect in transverse direction.

There are three groups of three lines in anomalous Zeeman effect. when the analyser is inserted into the typical Zeeman effect, the σ-lines maybe seen, and when it is turned horizonaltally only π-lines are visible.

To calculate the Bohr Magneton, the working formula is:

$$\Delta K = \frac{B\mu_B}{hc} \tag{2}$$

We linearly fit the graph of ΔK vs the B and the slope there gives us the value of Bohr Magneton (μB):

$$\mu_B = hc\frac{\Delta K}{B} = hc \times (slope\ of\ \Delta K\ vs\ B\ graph) \tag{3}$$

4.1 Observations

Order (p)	Radius (μm)					
	1		2		3	
pole separation (mm)	$\sigma-$	$\sigma+$	$\sigma-$	$\sigma+$	$\sigma-$	$\sigma+$
40	54.8	75.77	91.54	105.68	118.16	129.16
42	58.32	73.23	93.11	104.73	119.18	128.73
44	60.03	72.71	94.58	103.76	120.46	127.73
45	60.75	72.76	95.46	102.82		

Table 1: Radii of σ lines for different magnet positions

4.2 Calculations

Using the Formula $\Delta_\sigma^{i(i-1)} = \sigma_i^2 - \sigma_{i-1}^2$ we get Table 2.

$\Delta_{\sigma-}^{21}$	$\Delta_{\sigma+}^{21}$	$\Delta_{\sigma-}^{32}$	$\Delta_{\sigma+}^{32}$	Δ
5376.532	5427.17	5582.214	5514.043	5474.99
5268.25	5605.74	5534.4	5603.04	5502.858
5341.776	5479.394	5565.235	5548.815	5483.805
5422.049	5277.935			5349.992

Table 2: Calculating Δ

Using the Formula $\delta^i = \sigma +_i^2 - \sigma -_i^2$ we get Table 3.

δ^1	δ^2	δ^3	δ
2738.053	2788.691	2720.52	2749.0879
1961.411	2298.901	2367.54	2209.28393
1683.143	1820.761	1804.341	1769.41523
1603.455	1459.341		1531.39795

Table 3: Calculating δ

Using the Formula $\delta^i = \sigma +_i^2 - \sigma -_i^2$ we get Table 3.

pole separation (mm)	B (mT)	Δ	δ	ΔK
40	1900	5474.99	2749.0879	57.47682
42	1700	5502.858	2209.28393	45.95689
44	1050	5483.805	1769.41523	36.93475
45	800	5349.992	1531.39795	32.76592

Table 4: B vs ΔK

$$m = 20.115 \ \pm \ 4.214 \ and$$

$$c = 15.877 \ \pm \ 6.049$$

$$\mu_B = hc\frac{\Delta K}{B} = hc \times 20.115 = 3.998 \times 10^{-24} Am^2$$

The above tables have all the data that was collected during the experiment, the verified data sheet is attached at the end of the document. The pictures of the lines observed is attached in the next section after references.

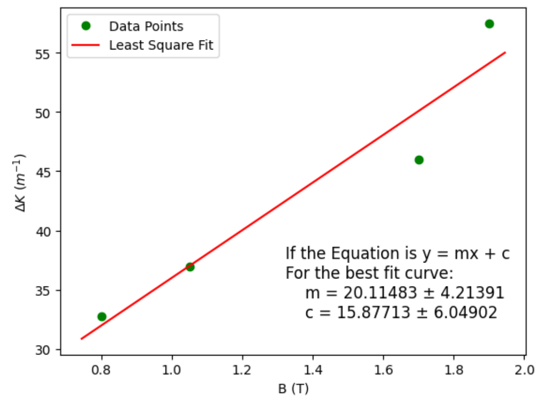

Figure 4: ΔK vs B graph

4.3 Error Calculation

$$\Delta\mu_B = \mu_B \frac{\Delta slope}{slope} = \mu_B \times \frac{4.214}{20.115}$$

$$\Delta\mu_B = 8.3 \times 10^{-25} Am^2$$

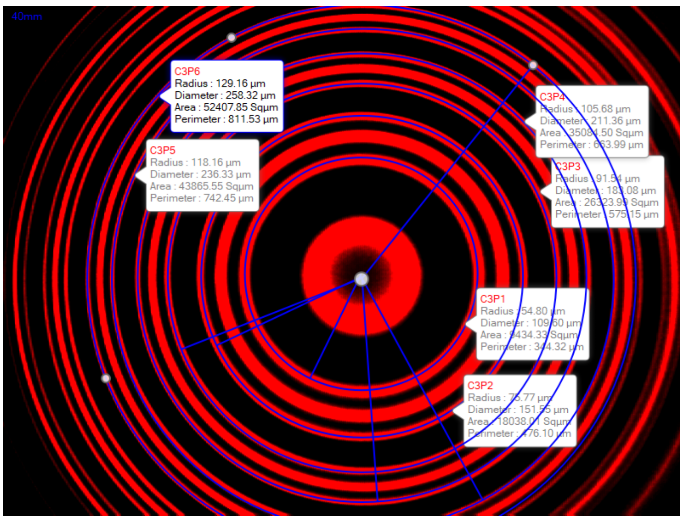

Figure 5: 40 mm

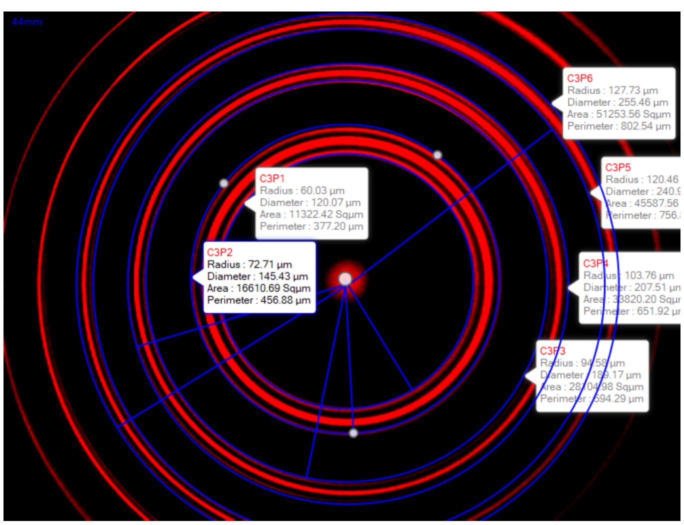

Figure 6: 44 mm

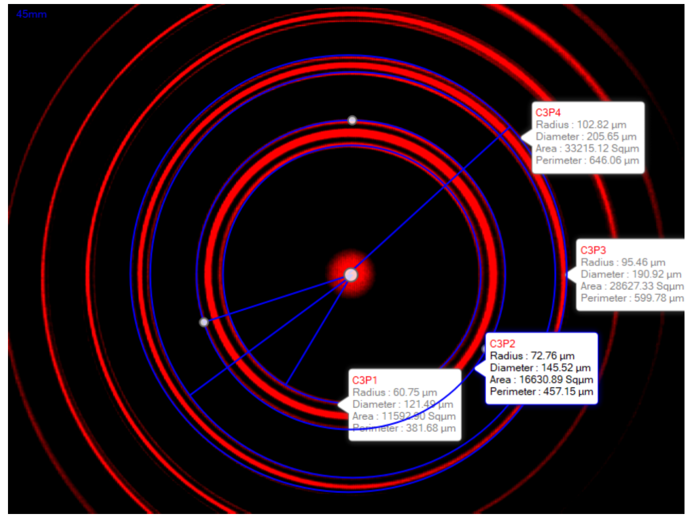

Figure 7: 45 mm

5 Result and Discussion

$$\mu_B = (3.998 + 0.83) \times 10^{-24} Am^2$$

- The value of μ_B obtained is quite away from the actual value. I think the primary reason is, these magnets are not properly calibrated with the data graph provided to us. Maybe these magnets are old and have degraded over time. To support my claim, I calculated the values of the magnetic fields which should have been to obtain an accurate value of μ_B.

pole separation (mm)	B (from graph) (mT)	B fro accurate μ_B (mT)
40	1900	1232.086
42	1700	985.1424
44	1050	791.7417
45	800	702.3776

We should have been given equipments to calibrate the magnetic fields with distances before the experiment. This would have given us a more accurate value of μ_B.

- According to me, the change in magnetic field should be done with a change in current and an electomagnet and not a distance from permanent magnet. This would have given us a more accurate value of μ_B.

References

[Kotit, 2017] Kotit, M. (2017). Estimation of the bohr magneton by utilising the normal zeeman effect for cadmium [this is a lab report, not an actual scientific paper.].

[SPS, 2022] SPS (2022). Lab manual. *Website*. `https://www.niser.ac.in/sps/sites/default/files/basic_page/Zeemaneffect-manual.pdf`.