Exam in atomic physics 3

Material: TeFyMa or a similar table, the formulae collection from the course and a calculator

Instructions: Each problem gives at most 4 points, after a holistic judgment, and you need a total of 12 and 19 points for a passing and an excellent degree, respectively. Your answers must be logical, well motivated and easy to read. Answers may be given in English or in Swedish.

You may NOT use the back sides of the papers

Solutions will be posted on the home page after the exam.

Preliminary results (anonymous) will also be posted continuously as I grade your work

Remember not to have your phone with you during the exam!

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1. Estimate as accurately as you can the wavelength of the infrared transition 4s - 4p in neutral sodium (Na) when we know that the 3s – 3p transition occur at 589,36 nm. Neglect all fine structure in this problem. Some data for Na is given below

   Atomic Number = 11, Atomic Weight = 22.989768, Nuclear spin 3/2, Magnetic moment 2,2175μ_N, Ground State $1s^2 2s^2 2p^6 3s\ ^2S_{1/2}$, Ionization energy 41449.451 cm^{-1} (5.139076 eV).

2. In neutral Ca (Ca I) there are, among many others, the configurations $4s^2$, 4s4p and $4p^2$. These configurations are well described by LS coupling.
   a) Write down all *LSJ* levels in these configurations.
   b) Write down all possible (E1 allowed) transitions between them.
   c) Absorption from atoms and ions in the interstellar medium can be observed in the direction towards a bright star. The absorption lines are very narrow due to the low Doppler broadening in the cold (3 K) interstellar medium. Which transitions would you expect to observe in Ca I? Motivate your answer.

3. The 3s3p ^1P - 3s5s ^1S transition in Mg occurs at 5711.09 Å.
   a) Draw a schematic diagram showing how this spectral line is split up if we measure it perpendicularly to a weak magnetic field with sufficient spectral resolution. Give the state of polarization of all the components.
   b) Calculate the magnetic field required to produce a wavelength splitting of 0,11 Å between adjacent components.

4. The transition 3p $^2P_{3/2}$ - 3d $^2D_{3/2}$ in aluminum (^{27}Al) is investigated using a Doppler free laser technique. The frequency difference between the 4 hyperfine states in $^2P_{3/2}$ is measured to be 188, 284 and 381 MHz from the lowest to the highest in energy.
   a) Determine the nuclear spin in ^{27}Al and derive the hyperfine structure constant for $^2P_{3/2}$
   b) Draw a schematic diagram of the hyperfine structure in the 2 fine structure levels and mark all allowed transitions between them

5. *Angular momentum.*

   a) What are the eigenvalues of L^2 and L_z for a 5d electron?

   b) Write the eigenfunction of L^2 and L_z for a 5s electron.

   c) What do you get if the operator $L_+ = L_x + iL_y$ is applied to the function $Y_{1,1}(\theta,\varphi)$?

   d) Why are angular momentum so important in atomic physics (indeed in all of physics)?

6. Discuss the energy structure and spectra in a diatomic molecule. Your answer should contain estimates of the order of magnitude of the different energy contributions as well as the typical wavelength regions where the different types of transitions occur.