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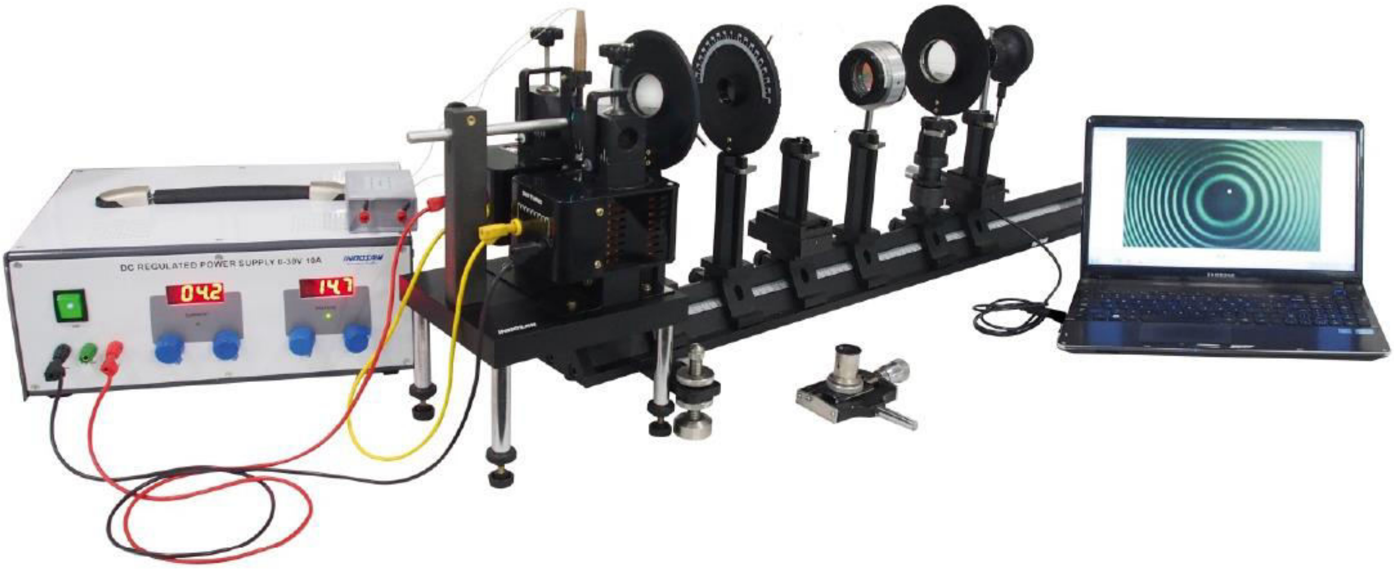
ZEEMAN EFFECT

Instruction Manual



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Scope of Supply:

S.No.	Item Name	Qty.
1.	Optical Bench	01
2	Fixed Saddle	04
3	Transversal Saddle	03
4	Convex Lens on Holder (FL 15cm)	01
5	Convex Lens on Holder (FL 15cm)	01
6	Polarizer	01
7	Quarter Wave Filter	01
8	Electromagnet	01
9	Power Supply for Electromagnet	01
10	Mercury Lamp With Supply	01
11	Mercury Lamp Holder	01
12	Fabry Perot Etalon	01
13	USB camera with software	01
14	Digital gauss meter	01
15	Micrometer eye piece	01
16	Filter with holder	01
17	Connecting lead (red, yellow and black)	1 each
18	Power cord	02
19	Instruction manual	01

Aim:

1. The splitting of central line into two σ line is measured in wave number as a function of magnetic flux density using febry-perot interferometer.
2. To determine the bohr magneton.
3. To determine specific charge i.e. e/m of electron.
4. To determine Lande's g Factor

THEORY

In general, an atom will have a total magnetic dipole moment, $\boldsymbol{\mu}$, due to the orbital and spin magnetic dipole moments, $\boldsymbol{\mu}_{l1}, \boldsymbol{\mu}_{l2}, \ldots$ and $\boldsymbol{\mu}_{s1}, \boldsymbol{\mu}_{s2}, \ldots$ of its optically active electrons. The other electrons are in completely filled sub-shells which have no net magnetic dipole moments. When this magnetic dipole moment of the atom is in an external magnetic field B , it will have the usual potential energy of orientation

$$\Delta E = -\boldsymbol{\mu}.\boldsymbol{B} \ . \qquad (1)$$

Each of the atom's energy levels will be split into several discrete components corresponding to the various values of ΔE associated with the different quantized orientations of $\boldsymbol{\mu}$ relative to the direction of $\boldsymbol{B}$. Let us evaluate $\boldsymbol{\mu}$ in terms of orbital and spin magnetic moments of optically active electrons expressed in terms of their respective orbital and spin angular moment.

$$\begin{aligned}
\boldsymbol{\mu} &= (\boldsymbol{\mu}_{l1} + \boldsymbol{\mu}_{l2} + \ldots..) + (\boldsymbol{\mu}_{s1} + \boldsymbol{\mu}_{s2} + \ldots..) \\
&= \left(-\frac{g_l \mu_b}{\hbar}\mathrm{L}_1 - \frac{g_l \mu_b}{\hbar}\mathrm{L}_2 - \ldots...\right) + \left(-\frac{g_s \mu_b}{\hbar}\mathrm{S}_1 - \frac{g_s \mu_b}{\hbar}\mathrm{S}_2 - \ldots...\right) \\
&= -\frac{g_l \mu_b}{\hbar}(\mathrm{L}_1 + \mathrm{L}_2 + \ldots...) - \frac{g_s \mu_b}{\hbar}(\mathrm{S}_1 + \mathrm{S}_2 + \ldots...) \\
&= -\frac{\mu_b}{\hbar}[(\mathrm{L}_1 + \mathrm{L}_2 + \ldots..) + 2(\mathrm{S}_1 + \mathrm{S}_2 + \ldots..)] \ .
\end{aligned}$$

Here $\boldsymbol{L}_1, \boldsymbol{L}_2, \ldots..$ are orbital angular momenta and $\boldsymbol{S}_1, \boldsymbol{S}_2, \ldots..$ spin angular momenta of active electrons, $\mu_b = e\hbar/2mc$ is Bohr magneton , and g_l and g_s are orbital and spin g factors. These factors have values $g_l = 1$ and $g_s = 2$. If the atom obeys LS coupling, the individual orbital angular momenta couple to give the total orbital angular momentum $\boldsymbol{L}$, and the individual spin angular momenta couple to give total spin angular momentum $\boldsymbol{S}$. The expression for the total magnetic dipole moment of the atom now simplifies to

$$\mu = -\frac{\mu_b}{\hbar}[\mathrm{L} + 2\mathrm{S}] \ . \qquad (2)$$

Note that the total magnetic dipole moment of the atom is not antiparallel to its total angular momentum

$$\boldsymbol{J} = \boldsymbol{L} + \boldsymbol{S} \ . \qquad (3)$$

This has come about because of different values of the orbital and spin g factors. The result is that the behavior of $\boldsymbol{\mu}$ is quite complicated. It precesses about $\boldsymbol{J}$ with a precessional frequency which is proportional to the strength of the internal magnetic field of the atom. The result is that the average value of $\boldsymbol{\mu}$, which is the component μ_J of $\boldsymbol{\mu}$ along the direction of $\boldsymbol{J}$ enters in Eq.(1) for ΔE

$$\Delta E = -\boldsymbol{\mu}_J . \boldsymbol{B} \qquad (4)$$

The component $\boldsymbol{\mu}_J$ is given by

$$\boldsymbol{\mu}_J = \left(\frac{\boldsymbol{\mu}.\boldsymbol{J}}{J^2}\right)\boldsymbol{J}$$

$$= -\frac{\mu_b}{\hbar}\frac{(\mathrm{L}+2\mathrm{S}).(\mathrm{L}+\mathrm{S})}{J^2}\mathrm{J}$$

$$= -\frac{\mu_b}{\hbar}\left(\frac{\mathrm{L}^2+2\mathrm{S}^2+3\mathrm{L}.\mathrm{S}}{J^2}\right)\mathrm{J}$$

$$= -\frac{\mu_b}{\hbar}\left(1+\frac{\mathrm{J}^2+\mathrm{S}^2-\mathrm{L}^2}{2J^2}\right)\mathrm{J}$$

$$= -\frac{\mu_b}{\hbar} g_{lsj}\,\mathrm{J} \ , \qquad (5)$$

as $\qquad \boldsymbol{L}.\boldsymbol{S} = (J^2 - L^2 - S^2)/2$.

The factor g_{lsj} is called Lande's g – factor and is given by

$$g_{lsj} = 1 + \frac{J^2 + S^2 - L^2}{2J^2}$$

$$= 1 + \frac{j(j+1) + s(s+1) - l(l+1)}{2j(j+1)} \ , \qquad (6)$$

where l, s and j are respectively the values of orbital, spin and total angular momenta in the state characterized by L, S and J.

The potential energy of interaction in an external magnetic field B is now given by

$$\Delta E = -\left(-\frac{\mu_b}{\hbar} g_{lsj}\right)\mathrm{J}.\mathrm{B}$$

$$= \frac{\mu_b}{\hbar} g_{lsj} J_Z B$$

$$= \mu_b B g_{lsj} m_j \ , \qquad (7)$$

taking z-axis along B and $J_Z = m_j \hbar$.

Thus an energy level characterized by L , S and J will get split up into $(2j + 1)$ sublevels corresponding to $m_j = -j, -(j-1), -(j-2), \ldots\ldots, (j-1), j$ with energy separation between the adjacent sublevels given by $\mu_b B g_{lsj}$.

An optical transition can take place between any two levels provided

$$\Delta l = \pm 1$$

$$\Delta j = 0, \pm 1 \quad \text{but not} \quad j = 0 \rightarrow j = 0$$

$$\Delta m_j = 0, \pm 1 \ .$$

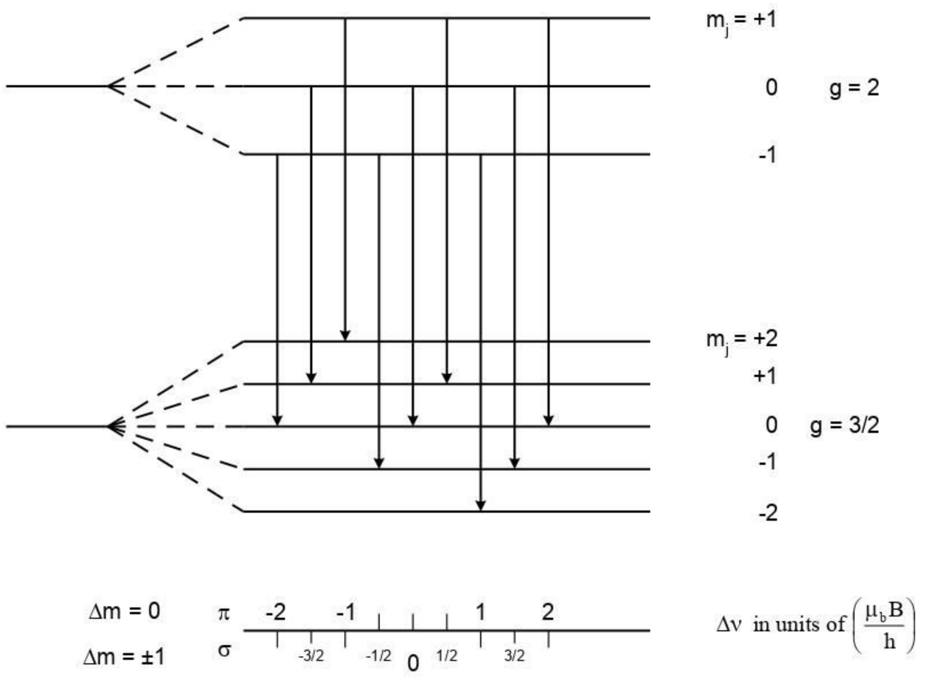

Fig. 1 : Structure of the Zeeman multiplet arising in a transition from a $^3S_1$ to a $^3P_2$ level; the mercury green line at 5461A is an example of such a transition.

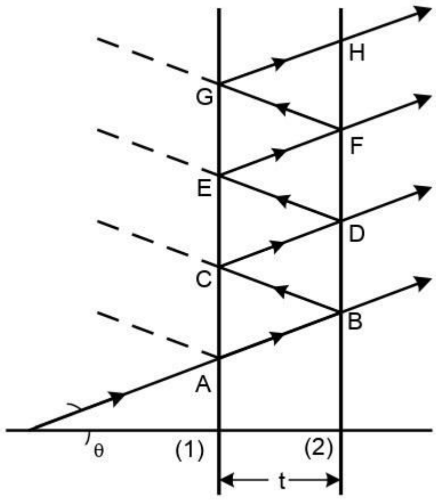

Fig. 2 : Reflected and transmitted rays at the two parallel surface (1) and (2) of a Fabry Perot etalon. The etalon spacing is t.

Let us consider the transition corresponding to the 546.1 nm prominent green line of mercury spectrum with which we are concerned here. This line arises from a transition between the $^3S_1(6s7s)$ state to the $^3P_2(6s6p)$ state. Figure 1 shows the energy-diagram for these two states without and with a magnetic field. The upper level gets split into three corresponding to m_j = 1, 0 and -1 , and the lower into five corresponding to m_j = 2 , 1 , 0 , -1 and -2 . The g-factors for the upper and lower states are

$$^3S_1(J=1, L=0, S=1) \qquad g_{lsj}=2$$
$$^3P_2(J=2, L=1, S=1) \qquad g_{lsj}=3/2$$

As shown in Fig.1 , in the presence of the magnetic field, the 546.1 n.m. line gives rise to nine components. This is because of different g-factors for the initial and final states. This is a case of the (*so called*) anomalous Zeeman effect.

When viewed in the transverse geometry, (i) the first group where $\Delta m_j = -1$ gives σ-lines whose light is polarized perpendicular to the magnetic field, (ii) the middle group where $\Delta m_j = 0$ gives π-lines whose light is polarized parallel to the direction of the field and (iii) the last group where $\Delta m_j = 1$ gives σ-lines whose light is again polarized perpendicular to the magnetic field.

In the longitudinal geometry where the light beam is along the direction of the magnetic field, the beam corresponding to π-lines which is polarized along the direction of the magnetic field (has electric vector along the direction of the magnetic field) cannot travel as light waves are transverse electromagnetic waves. The beam corresponding to π-lines is therefore not observed. The beam corresponding to six σ- lines is circularly polarized when viewed in the longitudinal direction, the three components corresponding to $\Delta m_j = -1$ as right circularly polarized while those corresponding to $\Delta m_j = 1$ as left circularly polarized.

The shift in frequencies of these nine lines is indicated in the lower part of Fig.1 in units of $\mu_b B/h$.

We are interested in the three π-lines for the measurement of Bohr Magneton and use transverse geometry. These are picked out by using a polarizer whose pass-direction is kept parallel to the direction of the magnetic field. The σ- lines which are polarized perpendicular to the magnetic field get blocked. The frequencies of these three π- lines are

$$\nu_0 - \frac{\mu_b B}{2h}\ , \quad \nu_0\ , \quad \nu_0 + \frac{\mu_b B}{2h}\ . \tag{8}$$

This frequency shift $\Delta\nu = \mu_b B/2h = eB/8\pi m$ is measured in this experiment. As this is very small, a high resolution device, a Fabry Perot etalon, based on multiple beam interferometry, is used.

The Fabry Perot etalon consists of two optically flat (to within about 20 nm) glass plates, coated on the inner surface with a partially transmitting metallic layer (reflection coefficient ≈ 0.95) (Fig. 2). The outer surface is slightly inclined (about 0.1°) with respect to the inner one, to avoid multiple reflections, which give rise to "ghost" fringes. The plates are assembled in a holder (Fig. 3) and held apart (with spacing t) by three very accurately machined spacers. Three spring-mounted screws are used to apply pressure, and by careful adjustment, the plates are made parallel.

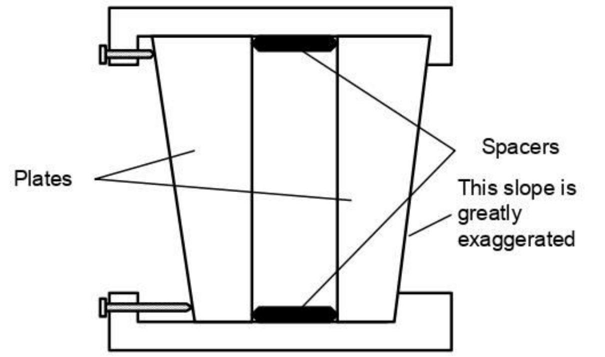

Fig. 3: Mounting of the interferometer plates into a Fabry Perot etalon. Note that the slight slope of the two sides of a plate is usually of the order of 1/10 degree

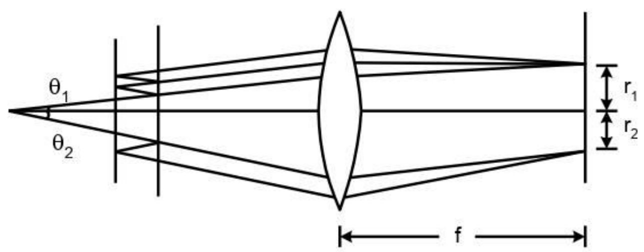

Fig. 4: Focusing of the light emerging from a Fabry-Perot etalon. Light entering the etalon at an angle θ is focused onto a ring of radius r=fθ where f is the focal length of the lens.

An *almost* parallel beam, from an extended source at the focus of a lens, falls on the etalon. The emerging parallel rays *B, D, F,* etc are brought to a focus by the use of a good quality lens of focal length f as shown in Fig. 4. Light entering the etalon at an angle θ is focused onto a ring of radius $f\theta$. When θ satisfies the condition

$$2t\cos\theta = n\lambda ,$$

with n an integer, a bright ring will appear in the focal plane with radius being given by

$$r_n = f\,\theta_n$$

The order n_o corresponding to the interference at the centre is $2t/\lambda$. n_o is in general *not* an integer.

Now

$$n_0 = \frac{2t}{\lambda} = \frac{n}{\cos\theta_n} = \frac{n}{\left(1-\theta_n^2/2\right)}$$

since θ_n is small. This leads to

$$\theta_n = \sqrt{\frac{2(n_o - n)}{n_o}}$$

and

$$r_n^2 = \left(\frac{2f^2}{n_0}\right)(n_0 - n) . \qquad (9)$$

The order n_1 of the first bright ring counting from the centre is less than n_0 since $n_1 = n_0 \cos\theta_1$. Let us take $n_1 = n_0 - \varepsilon$, with fractional order ε lying between zero and one. In general for the p^{th} ring of the pattern as measured from the centre

$$n_p = (n_o - \varepsilon) - (p-1)$$

or

$$n_o - n_p = (p -) + \varepsilon . \qquad (10)$$

From Eqs. (9) and (10) we obtain for square of the radius of the p^{th} ring

$$r_p^2 = \left(\frac{2f^2}{n_0}\right)(p - 1 + \varepsilon) \qquad (11)$$

and the difference between the squares of the radii of adjacent rings

$$r_{p+1}^2 - r_p^2 = \frac{2f^2}{n_0} . \qquad (12)$$

This difference is constant. The squares of the radii of successive rings are linearly related and form an arithmetic progression.

Now if there are two components of a spectral line (in the present experiment we have three components) with wavelengths λ_a and λ_b very close to one another, their fractional orders at the centre will be given by

$$\varepsilon_a = \frac{2t}{\lambda_a} - n_1(a) = 2t\bar{\nu}_a - n_1(a)$$

$$\varepsilon_b = \frac{2t}{\lambda_b} - n_1(b) = 2t\bar{\nu}_b - n_1(b) .$$

Here, $\bar{\nu}_a$ and $\bar{\nu}_b$ are wave numbers, and $n_1(a)$ and $n_1(b)$ are orders of the first rings. As the wavelengths are very close, $n_1(a) = n_1(b)$. The difference in wave numbers between the two components is therefore

$$\bar{\nu}_a - \bar{\nu}_b = \frac{\varepsilon_a - \varepsilon_b}{2t} . \quad (13)$$

The fractional order ε can be obtained using Eq. (11):

$$\frac{r_{p+1}^{\ 2}}{r_{p+1}^{\ 2} - r_p^{\ 2}} - p = \varepsilon \quad (14)$$

Consider a line which has three components (as in the present experiment) a, b, c, and let the respective radii be $r_{1a}, r_{2a}, r_{3a}, \ldots,$ for component a; $r_{1b}, r_{2b}, r_{3b}, \ldots,$ for component b and similarly for component c. From Eq.(12), it is clear that the difference between the squares of the radii of any two adjacent rings of component a,

$$\Delta_a = r_{(p+1),a}^{\ 2} - r_{p,a}^{\ 2} = \frac{2f^2}{n_{0,a}}$$

is equal (to within a very small amount) to the similar difference for component b,

$$\Delta_b = r_{(p+1),b}^{\ 2} - r_{p,b}^{\ 2} = \frac{2f^2}{n_{0,b}}$$

or any other component of the same line. We shall take the average of these. Let these differences be designated by Δ. Eq.(14) now leads to

$$\varepsilon_a = \frac{r_{(p+1),a}^{\ 2}}{\Delta} - p$$

$$\varepsilon_b = \frac{r_{(p+1),b}^{\ 2}}{\Delta} - p$$

$$\varepsilon_c = \frac{r_{(p+1),c}^{\ 2}}{\Delta} - p ,$$

and the required separation (in wave numbers) between the two components, a and b, using Eq.(13), is given by

$$\Delta\bar{\nu} = \frac{\varepsilon_a - \varepsilon_b}{2t} = \frac{r_{p,a}^{\ 2} - r_{p,b}^{\ 2}}{2t\Delta} . \quad (15)$$

The difference $\delta_{a,b}^{p}$ between the squares of the radii of the p^{th} rings of components a and b is found to be independent of p. We shall take the average of these. Let these be designated by δ_{ab}. The required separation between the two components is finally given by

$$\Delta\bar{\nu}_{ab} = \frac{\delta_{ab}}{2t\Delta} . \quad (16)$$

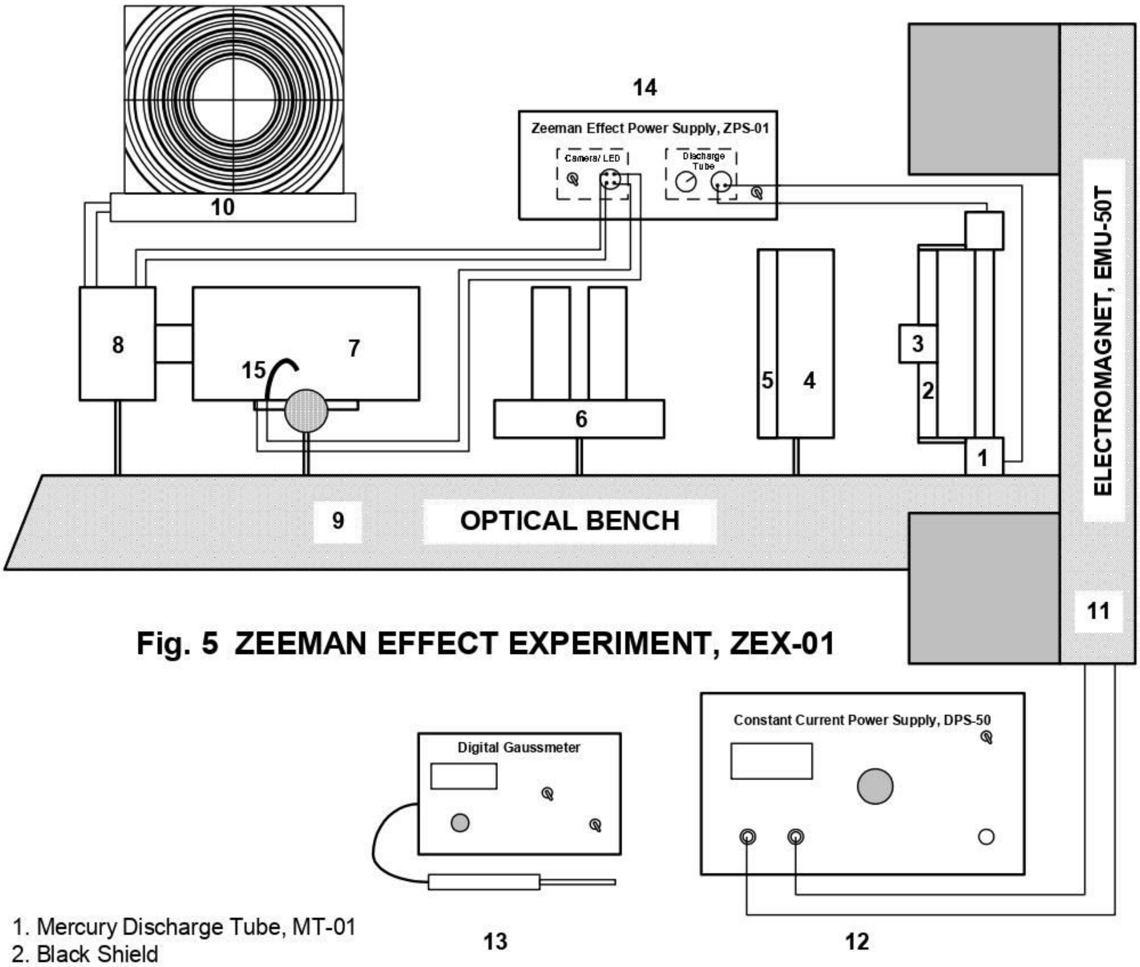

Fig. 5 ZEEMAN EFFECT EXPERIMENT, ZEX-01

1. Mercury Discharge Tube, MT-01
2. Black Shield
3. Monochromator, IF-01
4. Focussing Lens, FL-01
5. Polariser, PL-01
6. Fabrey Perot Etalon, FPE-01
7. Telescope with Focussing Lens Triplet, FL-3
8. CCD Camera, CAM-700
9. Optical Bench, OB-1
10. TV Monitor, TV-14
11. Electromagnet, EMU-50T
12. Constant Current Power Supply, DPS-50
13. Digital Gaussmeter, DGM-102
14. Zeeman Effect Power Supply, ZPS-01
15. LED Torch Light

As the result depends on the ratio δ_{ab}/Δ, the dimensions used in measuring the radii of the ring system or the amplification of the interference pattern do not matter.

Using this wave number separation in Eq.(8) for the Zeeman line splitting, we get

$$\Delta\nu = \frac{\mu_b B}{2h} = \frac{eB}{8\pi m} = c\Delta\bar{\nu} = \frac{c\,\delta}{2t\Delta}$$

or

$$\frac{e}{m} = \frac{8\pi c}{B}\left(\frac{\delta}{2t\Delta}\right). \qquad (17)$$

Further the **Bohr Magneton μ_b** is given by $\mu_b = \frac{2hc}{B}\left(\frac{\delta}{2t\Delta}\right)$

Average values Δ and δ are required

PROCEDURE

(I) Calibration of EMU-50V

(a) Adjust spacing between pole pieces using space provided.

(b) The space between the pole piece should be centered along the electromagnet center line marked in white.

(c) Take out the Hall Probe of the Gaussmeter from its casing and switch ON the unit, keeping the probe away from electromagnet or any other magnetic material. Adjust the Gaussmeter reading to Zero by "Zero Adj." knob.

(d) Place the DGM-102 Hall Probe along the centre of EMU-50 using the Probe Holder provided. The alignment of probe should be parallel to the face of the pole pieces, i.e. perpendicular to the magnetic field.

(e) Check the sign in Gaussmeter. In case it shows -ve sign, turn the direction of Hall Probe by 180°.

(f) Take the reading of Gaussmeter at zero current. It corresponds to the residual magnetic field of electromagnet.

(g) Now slowly increase the DPS-50 current in small steps and make a table of current vs. magnetic field upto a maximum current of 4A.

(h) Plot a graph between the current and the magnetic field. It will be used later in the calculation.

(II) Setting up of Experiment

(a) Remove the gaussmeter probe from electromagnet.

(b) Place Mercury Discharge Tube using the Holder provided, aligning the same with the center of electromagnet. The position of light emitting hole should face the narrow band filter on the optical bench.

(c) Place the set of converging lens and polarizer as near to the filter as possible.

Setting :

1. Arrange the apparatus as shown fig.-2.
2. Mount the pole pieces of electromagnet using the clamps so that about 10mm distance is left between the pole pieces.
3. Mount the mercury lamp between the pole of magnet see that mercury lamp is exactly at the middle and the leads of bulb are out of the ray path, so for as possible.
4. Reduce the distance between the pole piece to achieve the max. strong field.
5. Mount the optical components according to fig.2
6. Connect the mercury lamp to source and wait for 5 minutes, so that light emission is sufficiently strong.
7. Connect the coils of electromagnet in series and then to current power supply.

Adjusting the optical components without inserting the polarization filter and the quarter wave plate. Set apparatus so that clear, Circular fringe pattern is observed.

1. Set the eyepiece on line graduation.
2. Set the imaging lens, till a sharp circular fringe pattern is observed.
3. Move the condensing lens, till the observed image is uniformly illuminated.
4. Set the centre of circular fringe pattern to the middle of line qraduaction by slightly setting (tipping) the fabry-perot-etalon with adjusting screws .

Note: - It the adjustment is not sufficient, set the height of imaging lens and occular (eyepiece) in line to each other.

Experimental Procedure:

1. Transverse observation.

a) First without magnetic field(i=0) observe the circular fringe pattern.

1. Increase the magnet current to about 7 to 9 A till the fringes are clearly separated .

Distinction between π and 6 components

a) Insert the polarization filter into the ray path and set to 90°, till the both two outer components of the triplet structure disappear.

Adjust the polarization filter to 0° until the un-shifted component in the middle disappear.

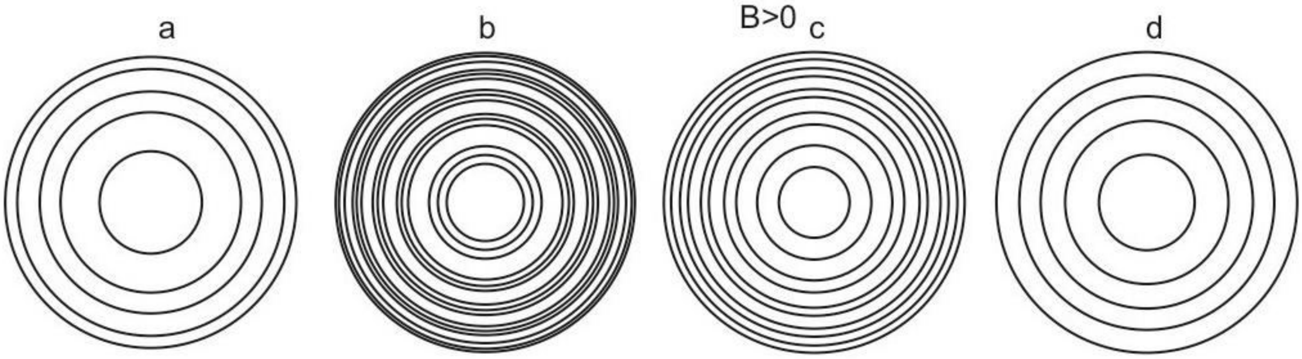

Fig.-8

Fig-x: Zeeman pattern in transverse mode

a) Without field.
b) With field.
c) Direction of polarization filter perpendicular to the magnetic field.
d) Direction of polarization filter parallel to the magnetic field.

Observation in longitudinal mode

1. Rotate the complete set of mercury lamp. and magnet by 90°
2. Observe the fringe pattern without magnetic field (i.e when B=0)
3. Gradually increase the magnetic current to 7 to 9 amp, till the split fringes are clearly visible.

For Distinction between σ^- and σ^+ components:

a) Insert the quater wave plate into the ray path, between the mercury lamp and polarization filter and fix it at 0°.
b) Adjust the polarization filter to +45° and -45°. In each case one of the two doublet components disappears.

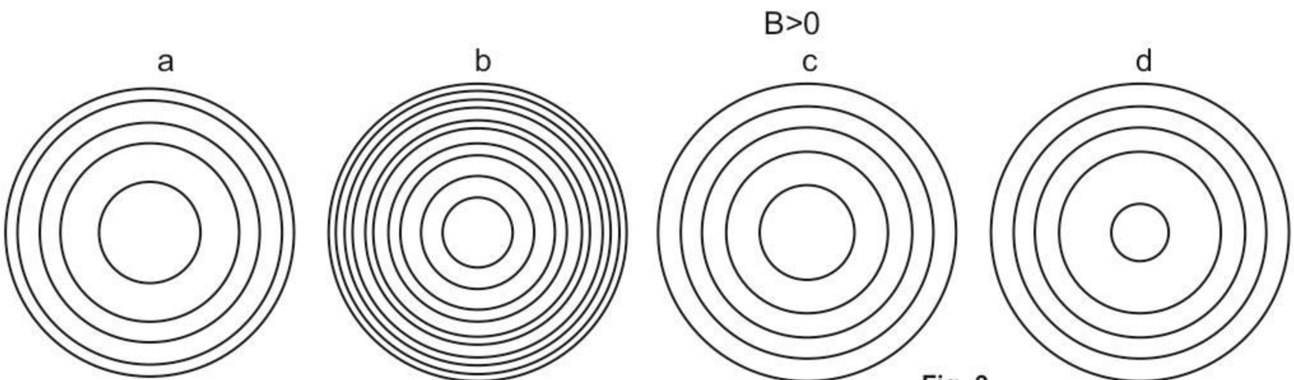

Fig.-9

Fig-Y Fringe pattern in longitudinal mode

a) Without magnetic field.
b) With field.
c) c and d with quarter wave plate and polarization filter for observing circular polarization.

Note: The total intensity of all zeeman components is same in all direction. In transverse mode the intensity of the two components of σ , is equal to the intensity of the π component.

Observation:

Normal zeeman effect :- This type of splitting is observed for states in which the only orbital angular momentum is involved and spin does not contribute to the total angular momentum.

ANOMALOUS ZEEMEN EFFECT :- This type of splitting is observed for slates in which electron spin is also included to the total angular momentum.

Introduction :-

The selection rules for optical transitions are. $\Delta m_J = \pm 1, 0$ The transition belonging to $\Delta m_J = 0$ are called as π lines and those with $\Delta m_J = \pm 1$ are called as σ – lines. When the magnetic field is applied without amalyser, three lines are observed simultaneously, in transversal, normal zeeman effect. In the case of Anamolus Zeeman effect (Green filter used in front of cadmium source) three groups of three lines is observed.

When polariser (analyser) is inserted in between lenses in the vertical position two s – lines are observed. When the analyser is turned into the horizontal position only the π lines appears.

In longitudinal mode, the light is circularly polarised. $A\frac{\lambda}{4}$ plate is used to convert linearly polarised light into elliptical polarised light. In this experiment the $\frac{\lambda}{4}$ plate used in opposite way. By placing the $\frac{\lambda}{4}$ plate, before the analyser, the light of the longitudinal Zeeman effect is investigated. When the optic axis of $\frac{\lambda}{4}$ plate coincide with vertical it is observed that some rings disappear, if the analyser is at angle of 45^0 with vertical, while other rings dissappear for a position of -45^0.

The establishes that light of longitudinal Zeeman effect is polarised, in circular (opposed) way. The π lines are not observed in longitudinal mode.

Note:- In Anamalous Zeeman effect nine equidistant lines are observed instead of three without spin in normal Zeeman effect.