ZEEMAN EFFECT IN STARS

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Reference: Carroll, Bradley W. & Ostlie, Dale A. (2007), *An Introduction to Modern Astrophysics*, 2nd Edition; Pearson Education - Chapter 5, Problems 5.16 - 5.17.

Earlier, we had a look at the weak field Zeeman effect, which results in the splitting of atomic spectral lines due to an external magnetic field. In the earlier post, we looked at the complete theory of the Zeeman effect that includes the effect of the external field on both the orbital and spin angular momenta of the hydrogen atom.

The formula 5.22 in Carroll & Ostlie applies to the simpler case, called the *normal Zeeman effect*, where spin is ignored. In that case, the transition $2p \to 1s$ in hydrogen is split into 3 lines with frequencies of

$$\nu = \nu_0 \pm \frac{eB}{4\pi m_e} \tag{1}$$

where ν_0 is the frequency in the absence of the external field B.

In fact, the true number of split lines is a lot more complicated. In the hydrogen atom, for the principal quantum number n, we have n possible values of the angular momentum quantum number $\ell = 0, 1, 2, \ldots, n-1$, and for each ℓ, there are $2\ell+1$ values of the z component of angular momentum $m_\ell = -\ell, -\ell+1, \ldots, \ell-1, \ell$. The total number of states is therefore

$$\sum_{\ell=0}^{n-1} (2\ell+1) = 2\left(\frac{1}{2}n(n-1)\right) + n \tag{2}$$

$$= n^2 \tag{3}$$

For each of these states, the electron can be in one of two spin states, so the total number of states is $2n^2$. In the absence of an external field, all these states have the same energy E_n, but applying the field B splits all these states into separate energy levels. For $n = 2$, for example, we now have 8 separate energy levels.

As stars have magnetic fields, the Zeeman effect is visible in their spectra. A star with a strong magnetic field is Babcock's star (otherwise known as HD215441) which has a field of around 3.4 Tesla. [In 2009, a star HD75049 was found that has a similar magnetic field of around 3 Tesla.] The normal Zeeman effect in Babcock's star produces a splitting of the Hα line:

$$\begin{aligned}
\nu_0 &= \frac{c}{\lambda} = \frac{3\times10^8\text{ m s}^{-1}}{656.28\times10^{-9}\text{ m}} &(4)\\
&= 4.571\times10^{14}\text{ s}^{-1} &(5)\\
\Delta\nu = \frac{eB}{4\pi m_e} &= \frac{\left(1.60217657\times10^{-19}\right)(3.4)}{4\pi\left(9.10938291\times10^{-31}\right)} &(6)\\
&= 4.759\times10^{10}\text{ s}^{-1} &(7)
\end{aligned}$$

Thus the frequency shift is a small fraction of the normal frequency. The effect on the wavelength is

$$\begin{aligned}
\Delta\lambda &= \left|\Delta\left(\frac{c}{\nu}\right)\right| &(8)\\
&= \frac{c\Delta\nu}{\nu^2} &(9)\\
&= \frac{\left(3\times10^8\right)\left(4.759\times10^{10}\right)}{\left(4.571\times10^{14}\right)^2} &(10)\\
&= 6.83\times10^{-11}\text{ m} &(11)\\
&= 0.0683\text{ nm} &(12)
\end{aligned}$$

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