Spectrum of the field free hydrogen atom is simple, in the sense that \( L_{\alpha} \) (first member of Lyman series) has doublet fine structure whereas \( H_{\alpha} \) (first member of the Balmer series) has very close lying seven components. Though the fine structure is very small (less than half a wave number), it could be experimentally observed. Zeeman spectrum of hydrogen is not that simple and can be understood by taking \( L_{\alpha} \) and as \( H_{\alpha} \) lines as the examples.

The doublet fine structure of hydrogen Lyman alpha line arises as a result of two transitions:

\[
2^2P_{1/2} \rightarrow 1^2S_{1/2}
\]

and

\[
2^2P_{3/2} \rightarrow 1^2S_{1/2}
\]

In the presence of an external weak magnetic field, the Zeeman effect splits the \( ^1S_{1/2} \) and \( ^1P_{1/2} \) states into 2 levels each with \( m_J = \pm 1/2 \) and the \( ^2P_{3/2} \) state into four Zeeman levels \( m_J = 3/2 \), \( m_J = 1/2 \), \( m_J = -1/2 \), \( m_J = -3/2 \). The corresponding Lande g-factors for these three levels are:

- \( g = 2 \) for \( ^2S_{1/2} \) state (i.e., \( J=1/2, l=0 \))
- \( g = 2/3 \) for \( ^2P_{1/2} \) state (i.e., \( J=1/2, l=1 \))
- \( g = 4/3 \) for \( ^2P_{3/2} \) state (i.e., \( J=3/2, l=1 \))

Note in particular that the size of the energy splitting \( m_J g \) is different for the different states, because the \( g \) values are different. On the left of the Figure \( \PageIndex{1} \), the fine structure splitting is because of the spin-orbit coupling that occurs even in the absence of a magnetic field. Zeeman levels that show up only in the presence of external magnetic field are shown on the right side of the figure.
Figure \(\PageIndex{1}\): Transitions

\[2\,^2P_{1/2} \rightarrow 1\,^2S_{1/2}\]
and

\[2\,^2P_{3/2} \rightarrow 1\,^2S_{1/2}\]

with and without external magnetic field

Under normal magnetic field, say 1 tesla, all the Zeeman components will be within less than half a wave number rendering the structures too close to observe all the components. Consequently, one may not confirm experimentally the value of

\[g\]

with Zeeman spectra in

\[H\]

. When the external magnetic field is stronger than the internal magnetic field, the orbital and spin magnetic moments become quantized independently in the direction of the magnetic field,
$H$, 

is then replaced by the quantum number

$m_l + 2m_s$, 

This reduces the anomalous Zeeman spectra to a normal Zeeman triplet. Therefore, Paschen-Back effect of the hydrogen atom is just a normal Zeeman effect.

$H_\alpha$, 

has fine structure comprising of the seven components arising from the transitions

$^2P \rightarrow ^2S$, $^2S \rightarrow ^2P$ 

and 

$^2D \rightarrow ^2P$ 

When subjected to weak magnetic field, each of the seven fine structure components will exhibit anomalous Zeeman components placed symmetrically around the fine component. Again all the seven anomalous Zeeman patterns will lie within half a wave number thereby making the observation of anomalous Zeeman effect of $H_\alpha$, line extremely difficult. With the increase of the field strength, Zeeman levels of all the fine components start overlapping until in a field strength of few tesla, the Paschen Back effect sets in. Under these conditions, the strong field Zeeman pattern turns, approximately out to a normal triplet. Paschen and Back observed such normal triplet when the atom was subjected to a field of greater than three teslas.

Quantum mechanical treatment also yields the same Zeeman splitting of the field free lines. The Hamiltonian in the presence of magnetic field is sum of the field free Hamiltonian $(H_o)$ 

\[
H = H_0 + \Delta E
\]

Average value of the

$\Delta E$, 

has been derived to be

$gH\mu_B m_j$, 

If this interaction energy is small compared to the internal spin-orbit interaction, which is usually the case with external magnetic field of 1 Tesla, it can be treated as perturbation. Application of first-order perturbation theory yields the shift equal to the magnitude of the perturbation, i.e.

$gH\mu_B m_j$, 

.