Chemistry 121

The University of British Columbia

Midterm Examination II

November 16, 2011

ANSWER KEY

Part 1. Multiple Choice (14 marks total)

For each numbered statement below, circle the letter that corresponds to the best answer. There is only one correct answer per question. Each question is worth 2 marks.

1. Which one of the following orbitals is lowest in energy in a Li^{2+} ion?

(a) 37*s*
(b) 12p_z
(c) 2$d_{x^2-y^2}$
(d) 5f_{xyz}
(e) 4d_{xz}

2. Arrange the following species in order of decreasing melting point:

CH_3OH ClBr S_8 Al Ar

(a) $S_8 > CH_3OH > ClBr > Ar > Al$
(b) $Al > ClBr > CH_3OH > S_8 > Ar$
(c) $S_8 > Al > ClBr > CH_3OH > Ar$
(d) $Al > S_8 > CH_3OH > ClBr > Ar$
(e) $CH_3OH > ClBr > S_8 > Ar > Al$

3. For a particular orbital of a hydrogen atom, there is a region of space where the wavefunction has a negative phase. Which one of the following statements is true?

(a) The oxidation state of the atom must be less than zero.
(b) Only destructive interference of the wavefunction can occur in that region.
(c) The wavefunction must correspond to a lobe of a *p*-orbital.
(d) There is a chance of finding the electron in that region of the orbital.
(e) The atom must be growing a moustache for Movember.

4. Which one of the following sets of quantum numbers {n, ℓ, m_ℓ,} would specify a wavefunction $\psi_{n,\ \ell,\ m_\ell}(r,\theta,\phi)$ that is a solution to the Schrödinger equation?

(a) {5, 2, −7}
(b) {8, 1, −1}
(c) {6, 6, −2}
(d) {0, 0, 0}
(e) {4, −2, 1}

5. Which of the following is <u>not</u> used or produced in the process to obtain white phosphorus?

(a) NaOH
(b) CO
(c) SiO_2
(d) C
(e) $Ca_3(PO_4)_2$

6. The melting point (mp) of xenon is −112 ˚C and the boiling point (bp) of xenon is −108 ˚C. The melting and boiling points of radon (Rn) are:

(a) mp = −137 ˚C; bp = −118 ˚C
(b) mp = −122 ˚C; bp = −110 ˚C
(c) mp = −35 ˚C; bp = 42 ˚C
(d) mp = −71 ˚C; bp = −62 ˚C
(e) mp = −53 ˚C; bp = −57 ˚C

7. A chemist shines a light on a metal surface, but no electrons are ejected. In order to make electrons eject from the surface of the metal, the chemist should:

(a) Increase the intensity of the light.
(b) Decrease the intensity of the light.
(c) Increase the frequency of the light.
(d) Decrease the frequency of the light.
(e) Choose a metal with a higher binding energy.

Part 2. Short Answer Questions

6 marks 1. For this question, consider only the following elements as possible answers:

Al, Si, P, S, Cl, Ar

For each part, give the symbol from the above list that makes the statement correct. Answers may be used more than once.

(a) __Al_____ is involved in the thermite reaction.

(b) __ P____ exists as an allotrope with only one lone pair per atom.

(c) __Ar___ is isoelectronic with Si in Mg_2Si.

(d) __ P___ exists as an allotrope that ignites spontaneously in dry air.

(e) ___Cl___ has the highest electronegativity.

(f) ___S___ commonly has an oxidation state of +2, +4, or +6 in compounds.

8 marks 2. Complete and balance the following reactions (assume sufficient heat is present to give a reaction – "no reaction" is not an acceptable answer):

(a) _4_ Al + _3_ O_2 → $2Al_2O_3$

(b) _2_ Mg + ___ CO_2 → 2MgO + C

(c) _2__ H_2S + ___ SO_2 → 3S + $2H_2O$ (300 ˚C)

(d) ___ P_4O_6 + _6_ H_2O → __4_ H_3PO_3

6 marks

2 marks

3. Silicon, germanium, and the grey allotrope of tin all have the same crystalline structure as diamond. The boiling points of these substances are:

C (diamond)	bp ~4300 K
Si	bp = 3538 K
Ge	bp = 3106 K
Sn (grey form)	bp = 2875 K

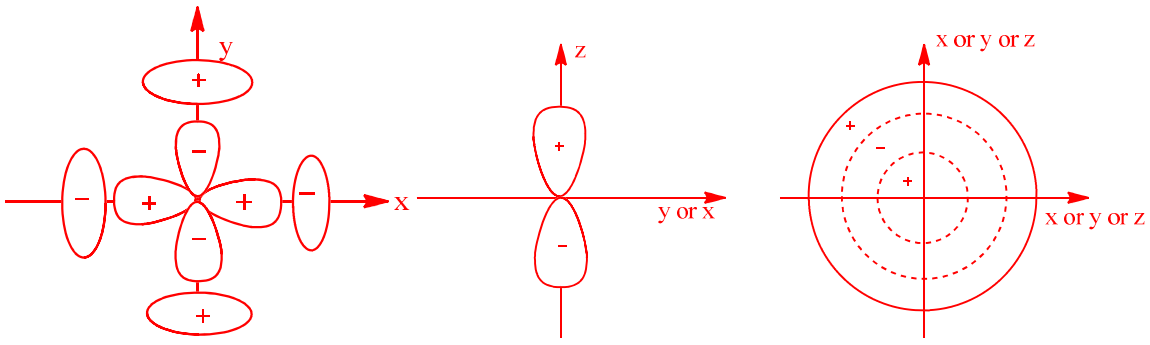
Briefly rationalize the trend of decreasing boiling points in order of C > Si > Ge > Sn.

Diamond is a network covalent solid. Since silicon, germanium and the grey allotrope of tin are similar to diamond, they are all covalent solids as well. Boiling of the elements will require breaking the covalent bonds in the network. In network covalent solids, the bond strength will decrease as the atoms get bigger. Following the periodic trend for size, Sn > Ge > Si > C. Decreasing bond strength leads to increasing boiling points.

6 marks

4. (a) Draw cross-sections for the following orbitals of the hydrogen atom. Show phases as (+) and (–) and label the axes.

$4d_{x^2-y^2}$ $2p_z$ $3s$

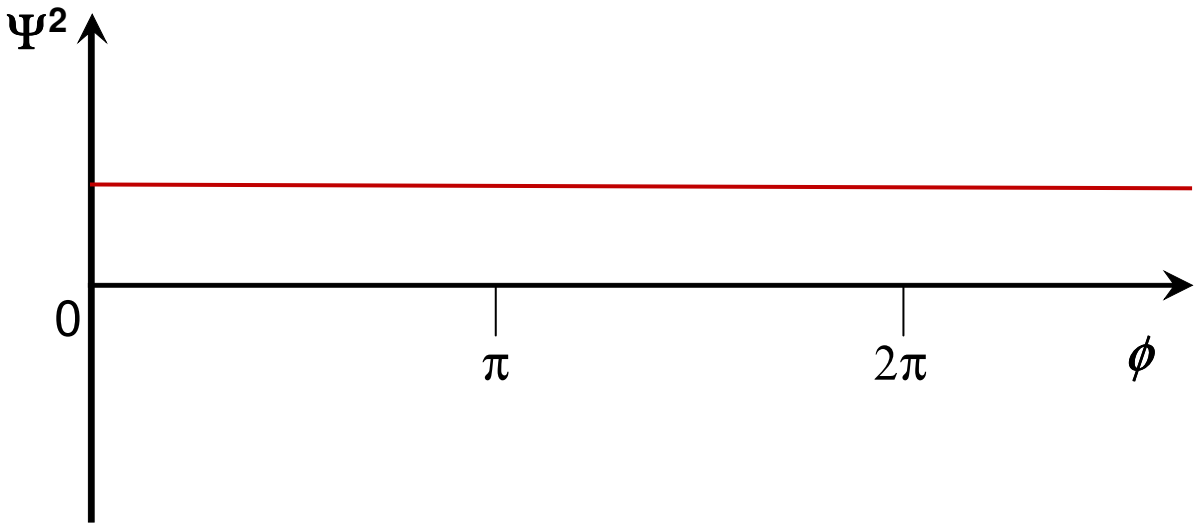


6 marks 5. Answer the following questions about the $6d_{z^2}$ orbital:

(a) The number of radial nodes in a $6d_{z^2}$ orbital is ___3_____ .

(b) The number of angular nodes in a $6d_{z^2}$ orbital is __2_____.

(c) If $\Psi(r, \theta, \phi) < 0$ when $(r, \theta, \phi) = (q, 0, \pi/2)$, then plot Ψ^2 vs. ϕ for the $6d_{z^2}$ orbital when $r = q$ $(q > 0)$ and $\theta = \pi/2$ from $\phi = 0$ to 2π using the axes below.



4 marks

6. For parts (a) and (b), consider an electron moving with velocity = 3.5×10^5 m s^{-1}. Show all work for full credit.

(a) Calculate the de Broglie wavelength (in nm) of the electron.

$$\lambda = \frac{h}{mv} = \frac{6.626\times10^{-34}\,Js}{(9.11\times10^{-31}\,kg)(3.5\times10^{5}\,ms^{-1})} = 2.1\times10^{-9}\,m \Rightarrow 2.1nm$$

(b) Calculate the wavelength (in nm) of light with energy that matches the kinetic energy of the electron.

$$\Delta E_{kinetic} = E_{light}$$

$$\tfrac{1}{2}mv^2 = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{\frac{1}{2}mv^2} = \frac{(6.626\times10^{-34}\,Js)(3.0\times10^{8}\,ms^{-1})}{\frac{1}{2}(9.11\times10^{-31}\,kg)(3.5\times10^{5}\,ms^{-1})^2}$$

$$\lambda = 3.6\times10^{-6}\,m \Rightarrow 3600nm$$

6 marks

7. A sample of hydrogen-like ions initially in the ground state was selectively excited with a light pulse to generate ions in an excited state with n = 10. (Assume only one photon was absorbed by each ion to generate the excited state.) As the ions relaxed, photons were emitted from the sample. The lowest energy photons were selectively reflected onto a metal foil. When the metal was a sodium foil, electrons were ejected. No electrons were ejected when a calcium foil was used. (The binding energy of Na is 228.00 kJ mol^{-1} ; the binding energy of Ca is 277.00 kJ mol^{-1}). Show all work for full credit.

(a) Which transition(s) correspond to the lowest energy photons emitted from the sample? Specify the orbitals involved (e.g., 4p→1s).

The initial state must be 10p, as the electron is excited from the 1s ground state by absorption of a single photon. The lowest energy photons must correspond to n = 10 → n =9 transitions.

Following the selection rules, the transitions must therefore be:
10p → 9s
10p → 9d

(b) Identify the ion (and its charge) present in the sample: ___F^{8+}_____

Considering the photoelectric effect, the photon's energy (ΔE) must be bigger than 228 kJ mol^{-1} and must be smaller than 277 kJ mol^{-1}.

$$228 kJ\ mol^{-1} \times \frac{1 mol}{6.02\times10^{23}\ photons} \times \frac{1000 J}{1 kJ} = 3.79\times10^{-19}\ J\ photon^{-1}$$

$$277 kJ\ mol^{-1} \times \frac{1 mol}{6.02\times10^{23}\ photons} \times \frac{1000 J}{1 kJ} = 4.60\times10^{-19}\ J\ photon^{-1}$$

$$\Delta E = 2.18\times10^{-18} Z^2 \left(\frac{1}{9^2} - \frac{1}{10^2}\right) = 5.11\times10^{-21} Z^2\ J\ photon^{-1}$$

$$3.79\times10^{-19}\ J\ photon^{-1} < 5.11\times10^{-21} Z^2\ J\ photon^{-1} < 4.60\times10^{-19}\ J\ photon^{-1}$$

Solving for a Z-value that satisfies BOTH criteria **proves that** Z = 9.

The ion must be a fluorine ion and since it is hydrogen-like, the ion is F^{8+}.

(c) If the scientist inserts potassium foil into the beam path, predict whether she will detect electrons ejected from the potassium foil. Justify your answer.

Yes, because we would expect the binding energy of the electron in K(s) to be less than Na(s), following the periodic trend for ionization energy.

8 marks 8. Under appropriate conditions (high temperature and pressure), the reaction of xenon (1 mol) with fluorine gas (3 mol) gives a new product **W** that is a colourless solid (**W** is the only product formed). Treating **W** (0.4 mol) with water (0.8 mol) gives a new product **Y** (0.4 mol) plus a weak acid **A** (1.6 mol). Compound **Y** reacts with additional water to give a new molecular compound **Z** and a by-product **Q** that does not contain oxygen. Analysis of the highly explosive solid **Z** shows that it contains only xenon and oxygen, and it has a polar structure.
(All of **A**, **Q**, **W**, **Y** and **Z** have a molecular weight < 320 g mol^{-1}.)

(a) Identify compounds **A**, **W**, **Y**, and **Z** with a chemical formula.

A: HF	**W: XeF_6**	**Y: XeF_2O_2**	**Z: XeO_3**

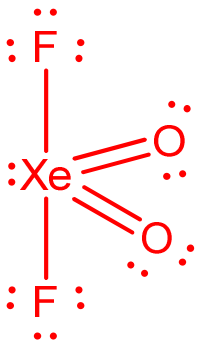
$$Xe + 3F_2 \longrightarrow XeF_6\ (W)$$

$$XeF_6\ (W) + 2H_2O \longrightarrow 4HF\ (A) + XeF_2O_2\ (Y)$$

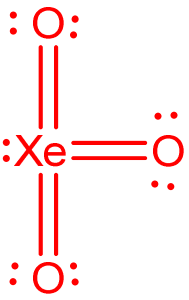
$$X_eF_2O_2\ (Y) + H_2O \longrightarrow XeO_3\ (Z) + 2HF\ (Q)$$

(b) Draw the best Lewis structure for compounds **Y** and **Z**. Draw only one resonance structure if resonance is possible. Clearly indicate any formal charges and show all lone pairs of electrons as pairs of dots and all bond pairs as lines.

Y:



Z:



End of Examination