**ZEEMAN EFFECT**

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**Introduction**

An electron in an atom is described by the quantum numbers n, l and ml. The first quantum number describes the energy and the size of the orbital and takes values n=1,2… l which is the angular quantum number specifies the shape of an orbital corresponding to the principal quantum number n and takes values l=0,1,2…n-1. For a given energy(n) and shape(l) magnetic quantum number ml specifies the orientation in space and take values from -l to +l.

Magnetic dipole moment of electron is caused by its intrinsic characteristics such as charge and spin. When we think of an electron moving in a spherical path as around the proton we can consider it as if current passes through a loop. We can find the magnitude of this orbital magnetic dipole moment for a current loop of area A with the help of

where I is the current .

Furthermore, we can obtain a relation between this magnetic dipole moment and orbital angular momentum when we ignore the spin angular momentum

where the L is the orbital angular momentum, e is the charge of the electron and m is the mass of the electron.

In the presence of a magnetic field electron acquires additional energy which results in positive, negative or zero shift of energy depending on the angle between the magnetic dipole and the external magnetic field. Quantum mechanically the magnetic potential energy of an atom in the presence of a magnetic field is

where is the angle between and the z direction which has specific values

along with the specific values of which gives us the magnetic energy

We call Bohr magneton In a magnetic field a state of quantum number n divides into substates that has a little more or less energy than that of when magnetic field is not present. As a result, we observe splitting of the spectral lines into separate lines. This effect is called the Zeeman effect[1]. Since ml takes the values between -l and l the energies of the levels is given by

But we cannot observe the energy levels, instead we observe transitions between them. Considering initial and final energies of the levels are given by

The frequency of the photon making a transition between the initial and the final states is found by subtracting these equations and dividing by the Planck’s constant. Denoting where the frequency is ν, we get

Due to selection rules can take only values of -1,0,1.

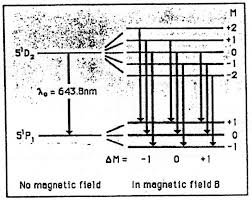


Figure 1[[1]](#footnote-1). Interference lines corresponding to transitions of Cd in magnetic field.

Figure 1. Shows the transition between the energy levels for Cd while the magnetic field is present. These transitions obey the selection rules.

**Experimental Details**

In the experiment we use a Cd lamp which provides us with the light of wavelength of 643.8 nm that correspond to the red light in the visible spectrum. The light coming from the lamp first passes through a red light filter which doesn’t allow the light of other wavelengths and a polarizer which is placed in a way that lets the components of the light that are perpendicular to the direction of the magnetic field only. The magnetic field is provided by an electromagnet on which magnetic field is created by the current passing through the coils. By changing the current we change the magnetic field strength.

The Lummer-Gehrcke Plate is used for observing the light that comes from the lamp as a result of transitions of the electrons between energy levels. The Lummer-Gehrcke Plate is a multiple-beam interferometer that has a resolving power of 50000 which enables us to measure the difference of 0.01 Ǻ in wavelength. Resolving power is the capacity to distinguish between the close points. The Lummer-Gehrcke Plate is a parallel plate of quartz with a prism at one end. The light falling on the prism bounces back and forth inside the plate in a very close value to the critical angle. Then the emerging beams are collected by a lens and they form an interference pattern. We use the Lummer-Gehrcke Plate as it has a very high resolving power rather than a prisma or grating as they don’t have the sufficient resolving power to distinguish this closely spaced lines. After considering the constructive interference condition for the interferometer we get an equation for the e/m ratio where e is the cahrge of the electrona and m is its mass.

The light coming out of the interferometer is observed with a telescope

**Measurement & Data Analysis**

*Data:*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Spacing between successive lines without a magnetic field Δa= 13[mm] | | | | |
| Magnet Current I [A] | Magnetic Field Strength [T] | Spacing between 2 extreme lines 2δa [x10-2] | Spacing between successive lines δa [x10-2] | Δa/ Δa |
| 18 | 0.494 | 6 | 3 | 0.2 |
| 16 | 0.445 | 5 | 2.5 | 0.19 |
| 14 | 0.421 | 4 | 2 | 0.15 |
| 12 | 0.336 | 4 | 2 | 0.15 |
| 10 | 0.279 | 3 | 1.5 | 0.115 |

Table 1: Splitting of spectral lines with changing magnetic field strength

Table 1 describes how the splitting of the spectral lines changing with the changing magnetic field. We can see that the splitting is increasing with the increase in the magnetic field strength.

*Plots:*

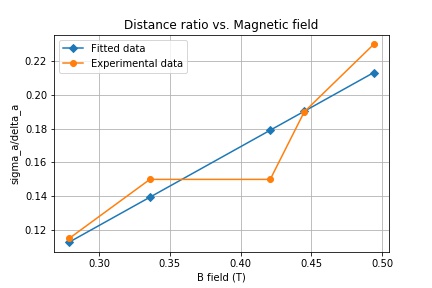


Figure 2. Voltage vs current plot under the same wavelength of light for different aperture sizes.

Figure 2 corresponds to the Table 1 in Data part. It’s the fitted version of the data with magnetic field on x, and the ratio of the spacings on y axis. The slope of the line gives us = from where we can determine the e/m ration.

*Calculations:*

Slope of the graph==0.467 1/T

Using the equation

Experimental:

Theoretical: e/m≈1.759\*1011C/kg

**Results and Discussion**

*Comments:*

Before the experiment performed we had the theory that in the presence of a magnetic field spectral lines of energy level splits into several substates. We expected to see a difference in the distance between the lines after applying an external field and that’s exactly what we observed. While the difference between the lines was 13mm without any magnetic field, with the application of the magnetic field the spacing changed o a much smaller value depending on the magnetic field’s strength which can be seen from the table one that corresponds to the splitting effect. It means we successfully confirmed the Zeeman effect in our experiment and determined the charge to mass ratio of electron as within the range of 16% error.

The Zeeman effect has a wide range of applications. Which include NMR, ESR and other astrophysical applications. Using NMR spectroscopy chemical, electronic and physical properties of a molecule can be obtained. For the nuclear spins in the molecule shift occurs in the resonance frequency and information about the molecule can be obtained with the help of the shift. In ESR electron spin is used with similar principle. Magnetograms are produced by the usage of Zeeman effect which are used to picture the spatial changes of solar magnetic field.[[2]](#footnote-2) [3]

*Errors:*

One of the sources of the error is related to human eye. The spectral lines are dim, and the exact position of the cross hair might not be exactly seen. There are some other approximations in the formula as well which contribute a slight error too.

**Reference:**

[1] ] A. Beiser(2003), *Concepts of Modern Physics,* McGraw-Hill p224-225

[2] Figure 1: Retrieved from Website of University of Toronto, *Zeeman Effect, p.11*

[3] Wikipedia: The Free Encyclopedia,*” Magnetogram”* (Accessed May 3, 2019)

1. https://www.physics.utoronto.ca/~phy224\_324/experiments/zeeman-effect/zeeman-effect.pdf [↑](#footnote-ref-1)
2. <https://en.wikipedia.org/wiki/Magnetogram> [↑](#footnote-ref-2)