EXAMINATION 03-02-2017

ATOMS AND MOLECULES. 14:00-17:00, 5419.0013, # QUESTIONS: 5

You can make use (if you think you have to) of the following formula's:

$$g_J = 1 + \frac{J(J+1) + S(S+1) - L(L+1)}{2J(J+1)}$$

$$g_F = \frac{F(F+1) - I(I+1) + J(J+1)}{2F(F+1)} g_J$$

1. Potassium electronic and fine structure - 10 points

A. Give the term for the ground state and the first excited state of the Potassium atom (ground-state electron configuration $1s^2 2s^2 2p^6 3s^2 3p^6 4s$). Briefly explain what spin-orbit coupling is and why the ground state is not split but the first excited state is. The light that is emitted as this split excited state decays to the ground state consist of two components with wavelengths of 764.49 and 769.90 nm. Calculate the size of the spin-orbit coupling constant β [in cm^{-1}].

B. Consider the light from a glowing Potassium gas. This light is observed by an old spectrometer (that can not resolve the small effects caused by the nuclear spin). In how many components does the line between the ground state and the first excited state split? Calculate the energy shift of each line, with respect to the zero-magnetic field case, expressed in units of $\Delta = \mu_B B$.

2. Atomic beam deflection of ^{87}Rb - 30 points

A. The ground state of ^{87}Rb is 5 $^2\mathrm{S}_{1/2}$, and it is split by the hyperfine structure into two components, $F = 1$ and $F = 2$. What is the nuclear spin of ^{87}Rb? 3/2

B. Make a plot of the Zeeman splitting of these two levels, showing both the low-field and the high-field regime. Indicate the m_F labels of each state. The hyperfine constant A is positive.

C. Consider an atomic beam of ^{87}Rb, with population in both hyperfine levels of the electronic ground state, which is sent on the y-axis through an interaction region. Our goal is to measure the energy separation between the F=1 and F=2 hyperfine level. To do this, we first need to separate the atoms in high-field seeking states from the atoms in low-field seeking states. Draw a magnet assembly (XZ plane cut-through) that will do this. Indicate the direction in which atoms in low-field seeking states will be deflected.

D. Continuing with the deflected beam of low-field seeking atoms, which steps, and in which sequence, are needed to measure the energy separation between the F=1 and F=2 level?

E. Let us assume that Rubidium atoms in an atomic beam, distributed over both hyperfine states, all move at the same speed initially. These atoms travel adiabatically from a field-free region into a very strong, homogenous magnetic field. Draw the new velocity distribution of the atoms a) inside the magnetic field and b) when the atoms have left the magnetic field.

F. Is there any qualitative difference if we repeat the experiment of question E, but now with a very weak homogenous magnetic field? If so, draw the velocity distribution, if not, argue why not.

3. SODIUM LINEWIDTH, SPECTROSCOPY AND COLD ATOMS (20 POINTS)

A. The 3s-3p transition in ^{23}Na atoms can be excited by light at a wavelength of 589 nm. The lifetime of the excited state is 16 ns. If we have to stabilise a laser to half the natural linewidth, what fractional stability is required?

B. The laser frequency can be locked to an atomic transition using Doppler-free spectroscopy. Sketch a typical setup, and explain the operating principle for a simple two-level system.

C. A student is performing Doppler free spectroscopy on a system with 2 ground state levels, that are separated by 200 MHz, and a single excited state. Draw the Doppler-free transmission spectrum of the probe beam that is obtained in this case, and explain all features.

D. Explain the techniques required to bring a hot gas of sodium atoms to quantum degeneracy (=Bose-Einstein Condensation). Indicate at each step either the typical velocity or the typical temperature that can be reached, and what the limiting mechanism of that technique is.

4. RAMSEY SPECTROSCOPY AND QUANTUM COMPUTATION (10 POINTS)

A hyperfine transition in the electronic ground state of Cesium is being used for the definition of the second. This is done using Ramsey spectroscopy on a beam of laser-cooled atoms.

A. Draw the typical spectrum that is obtained in Ramsey spectroscopy, and point out the feature that arises from the use of the separated oscillatory fields.

B. Explain how this experiment works using pictures of a Bloch sphere with the state vector that describes the state of the Cesium atom. Use these pictures to explain the minima and maxima in the spectrum that is obtained.

5. MOLECULAR STRUCTURE, COLD MOLECULES - 20 POINTS

A. Make a schematic drawing of the first four rotational levels of a diatomic molecule in a vibrational ground state $v'' = 0$ and an excited vibrational state $v' = 1$. Indicate the spacing between the rotational levels in terms of the rotational constant B.

B. Give the magnetic moment μ_Ω of these molecular states: a) $^1\Pi$ b) $^3\Sigma$ c) $^2\Pi_{3/2}$ d) $^2\Pi_{1/2}$

C. The price you pay for a closed rotational cycle in the laser cooling of the SrF molecule is that the total angular momentum in the ground state is higher than the total angular momentum in the excited state. Indicate which sublevels are dark states for excitation using right-handed circularly polarized light, inducing σ^+ transitions, from a pair of $J'' = 3/2$ and $J'' = 5/2$ levels to an excited state $J' = 3/2$ level.

D. Explain using a vector model for angular momentum coupling in a diatomic molecule why the effective magnetic moment, and therefore the Zeeman shift, is decreasing with increasing rotational excitation.