Zeeman Effect.

It is a magneto-optical phenomenon discovered by Zeeman by 1896. He discovered that when atoms are placed in a magnetic field, the spectral lines emitted by the atoms may be split into several lines, such splitting is called "Zeeman effect".

The phenomenon of splitting of the spectral lines under the influence of an external magnetic field is called "Zeeman effect".

It is of two types:

1) Normal Zeeman effect:

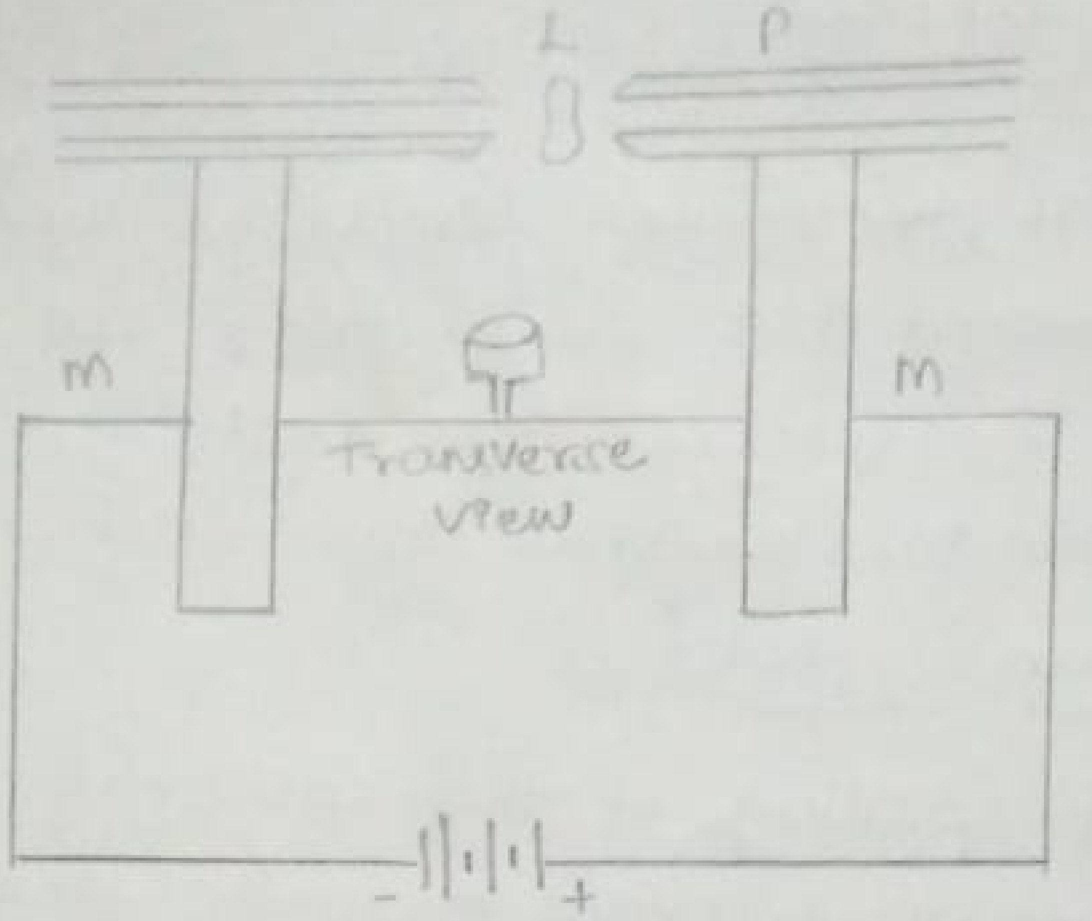
If electron spin is not involved in the Zeeman effect then it is called Normal Zeeman effect.

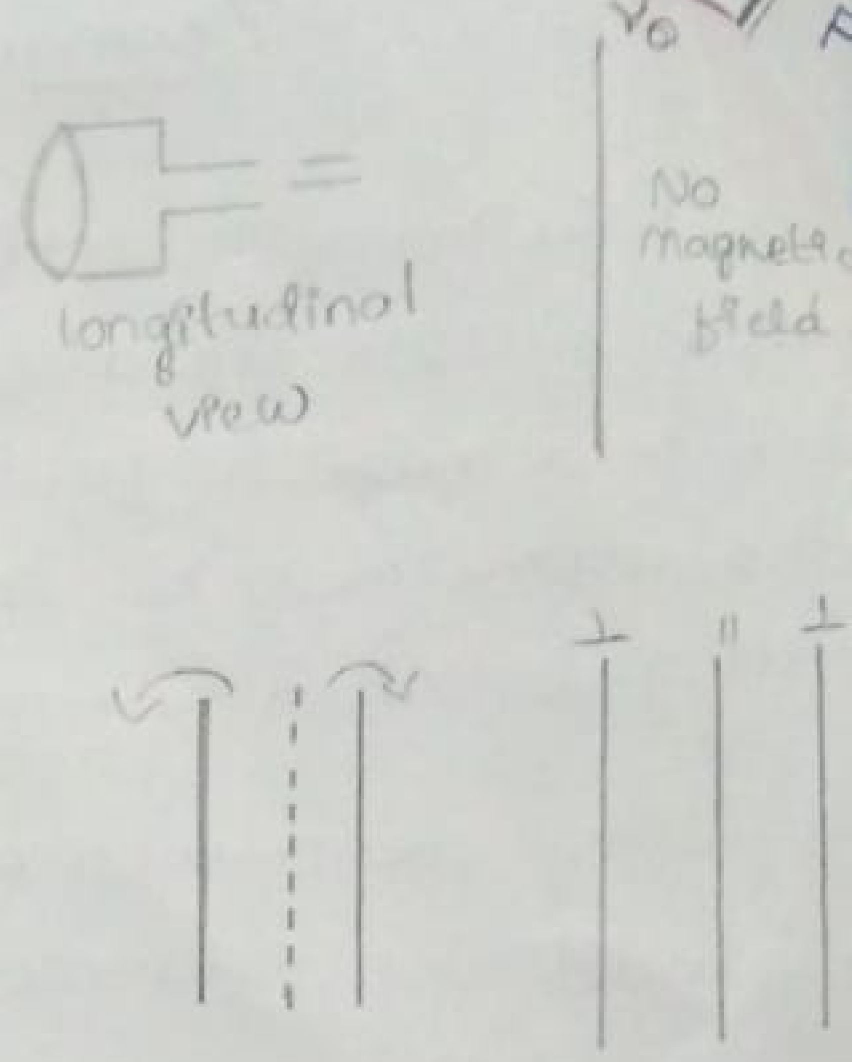
2) Anamalous Zeeman effect:

If electron spin is involved in the Zeeman effect then it is called anamalous Zeeman effect.

Experimental Arrangement:

Arrangement consists of electromagnet (MM) which have conical pole pieces (PP) longitudinal hole is drilled through them. A source of light L is placed b/w the poles. The spectral lines are observed with the help of a spectrograph (S) of high resolving power.





Observation:

The zeeman effect may be observed in two ways

1) The spectral lines are viewed longitudinally through the hole drilled in the poles (i, e parallel to field direction).

It is found that the spectral line is split into two components one slightly shorter in wavelength than original line and the other slightly longer wavelength than original line. The original line is absent. Analysing the two lines with Nicol prism both are found to be circularly polarised in opposite direction

2) The spectral lines are viewed in a direction $\perp^r$ to the applied magnetic field (Transverse view).

In this case spectral line is split up into 3 components. The central line has the same wavelength as the original line. The shift of either outer components from the central line is known as "Zeeman shift".

The two outer lines are plane polarised having vibration in a direction $\perp^r$ to the field. Central line having vibrations parallel to the magnetic field.

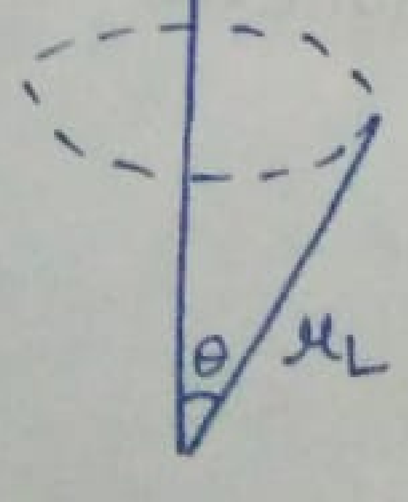
Explanation of Normal Zeeman effect on the basis of vector model.

The Zeeman effect is due to the interaction of the magnetic moment of the atom with magnetic field. Consider the hydrogen atom, neglect the spin of the electron, then the magnetic moment of the atom is due to the orbital motion.

$$\mu_L = -\frac{e}{2m} L$$ where $L \rightarrow$ orbital angular momentum.

$$L = \frac{lh}{2\pi}$$ $l \rightarrow$ orbital quantum number

When strong magnetic field (B) is applied atomic magnet Experience torque $\vec{\tau} = \vec{\mu_L} + \vec{B}$ which causes change in the angular momentum vector L.



$$\tau = \vec{\mu_L} \times \vec{B} = \frac{-eL}{2m} \times \vec{B}$$

Since torque is acting on the moving system the vector L processes around B with angular frequency. Due to this Precession there is change in the energy of the atom. The additional energy of the atom in the external magnetic field is given by V_m.

$$V_m = -\mu_L \cdot \vec{B}$$

$$= -\mu_L B \cos\theta$$

$$= \frac{e}{2m} L B \cos\theta$$

$$= \frac{e}{2m} \frac{lh}{2\pi} B \cos\theta$$

$$= \frac{eh}{4\pi m} B l \cos\theta$$

$$= \mu_B \cdot B m_l \qquad [\because m_l = l\cos\theta,\ m_l = \text{magnetic Quantum no.}]$$

m_l can take $(2l+1)$ values for given l.

Due to this each energy state is split into $(2l+1)$ states in the presence of magnetic field.

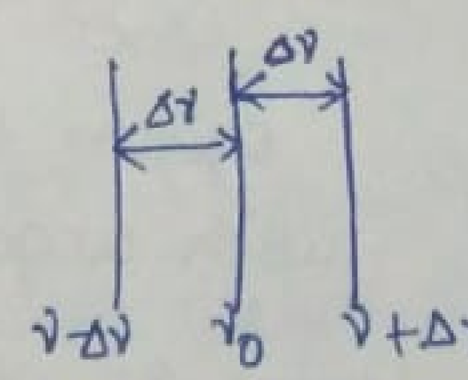
Consider a spectral line due to the transition from d state to p state.

for d, $l=2$ It splits into 5 sublevels.

for p, $l=1$ It splits into 3 sublevels

If E_0' & E_0'' represents the energy of the levels $l=1$ & $l=2$ respectively in the absence of magnetic field.

$$E_0'' - E_0' = h\nu_0$$



In the presence of the magnetic field E_B' & E_B'' represents the energies of level 1 & 2. Then

$$E_B' = E_0' + V_m = E_0' + \mu_B B m_l'$$

$$E_B'' = E_0'' + V_m = E_0'' + \mu_B B m_l''$$

Energy radiated in the presence of magnetic field.

$$E_B'' - E_B' = E_0'' - E_0' + \mu_B B(m_l'' - m_l')$$

$$h\nu = h\nu_0 + \mu_B B \Delta m_l.$$

$$\nu = \nu_0 + \frac{\mu_B B}{h} \Delta m_l.$$

$$= \nu_0 + \frac{eh \cdot B}{4\pi m \cdot h} \Delta m_l.$$

$$\nu = \nu_0 + \frac{eB}{4\pi m} \Delta m_l.$$

where ν is the frequency of the spectral line in presence of magnetic field.

Selection for $\Delta m_l = 0, \pm 1$, Hence 3 possible transitions results in 3 spectral lines.

for $\Delta m_l = 0$ | $\Delta m_l = +1$ | $\Delta m_l = -1$.

$\nu = \nu_0$ | $\nu = \nu_0 + \frac{eB}{4\pi m}$ | $\nu = \nu_0 - \frac{eB}{4\pi m}$

$\Delta\nu = \frac{eB}{4\pi m}$ —① | $\Delta\nu = -\frac{eB}{4\pi m}$ —②

$\Delta\nu \rightarrow$ is called zeeman shift

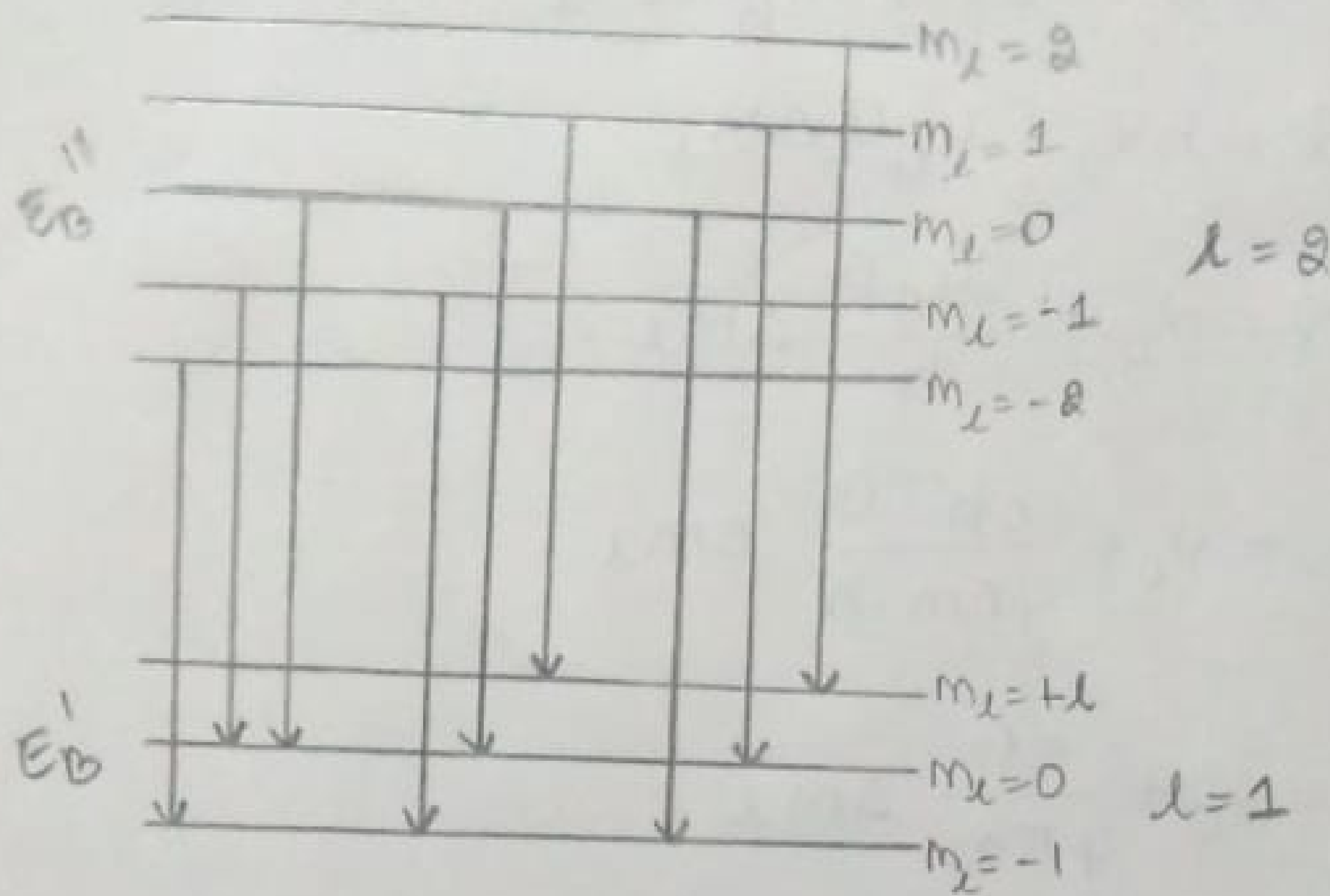
we have $C = \nu\lambda$ $\quad \nu = \frac{c}{\lambda}$

$$\Delta\nu = -\frac{c}{\lambda^2}\Delta\lambda$$

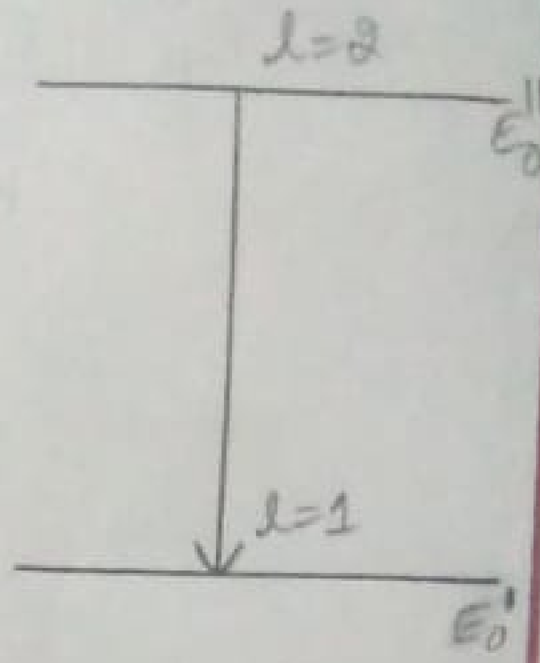
then from ①

$$\Delta\nu = -\frac{c}{\lambda^2}\Delta\lambda = \pm\frac{eB}{4\pi m}$$

$$\boxed{\Delta\lambda = \pm\frac{eB\lambda^2}{4\pi mc}}$$ $\Longrightarrow$ This is called Zeeman shift.



E_B''
$m_l = 2$
$m_l = 1$
$m_l = 0$
$m_l = -1$
$m_l = -2$
$l = 2$
E_B'
$m_l = +l$
$m_l = 0$
$m_l = -1$
$l = 1$



$l=2$
E_0''
$l=1$
E_0'