1.) In the following diagrams (a) and (b), the wavefunction for a particle with energy E is shown. Sketch in a potential energy $U(x)$ which should generate the wavefunction shown. Identify with Roman Numerals (I, II, III, etc.) each region with a particular $U(x)$ that requires a separate solution. (Essentially this problem is the reverse of those in the Sample Exams…). PLEASE NOTE: Windows Paintbrush draws lousy sine curves!

(a)

(b)

(c)

(d) For the problem in (c), write down the quantum number $n$ of the state shown for your choice of potential.

For both case, the wave shows a node in the middle, so this is the second state.

For the Finite Well on the LEFT For the Quantum Harmonic Oscillator on the RIGHT

\[ n = 2 \] \[ n = 1 \] (because we start with $n=0$)

(e) The following illustration was drawn to show allowed circular orbits in the Bohr hydrogen atom. What’s wrong with this picture? Short answer, please.

The allowed Bohr orbitals for the hydrogen atom (and the hydrogenic ions) have a radius given by:

\[ r_n = \frac{n^2}{Z} a_0 \]

So the distance between orbitals should be getting LARGER, not SMALLER.

(However, this ends up taking up a lot of space, which is why the illustrations have been kept.)

2.) (a) A Zinc atom, $Z = 30$, has 30 electrons. Write down the electronic configuration of the ground state.

(Starts with 1s²…)

30

Zn

Zinc

65.39

3s² 3p⁶ 3d¹⁰ 4s² 4p⁶ 5s² 5p⁶ 6s² 6p⁶

(b) The last electron to be added to the ground state closes the 3d sub-shell. Identify by letter and value the four quantum numbers of this last electron.

\[ n = 3 \quad l = 2 \quad m = -2 \quad m_s = -\frac{1}{2} \]

(c) For a hydrogenic zinc ion, $Zn^{29+}$, find the energy $E_3$ and radius $r_3$ of an $n = 3$ electron.

\[ r_n = \frac{n^2}{Z} a_0 \]

\[ E_n = -\frac{n^2}{3n} \left(13.6eV\right) = -\frac{30^2}{3}(13.6eV) = -1360eV \]
(d) For the QM hydrogen atom, there are no transitions between 4p and 4d under normal circumstances, because they are degenerate in energy. If we have Zeeman splitting due to an applied magnetic field $B$, identify which 4d states the 4p state $\psi_{411}$ can drop down to, emitting a photon:

There are three allowed transitions:

$\psi_{411} \rightarrow \psi_{420}$
$\psi_{411} \rightarrow \psi_{42-1}$
$\psi_{411} \rightarrow \psi_{42-2}$

Repeat this for the general QM atom with Zeeman splitting.

There are NO allowed transitions, because all of the 4d states are above the 4p states.

(e) Identify and count all the allowed 4s → 1s pathways for:

(1) Hydrogen – with the $\Delta l = \pm 1$ Selection Rule

With the Selection Rule, there are only two spin-up pathways:

$4s \rightarrow 3p \rightarrow 1s$ (degeneracy = $1 \times 3 \times 1 = 3$)
$4s \rightarrow 2p \rightarrow 1s$ (degeneracy = $1 \times 3 \times 1 = 3$)

(2) the Multielectron Atom – with the $\Delta l = \pm 1$ Selection Rule

With the Selection Rule, there are now three spin-up pathways:

$4s \rightarrow 3p \rightarrow 3s \rightarrow 2p \rightarrow 1s$ (degeneracy = $1 \times 3 \times 1 \times 3 \times 1 = 9$)
$4s \rightarrow 3p \rightarrow 1s$ (degeneracy = $1 \times 3 \times 1 = 3$)
$4s \rightarrow 2p \rightarrow 1s$ (degeneracy = $1 \times 3 \times 1 = 3$)