

EXPERIMENT 5

THE ZEEMAN EFFECT

AIM:

This experiment demonstrates the splitting of the spectral lines in the presence of a constant magnetic field. The ratio e/m is experimentally calculated and compared with the theoretical value.

APPARATUS:

Fabry Perot interferometer, electromagnet, millimeter, Teslameter

METHODOLOGY:

Pieter Zeeman noted within the field of experimental spectroscopy that a constant magnetic field imposed on an atomic discharge tube produced a splitting of the spectral lines. This effect is due to the extra energy possessed by the atomic electrons due to the external \mathbf{B} field, and obviously its interaction due to both orbital and spin angular momentum of the atom must be taken into account.

However one can experiment with particular atomic gases, where the total spin is zero. In such a case the external magnetic field will exert a torque on a magnetic dipole and the magnetic potential energy will increase from E_o to $E = E_o + U$ where:

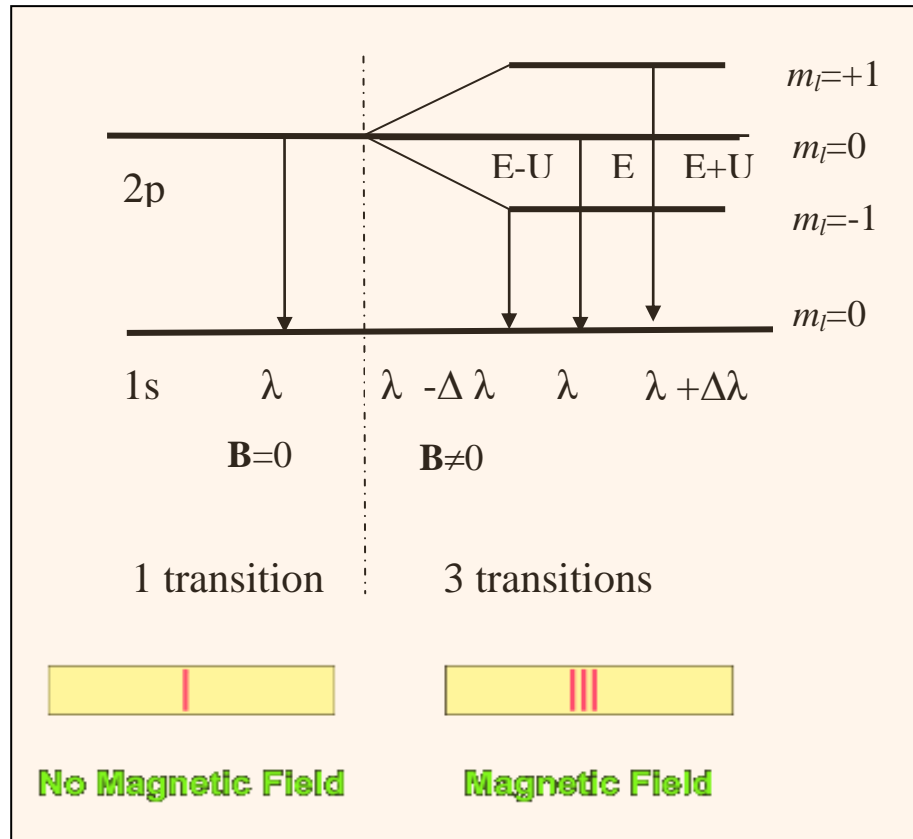
$$U = m_l \mu_B B \quad (5.1)$$

$\mu_B = 9.274 \times 10^{-24} \text{ J/T}$ is the Bohr magneton.

The change in wavelength would thus be:

$$E = \frac{hc}{\lambda} \Rightarrow dE = -\frac{hc}{\lambda^2} d\lambda \quad \text{or} \quad \Delta\lambda = \frac{\lambda^2}{hc} \Delta E \quad (5.2)$$

Figure 5.1 The normal Zeeman effect in Hydrogen. Looking at the 1s to 2p transition. (Total Spin=0)



In the absence of the constant magnetic field, the hydrogen energies depend only upon the principal quantum number n and the emissions occur at a **single (1) wavelength**. As we can see that is not the case when a magnetic field is applied. The emissions occur at **three (3) wavelengths**.

We note that the only possible transitions are governed by the light polarization rules in Table 5.1

Table 5.1: Possible polarisations

$\Delta m_l = 0$	Linearly Polarised Light	
$\Delta m_l = 1$	Circularly Polarised Light	
$\Delta m_l = -1$	Circularly Polarised Light	

Table 5.2. The rules governing the quantum numbers (n, l, m_l)

$n = 1, 2, 3, \dots$
$m_l = 0, \pm 1, \pm 2, \dots, \pm l$
$l = 0, 1, 2, \dots, n - 1$

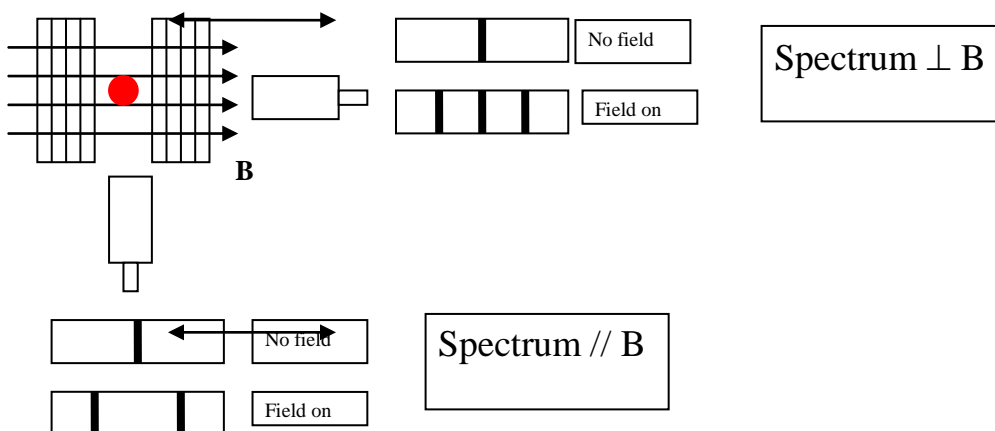
The number of split levels in the magnetic field is $2 * l + 1$.

Table 5.3 The angular momentum states

l	0	1	2	3	4	5	6
	s	p	d	f	d	h	i

Atomic physicists use the abbreviation "s" for a level with $l=0$, "p" for $l=1$, and "d" for $l=2$, and so on. It is also common to precede this designation with the integer principle quantum number n . Thus, the designation "2p" means a level that has $n=2$ and $l=1$. In the preceding example the lowest level is an "s" level, so it has $l=0$ and $2l + 1 = 1$, so it isn't split in the magnetic field, while the first excited state has $l=1$ ("p" level), so it is split into $2l + 1 = 3$ levels by the magnetic field.

Figure 5.2 Using your experimental apparatus note that the direction of viewing changes the effect seen.



PROCEDURE:

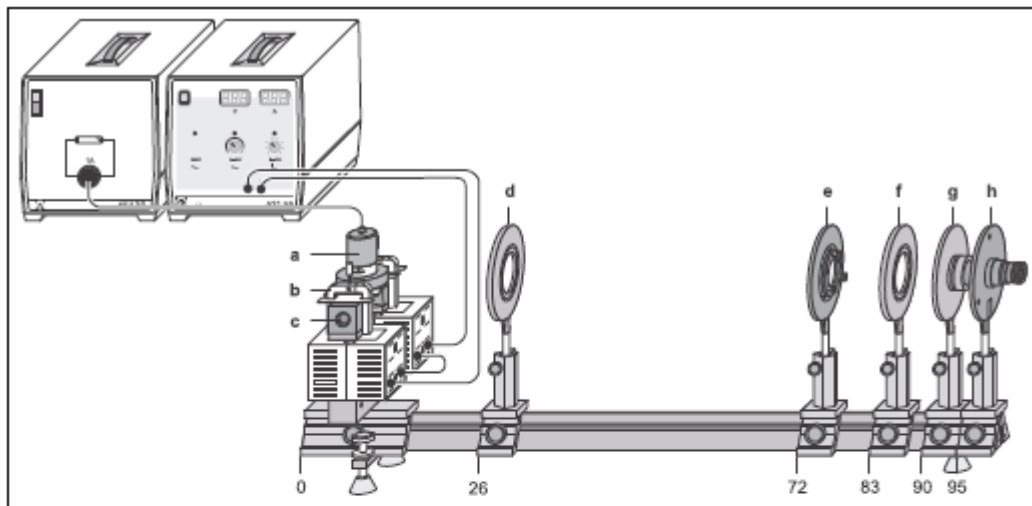
Electrical connection:

1. Connect the coils of the electromagnet in series and then to the high current power supply.
2. Connect the B sensor S to the Universal measuring instrument.
3. Connect the cadmium lamp to the universal choke.
4. Connect the VideoCom to the computer.

Adjusting the observing optics:

1. Mount the optical components according to Fig. 5.3.
2. After switching on the universal choke wait 5 min until the light emission is sufficiently strong.

Figure 5.3



Experimental setup for observing the *Zeeman* effect in transverse configuration. The position of the left edge of the optics riders is given in cm.

- | | |
|---|--|
| a | Cadmium lamp with holding plate |
| b | Clamps |
| c | Pole pieces |
| d | Positive lens, $f = 150$ mm (Condenser lens) |
| e | <i>Fabry-Perot</i> etalon |
| f | Positive lens, $f = 150$ mm (imaging lens) |
| g | Interference filter in holder |
| h | VideoCom (it is helpful to use an ocular for adjustment) |

VideoCom:

1. It is possible to optimize the exposure time so that the peaks have an intensity of approximately 50 %.
2. To ensure that the CCD is in the focal plane of the imaging lens, move the imaging lens along the optical axis until the peaks of the observed curve are sharply imaged and show the maximum intensity. The center of the ring system must then be imaged on the CCD line. For this, you can either move VideoCom perpendicular to the optical axis or tilt the etalon slightly using the adjusting screws. You have found the center of the ring system when further adjustment does not cause any more peaks to emerge and the two central peaks (left and right intersections of the innermost rings) are the maximum distance apart.
3. Move the condenser lens until you obtain the most uniform possible illumination of the entire CCD line, so that the maxima in the middle are nearly at the same intensity (see Fig. 5.4).
4. For angular calibration of the VideoCom, the focal length of the imaging lens is specified (here $f = 150$ mm). To shift the zero point, determine the angles of the two central peaks using the function “Calculate Peak Center” and enter the negative mean value of the two peak centers manually. This sets the center of the ring system to 0° on the angular scale.

a) Measuring the magnetic field

1. Hold the tangential probe vertically in the center of the pole pieces, while the cadmium lamp is not mounted.
2. Starting from 0A to 5A, increase the current in steps of 0.5A through the coils and measure the magnetic field in dependency of the current.

b) Measuring the splitting of the cadmium line

1. Cautiously insert the cadmium lamp between the pole pieces without changing the distance of the pole pieces. Start the software “VideoComInt” and adjust the observing optics.
2. The intensity of the peak should be around 50 %.
3. The table “Zeeman” is provided for evaluation; switch to this table by clicking on the corresponding tab. This table contains columns for the magnetic field B, the angle α_1 of the non-displaced line (p-component), the angle α_2 of the displaced line ($\sigma+$ or $\sigma-$) and the corresponding wavelength and energy shifts. These last two values are calculated automatically after entry of α_1 and α_2 using:

$$\frac{\Delta\lambda}{\lambda} = \frac{\cos\beta_2}{\cos\beta_1} - 1 \text{ with } \frac{\sin\alpha}{\sin\beta} = n = 1.46 \text{ for the etalon and}$$

$$\Delta E \approx \frac{-\Delta\lambda}{\lambda} \cdot E = -h c \cdot \frac{\Delta\lambda}{\lambda^2} \text{ with } \lambda = 643.8 \text{ nm for the Cd line.}$$

4. Start the evaluation by marking a peak (p) with “Calculate Peak Center”.
5. Transfer this value to the “Zeeman” table by dragging it from the status line to column α_1 of the table (drag and drop).
6. To determine the origin in the diagram, drag the value to column α_2 as well.
7. Enter the value 0 in column B (non-displaced ring without magnetic field).
8. Examine the ring as it is split in the magnetic field (σ^+ or σ^-).
9. Determine the displaced angle α_2 using “Calculate Peak Center” and drag it to column α_2 in the “Zeeman” table. The non-displaced angle α_1 remains unchanged (you can e.g. import it from a previous measurement using drag and drop), and the magnetic flux density is entered.
10. Using these values, the software calculates the percentage shift in wavelength and the energy split. Additionally, the corresponding point is plotted in the diagram. (To confirm the effect for other rings at equal flux densities or for repetition with different flux densities, it is necessary to examine peaks with identical components (σ^+ or σ^-) each time.)
11. To get the gradients of the line splitting fit straight lines through the measured points and find the slope.
12. Find the average of the absolute values of the two slopes. This value represents the Bohr's magneton μ_B .
13. Find e/m using

$$\frac{e}{m} = \frac{4\pi\mu_B}{h} \text{ where } h = 6.626 \times 10^{-34} \text{ J}\cdot\text{s}. \quad (5.3)$$

14. Compare your result to the literature value:

$$\frac{e}{m} = 1.759 \times 10^{11} \text{ C/kg}$$

Figure 5.4

