EXPERIMENT 11

THE ZEEMAN EFFECT (Lummer-Gehrcke Plate)

AIM:

To use the Lummer-Gehrcke Plate to observe the Zeeman Effect in the Cadmium Spectrum, and to determine e/m for the electrons.

APPARATUS:

Lummer-Gehrcke Plate interferometer, electromagnet, Ammeter, Teslameter.

METHODOLOGY:

The splitting of the spectral lines of a light source by an applied magnetic field is called "Zeeman effect". In this experiment, the spectral lines of a cadmium light source are examined. The emission of the red line (= 643.8 nm), of the cadmium atom is mainly produced by the transition.

5^1D_2 to 5^1P_1

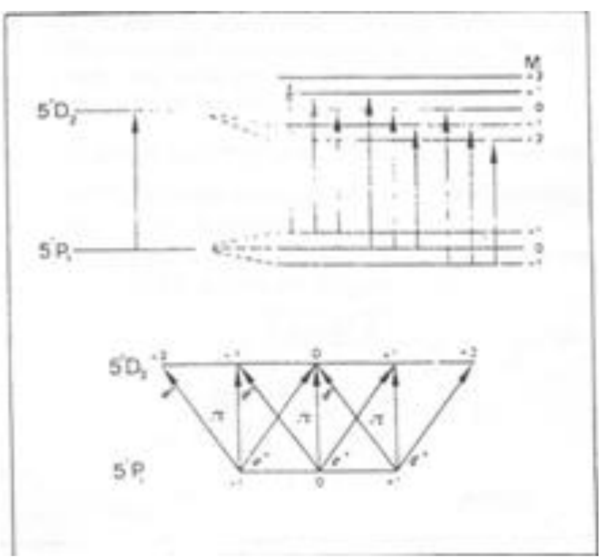

Fig 11.1: Level splitting and transition of the normal Zeeman effect in cadmium

The red line of cadmium is split in the magnetic field into two outer σ-components and one π-component. This applies to transverse viewing, that is, observation perpendicular to the direction of the magnetic field. All three visible lines of this Lorentz-triplet are linearly polarized. The central line, which corresponds to the spectral line of the light source (in the absence of an applied magnetic field), is polarized in direction of the magnetic field, while the two outer lines are polarized perpendicular to the direction of the magnetic field. However, when viewing in the longitudinal direction, i.e., in the direction of the external magnetic field, a doublet is observed. No central line is visible here. The two split lines are circularly polarized against each other.
The splitting mentioned above is a consequence of the additional energy shift resulting from the interaction of the electronic magnetic moment with the magnetic field. The corresponding frequency shift can be expressed as:

$$\nu = \frac{B}{4\pi} x \frac{e}{m}$$

Where ν is the Larmor frequency.

To observe the splitting of spectral lines in magnetic field, a spectroscope of high resolving power is required. In the experimental assembly a Lummer-Gehrcke plate, with a resolving power of approximately 500000, is used.
From the visible displacement of the spectral lines a measurable change of the wavelength or frequency is obtained. The two σ-components are shifted, for example, to a frequency $\nu + \Delta\nu$ or $\nu - \Delta\nu$, where

$$\Delta\nu = \frac{B}{4\pi} x \frac{e}{m}$$

Where
B = magnetic flux density (teslas)
$\Delta\nu$ = frequency shift
$\Delta\nu$ is to be derived from the resolution of the Lummer-Gehrcke plate and from the wavelength displacement determined at a certain B.
Using the velocity of light . $C = \nu \lambda$, $\Delta\nu = C\, \Delta\lambda / \lambda^2$

The differences of wavelength observed at a Lummer-Gehrcke plate are

$$\Delta\lambda = \frac{ds}{\Delta s} \times \frac{\lambda^2 \sqrt{n^2 - 1}}{2d(n^2 - 1)}$$

Where

ds = distance of one of the split lines from the original position of the interference lines (without magnetic field)

Δs = distance between two adjacent interference lines without magnetic field

λ = wavelength of the red line of cadmium = 643.8 nm

n = refractive index of the Lummer-Gehrcke quartz glass = 1.4567

d = the thickness of the Lummer-Gehrcke plate = 4.04 mm

The e/m ratio can then be calculated by using the following formula:

$$\frac{e}{m} = \frac{4\pi c}{B} \frac{ds}{\Delta s} \frac{\sqrt{n^2 - 1}}{2d(n^2 - 1)}$$

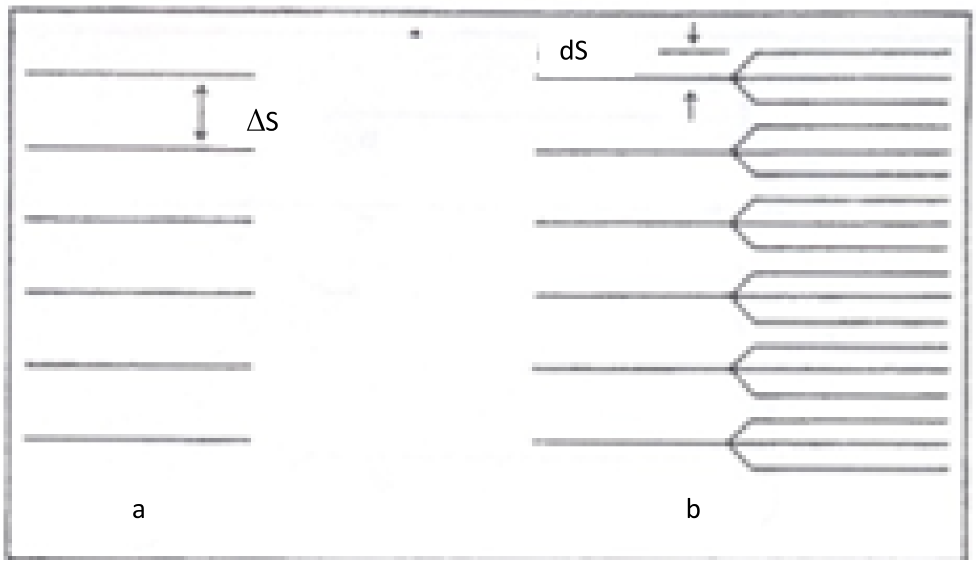

Fig 11.2 : Splitting-up while observing the triplet

a) Before switching on the magnetic filed
b) After switching on the magnetic field

PROCEDURE:

a) 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.

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.

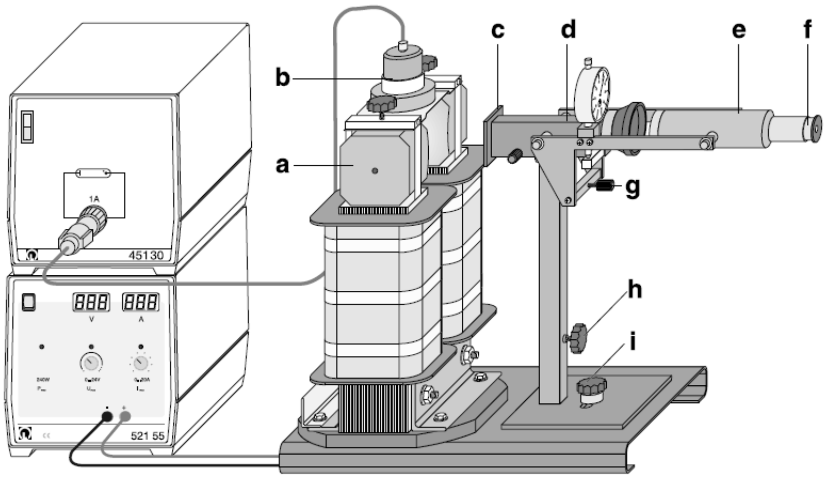

Fig 11.3: Experiment setup for the Zeeman effect in the transverse configuration
(a) pole pieces
(b) cadmium lamp with holder
(c) plug-in holder for red filter
(d) cover
(e) telescope
(f) ocular
(g) height adjustment for telescope
(h) arresting screw for column
(i) arresting screw for column base

b) 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 10A to 20A, increase the current in steps of 1A through the coils and measure the magnetic field in dependency of the current.

c) Measurement of the separation (Δs) of the line pattern at B = 0 tesla:

Make the crosshair in the eyepiece and the line which needs to be measured coincide and set the micrometer clockwise to zero. By turning the screw at the bottom of the clockwork, make the crosshair in the eyepiece coincide with the next line and then read the separation Δs between adjacent lines on the micrometer clockwork.

d) Measurement of the Zeeman splitting ds (distance between two neighbouring lines of a triplet):

Turn on magnetic field, watch the splitting of the line into three components. Rotate the polarization filter to filter out the middle line whose position is independent of magnetic field.

Make the cross in the eyepiece coincide with the lowest component of the triplet. Set the micrometer clockwork to zero and measure the splitting 2(ds) which is dependent on magnetic field.

Note: Because the system of lines generated by the Lummer-Gehrcke plate is not equidistant, ds and Δs must be measured on the same triplet.

e) Draw a graph between ds and B and find the slope

f) Find e/m using

$$\frac{e}{m} = \frac{4\pi c}{B} \frac{ds}{\Delta s} \frac{\sqrt{n^2 - 1}}{2d(n^2 - 1)}$$

g) Compare your result to the literature value:

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