Atoms and Molecules – Exam

October 27, 2025

Without explanation or calculation steps no points will be awarded to a sub-problem even if the answer is correct!

PROBLEM 1. Atomic Structure [11 points]

Based on its nuclear charge of 42, Molybdenum atoms are expected to have the following electronic configuration: $[Kr]5s^2 4d^4$

a) Following the Hund's rules (indicate clearly the rule you are using and in which sequence you are applying the rules) determine the ground level of Mo atoms. Explain your answer [5 pnts]

b) In reality the electronic configuration is $[Kr]4d^5 5s$, what is the real ground level of Mo? Explain your answer [3 pnts]

c) The nuclear spin of ^{87}Mo is 7/2. How many hyperfine structure states does ^{87}Mo have in its ground level? Explain your answer [3 pnts]

PROBLEM 2. Binding Energies and Decay channels [15 points]

Consider Ne particles with an innershell hole in the 1s subshell: $Ne^+(1s2s^2 2p^6)$.

a) Indicate the final electronic configuration of the Ne particles after radiative decay. Motivate your answer [2 pnts]

b) Indicate the final electronic configuration of the Ne particles after Auger decay. Motivate your answer [3 pnts]

c) Which of the decay channels is most likely? Motivate your answer [2 pnts]

Consider an $Ne^{3+}(1s^2 2s^2 4p^3)$ ion*. The* $4p^3$ *has a binding energy of 80 eV.*

d) Calculate the effective charge experienced by each of the *4p* electrons. Explain your calculation steps. [3 pnts]

e) For such a *4p* electron, how much of the nuclear charge is shielded by another *4p* electron. You may assume that the shielding by the 1*s and 2s* electrons is perfect. Motivate your answer. [2 pnts]

f) How much energy does it take to ionize a $Ne^{3+}(1s^2 1s^2 4p^3)$ ion. Explain your answer [3 pnts]

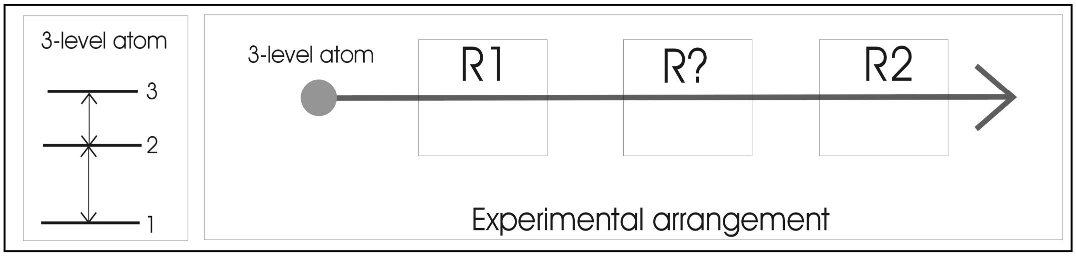
PROBLEM 3. Entangled States [4 points]

Verify whether the following wave functions of a system of two identical particles (each particle has as eigenstates $|0\rangle$ and $|1\rangle$) are entangled:

a) $|01\rangle + |10\rangle$. Explain your answer. [2 pnts]

b) $|00\rangle + |01\rangle + |10\rangle + |11\rangle$. Explain your answer. [2 pnts]

PROBLEM 4. Non-destructive detection [10 points]



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 an area R?, which might or might not contain an oscillating field of which the frequency is resonant with the transition between state $|2\rangle$ and $|3\rangle$. When the R? field is present its pulse length corresponds to a 2π pulse.

Initially the atom is in state $|2\rangle$ i.e., the atomic wavefunction is $\Psi = |2\rangle$.

a) The field in R1 corresponds to a $\frac{\pi}{2}$ pulse. Determine the wave function after passage through R1. [3 pnts]

b) What is the atomic wave function after passage through R? if the field is on. Motivate your answer. [3 pnts]

c) What should be the pulse length of field R2 to determine whether R? was switched on or off? NB. Behind R2 a detector is positioned that can measure the population of states $|1\rangle$ and $|2\rangle$. Explain your answer. [4 pnts]

PROBLEM 5. Zeeman slowing of H [15 points]

To decelerate a beam of hydrogen atoms a Zeeman slower is used.

a) Sketch the shape of the magnetic field of a Zeeman slower, indicate the directions of the H beam and the slowing-laser beam. Explain your answer. [3 pnts]

b) Make a sketch of the level structure of the 1s and 2p states of hydrogen, and argue which single optical transition should be driven to maximize the slowing down efficiency. You can neglect the nuclear spin coupling and treat H(1s) as having I=0. Explain your answer. [3 pnts]

c) How many photons of 121 nm need to be scattered (on average) to bring hydrogen atoms with v_0=2250 m/s to a stop? Recall that the recoil velocity $v_r = \frac{h}{\lambda m}$. [2 pnts]

d) Given that the lifetime of the excited state is 1.6 ns, what length must the Zeeman slower have in order to bring the atoms to a standstill? Explain your answer. [3 pnts]

e) Consider a 121-nm laser which has a pulse length of 10 ns and a repetition rate of 50 pulses per second. Comment on the suitability of this pulsed laser for use in the Zeeman slower. Motivate your answer. [4 pnts]

Constants in SI units: $m_H = 1.67 \times 10^{-27}$ kg and $h = 6.626 \times 10^{-34}$ Js·