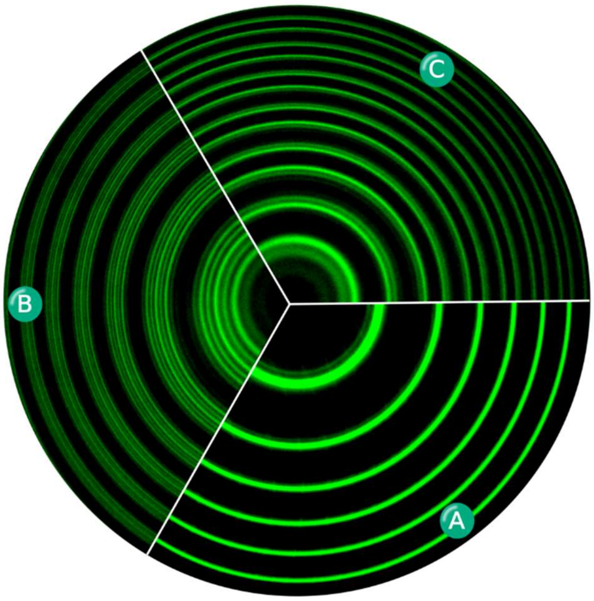
The Zeeman Effect

The Zeeman Effect is easily derived from the laws of optics we have described earlier.

We know that any change is momentum of an electron must obey the law $\Delta\vec{P}_{e^-} = m_{e^-}\vec{\rho}$. That tells us that, absent of any other effects acting on it, an electron it can absorb a photon γ if and only if $\vec{P}_{\gamma} = m_{e^-}\vec{\rho}$. This relation allows us to predict the different states of atomic electrons.

But when magnetic field $\Delta\vec{\Theta} > \vec{0}$ is applied to the electron, then the magnetic field and the photon will both act on the electron. A photon must still obey the law $\Delta\vec{P}_{e^-} = m_{e^-}\vec{\rho}$ but here we have $\vec{P}_{\gamma'} = m_{e^-}\vec{\rho} - \Delta\vec{\Theta}$ and $\vec{P}_{\gamma''} + \Delta\vec{\Theta} = m_{e^-}\vec{\rho}$ where $\vec{P}_{\gamma'}$ is in direction opposite to the imparted momentum of the magnetic field and $\vec{P}_{\gamma''}$ is in the same direction. Therefore, photons with lower and higher momentum will be absorbed, and photons that could be absorbed in the absence of a magnetic field can no longer be. This explains the longitudinal Zeeman effect (see section C in the image on the following page).



The spectral lines of mercury vapor lamp at wavelength 546.1nm, showing anomalous Zeeman effect. **A**. without magnetic field. **B**. With magnetic field, spectral lines split as transverse Zeeman effect. **C**. With magnetic field, split as longitudinal Zeeman effect.

Image Warren Leywon/Wikimedia Commons

From the above, we have $\vec{P}_{\gamma''} - \vec{P}_{\gamma'} = 2\Delta\vec{\Theta}$ so it follows that the gaps between absorption bands of the spectrum due to the Zeeman effect are proportional the momentum imparted by the magnetic field. That is: $\vec{P}_{\gamma''} - \vec{P}_{\gamma'} \propto \Delta\vec{\Theta}$.

When a transverse magnetic field is applied, its longitudinal momentum is $\Delta\vec{\Theta}_l = \vec{0}$ and $\vec{P}_{\gamma} + \pm\Delta\vec{\Theta}_l = m_{e^-}\vec{\rho}$. So, photons with longitudinal momentum $\vec{P}_{\gamma_l}$ with momentum $\vec{P}_{\gamma_l} = m_{e^-}\vec{\rho}$ will be absorbed. Additionally, the transverse magnetic field will induce a Zeeman effect with so that transverse photons with momentum $\vec{P}_{\gamma_t} + \Delta\vec{\Theta}_t = m_{e^-}\vec{\rho}$ will also be absorbed. Partition B of the image on the left shows the absorption of both longitudinal and transverse photons.