

ZEEMAN EFFECT FOR L=0

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References: Griffiths, David J. (2005), Introduction to Quantum Mechanics, 2nd Edition; Pearson Education - Problem 6.24.

In the strong field Zeeman effect, we used eigenstates of the Zeeman hamiltonian to calculate the perturbations. This gave rise to the fine-structure correction

$$(1) \quad E_{fs1,s} = \frac{13.6 \text{ eV}}{n^3} \alpha^2 \left[\frac{3}{4n} - \frac{\ell(\ell+1) - \ell_z s_z}{\ell(\ell + \frac{1}{2})(\ell+1)} \right]$$

We noted that the second term in parentheses is indeterminate if $\ell = 0$, so here we'll address this point.

If $\ell = 0$, then the total angular momentum quantum number j becomes equal to the spin $s = \frac{1}{2}$ and $j_z = s_z$. The energy correction for the strong field Zeeman effect is then

$$(2) \quad E_{Z1,s} = \mu_B (\ell_z + 2s_z) B_{ext} = 2\mu_B s_z B_{ext}$$

and for the weak field it is

$$(3) \quad E_{Z1,w} = \mu_B B_{ext} j_z \left(1 + \frac{j(j+1) + \frac{3}{4} - \ell(\ell+1)}{2j(j+1)} \right) = 2\mu_B s_z B_{ext}$$

Thus the Zeeman corrections are the same for both types of field strength when $\ell = 0$.

The fine structure correction we used in the weak field case is

$$(4) \quad E_{fs1,w} = \frac{13.6 \text{ eV}}{n^3} \alpha^2 \left(\frac{3}{4n} - \frac{1}{j + \frac{1}{2}} \right)$$

With $j = \frac{1}{2}$, this becomes

$$(5) \quad E_{fs1,w} = \frac{13.6 \text{ eV}}{n^3} \alpha^2 \left(\frac{3}{4n} - 1 \right)$$

This agrees with $E_{fs1,s}$ at $\ell = 0$ if we take

$$(6) \quad \left. \frac{\ell(\ell+1) - \ell_z s_z}{\ell(\ell + \frac{1}{2})(\ell+1)} \right|_{\ell=0} = 1$$

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