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Date: [illegible]
Time: 01 pm

MPHYCC10-17

Example of Anomalous Zeeman spliting:-

Zeeman spliting of the resonance lines D_1 & D_2 of Sodium.
D_1 & D_2 lines arises from the transition

$$^2P_{1/2} - {}^2S_{1/2} \quad \& \quad {}^2P_{3/2} \rightarrow {}^2S_{1/2}$$

The Zeeman levels, g-factors and the Zeeman shift for the various term involved in these transitions are as follows

$$g: \text{Lande 'g' factor}: 1 + \frac{J(J+1) + S(S+1) - L(L+1)}{2J(J+1}$$

Terms	No of Zeeman levels $2J+1$	Lande g factor	M_J $(+J \cdots -J)$	Shift in lorentz unit gM_J
$^2S_{1/2}$ $L=0, S=\frac{1}{2}, J=\frac{1}{2}$	2	2	$\pm\frac{1}{2}$	± 1
$^2P_{1/2}$ $L=1, S=1, J=\frac{1}{2}$	2	$\frac{2}{3}$	$\pm\frac{1}{2}$	$\pm\frac{1}{3}$
$^2P_{3/2}$	4	$\frac{4}{3}$	$\pm\frac{3}{2}, \pm\frac{1}{2}$	$\pm 2, \pm\frac{2}{3}$

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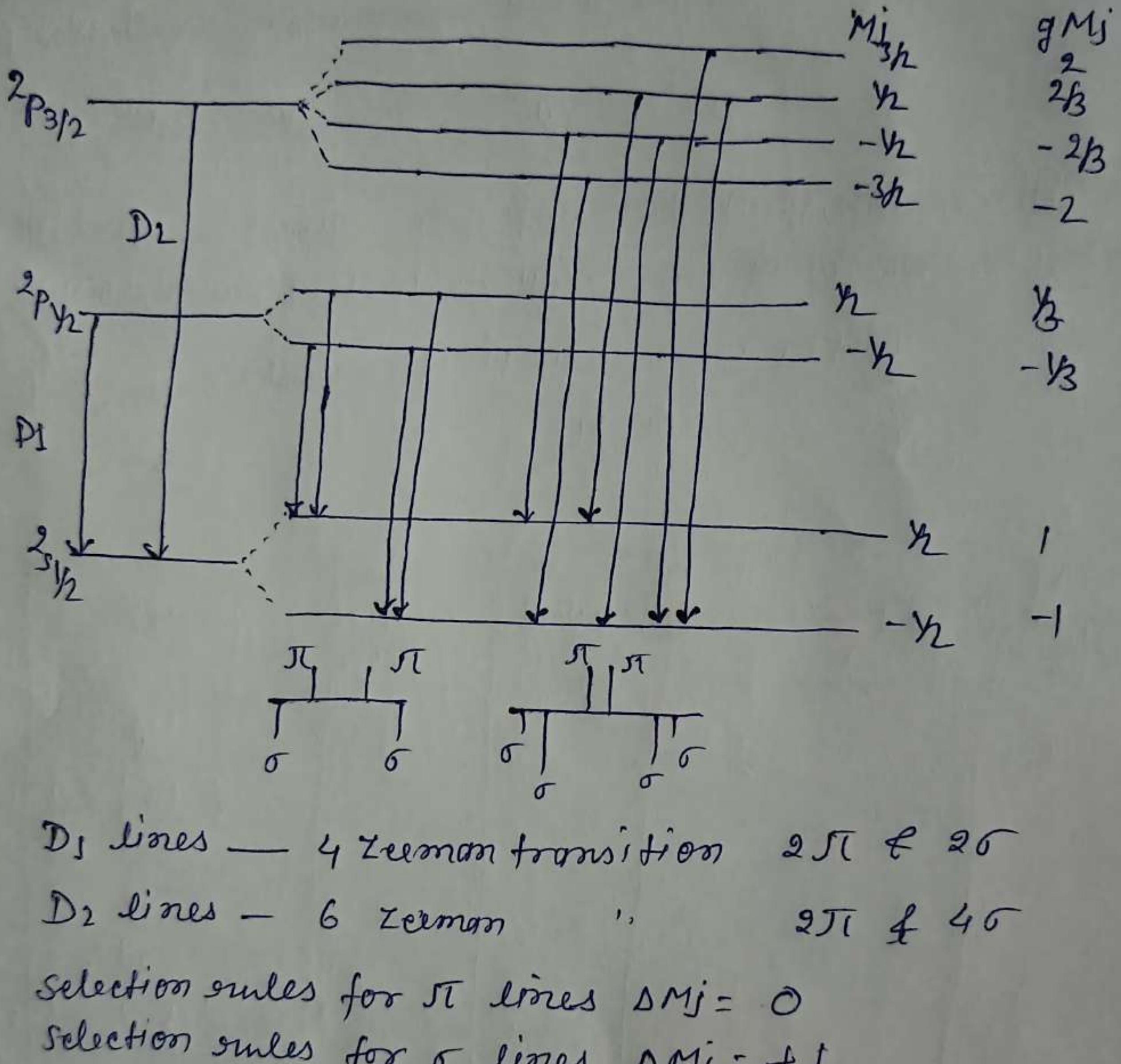
The splitting and different transitions have been shown in the following figure —



D_1 lines — 4 Zeeman transition 2π & 2σ

D_2 lines — 6 Zeeman " 2π & 4σ

Selection rules for π lines $\Delta M_j = 0$

Selection rules for σ lines $\Delta M_j = \pm 1$

Selection rules for Normal Zeeman splitting $\Delta M_L = 0, \pm 1$.

Selection rules for Anomalous Zeeman splitting $\Delta M_j = 0, \pm 1$

But $M_j = 0 \not\leftrightarrow M_j = 0$
if $\Delta J = 0$

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Paschen Back effect :-

To observe Zeeman effect (Both normal and anomalous) the external magnetic field is kept weak in comparision to the internal magnetic field created due to spin and orbital motion of valence electron.

On increasing strength of the external magnetic field sepration between Zeeman components increases until they become greater than the seprations between multiplet fine structure components. Then the Anomalous Zeeman pattern change like a Normal Zeeman pattern. This effect is called "Paschen-Back" effect

Explanation of "Paschen-Back effect"

In the presence of external magnetic field $\vec{B}$ stronger than the internal magnetic field created due to spin & orbital motion of the ~~elec~~ valence electron.

The magnetic coupling between $\vec{J}$ & $\vec{B}$ become greater than coupling between $\vec{L}$ & $\vec{S}$.

Then precession of $\vec{J}$ about $\vec{B}$ becomes faster than that of $\vec{L}$ & $\vec{S}$ about $\vec{J}$. i.e coupling between $\vec{L}$ & $\vec{S}$ is partially broken & magnitude of $\vec{J}$ is no longer fixed.

On increasing $\vec{B}$, $\vec{L}$ & $\vec{S}$ start precessing independently about $\vec{B}$ with quantized components L_z & S_z along the field direction (z axis).

$$L_z = M_L \frac{h}{2\pi} \quad ---(1) \qquad \& \qquad S_z = M_S \frac{h}{2\pi} \quad ---(2)$$

$$M_L = L, L-1, L-2 \; --- \; -L \; --(3) \qquad M_S = S, S-1, S-2, --- \; -S \; -(4)$$

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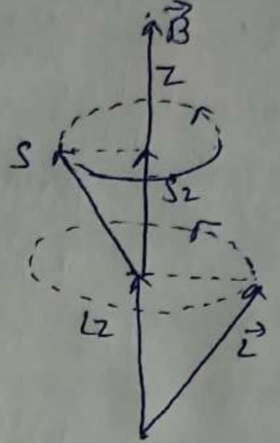

Using Larmor's theorem the angular velocity with which $\vec{L}$ precess around $\vec{B}$

$$\omega_L = \frac{e}{2m} \cdot B \quad \text{--- (5)}$$

Similarly

$$\omega_S = 2\frac{e}{2m} \cdot B \quad \text{--- (6)}$$

energy corresponding to precession of $\vec{L}$ along $\vec{B}$ direction can be written as

$$\Delta E_L = \omega_L \cdot L_Z = \frac{eB}{2m} M_L \frac{h}{2\pi} \quad \text{--- (7)}$$

similarly $$\Delta E_S = \omega_S \cdot L_S = 2\frac{e}{2m} B M_S \frac{h}{2\pi} \quad \text{--- (8)}$$

Sum of these two energy ΔE_L & ΔE_S is equal to the energy shift ΔE from the unperturbed energy level.

$$\Delta E = \Delta E_L + \Delta E_S$$

$$\Delta E = (M_L + 2M_S)\frac{eBh}{4\pi m} \quad \text{--- (9)}$$

$$\frac{eB}{4\pi mc} = L' = \text{Lorentz unit} \quad \text{--- (10)}$$

Energy shift in terms of wave number

$$-\Delta T = \frac{\Delta E}{hc} = (M_L + 2M_S)\frac{eB}{4\pi mc} = (M_L + 2M_S) L'$$

$$\boxed{-\Delta T = (M_L + 2M_S) L'}$$ = Expression for the strong-field magnetic interaction energy

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$-\Delta T = (M_L + 2M_S) L'$ ... (11) In this expression spin orbit interaction has been neglected.
i.e. each field free level split into $(2L+1)(2S+1)$ levels.

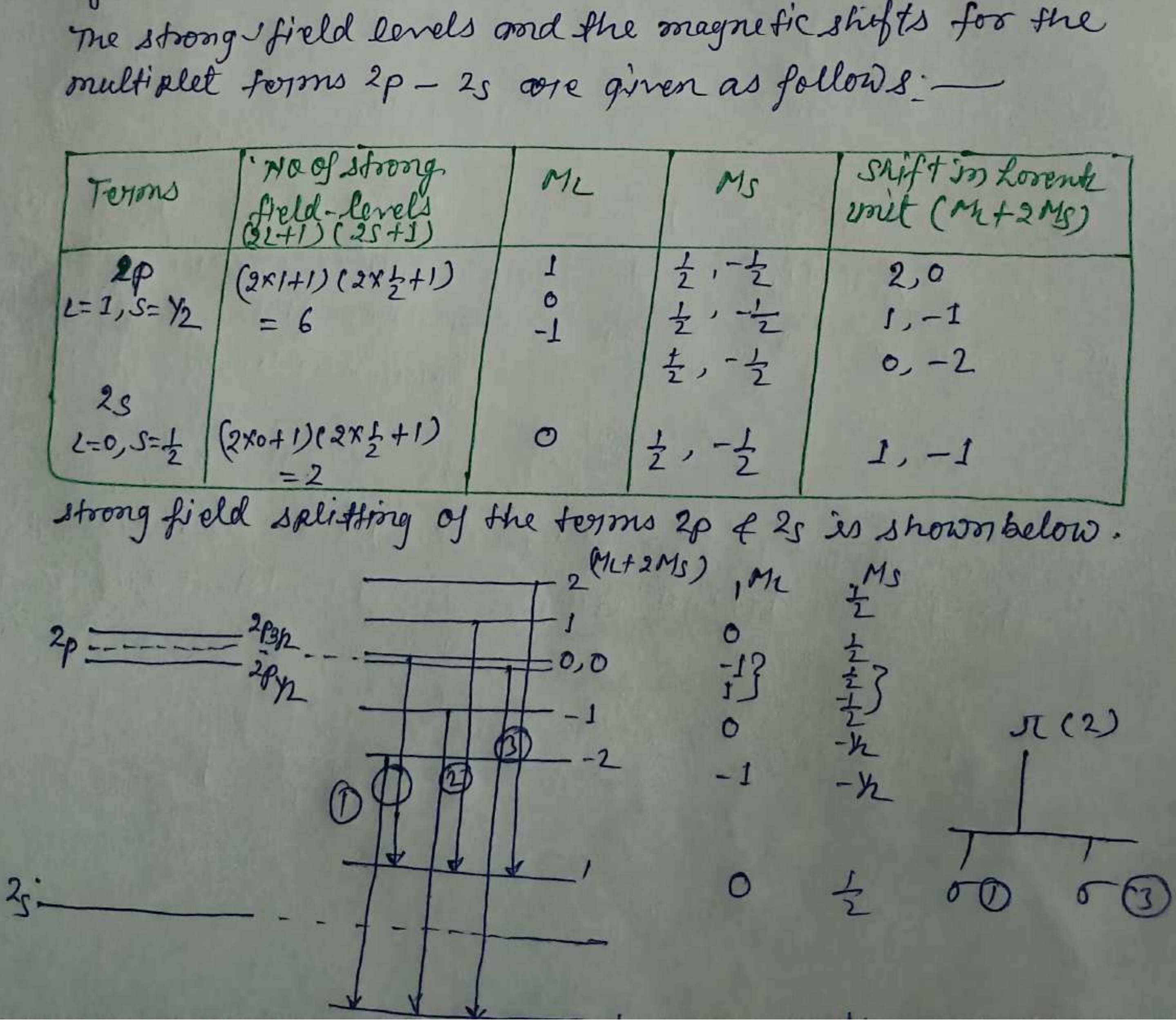
Example of "Paschen-Back effect"

2p — 2s — In presence of strong magnetic field.

2p — 2s — transitions gives rise to the D_1 & D_2 lines of sodium atom.
The strong field levels and the magnetic shifts for the multiplet terms 2p — 2s are given as follows:—

Terms	No of strong field-levels $(2L+1)(2S+1)$	M_L	M_S	Shift in Lorentz unit (M_L+2M_S)
2p $L=1, S=\frac{1}{2}$	$(2\times1+1)(2\times\frac{1}{2}+1)$ $= 6$	1 0 -1	$\frac{1}{2}, -\frac{1}{2}$ $\frac{1}{2}, -\frac{1}{2}$ $\frac{1}{2}, -\frac{1}{2}$	2, 0 1, -1 0, -2
2s $L=0, S=\frac{1}{2}$	$(2\times0+1)(2\times\frac{1}{2}+1)$ $=2$	0	$\frac{1}{2}, -\frac{1}{2}$	1, -1

strong field splitting of the terms 2p & 2s is shown below.



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$-\Delta T = (M_L + 2M_S)L'$ ... (11) In this expression spin orbit interaction has been neglected.
i.e. each field free level split into $(2L+1)(2S+1)$ levels.

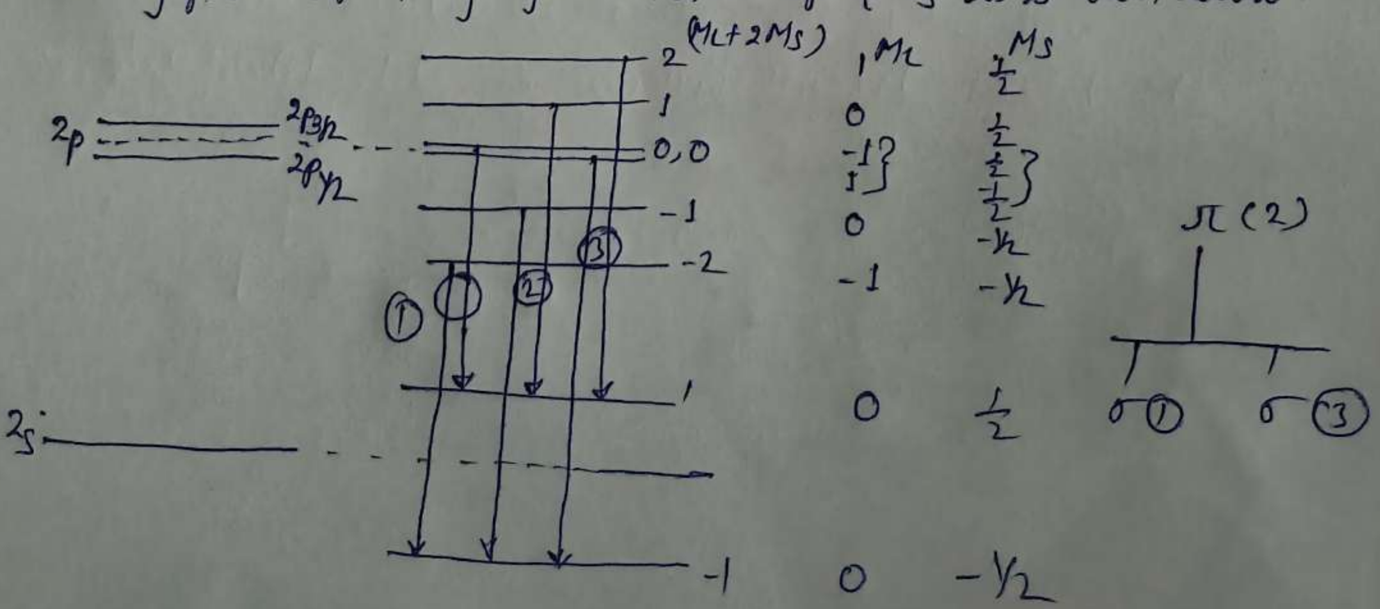
Example of "Paschen-Back effect"

$2p - 2s$ – In presence of strong magnetic field.

$2p - 2s$ – transitions gives rise to the D_1 & D_2 lines of sodium atom.
The strong field levels and the magnetic shifts for the multiplet terms $2p - 2s$ are given as follows:—

Terms	No of strong field-levels $(2L+1)(2S+1)$	M_L	M_S	Shift in Lorentz unit (M_L+2M_S)
2p $L=1, S=1/2$	$(2\times1+1)(2\times\frac{1}{2}+1)$ $=6$	1 0 -1	$\frac{1}{2}, -\frac{1}{2}$ $\frac{1}{2}, -\frac{1}{2}$ $\frac{1}{2}, -\frac{1}{2}$	2, 0 1, −1 0, −2
2s $L=0, S=\frac{1}{2}$	$(2\times0+1)(2\times\frac{1}{2}+1)$ $=2$	0	$\frac{1}{2}, -\frac{1}{2}$	1, −1

strong field splitting of the terms 2p & 2s is shown below.



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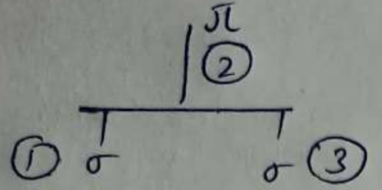


→ v. strong field pattern

Selection rules for transitions taking place in strong field

$\Delta M_L = 0$ for π component whose electric field vector polarized parallel to the applied magnetic field.

$\Delta M_L = \pm 1$ for σ components whose electric field vector polarized $\perp^r$ (Perpendicular) to applied magnetic field

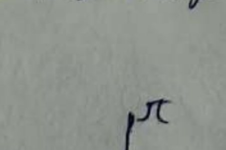
$\Delta M_S = 0$

Spin-orbit corrections :→

In practice, the residual spin-orbit coupling changes the relative energies of the components of different terms, Addition of small coupling term $aM_L M_S$ in the expression of the magnetic interaction energy

$$-\Delta T = (M_L + 2M_S)L' + aM_L M_S$$

Now due to spin-orbit interaction each of the two σ component of normal triplet splits into narrow doublet triplet etc.



→ Here we have 4 σ components.