Singlet series (i.e. spin is zero) of atoms was observed to split into three components when viewed in transverse direction with respect to the direction of the magnetic field and to two components in the longitudinal direction. In transverse view, the outer two components are equally placed (on energy scale) around the central component that has the same energy as that of the original line. Electric vector (\boldsymbol{\varepsilon}) of the outer components, designated as \(\sigma\), (also known as \(S\), (senkrecht) components) is perpendicular to the magnetic field direction whereas electric field vector of the undisplaced central component, named as \(\pi\), (also known as \(P\), (parallel) component) is parallel to the field lines of force. In the longitudinal view, the outer \(\pi\)-components are circularly polarized in the opposite direction and the central undisplaced component is not observed because of the transverse nature of the electromagnetic radiation (Fig. 5).

Figure 5 Polarization of \(\pi\) and \(\sigma\) radiation for the Zeeman effect

Multiplet lines split into several components. We will see below that strength of the external magnetic field relative to the internal decides whether there are three components with equal spacing (Normal Zeeman Effect) or more than three
components with unequal spacing (Anomalous Zeeman Effect). H.A. Lorentz successfully interpreted the normal Zeeman Effect by using the laws of classical physics. He assumed that the motion of electron in atom is harmonic. Since the electron is revolving (say with angular velocity \( \omega \), around the nucleus in an orbit of radius \( r_0 \), the restoring force is centrifugal force. Therefore,

\[
 m_e \omega^2 r_0 = k r_0 \quad \text{(35)}
\]

Application of homogeneous magnetic field, \( H \) in a direction perpendicular to the plane of the orbit provides additional radial force, \( Hev \). The motion of a linearly oscillating electron may be divided into two components; first, a linear oscillation along the direction of the field and second, two rotary oscillations (with opposite directions of rotation) in a plane perpendicular to \( H \) (Fig. 6). In case of clockwise rotary motion, the additional force (\( Hev \)) is directed outward (away from the nucleus) and for the anticlockwise additional force is directed inward as shown in the fig. The magnetic field does not act on the component parallel to it and therefore the

![Fig. 6 Classical picture explaining Zeeman effect & the rotary oscillatory components in green colours, of linear oscillation.](image)

Frequency remains unchanged, undisplaced line (\( \pi \) component). That is, there is additional radial force, \( (Hev) \) on the rotary components that makes the motion complicated. The resulting motion turns out to be Larmor’s precession yielding different frequencies; the difference in frequencies same in magnitude but opposite in sign (\( \sigma \) component). According to Larmor’s theorem frequencies of the outer
\( \sigma \)-components are
\( \nu_0 \pm \nu_L; \nu_L = eH/4\pi m_e \)
(in mks system) is Larmor's frequency.

Alternatively, one can interpret the Normal Zeeman Effect as follows:

To compensate the additional radial force due to the external magnetic field, centrifugal force has to change keeping the orbit radius constant. Therefore, if new angular velocity is \( \omega' \)

\[
m_e \omega'^2 r_o - m_e \omega^2 r_o = He \omega' r_o \tag{36}
\]

or

\[
m_e ( \omega'^2 - \omega^2) = He \omega' \tag{37}
\]

If

\[
|\omega' - \omega| \ll \omega; \quad \omega \sim \omega'
\]

therefore, to first approximation

\[
\omega'^2 \approx \omega^2 + 2, \omega'
\]

equation \( \text{(37)} \) then reduces to

\[
\Delta \omega = eH/2m_e \tag{38}
\]

or

\[
\Delta \nu = eH/4 \pi m_e = \nu_L \tag{39}
\]

where \( \nu_L \) is the Larmor's frequency.

It may be mentioned that there had been numerous studies to arrive at some general interpretation that might explain normal as well as anomalous Zeeman Effect but all of them resulted in the explanation of normal Zeeman triplet. A survey of all the attempts is given in 'The historical development of quantum theory', Jagdish Mehra, Helmut Rechenberg (Springer, 2001). In most of the earlier interpretations, either spin was not introduced or if it was, its gyro magnetic ratio (ratio of its magnetic dipole moment to its angular momentum) was not correctly understood. To explain the anomalous Zeeman Effect, one not only needs to introduce the concept of the spin of the electron & magnetic moment associated with its mechanical motion, but also its (spin magnetic moment) differentiation from the orbital magnetic moment and
finally the interaction between the two in the presence of the external magnetic field.