Unit - II

Zeeman effect :

- Importance
- development of quantum theory
- illustrates Phenomenon of space quantization, which refers to the angular momentum L of the atom asuming only a set of discrete orientations w.r.t. external megnetic field B.

Spin angular momentum S

$$\mu = -\frac{\mu_0}{\hbar}(L + 2S) \quad \text{---} \quad (1)$$

whereas the total angular momentum J is simply the vector sum

$$J = L + S.$$

→ Factor of 2 appearing in the expression for magnetic dipole moment means that the magnetic dipole moment vector is not, in general, collinear with the total angular momentum,

If, however the total electron spin couples to zero i.e. S=0, then the expression reduces to that in eqn (1)

Historically the case with zero spin was the first one discovered by Zeeman it has to come to be referred to as "normal" Zeeman splitting, as opposed to "anomalous" Zeeman splitting, which is the case of non-zero spin.

- Assume we are dealing with Regular Zeeman splitting.

(1) so $J = L$

assume, magnetic field is weak because if field is strong then it destroys the coupling between L & S

- fields are considered as "weak" if they are about 0.8 Tesla and lower & "strong" if > 1.5.

Torque on the atom due to the external field is

$$\tau = \mu \times B$$
$$= -\frac{\mu_0}{\hbar} L \times B$$

, Perpendicular to both L & B.

Causes the tip of the orbital angular momentum vector L to precess in a circular orbit about B

Interaction energy betn. atom's magnetic dipole moment and the field is,

$$\boxed{\Delta E = -\mu \cdot B = +\frac{\mu_0}{\hbar} L \cdot B} \quad -(2)$$

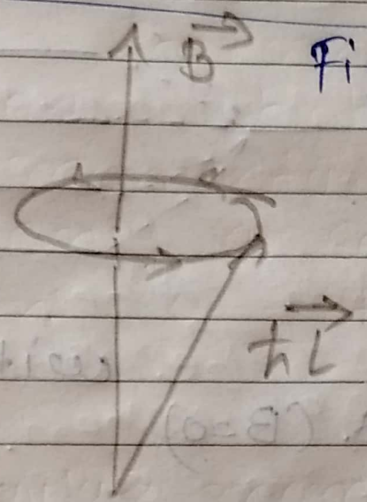


Fig: Precession of the Orbitell angular momentum $\vec{L}$ about the direction of the magnetic field B.

let $B = B_z$

$$\Delta E = \frac{\mu_0}{\hbar} B L_z.$$

L_z = Projection of the L on z axis

according the quantum mechanics

$$L_z = m_l \hbar$$

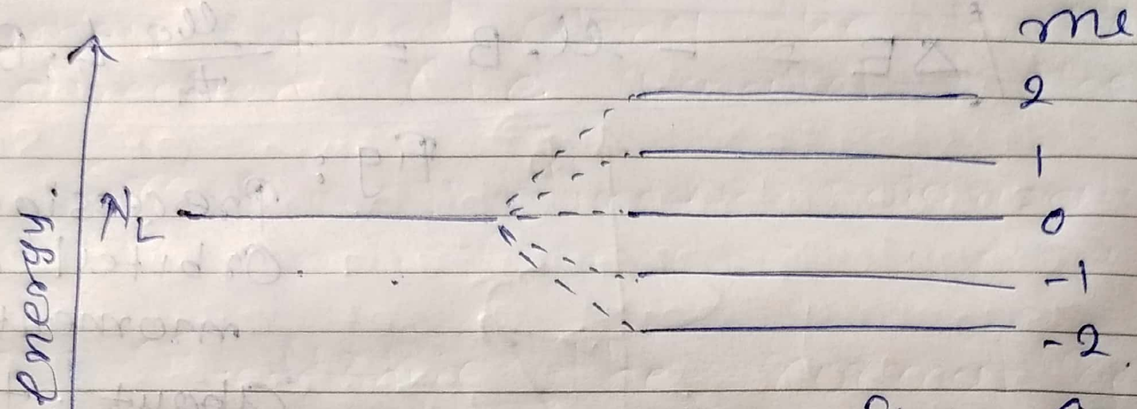
where $m_l = -l, -l+1 \ldots +l-1, +l$

Hence we obtain for the energy levels

$$\boxed{\Delta E = \mu_0 B m_l} \quad — (3)$$

Therefore, when an atom is placed in a magnetic field, the energy level with principal quantum number n and orbitell angular momentum indexed by azimuthal quantum

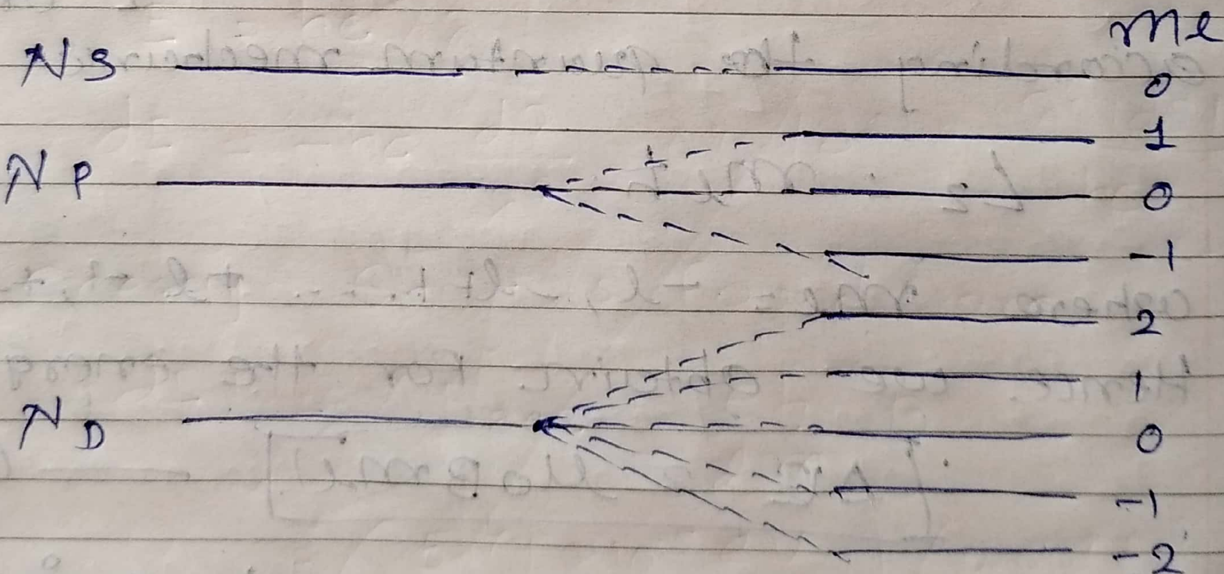
number l will split into $2l+1$
Sub levels



with field (B>0)

no field (B=0)

fig 2: energy level splitting Corresponding to different projections of orbital angular momentum onto the axis of the magnetic field.



no field (B=0) with field (B>0)

Fig 3: energy level splitting for different orbitals. (i.e. diff^n angular momen

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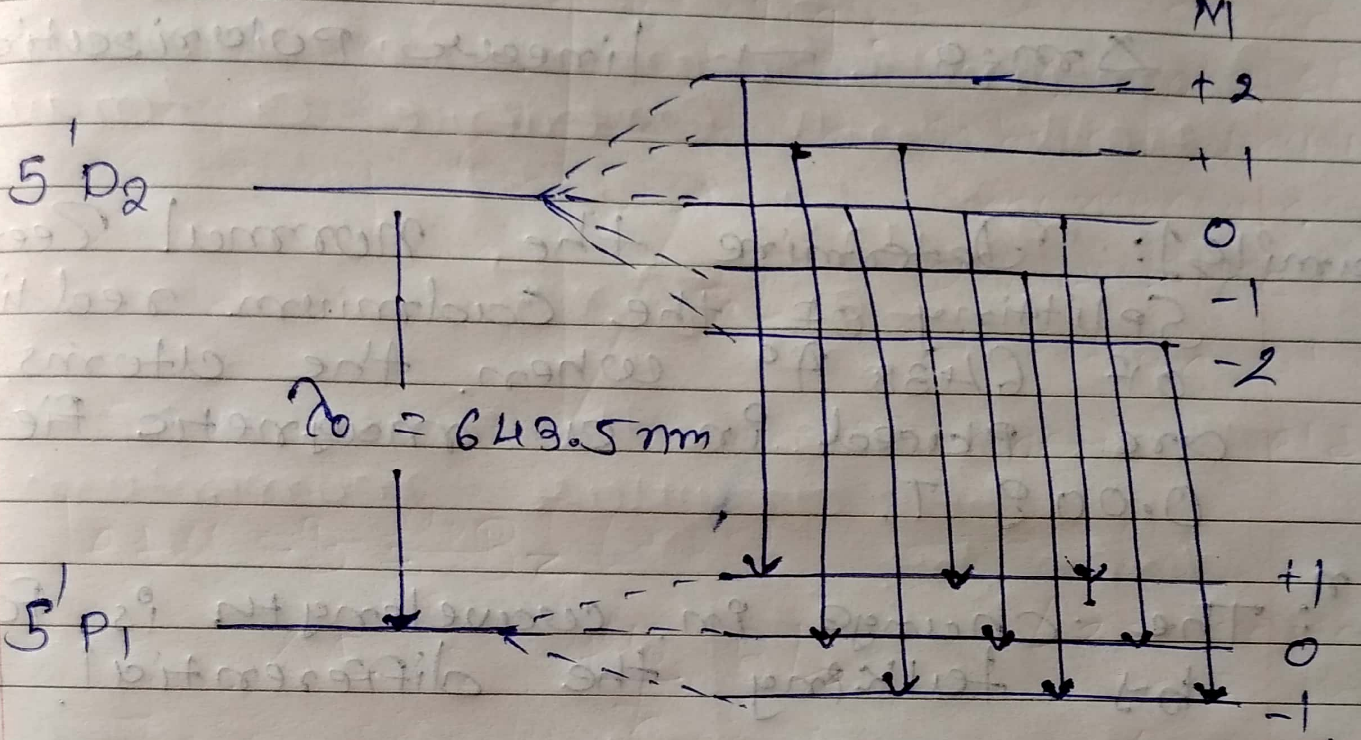
By Convention. Orbital angular moment of states of the atom are given letter labels. S ($l=0$), P ($l=1$), D ($l=2$), F ($l=3$), G ($l=4$), H ect.



No magnetic field. In. Magnetic field.

Fig 4: allowed energy level transitions of Cadmium (Cd)

- we have three allowed electric dipole transitions with magnetic field on. they have Frequencies

$$\nu = \nu_0$$

$$\nu = \nu_0 + \mu_0 B$$

$$\nu = \nu_0 - \mu_0 B.$$

m magnitudes)

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last two, with $\Delta m = +1$ and -1

Correspond to circularly polarized light when viewed along the B field (i.e. parallel to the field direction)

$\Delta m = 0$ → linear polarization.

Example 1: Determine the normal Zeeman splitting of the cadmium red line of 6438 A° when the atoms are placed in a magnetic field of 0.009 T.

Sol^n: The change in wavelength is found by taking the differential of

$$E = hc/\lambda$$

$$dE = -hc\frac{d\lambda}{\lambda^2} \quad \text{or} \quad |d\lambda| = \frac{\lambda^2 |dE|}{hc}$$

energy shift is found from

$$|dE| = \Delta E_{zee} = \frac{eh}{2m}B$$

$$= \left(5.79 \times 10^{-5} \frac{eV}{T}\right)(0.009T)$$

$$= 5.21 \times 10^{-7} eV$$

given $|d\lambda| = \frac{\lambda^2 |dE|}{hc}$

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$$= \frac{(6438 A^\circ)^2 (5.21 \times 10^{-7} ev)}{12.4 \times 10^3 \, ev \, A^\circ}$$

$$\boxed{|d\lambda| = 1.74 \times 10^{-3} A^\circ}$$

example 2: what magnetic flux density B is required to observed the normal Zeeman effect if a spectrometer can resolve spectral lines seperated by 0.5A° at 500 A°?

$$\frac{|d\lambda|}{\lambda} = \frac{|dE|}{hc/\lambda} = \frac{(e\hbar/2m) B}{hc/\lambda}$$

giving $B = \frac{|d\lambda|}{\lambda}\left(\frac{hc}{\lambda}\right)\left(\frac{2m}{e\hbar}\right) = \left(\frac{0.5 A^\circ}{5000 A^\circ}\right)$

$$\sim \left(\frac{12.4 \times 10^3 \, ev \, A^\circ}{5000 A^\circ}\right)$$

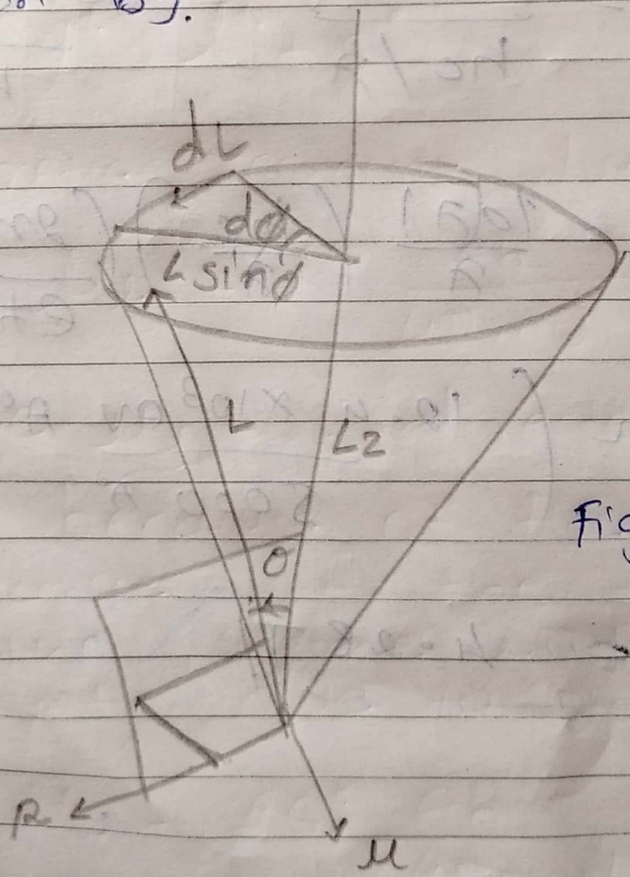
$$\boxed{B = 4.28 T}$$

Example: 3
Calculate the freq^{n}. at which an electron's orbital magnetic moment μ precesses in a magnetic field B

A magnetic moment in a magnetic field will experience a torque τ,

$$\tau = \mu \times \vec{B}$$
$$= \frac{-e}{2m} \vec{L} \times \vec{B}$$

This torque will cause a change in the angular momentum given by.



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$$\tau = \frac{d\vec{L}}{dt} = -\frac{e}{2m} \vec{L} \times \vec{B}.$$

change in L, dL, is a perpendicular to both L and B. as shown in fig 1

resulting in a Precession of L about the direction of B. from fig. it is seen that

$$d\phi = \frac{|dL|}{L\sin\theta}.$$

which gives

$$\omega_p = \frac{d\phi}{dt} = \frac{\left|\frac{dL}{dt}\right|}{L\sin\theta}$$

$$= \frac{e}{2m} \frac{LB\sin\theta}{L}$$

$$= \frac{e}{2m} B.$$

This is known as Larmor Precession. ω_p, is equal to the frequency difference observed in the Normal Zeeman effect.

Vector Model and Anomalous Zeeman effect

- Anamalous Zeeman effect finds its explanation when we introduce spin of the electron in Vector atom model with the introduction of electron spin, we say that l^* & s^* Vectors.

$$l^* = \sqrt{l(l+1)}$$

$$s^* = \sqrt{s(s+1)}$$

Process around the result Vector g^*. (total angular momentum Vector)

$$g^* = l^* + s^*$$

magnetic moment due to orbital motion

$$\mu_l = l^* \frac{eh}{4\pi m v}$$

where μ_l is directed opposite to l^* because of the negative charge of the electron.
In the same way magnetic moment due to spin is given by

$$\mu_s = 2s^* \frac{eh}{4\pi m v}$$

which is directed opposite to s^* due to the reason stated above