Chapter 8 Many electron atoms

The periodic table can be understood from the order of energies in hydrogen modified by other electrons and the Pauli exclusion principle.

Fermion: Object with total angular momentum (spin) $\frac{1}{2}, \frac{3}{2}, \frac{5}{2}, \ldots$ (electron, proton, neutron, quark, neutrino, ...)

Pauli Exclusion Principle: Two identical fermions can not be in the same quantum state (all quantum numbers can't be same). (Chap 8 slides 1, 2)

For hydrogen atom, the electron quantum numbers are n, l, m_l, m_s $\quad \underbrace{m_l = -l, -l+1, \ldots, l-1, l}_{2l+1 \text{ values}} \quad m_s = -\frac{1}{2}, \frac{1}{2}$

(n, l, m_l, m_s) Ground state combos

He $(1,0,0,\frac{1}{2}), (1,0,0,-\frac{1}{2})$

Li $(1,0,0,\frac{1}{2}), (1,0,0,-\frac{1}{2}), (2,0,0,\frac{1}{2})$ Why not $(2,1,-1,\frac{1}{2})$?

Be $(1,0,0,\frac{1}{2}), (1,0,0,-\frac{1}{2}), (2,0,0,\frac{1}{2}), (2,0,0,-\frac{1}{2})$

B $(1,0,0,\frac{1}{2}), (1,0,0,-\frac{1}{2}), (2,0,0,\frac{1}{2}), (2,0,0,-\frac{1}{2}), (2,1,1,\frac{1}{2})$

(Chap 8 slides 3, 4)

Gives an idea for why certain atoms bind to others

Methane CH_4, Ammonia NH_3, Water H_2O, Hydrogen Fluoride HF

Neon Ne (See Chap 9 for more about molecular structure)

The total orbital angular momentum, L, and total spin, S, angular momentum are approximately conserved for light atoms. Total electronic angular momentum, J, very well conserved for most atoms. Total angular momentum, F, of electrons plus spin of nucleus is conserved.

Angular momentum adds in a funny way in quantum mechanics

$\vec{L} = \vec{L}_1 + \vec{L}_2$ classical and quantum

Depending on orientation of $\vec{L}_1$, $\vec{L}_2$ can get different values for $|\vec{L}|$.

If $\vec{L}_1^{\,2} \chi_{l_1 m_1} = \hbar^2 l_1(l_1+1)\chi_{l_1 m_1}$ $\quad L_{1z}\chi_{l_1 m_1} = \hbar m_1 \chi_{l_1 m_1}$

$\vec{L}_2^{\,2} \chi_{l_2 m_2} = \hbar^2 l_2(l_2+1)\chi_{l_2 m_2}$ $\quad L_{2z}\chi_{l_2 m_2} = \hbar m_2 \chi_{l_2 m_2}$

$(\vec{L}_1+\vec{L}_2)^2 \chi_{LM} = \hbar^2 L(L+1)\chi_{LM}$ $\quad (L_{1z}+L_{2z})\chi_{LM} = \hbar M \chi_{L,M}$

$\max(L) = l_1 + l_2 = L_{max}$ $\quad \min(L) = |l_1 - l_2| = L_{min}$

$M = -L, -L+1, \ldots, L-1, L$

Suppose there are 2 elecrons $\overset{l=1}{2p}$, $\overset{l=2}{3d}$ What are the allowed L, S, J? $(3\times2=6 \quad 5\times2=10) \to 60$ states

$S_{max} = \frac{1}{2} + \frac{1}{2} = 1$ $\quad S_{min} = |\frac{1}{2} - \frac{1}{2}| = 0$

$L_{max} = 1+2 = 3$ $\quad L_{min} = |1-2| = 1$

$(L,S) = \underset{7\times3=21}{(3,1)}, \underset{7\times1=7}{(3,0)}, \underset{5\times3=15}{(2,1)}, \underset{5\times1=5}{(2,0)}, \underset{3\times3=9}{(1,1)}, \underset{3\times1=3}{(1,0)} \quad = 60$

$(3,1) \to J = 4, 3, 2$ $\quad (3,0) \to J = 3$ $\quad (2,1) \to J = 3, 2, 1$ etc

For excited atoms in free space, they lose energy by emitting photon. Fastest rates are for electric dipole allowed transition $\Delta l = \pm 1$, $\Delta L = 0, \pm 1$, $\Delta S = 0$

Electric quadrupole is slower $\Delta l = \pm 2$

Some transitions only by 2 photon emission.

(Chap 8 slides 5,6)

Spontaneous emission has characteristic features

excited "atom" $\rightarrow$ less excited + photon

Population excited $P_{exc}(t) = e^{-\Gamma t}$ $\qquad \Gamma = 1/\text{life time}$

Frequency distribution of photons $D(\omega) = \dfrac{C}{(\omega-\omega_0)^2 + (\Gamma/2)^2}$

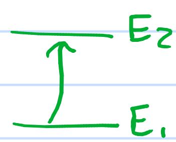
$\omega_0 = \dfrac{E_{init} - E_{fin}}{\hbar}$ $\qquad E_{init} - E_{fin} = -(\text{change of energy of atom})$

Why is there a spread of photon frequencies? Energy conservation?

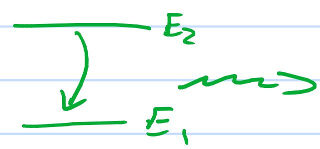
Long lifetime $\rightarrow$ good clock (Chap 8 slide 7)

Photon processes we know

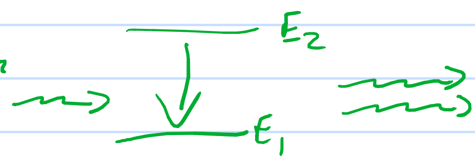
Photon absorb



Spontaneous emission



Also stimulated emission



Stimulated emission is roughly in same direction as incoming photon. More incoming photons $\rightarrow$ closer to same direction. Boost by putting in a "cavity".
(Chap 8 slides 8-10)