04-02-2008

Applications of Quantum Physics

1. Binding Energies

Consider a magnesium-like iron ion, i.e., a iron 14+ ion: $Fe^{14+}(1s^2 2s^2 2p^6 3s^2)$.

For reference, the binding energy of H(*1s*) is 13.6 eV.

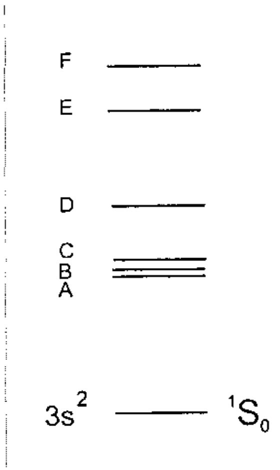
a) Calculate the ionization potential (in eV) of this ion. The quantum defect is δ=0.41.

b) Calculate the effective charge experienced by the least-bound electron.

c) The total binding energy of the two 3s electrons together is 947 eV. Calculate the quantum defect describing the binding energy of the 3s electron in $Fe^{15+}(1s^2 2s^2 2p^6 3s)$.

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

2. Configurations, Terms, and States

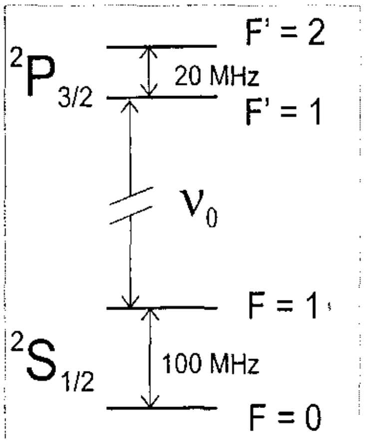


The figure on the right shows schematically the binding energies of the 7 lowest levels of magnesium. The ground level of Mg (.....$3s^2$) $^1S_0$ is indicated in the figure.

a) Assume LS coupling to determine the nomenclature of the 6 excited levels (A-F).

b) How would the figure change if JJ coupling would apply.

3. Doppler-free saturation spectroscopy



The figure on the right depicts the electronic structure of the atoms in the gas cell.

Sketch the Doppler-free saturation spectrum and indicate the frequencies of the individual features in the spectrum.

4. Magnetic field effects

Consider the Li isotope ^{6}Li which has a nuclear spin of $I = 1$.
The hyperfine constant A is positive.
Sketch the binding energies of the states belonging to the ground state ($1s^2 2s$) $^2S_{1/2}$ term of ^{6}Li as a function of increasing magnetic field. Indicate the relevant quantum numbers for magnetic field regimes of B=0, B="weak" and B="strong".

5. Quantum interrogation

Two weeks after this examination your grade isn't yet available in Progress. You're so curious about your grade that you sneak into KVI. But, oops, the drawer containing the results of the examination contains a lock which if activated will explode when the drawer is opened. You wonder: is it really activated? There are two keys. With one of the keys (K1) you can open the drawer when not activated. With the other key (K2) the lock can not be opened but it can always be safely inserted into the lock even when activated.
It seems you are stuck. If you use K2, you don't learn anything, because you can't tell the difference between activated or not activated. If you use K1, you may ignite the explosive.
Since you were well-prepared for the exam you realize that quantum physics has a solution to this problem, namely to create a *Key* wavefunction that is a superposition of K1 and K2

$|\mathrm{Key}\rangle = a|K1\rangle + b|K2\rangle$ and $|a|^2 + |b|^2 = 1$

You start out with $|\mathrm{Key}\rangle = |K2\rangle$ and using a Quantum Key Processor you apply a $\Pi/2$ pulse to the wavefunction.
Put the $|\mathrm{Key}\rangle$ into the lock. Nothing happens. Retract the $|\mathrm{Key}\rangle$ from the lock and put it into the quantum key processor and apply once again a $\Pi/2$ pulse.

a) After the second $\Pi/2$ pulse give the wavefunction $|\mathrm{Key}\rangle$ if the lock wasn't activated.
b) After the second $\Pi/2$ pulse give the wavefunction $|\mathrm{Key}\rangle$ if the lock was activated.
c) What is the probability for you to know whether the lock is activated
d) Do your changes of finding out whether the lock is activated improve if you use 3 pulses of length $\Pi/3$ ($\Pi/3$ – $|\mathrm{Key}\rangle$ into lock, $|\mathrm{Key}\rangle$ out of lock – $\Pi/3$ – $|\mathrm{Key}\rangle$ into lock, $|\mathrm{Key}\rangle$ out of lock – $\Pi/3$ – detection)?
e) Determine a pulse sequence to find out with a probability of more than 99% whether the lock is activated or not.