First Name (Print) ____________ Last or Family Name (Print) ____________

Student ID Number ____________ Signature ____________

Chemistry 101/103, Section H1/H01

Dr. W.Jaeger, CCIS 4-244

Mid-Term Examination

Thursday, 27 September 2012, 09:30 to 10:40 (you have 70 minutes to finish the exam).

This set includes: the cover page, 7 pages of questions, one page for rough work, the Chemistry Data Sheet

This exam counts 10.0 % / 12.5 % towards your total mark for CHEM 101 / 103. Answer all 7 questions on the space provided. If you need more space, please use the back of the preceding sheet, and indicate that you have done so.

SHOW YOUR WORK. Answers without supporting work will be assigned zero marks.

Your exam will not be eligible for re-marking if it is written in pencil.

This is a closed book exam.

Question #	Mark Possible	Mark Obtained
1	9	.
2	5	.
3	5	.
4	6	.
5	9	.
6	9	.
7	7	.
Total	50	.
		Percentage

1. (9 marks)

a) (1 mark) Determine the mass of one mole of apples in kg. Assume that each apple weighs on average 200 g. Do you think the mass of one mole of apples is more or less than the mass of the Moon?

$N_A \times 0.200$ kg = $6.022*10^{23} \times 0.200$ kg = $1.2044*10^{23}$ kg
Mass of Moon: $7.34767309 \times 10^{22}$ kg; 1 mol of apples are heavier than Moon

b) (2 marks) Complete the following table:

Symbol	Number of protons in nucleus	Number of neutrons in nucleus	Number of electrons	Net charge
$^{148}_{62}Sm$	**62**	**86**	**58**	4^+
$^{37}_{17}$**Cl**	17	20	18	**1^-**

c) (2 marks) Which of the following sets of quantum numbers are not allowed in a hydrogen atom? For the sets of quantum numbers that are incorrect, state what is wrong.

a) $n = 2, \ell = 1, m_\ell = -1$ **allowed**

b) $n = 1, \ell = 1, m_\ell = 0$ **not allowed; ℓ can take the following values: 0 … (n-1)**

c) $n = 8, \ell = 7, m_\ell = 6$ **allowed**

d) $n = 1, \ell = 0, m_\ell = 2$ **not allowed; m_ℓ can take the following values: - ℓ ... 0 … +ℓ**

d) (2 marks) List the values of the four quantum numbers for a 5d electron. Where more than one value is allowed, list all possible allowed values.

$n = 5, l = 2, m_l = -2, -1, 0, 1, 2; m_s = +1/2, -1/2$

e) (2 marks) Classify each of the following atomic electron configurations as (i) ground state, (ii) an excited state, or (iii) a forbidden state. Write the ground state and/or allowed configuration if applicable. Write the element name.

i) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^8$ **excited state; $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^6\ 4s^2$; Fe**

ii) [Kr] $4d^{10}\ 5s^3$ **forbidden state; [Kr] $4d^{10}\ 5s^2\ 5p^1$; In**

2. (5 marks)
Assume that chalkboard chalk is a solid mixture of $CaCO_3$ and $CaSO_4$. A piece of chalk with mass 3.586 g is ground in a mortar and mixed with water (assume that $CaSO_4$ is not soluble in water). Excess sodium sulfate is added to precipitate all the calcium in solution as $CaSO_4$(s). The combined amount of $CaSO_4$ is dried and found to have a mass of 4.516 g.

a) Determine the number of moles of $CaCO_3$ and $CaSO_4$ in the original piece of chalk.

b) Calculate the mass percentages of $CaCO_3$ and $CaSO_4$ in the piece of chalk.

$CaCO_3$ (aq) + Na_2SO_4 (aq) → $CaSO_4$ (s) + Na_2CO_3 (aq)

Let x be the number of moles of $CaCO_3$ in the original piece of chalk.
Let y be the number of moles of $CaSO_4$ in the original piece of chalk.

The total mass of the original piece of chalk can be calculated from the molar masses of $CaCO_3$ (M_{CaCO3} = 100.0872 g mol^{-1}) and $CaSO_4$ (M_{CaSO4} = 136.1416 g mol^{-1}):

$x * 100.0872 \text{ g mol}^{-1} + y * 136.1416 \text{ g mol}^{-1} = 3.586 \text{ g}$ Eq.(I)

From the y mol $CaCO_3$ in the original piece of chalk one will obtain y mol $CaSO_4$ in the precipitate.

The x mol $CaSO_4$ in the original piece of chalk do not dissolve in the water and will also appear in the precipitate. The total mass of the precipitate can be calculated by adding these two contributions:

$(x + y) * M_{CaSO4} = x * 136.1416 \text{ g mol}^{-1} + y * 136.1416 \text{ g mol}^{-1} = 4.516 \text{ g}$ Eq.(II)

subtract Eq.(I) from Eq.(II):

$x * (136.1416 \text{ g mol}^{-1} - 100.0827 \text{ g mol}^{-1}) = 4.516 \text{ g} - 3.586 \text{ g}$

Solve for x: x = 0.02579 mol $CaCO_3$, insert into Eq.(I) or Eq.(II): y = 0.007381 mol $CaSO_4$

Total mass of $CaCO_3$ in the original piece of chalk = 0.02579 mol * M_{CaCO3} = 2.5811 g

Percentage of $CaCO_3$ in the original piece of chalk: 100% * 2.5811 g / 3.586 g = 71.98 %

Percentage of $CaSO_4$ in the original piece of chalk: 100% - 71.98 % = 28.12%

3. (5 marks) An important photochemical reaction in the upper atmosphere is the decomposition of ozone (O_3). The energy needed to break the O–O bond in O_3 is 373.8 kJ/mol.

a) (2 marks) Which wavelength of light is needed to break the O–O bond?

Energy needed per O_3 molecule: $E = 373.8\ kJ\ mol^{-1}\ /\ N_A = 6.207*10^{-19}\ J$

Energy of photon: $E = h*\nu = h*c / \lambda$

→ $\lambda = h*c / E = 6.626*10^{-34}\ J\ s * 2.998*10^{8}\ m\ s^{-1} / 6.207*10^{-19}\ J = 3.200*10^{-7}\ m = 320.0\ nm$.

b) (2 marks) How many photons are needed to decompose 0.320 mg of O_3?

Molar mass of O_3: 3 * 15.999 g/mol = 47.997 g/mol

1 mol / 47.997 g = x mol / 0.000320 g

→ x = 1 mol * 0.000320 g / 47.997 g = $6.667*10^{-6}$ mol

$6.667*10^{-6}$ mol photons are needed to decompose $6.667*10^{-6}$ mol O_3

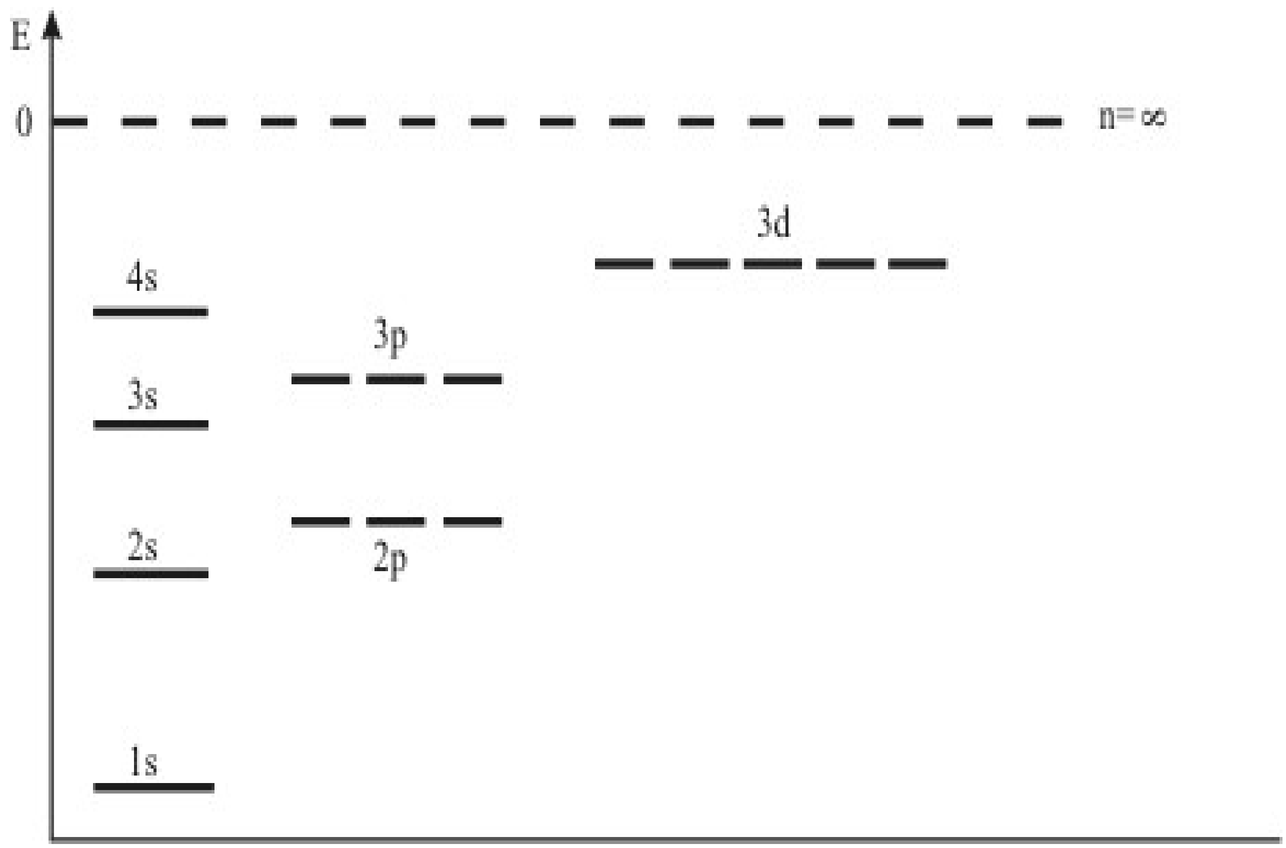
$6.667*10^{-6}\ mol * N_A = 6.667*10^{-6}\ mol * 6.022*10^{23} = 4.015*10^{18}$ photons are needed to decompose 0.320 mg of O_3.

c) (1 mark) Which region of the electromagnetic spectrum does this wavelength correspond to?

Ultraviolet

4. (6 marks)

Draw a qualitative energy level diagram of the electron in a multi-electron atom according to the quantum wave mechanical (Schrödinger) model. Include the seven lowest energy levels with distinct energies and indicate also the dissociation level. If several orbitals have equal energy, i.e. are degenerate, indicate the number of degenerate orbitals. Label all seven energy levels and the dissociation level with the appropriate quantum numbers. Label also the vertical axis appropriately and indicate the zero point of the energy.



5. (9 marks)

The emission spectrum below for a one-electron (hydrogen-like) species in the gas phase shows all the lines, before they merge together, resulting from transitions to the state with n=2 from higher energy states. Line A has a wavelength of 27.13 nm. The Rydberg constant R_H=2.179*10^{-18} J.

a) (2 marks) What are the upper and lower principal quantum numbers corresponding to the lines labelled A and B?

All transitions end on the first excited state with n=2.

The transition with the longest wavelength must be n=3 → n=2
The next transition is: n=4 → n=2
Transition A is: n=5 → n=2
Transition B is: n=6 → n=2

b) (5 marks) Identify the one-electron species that exhibits the spectrum.

Energy of photon with λ = 27.13 nm: E = h*c / λ = 7.322*10^{-18} J

Energy of orbital with n=2: $E_{n=1} = -R_H * Z^2 / n^2 = -R_H * Z^2 / 4$

Energy of orbital with n=5: $E_{n=4} = -R_H * Z^2 / n^2 = -R_H * Z^2 / 25$

Energy difference $E_{n=4} - E_{n=1} = \Delta E = R_H * Z^2 * (1/4 - 1/25) = 7.322*10^{-18}$ J

→ $Z^2 = 7.322*10^{-18}$ J / [R_H * (1/4 - 1/25)] = 16.00 → Z = 4

The one-electron species is Be^{3+}

c) (2 marks) Calculate the energy that is needed to ionize this one-electron species if it is in the upper state of the transition that leads to line B. Express this energy in units kJ/mol.

Energy needed to ionize Be^{3+} in the state with n=6: $E_{n=6} = R_H * 4^2 / 6^2 = 9.684*10^{-19}$ J

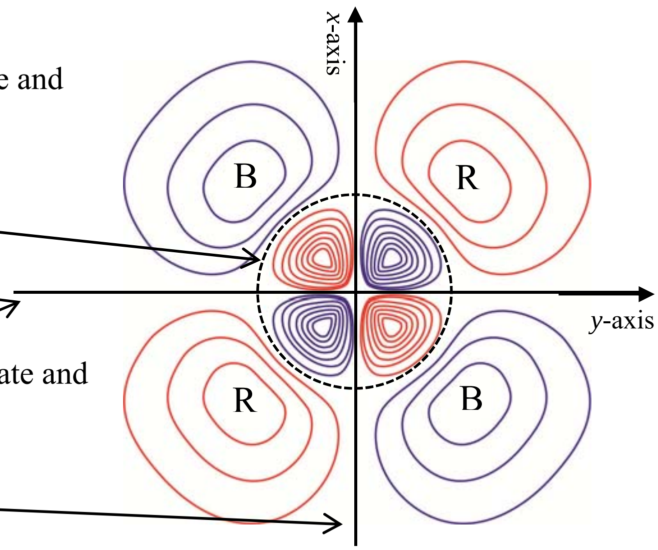
Energy needed to ionize one mol of Be^{3+} in n=6:

$9.684*10^{-19}$ J * N_A = $9.684*10^{-19}$ J * $6.022*10^{23}$ = 583.2 kJ / mol

6. (9 marks)
a) (4.5 marks) Shown below is a contour plot for an atomic orbital of the hydrogen atom in the *xy*-plane. (B = blue lobe; the other lobes are red)

a) Determine the number of radial nodes. Indicate and label the radial nodes in the contour plot.

1 radial node



b) Determine the number of angular nodes. Indicate and label the angular nodes in the contour plot.

2 angular nodes

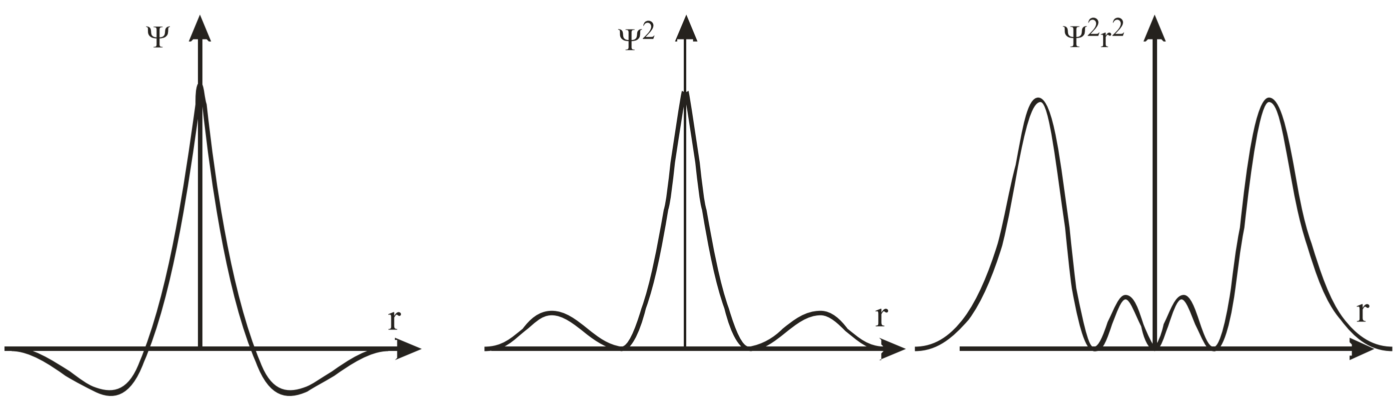
c) Identify the orbital. Explain!

Total number of nodes = 3 = n-1 → n=4

Number of angular nodes = 2 = ℓ → d-orbital

The contour plot belongs to a 4d orbital

b) (4.5 marks)
Plot qualitatively the wavefunction, the probability density, and the radial probability distribution of the 2s orbital. Label the axes in the diagrams appropriately.



7) (7 marks) True or false? (You don't need to do any calculations.)

a) A 2p orbital has one spherical node.

FALSE

b) At a node of a wavefunction, ψ, ψ^2, and $\psi^2 r^2$ are zero.

TRUE

c) Wave-particle duality applies to light AND to (microscopic) particles, such as electrons.

TRUE

d) An electron in a hydrogen atom with quantum numbers n=4, m_l=-2 may be in a *p*-, *d*-, or *f*-orbital.

FALSE

e) The Bohr model of the hydrogen atom is not in accord with the Heisenberg Uncertainty Principle.

TRUE

f) Each orbital can hold a maximum of two electrons as a result of the Pauli Exclusion Principle.

TRUE

g) The wavelength of the matter wave of a baseball is so large that the uncertainty principle is not significant.

FALSE

End of Paper