EXAMINATION 08-11-2012

ATOMS AND MOLECULES

YOU CAN MAKE USE 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 (35 POINTS)

A. Write down the electron configuration of K, which is first element in the fourth row of the periodic table of the elements.

B. The following quantum defect values are used to calculate the binding energy of the 3s, 3p and 3d states: $\delta_s = 2.21$, $\delta_p = 1.76$, $\delta_d = 0.2$. Briefly explain why this number is decreasing for increasing l, and calculate the binding energy of the three energy levels.

C. Give the term for the ground state and the first excited state of the Potassium atom. 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}].

D. Consider the light from a Potassium lamp, observed by an old spectrometer (that can not resolve the small effects caused by the nuclear spin). In how many components does the $^2S_{1/2} -^2 P_{1/2}$ line split if a weak magnetic field is applied? Calculate the energy shift of each line, with respect to the zero-magnetic field case, expressed in units of $\Delta = \mu_B B$. And in how many components does the $^2S_{1/2} -^2 P_{3/2}$ line split in a weak magnetic field?

E. Qualitatively, how does the splitting of the $^2S_{1/2} -^2 P_{1/2}$ line change in the limit of a very strong applied magnetic field? Explain the mechanism behind this change.

F. The most abundant isotope of Potassium, ^{39}K, has a nuclear spin $I = 3/2$. Because of this, the $^2P_{3/2}$ component has hyperfine splitting. Draw the splitting schematically, label the hyperfine states with their F quantum number and express the energy separation between these states in terms of the hyperfine constant A.

2. Maser, Atomic beam technique and Ramsey spectroscopy (20 points)

A. Draw a schematic diagram of a Hydrogen maser, and label the essential components. Also indicate the relevant quantum numbers of the hydrogen atoms in various parts of the setup.

B. Draw a schematic diagram of a standard Atomic beam setup for hydrogen with a single interaction zone, in the flop-in arrangement. Label the essential components, and indicate the relevant quantum numbers of hydrogen atoms in various parts of the setup. Also draw the typical spectrum that is obtained.

C. Draw a schematic diagram of a Ramsey setup making use of separated oscillatory fields. Label the essential components, and indicate the relevant quantum numbers for Cs atoms in various parts of the setup. Also draw the typical spectrum that is obtained.

D. Explain how the apparatus described in **C** benefits from the use of cold atoms, and give the reasons why such a machine is better suited as a frequency standard compared to the appatus described in **A**.

3. Non-destructive photon detection (20 points)

We start with an atom that has 3 states labelled $|i\rangle$, $|g\rangle$ and $|e\rangle$. There is a cavity, with or without a photon, that is tuned to resonance with the transition $|g\rangle \longleftrightarrow |e\rangle$. In this question we investigate how we can use the atoms to probe whether a photon is present in the cavity, without destroying the photon.

A. The atom has to be prepared in a superposition of states for this trick to work. Which states coupled, and how is this done? Give the initial atomic wave function and the wave function after preparation.

B. What kind of interaction of the atom and the photon can take place in the cavity that can be detected but does not lead to destruction of the photon? Give the wave function after passage through the cavity if the photon is present, and if it is not.

C. How does the final detection step work? Give the wave function following the detection step if the photon is present and if it is not.

4. Diatomic molecules in an external electric field (20 points)

A. Discuss (briefly) the essential difference in the interaction of atoms, homonuclear molecules and heteronuclear molecules with an external electric field.

B. Considering the above, explain the origin of the linear and quadratic term in the interaction energy of a particle in an external electric field.

C. What is the average permanent electric dipole moment of a diatomic molecule with angular momentum J?

D. What is the effective electric dipole moment of this molecule in an external electric field E?

E. In how many lines is a $J = 2$ rotational level of the above molecule split? Give the expression for the energy separation between these states.