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Toepassingen van de KwantumFysica

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1. Excited States and Auger Transitions

Consider a carbon atom C($1s^2 2s^2 2p^2$). (For reference, the binding energy of H($1s$) is 13.6 eV.)

a) Calculate the ionization potential (in eV) of this atom. The quantum defect is Δn=0.9.

b) The total binding energy of the two 2p electrons together is 35.6 eV. Calculate the quantum defect describing the binding energy of the 2p electron in C^{1+}($1s^2 2s^2 2p$).

c) Why is the quantum defect calculated under b) larger, equal or smaller than the one given at a).

One way or the other four inner shell electrons are removed from a carbon atom, creating a C^{4+}($2p^2$) ion.

d) This system is unstable and will decay via a Auger transition. What are Auger transitions?

e) Calculate the energy of the Auger electron, under the assumption that two there is a mutual screening of the two electrons of 0.3.

2. Hyperfine splitting, Doppler-free saturation spectroscopy and Magneto-Optical Trapping

Consider an atom which exhibits in its ground state a hyperfine splitting of 60 and 70 MHz between subsequent hyperfine states.

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

b) In a Stern-Gerlach type of experiment a beam of these atoms splits into three peaks. 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.

c) Briefly describe and/or sketch Doppler-free saturation spectroscopy.

d) Sketch the probe beam intensity and calculate the frequencies at which maxima and/or minima occur. The excited state is not hyperfine split. Take the frequency of the ΔF=0 transition as the zero point of the frequency scale.

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.

3. Configurations, Terms, States, and Hund's rules

Selenium has the following electronic ground state configuration: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^4$.

a) Which two-electron configuration can be used to describe the 34-electron ground state configuration of selenium? And why?
b) Use LS coupling to determine all possible terms of the electronic ground state configuration.
c) Determine all possible states associated with the terms found under b).
d) Which one of the states is the ground state.
e) Sketch the binding energy scheme of the terms and states.

Assume that two electrons are removed from Se, i.e., a two-fold charged Se ion is created.

f) Sketch the binding energy scheme of the terms and states of Se^{2+}.
g) Are all Se^{2+} terms found under f) possible if the Se atom was initially in its ground term and if the two removed electrons form a singlet state? And why?

4. Magnetic Resonance Imaging using ^{129}Xe

$\mu_B = 9.3 \times 10^{-24}$ [J/T], $k = 1.38 \times 10^{-23}$ [J/K], 1 [J] = 1.6×10^{-19} [eV]

For MRI diagnostics of interstitial cavities hyperpolarized atoms as ^{3}He and ^{129}Xe are used increasingly. Here ^{129}Xe will be considered. ^{129}Xe has a nuclear spin of $I = 1/2$ and a nuclear magnetic moment of $\mu = -0.78\ \mu_n$.

a) What is the value of g_I.
b) Sketch the behavior of the Xe(.....$5p^6$) ground state as a function of magnetic field and indicate the relevant quantum numbers.
c) For a magnetic field of $B = 0.5$ T, calculate the energy splitting between the states.
d) At this field of 0.5 T, calculate the difference in population (in %) between the relevant states at room temperature (T=300 K)
e) Why is it of importance for MRI diagnostics to increase this population difference.

To increase the population difference between nuclear spin states one lets the Xe atoms interact with spin-polarized Rb. In these interactions spin alignment is transferred from the Rb to the Xe. The following deals with the nuclear spin polarization of Rb by optical pumping between the Rb(5s $^2S_{1/2}$) groundstate and the excited Rb($5p$ $^2P_{3/2}$) state.

For Rb I=3/2 and g_I=1.8, g_J(5s $^2S_{1/2}$) = 2 and g_J($5p$ $^2P_{3/2}$) = 4/3.

f) Sketch the behaviour of the Rb(5s $^2S_{1/2}$) states as a function of magnetic field and indicate the relevant quantum numbers. Consider B = 0, B = "weak" and B = "strong". Recall that in the "strong"-field case the formula for the level shifts contains besides terms depending on the external field, a term which is external-field independent, namely $a m_J m_I$ (with a the hyperfine constant).
g) What is the origin of this term $a m_J m_I$.

Now, consider the laser pumping between Rb(5s $^2S_{1/2}$) and Rb($5p$ $^2P_{3/2}$) at B=0.

h) What is the most suitable hyperfine transition to be used to obtain nuclear spin orientation by laser light? Does the laser need to be polarized. Make a schematic drawing showing the magnetic substates and indicate the induced and/or spontaneous transitions.