16-04-2010

Applications of Quantum Physics

1. Binding Energies

Consider an aluminium 2+ ion: $Al^{2+}(1s^2 2s^2 2p^6 3s)$.

For reference, the binding energy of H(*1s*) is 13.6 eV.

a) Calculate the ionization potential (in eV) of this ion. The quantum defect is δ=0.92.

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

c) To remove two electrons from the Al^{2+} ion one needs at least 148 eV. Calculate the quantum defect of the least bound electron in $Al^{3+}(1s^2 2s^2 2p^6)$.

d) Discuss the nature of the quantum defects for ground state Al^{2+} and Al^{3+} and their different values.

2. Configurations, Terms, and States

H	Periodic Table of the Elements																He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	**S**	Cl	
																Br	

The figure represents the upper 4 rows of the periodic table of the elements. The position of Sulphur is indicated.

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

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

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

3. Magnetic field effects

Consider the hydrogen isotope deuterium which has a nuclear spin of I = 1.

The hyperfine constant A is positive.

Sketch the binding energies of the states belonging to the ground state term of D 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. For optical pumping the transition to one of the .....*nsnp* terms is used. In that specific term the atom exhibits hyperfine splittings of 90 and 70 MHz between subsequent hyperfine states when going from the strongest to the weakest bound states.

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

b) In a Stern-Gerlach type of experiment a beam of atoms in this *nsnp* term would split into three peaks. What is the J value of this *nsnp* term and what is 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.

c) 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.

d) 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.

e) Briefly describe the principle of Magneto-Optical trapping, especially mention what the roles are of the magnetic field and the laser beams.

5. Non-destructive detection

Consider a three-level atom which passes through two pulsed oscillating fields (labeled R1 and R2) of which the frequency is resonant with the transition between state $|1\rangle$ and $|2\rangle$. Between R1 and R2 the atom passes through a cavity R?, which might or might not contain a photon of which the frequency is resonant with the transition between state $|2\rangle$ and $|3\rangle$. If there is a photon present the field corresponds to a 2π pulse. After R2 there is a detector which can measure whether the atom is in state $|1\rangle$ or $|2\rangle$. Show that the atoms are detected in either state $|1\rangle$ or $|2\rangle$ depending on the presence or absence of a photon in cavity R? when the pulses in R1 and R2 are $9/2\pi$ and $1/2\pi$, respectively. Initially the atom is in state $|1\rangle$ i.e., its atomic wavefunction is $\Psi = |1\rangle$.