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Applications of Quantum Physics

1. Binding Energies

Consider a magnesium-like iron ion, i.e., an iron 14+ ion: $Fe^{14+}(1s^2 2s^2 2p^6 3s^2)$.

a) Calculate the ionization potential (in eV) of this ion. The quantum defect is δ=0.41.

b) Calculate the effective charge experienced by the least-bound electron.

c) The total binding energy of the two 3s electrons together is 947 eV. Calculate the quantum defect describing the binding energy of the 3s electron in $Fe^{15+}(1s^2 2s^2 2p^6 3s)$.

d) Discuss the origin of the quantum defects for ground state Fe^{14+} and Fe^{15+} ions and why the quantum defects have different values.

2. Configurations, Terms, and Levels

Periodic Table of the Elements

$1s$																	$1s^2$
$2s$	$2s^2$											$2p^1$					$2p^6$
$3s$	$3s^2$											$3p^1$					$3p^6$
$4s$	$4s^2$	$3d^1$									$3d^{10}$	$4p^1$	$4p^2$	$4p^3$	**Se**		

The figure represents the upper 4 rows of the periodic table of the elements. The position of **Se**lenium is indicated.

a) Determine the electronic configuration of Se in its ground state.

b) Use LS coupling to determine all possible terms and levels of the electronic ground state configuration.

c) Sketch the binding energy scheme of the terms and states. Assume that Hund's rules apply.

d) Discuss qualitatively what happens to the binding energy scheme if JJ coupling would apply and why.

3. Magnetic field effects

Consider the potassium isotope ^{42}K which has a nuclear spin of I = 2. The nuclear magnetic moment is negative and equal to $-1.14\mu_N$.

Sketch the binding energy of the states belonging to the ground state electronic configuration $1s^2 2s^2 2p^6 3s^2 3p^6 4s$ of K as a function of increasing magnetic field. Indicate the relevant quantum numbers for magnetic field regimes of B=0, B="weak" and B="strong".

4. Hyperfine splitting, Doppler-free saturation spectroscopy (DFSS) and Magneto-Optical Trapping

In this problem an atom is considered that in its ground state has an ....*ns*^{2} electronic configuration. Ultimately we want to cool and trap this atom in a Magneto-Optical Trap. For the cooling and trapping an optical allowed transition to one of the .....*nsnp* $^{2S+1}L_J$ levels is used.

a) Which *nsnp* $^{2S+1}L_J$ level is to be used and why?

In that specific term the atom exhibits hyperfine splittings of 120 and 90 MHz between subsequent hyperfine states when going from the strongest to the weakest bound states.

b) Determine the hyperfine constant [in MHz] and give the values of *F*.

c) What is the nuclear spin I of the atom?

To be able to manipulate these atoms with laser light, we need to stabilize the laser to the atomic transition between the ground state and the first excited state. To do so the method of Doppler-free saturation spectroscopy is used.

d) Determine the frequencies at which maxima and/or minima occur. Take the frequency of the $\Delta F=0$ transition (which is 2×10^8 MHz) as the zero point of the frequency scale.

e) Sketch the DFSS intensity as a function of frequency for a hot and a cold gas. The Full Width at Half Maximum of the velocity distributions of the hot and cold gas are 500 and 50 m/s, respectively.

Being able to stabilize and tune the laser, the atoms can be trapped in a Magneto-Optical trap.

f) Briefly describe the principle of Magneto-Optical trapping, especially address the roles and characteristics of the magnetic field and the laser beams.

Information:

Answers may be given in Dutch.

@ problem 3

$$g_F = \left\{1 + \frac{J(J+1) - L(L+1) + S(S+1)}{2J(J+1)}\right\}\left\{\frac{F(F+1) - I(I+1) + J(J+1)}{2F(F+1)}\right\}$$

@ problem 4c - In case you didn't figure out the value or values of J assume J = 10.
@ problem 4d – In case you didn't figure out the hyperfine structure of the upper and lower level, you may assume that the lower level is not hyperfine split and has F=10 and that the upper level is threefold split in F=9, 10 and 11, with splittings of 100 and 110 MHz between F=9 and 10, and F=10 and 11, respectively.