Lecture 20 Title: Effect of Static Magnetic field on the spectral lines.

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In this lecture we will discuss the effect of static magnetic field on the spectral lines.

The effect is known as Zeeman effect and the pattern seen after applying the magnetic field is known as Zeeman pattern.

We will also discuss the Normal and Anomalous Zeeman effect.

We will see also the change of the Zeeman pattern when the magnetic field is increased.

When a source of light emitting line spectra is placed under a static magnetic field, it is observed that the spectral lines split into several components.

Zeeman in 1896 first observed the phenomenon.
Applying the magnetic field his observations were made in two directions with respect to the magnetic field directions.
1. Observations perpendicular to the magnetic field:
(a) Spectral lines split into three components
(b) Central line has the same frequency as the original line before applying the magnetic field.
(c) Central line is linearly polarized and parallel to the magnetic field.
(d) The two other components are equally separated on both sides of the central frequency.
(e) Both of them are also linearly polarized and polarization is perpendicular to the magnetic field.

2. Observations along the magnetic field direction:
(a) Central line is absent
(b) The other two components are circularly polarized

This effect is known as Normal Zeeman effect. It was also later observed that in some cases there were more than three lines. To differentiate, it was named as Anomalous Zeemen effect. In the following, we will discuss this in details.

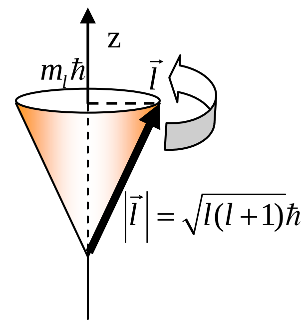
The interaction of atom and magnetic field can be described as the interactions of magnetic field with (a) orbital angular momentum and (b) spin angular momentum of electron.

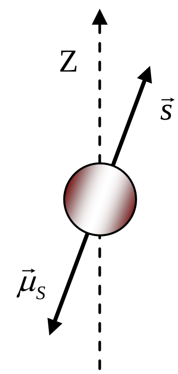
The Orbital magnetic moment in terms of Bohr magneton in the vector form is

$\vec{\mu}_l = -\frac{g_l \mu_B}{\hbar}\vec{l}$ and putting $g_l = 1$, $\vec{\mu}_l = -\frac{\mu_B}{\hbar}\vec{l}$

Substituting the value of the angular momentum

$$\left|\vec{\mu}_l\right| = \frac{\mu_B}{\hbar}\sqrt{l(l+1)}\hbar = \mu_B\sqrt{l(l+1)}$$





The spin dipole moment, in terms of spin Lande g-factor g_s.

$$\vec{\mu}_s = -\frac{g_s \mu_B}{\hbar}\vec{s}$$

$$\mu_{s_z} = -g_s \mu_B m_s$$

So the total magnetic moment of the atom due to the electron is

$$\begin{aligned}
\vec{\mu}_{electron} &= \vec{\mu}_{orbital} + \vec{\mu}_{spin} \\
&= \vec{\mu}_l + \vec{\mu}_s \\
&= -\frac{\mu_B}{\hbar}\vec{l} - \frac{g_S \mu_B}{\hbar}\vec{s} \\
&= -\mu_B[\vec{l} + 2\vec{s}]/\hbar
\end{aligned}$$

Since $\hbar$ in this expression will be cancelled with the eigenvalue in terms of $\hbar$, we will drop this and will consider

$$\vec{\mu}_{electron} = -\mu_B[\vec{l} + 2\vec{s}]$$

And the interaction energy with the applied magnetic field $\vec{B}_z$ is

$$E_{mag} = -\vec{\mu}_{electron}.\vec{B}_z$$

We know that the Hamiltonian for the atom in the L-S coupling scheme is written as

$$H = \underbrace{H_{CF}}_{\substack{|l_1 m_{l_1}\rangle|s_1 m_{s_1}\rangle \\ |l_2 m_{l_2}\rangle|s_2 m_{s_2}\rangle}} + \underbrace{H_{ee}}_{|Lm_l\rangle|Sm_s\rangle} + \underbrace{H_{so}}_{|Jm_J\rangle}$$

The total quantum number J is the good quantum number and arises from the uncoupled quantum numbers L and S.
We also know that this L and S are the orbital and spin quantum number for the single electron case [$L = l$, and $S = s$].
But for the multielectron case, these are the total orbital and spin quantum number
[$L = \sum l_i, \quad S = \sum s_i$]

When the magnetic field is applied, the interaction between the magnetic field and the magnetic moment is treated as perturbation. Depending on the magnitude we have to write the Hamiltonian.
At the first stage, we consider that the perturbation due to the magnetic field is lesser than the interaction due to spin orbit (weak field case). In this case, we can write the Hamiltonian as

$$H = \underbrace{H_{CF}}_{\substack{|l_1 m_{l_1}\rangle|s_1 m_{s_1}\rangle \\ |l_2 m_{l_2}\rangle|s_2 m_{s_2}\rangle}} + \underbrace{H_{ee}}_{|Lm_l\rangle|Sm_s\rangle} + \underbrace{H_{so}}_{|Jm_J\rangle} + H_{mag}$$

The meaning of this in the vector diagram is given in the figure-20.1.

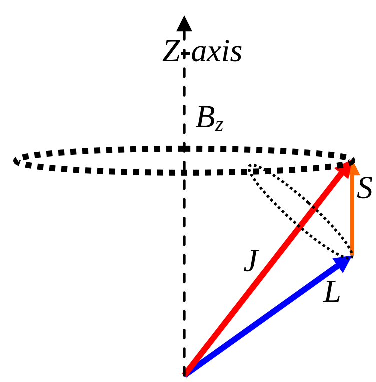


Figure-20.1

In LS-coupling, the spin-orbit interaction couples the spin and orbital angular momenta to give a total angular momentum J according to
$\vec{J} = \vec{L} + \vec{S}$

In an applied magnetic field, J precesses about B_z

L and S precess more rapidly about J due to spin-orbit interaction. Spin-orbit effect here is stronger than the magnetic field..

Now we will calculate the interaction energies due to the magnetic field perturbation. The interaction energy is

$$E_{mag} = -\vec{\mu}_{electron}.\vec{B}_z$$

So,

$$H_{mag} = \mu_B\left(\vec{L}+2\vec{S}\right)\cdot\vec{B}_z$$
$$= \mu_B\left(\vec{L}+2\vec{S}\right)\cdot\vec{B}_z$$
$$= \mu_B\left[\vec{L}+2\vec{S}\right]\cdot\vec{B}_z = \mu_B\left[L_z+2S_z\right]B_z$$

Since the good quantum number is J we have to calculate,

$$\left\langle J\ m'_J \mid H_{mag} \mid J\ m_J\right\rangle = \mu_B B_z\left\langle J\ m_J \mid \left(L_z+2S_z\right) \mid J\ m_J\right\rangle$$

Let us first calculate $\left\langle J\ m'_J \mid L_z+2S_z \mid J\ m_J\right\rangle$.

Using special case of Wigner-Eckart theorem, (Lande formula)

$$\left\langle J\,m' \mid \vec{A} \mid J\,m\right\rangle = \frac{\left\langle J\,m \mid \vec{A}\cdot\vec{J} \mid J\,m\right\rangle}{J\left(J+1\right)}\left\langle J\,m' \mid \vec{J} \mid J\,m\right\rangle$$

$$\left\langle J\ m'_J \mid L_z+2S_z \mid J\ m_J\right\rangle = \frac{\left\langle J\ m_J \mid \vec{J}\cdot\left(\vec{L}+2\vec{S}\right) \mid J\ m_J\right\rangle}{J\left(J+1\right)}\left\langle J\ m'_J \mid J_z \mid J\ m_J\right\rangle$$

$$\left\langle J\ m_J \mid \vec{J}\cdot\left(\vec{L}+2\vec{S}\right) \mid J\ m_J\right\rangle = \left\langle J\ m_J \mid J^2+\vec{J}\cdot\vec{S} \mid J\ m_J\right\rangle$$
$$= \left\langle J\ m_J \mid J^2+\frac{J^2+S^2-L^2}{2} \mid J\ m_J\right\rangle$$
$$= J\left(J+1\right)+\frac{J\left(J+1\right)+S\left(S+1\right)-L\left(L+1\right)}{2}$$
$$= \frac{3J\left(J+1\right)+S\left(S+1\right)-L\left(L+1\right)}{2}$$

$$\left\langle J\ m'_J \mid L_z + 2S_z \mid J\ m_J \right\rangle = \frac{3J(J+1)+S(S+1)-L(L+1)}{2J(J+1)} \left\langle J\ m'_J \mid J_z \mid J\ m_J \right\rangle$$

$$= \left[\frac{3}{2} + \frac{S(S+1)-L(L+1)}{2J(J+1)}\right] \left\langle J\ m'_J \mid J_z \mid J\ m_J \right\rangle$$

$$= g_J m_J$$

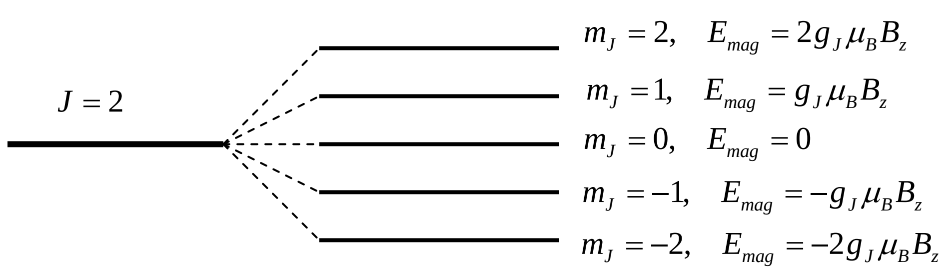
Where $g_J = \frac{3}{2} + \frac{S(S+1)-L(L+1)}{2J(J+1)}$ is known as Lande g-factor of electron

So,

$$\left\langle J\ m'_J \mid H_{mag} \mid J\ m_J \right\rangle = \mu_B B_z \left\langle J\ m_J \mid (L_z + 2S_z) \mid J\ m_J \right\rangle$$

$$E_{mag} = g_J\ \mu_B\ B_z\ m_J$$

So this energy correction due to the magnetic field tells us that for a particular J, the degeneracy for m_J will be removed by applying magnetic field.
The meaning is



The following block diagram (figure-20.2) represents the experimental arrangement for the Zeeman effect.

Sample is placed in the magnetic field.

Magnetic field axis is taken as Z-axis in the laboratory frame.

The light emitting from the sample is passed through the analyzer.

A high resolution monochromator with light detector is placed to record the spectrum.

The transitions are observed either perpendicular to the magnetic field direction (x-axis or Y axis) or the direction of the magnetic field (Z-axis) through the magnet by making a hole.

In the perpendicular direction, two observations are made (a) placing the analyzer parallel to the magnetic field, (b) perpendicular to the magnetic field.

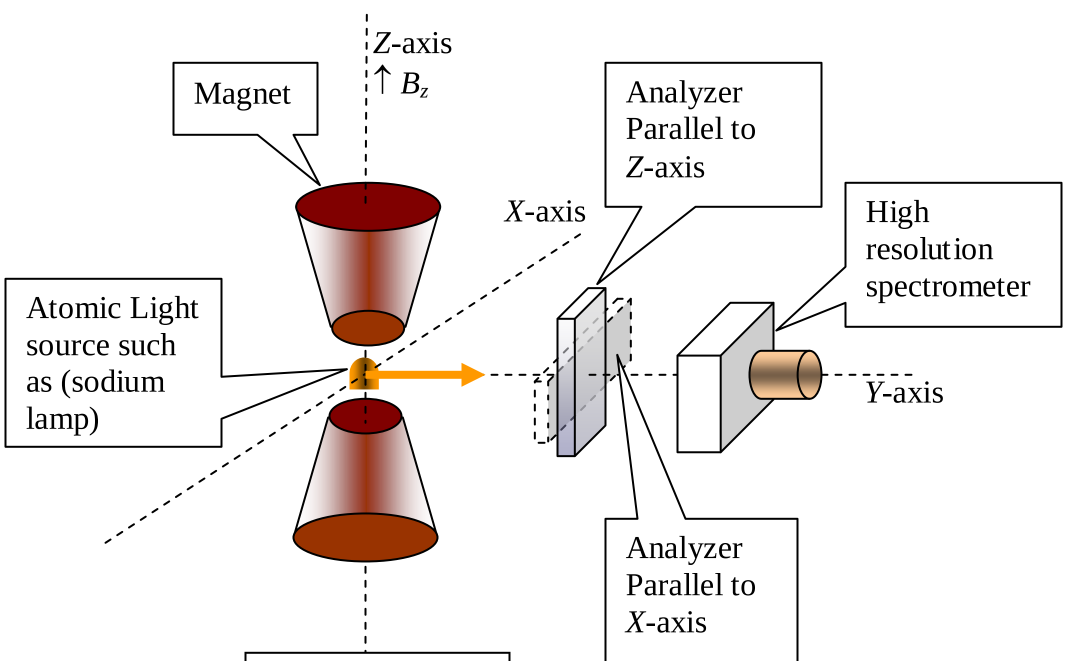


Figure-20.2

Let us take example of transition from a singlet (S = 0) state to a singlet (S = 0) state for this experiment.

For singlet states since S = 0 so J = L and thus $g_J = \frac{3}{2} + \frac{S(S+1) - L(L+1)}{2J(J+1)} = 1$

The following figure-20.3 illustrates the transition ${}^1D_2 \rightarrow {}^1P_1$

For ${}^1D_2$ we have $S = 0$, $L = 2$ and $J = 2$, $m_J = 2,1,0,-1,-2$.

So this level will split into 5 sublevels with energy separation $E_{mag} = g_J\, \mu_B\, B_z\, m_J$.

$m_J = 2, \quad E_{mag} = 2\mu_B B_z$

$m_J = 1, \quad E_{mag} = \mu_B B_z$

$m_J = 0, \quad E_{mag} = 0$

$m_J = -1, \quad E_{mag} = -\mu_B B_z$

$m_J = -2, \quad E_{mag} = -2\mu_B B_z$

Similarly, ${}^1P_1$ will split into 3 sublevels

$m_J = 1, \quad E_{mag} = \mu_B B_z$

$m_J = 0, \quad E_{mag} = 0$

$m_J = -1, \quad E_{mag} = -\mu_B B_z$

Note here that the separation between the sublevels is same $\mu_B B_z$ and depends on the magnitude of the magnetic field

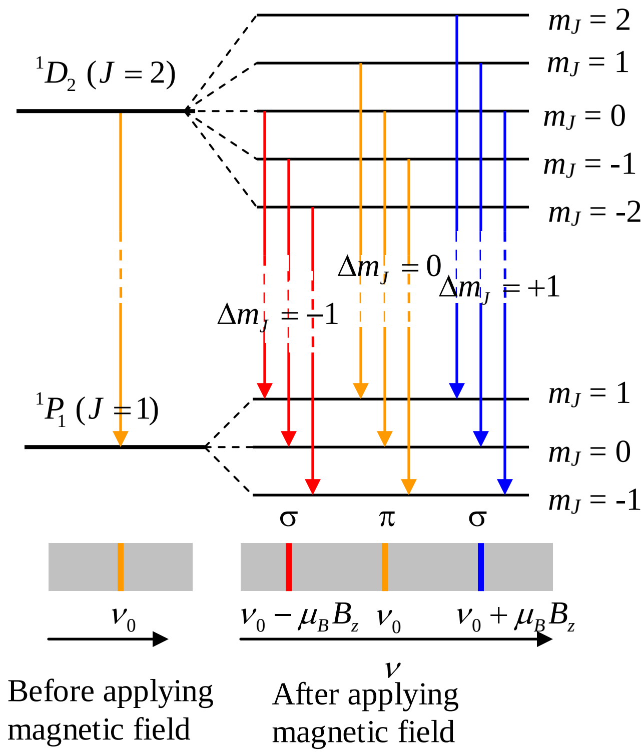


Figure-20.3

Now we will discuss the transition ν_0 after applying the magnetic field. As discussed in previous lectures that the rule for allowed electric dipole transition is to calculate the nonzero quantity of the dipole matrix element

i.e $\langle J'm'_J | e\vec{r} | Jm_J \rangle \neq 0$

Since the dipole is a vector quantity, we can use the rule obtained from Wigner-Eckart theorem.

For vector

$$\left\langle J'm' | T_q^1 | J\,m \right\rangle = 0 \quad unless \;\; \Delta J = 0, \pm 1$$

$$J' + J \geq 1$$

$$m' = m - q \quad (q = +1, 0, -1)$$

$$\Delta m = 0, \pm 1$$

Referring to the figure-20.2 and figure-20.3,

Using the relation $\Delta m_J = 0$, all the transitions have transitions energy = ν_0

Using the relation $\Delta m_J = -1$, all the transitions have transitions energy = $\nu_0 - \mu_B B_z$

Using the relation $\Delta m_J = +1$, all the transitions have transitions energy = $\nu_0 + \mu_B B_z$

So we will observe only three transitions with transition energies

$\nu_0 - \mu_B B_z$, ν_0 and $\nu_0 + \mu_B B_z$

This is known as NORMAL ZEEMAN EFFECT.

Now we will focus the observations in two directions.

(a) When these transitions are observed or the detector is placed perpendicular to the magnetic field (Y-direction in the figure-20.2 for experiment)

The theorem explains that the $\langle J'm'_J | e\vec{r} | Jm_J \rangle \neq 0$ when q = 0, or q = Z

This means that the transitions $\Delta m = 0$ will have the polarization in the Z-direction.

Again $\langle J'm'_J | e\vec{r} | Jm_J \rangle \neq 0$ when q = +1, or $X+iY$ that is circular polarization and

$\langle J'm'_J | e\vec{r} | Jm_J \rangle \neq 0$ when q = -1, or $X-iY$ that is also circular polarization.

So when the observation is made with analyzer parallel to the Z-axis, only the central component i.e for $\Delta m = 0$ only ν_0 is observed. This is termed as π component

When the observation is made with analyzer parallel to the X-axis, only the X component of the other two transitions i.e for $\Delta m = -1$, $\nu_0 - \mu_B B_z$ and $\Delta m = +1$ $\nu_0 + \mu_B B_z$ are observed. This is termed as σ component.

(b) When these transitions are observed or the detector is placed along the magnetic field (Z-direction in the figure-20.2) then since the light propagation direction is Z, $\Delta m = 0$ will not be observed. But the other two components $\nu_0 - \mu_B B_z$ and $\nu_0 + \mu_B B_z$ will be observed and the polarization will be left and right circular respectively.

Now let us consider the case of doublet to doublet transition

$$^2P_{\frac{1}{2}} \quad s=\frac{1}{2}, \quad L=1, \quad J=\frac{1}{2}$$

$$g_J=\frac{3}{2}+\frac{\frac{1}{2}.\frac{3}{2}-1.2}{2.\frac{1}{2}.\frac{3}{2}}=\frac{2}{3}$$

$$^2S_{\frac{1}{2}} \quad s=\frac{1}{2}, \quad L=0, \quad J=\frac{1}{2}$$

$$g_J=\frac{3}{2}+\frac{\frac{1}{2}.\frac{3}{2}}{2.\frac{1}{2}.\frac{3}{2}}=2$$

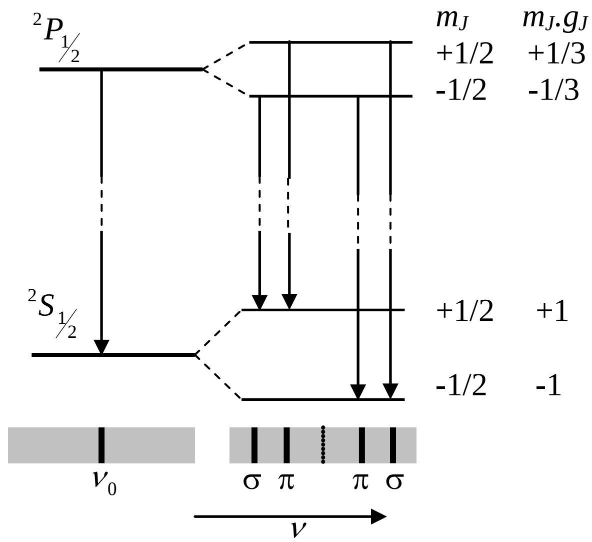


Figure-20.4

For

$$^2P_{\frac{1}{2}} \qquad m_J=\frac{1}{2} \qquad E_{mag}=\frac{1}{3}\mu_B B_Z$$

$$m_J=-\frac{1}{2} \qquad E_{mag}=-\frac{1}{3}\mu_B B_Z$$

And for

$$^2S_{\frac{1}{2}} \qquad m_J=\frac{1}{2} \qquad E_{mag}=\mu_B B_Z$$

$$m_J=-\frac{1}{2} \qquad E_{mag}=-\mu_B B_Z$$

Now the transitions are (using $^2P_{J,m_J}$ notation)

(1)

$$^2P_{\frac{1}{2},\frac{1}{2}} \rightarrow {}^2S_{\frac{1}{2},\frac{1}{2}} \quad \Delta m_J = 0, \quad \pi - polarisation$$

$$\nu_1 = \nu_0 + \frac{1}{3}\mu_B B_z - \mu_B B_z$$

$$= \nu_0 - \frac{2}{3}\mu_B B_z$$

(2)

$$^2P_{\frac{1}{2},-\frac{1}{2}} \rightarrow {}^2S_{\frac{1}{2},\frac{1}{2}} \quad \Delta m_J = -1, \quad \sigma - polarisation$$

$$\nu_2 = \nu_0 - \frac{1}{3}\mu_B B_z - \mu_B B_z$$

$$= \nu_0 - \frac{4}{3}\mu_B B_z$$

(3)

$$^2P_{\frac{1}{2},-\frac{1}{2}} \rightarrow {}^2S_{\frac{1}{2},-\frac{1}{2}} \quad \Delta m_J = 0, \quad \pi - polarisation$$

$$\nu_3 = \nu_0 - \frac{1}{3}\mu_B B_z + \mu_B B_z$$

$$= \nu_0 + \frac{2}{3}\mu_B B_z$$

(4)

$$^2P_{\frac{1}{2},\frac{1}{2}} \rightarrow {}^2S_{\frac{1}{2},-\frac{1}{2}} \quad \Delta m_J = +1, \quad \sigma - polarisation$$

$$\nu_3 = \nu_0 + \frac{1}{3}\mu_B B_z + \mu_B B_z$$

$$= \nu_0 + \frac{4}{3}\mu_B B_z$$

This example is the case of sodium D line. This $^2P_{1/2} \rightarrow {}^2S_{1/2}$ transition will split into four spectral lines as shown in the figure-20.4. The separation between them will depend on the magnetic field strength.

When the observation is made perpendicular to the magnetic field, ν_2 and ν_3 will be observed by placing the analyzer parallel to the Z-axis. These two lines will be missing if the observation is made along the direction of the magnetic field.

Similarly, ν_1 and ν_4 will be observed when the analyzer is placed parallel to the X-axis.
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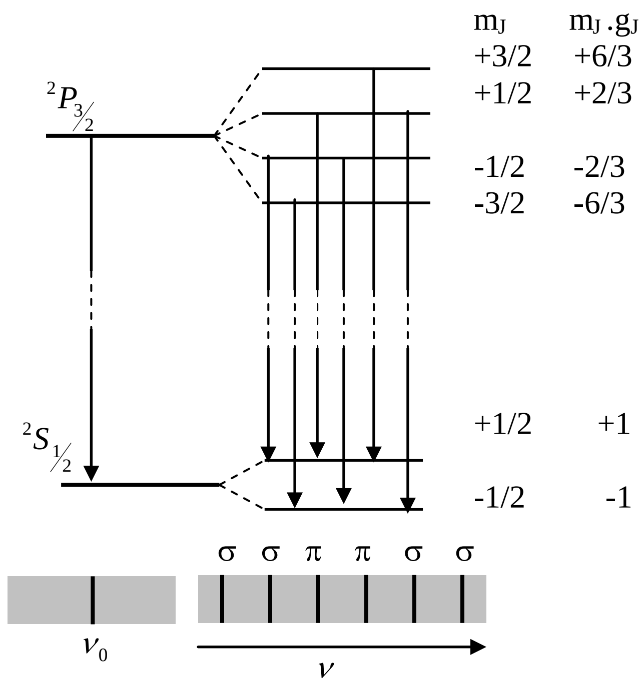
Let us take the case of the other D-line i.e. ${}^2P_{3/2} \rightarrow {}^2S_{1/2}$.

For

${}^2P_{\frac{3}{2}} \quad s = \frac{1}{2}, \quad L = 1, \quad J = \frac{3}{2}$

$$g_J = \frac{3}{2} + \frac{\frac{1}{2}.\frac{3}{2} - 1.2}{2.\frac{3}{2}.\frac{5}{2}} = \frac{4}{3}$$



For ${}^2P_{\frac{3}{2}} \quad m_J = \frac{3}{2} \quad E_{mag} = \frac{6}{3}\mu_B B_Z$

$m_J = \frac{1}{2} \quad E_{mag} = \frac{2}{3}\mu_B B_Z$

$m_J = -\frac{1}{2} \quad E_{mag} = -\frac{2}{3}\mu_B B_Z$

$m_J = -\frac{3}{2} \quad E_{mag} = -\frac{6}{3}\mu_B B_Z$

For ${}^2S_{\frac{1}{2}} \quad m_J = \frac{1}{2} \quad E_{mag} = \mu_B B_Z$

$m_J = -\frac{1}{2} \quad E_{mag} = -\mu_B B_Z$

Now the transitions are (using ${}^{2}P_{J,m_J}$ notation)

(1)

$${}^{2}P_{\frac{3}{2},-\frac{1}{2}} \rightarrow {}^{2}S_{\frac{1}{2},\frac{1}{2}} \quad \Delta m_J = -1, \quad \sigma - polarisation$$

$$\nu_1 = \nu_0 - \frac{2}{3}\mu_B B_z - \mu_B B_z = \nu_0 - \frac{5}{3}\mu_B B_z$$

(2)

$${}^{2}P_{\frac{3}{2},-\frac{3}{2}} \rightarrow {}^{2}S_{\frac{1}{2},-\frac{1}{2}} \quad \Delta m_J = -1, \quad \sigma - polarisation$$

$$\nu_2 = \nu_0 - 2\mu_B B_z + \mu_B B_z = \nu_0 - \mu_B B_z$$

(3)

$${}^{2}P_{\frac{3}{2},\frac{1}{2}} \rightarrow {}^{2}S_{\frac{1}{2},\frac{1}{2}} \quad \Delta m_J = 0, \quad \pi - polarisation$$

$$\nu_3 = \nu_0 + \frac{2}{3}\mu_B B_z - \mu_B B_z = \nu_0 - \frac{1}{3}\mu_B B_z$$

(4)

$${}^{2}P_{\frac{3}{2},-\frac{1}{2}} \rightarrow {}^{2}S_{\frac{1}{2},-\frac{1}{2}} \quad \Delta m_J = 0, \quad \pi - polarisation$$

$$\nu_4 = \nu_0 - \frac{2}{3}\mu_B B_z + \mu_B B_z = \nu_0 + \frac{1}{3}\mu_B B_z$$

(5)

$${}^{2}P_{\frac{3}{2},\frac{3}{2}} \rightarrow {}^{2}S_{\frac{1}{2},\frac{1}{2}} \quad \Delta m_J = 1, \quad \sigma - polarisation$$

$$\nu_5 = \nu_0 + 2\mu_B B_z - \mu_B B_z = \nu_0 + \mu_B B_z$$

(6)

$${}^{2}P_{\frac{3}{2},\frac{1}{2}} \rightarrow {}^{2}S_{\frac{1}{2},-\frac{1}{2}} \quad \Delta m_J = 1, \quad \sigma - polarisation$$

$$\nu_6 = \nu_0 + \frac{2}{3}\mu_B B_z + \mu_B B_z = \nu_0 + \frac{5}{3}\mu_B B_z$$

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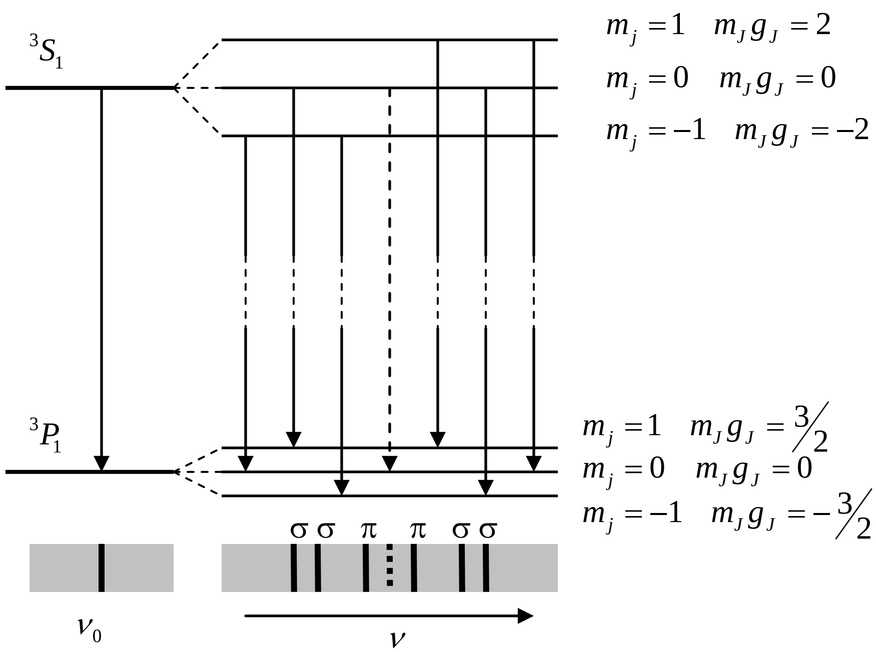
Triplet to triplet transition (${}^3S_1 \to {}^3P_1$

${}^3S_1$; $S=1,\quad L=0,\quad J=1$

$$g_J = \frac{3}{2} + \frac{1.2-0}{2.1.2}$$
$$=2$$

${}^3P_1$; $S=1,\quad L=1,\quad J=1$

$$g_J = \frac{3}{2} + 0$$
$$=\frac{3}{2}$$



Now the transitions are

(1)

$$^{3}S_{1,-1} \longrightarrow {}^{3}P_{1,0} \qquad \Delta m_J = -1; \quad \sigma - polarization$$

$$\nu_1 = \nu_0 - 2\mu_B B_z + 0$$
$$= \nu_0 - 2\mu_B B_z$$

(2)

$$^{3}S_{1,0} \longrightarrow {}^{3}P_{1,1} \qquad \Delta m_J = -1; \quad \sigma - polarization$$

$$\nu_2 = \nu_0 + 0 - \frac{3}{2}\mu_B B_z$$
$$= \nu_0 - \frac{3}{2}\mu_B B_z$$

(3)

$$^{3}S_{1,-1} \longrightarrow {}^{3}P_{1,-1} \qquad \Delta m_J = 0; \quad \pi - polarization$$

$$\nu_3 = \nu_0 - 2\mu_B B_z + \frac{3}{2}\mu_B B_z$$
$$= \nu_0 - \frac{1}{2}\mu_B B_z$$

(4)

$$^{3}S_{1,1} \longrightarrow {}^{3}P_{1,1} \qquad \Delta m_J = 0; \quad \pi - polarization$$

$$\nu_4 = \nu_0 + 2\mu_B B_z - \frac{3}{2}\mu_B B_z$$
$$= \nu_0 - \frac{1}{2}\mu_B B_z$$

(5)

$$^{3}S_{1,0} \longrightarrow {}^{3}P_{1,-1} \qquad \Delta m_J = 1; \quad \sigma - polarization$$

$$\nu_5 = \nu_0 + 0 + \frac{3}{2}\mu_B B_z$$
$$= \nu_0 + \frac{3}{2}\mu_B B_z$$

(6)

$$^3S_{1,1} \longrightarrow {}^3P_{1,0} \qquad \Delta m_J = 1; \quad \sigma - polarization$$

$$\nu_6 = \nu_0 + 2\mu_B B_z + 0$$
$$= \nu_0 + 2\mu_B B_z$$

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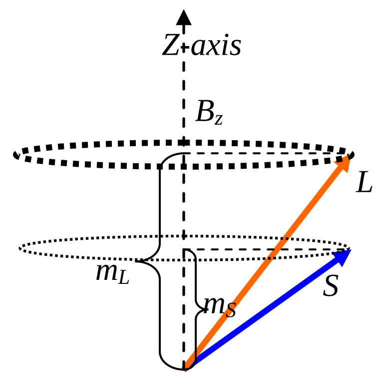
Strong field case: Paschen-Back effect

At this stage, we consider that the perturbation due to the magnetic field is stronger than the interaction due to spin orbit (strong field case). In this case, we can write the Hamiltonian as

$$H = \underbrace{H_{CF}}_{\substack{|l_1 m_{l_1}\rangle |s_1 m_{s_1}\rangle \\ |l_2 m_{l_2}\rangle |s_2 m_{s_2}\rangle}} + \underbrace{H_{ee}}_{|Lm_l\rangle |Sm_s\rangle} + H_{mag} + H_{so}$$

$$= H_{CF} + H_{ee} + \mu_B(\vec{L} + 2\vec{S}).\vec{B}_z + A_{SO}\vec{L}.\vec{S}$$



In *LS*-coupling, the spin-orbit interaction is weaker than the magnetic field interaction and can not couple the spin and orbital angular momenta.

If the magnetic field is applied in the *Z*-axis , *L* and *S* precess more rapidly about B_z .

$$E_{mag} = \langle Lm_l | \langle Sm_s | \mu_B(\vec{L} + 2\vec{S}).\vec{B}_z | Sm_s \rangle | Lm_l \rangle$$
$$= \mu_B B_z \langle Lm_l | \langle Sm_s | (L_z + 2S_z).| Sm_s \rangle | Lm_l \rangle$$
$$= \mu_B B_z (m_l + 2m_s)$$

And,

$$E_{SO} = \langle Lm_l | \langle Sm_s | A_{SO}(\vec{L}.\vec{S}) | Sm_s \rangle | Lm_l \rangle$$
$$= A_{SO} \langle Lm_l | \langle Sm_s | L_x S_x + L_y S_y + L_z S_z | Sm_s \rangle | Lm_l \rangle$$
$$= A_{SO} m_l m_s$$

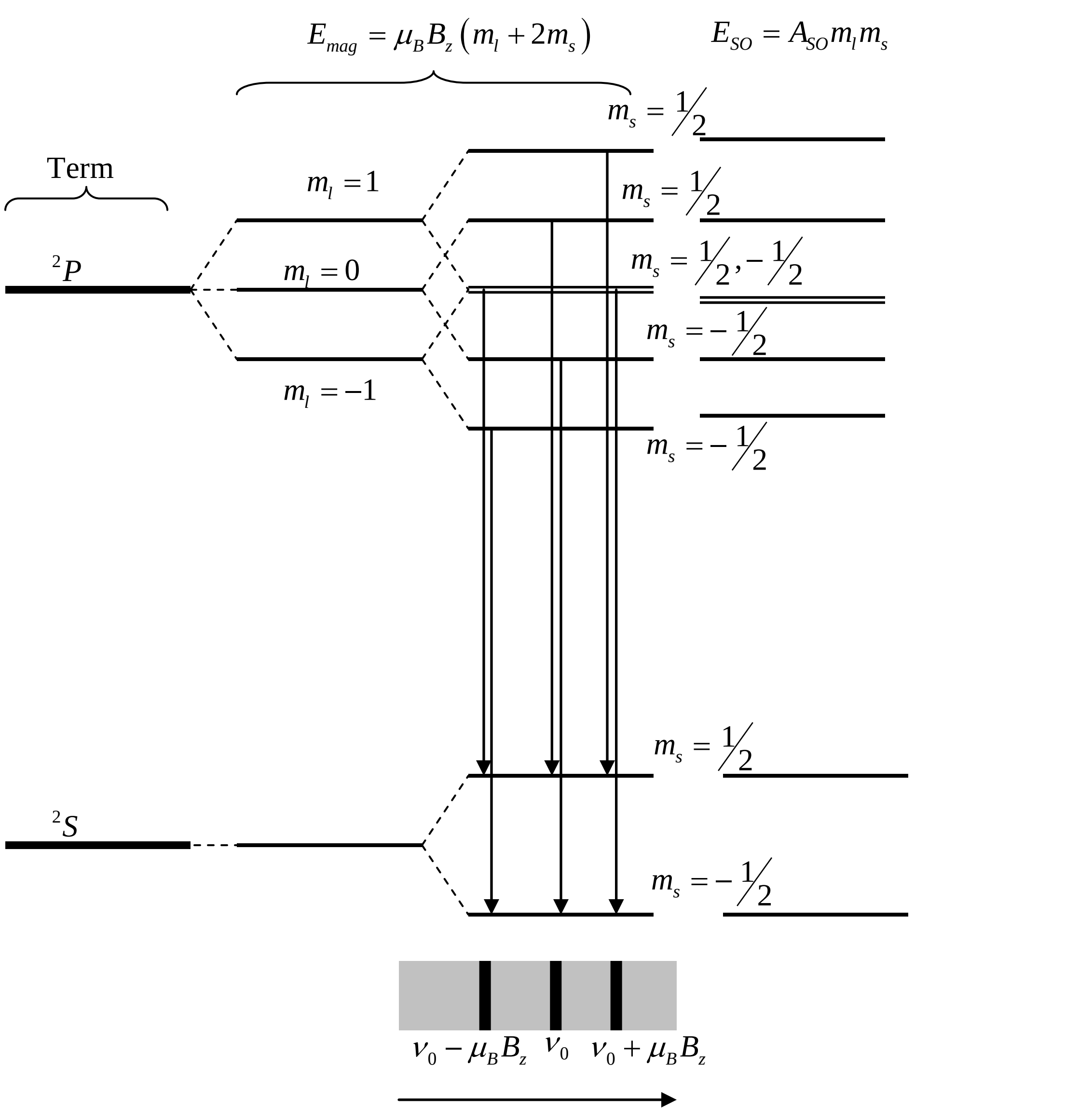
The components $L_x S_x$ and $L_y S_y$ are averaged out because these are precessing around the Z-axis and so only $L_z S_z$ will survive.

Now let us look at the transition of Sodium line under strong magnetic field. The transition selection rule used is $\Delta m_l = 0, \pm 1$, since the electric dipole operator can not change the spin of the electron $\Delta m_s = 0$.

The magnetic field splits the transition to three transitions, $\nu_0 - \mu_B B_z$, ν_0 and $\nu_0 + \mu_B B_z$.

The spin orbit interaction term only shifts the energy level a small amount.

In the weak magnetic field case, there was altogether 10 transitions (4 for ${}^2P_{1/2}$ and 6 for ${}^2P_{3/2}$). As the magnetic field increases these 10 lines merge into three lines. So the anomalous Zeeman pattern observed in weak field case slowly converted to normal Zeeman pattern in the strong field case.



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Recap

In this lecture we have discussed the magnetic field effect on the spectral lines.

We discussed that in the weak magnetic field the total angular momentum J precesses around the applied magnetic field direction.

In this condition, the singlet to singlet transitions show Normal Zeeman effect. Any other transitions show anomalous Zeeman effect.

Transitions corresponding to $\Delta m = 0$ will have the polarizations in the magnetic field direction.

Transitions corresponding to $\Delta m = \pm 1$ will have the circular polarizations.

In strong magnetic field, the coupling between spin and orbit breaks down and L and S precess around the magnetic field direction.