Chemistry 121

The University of British Columbia

Midterm Examination I

October 10, 2012

Time: 60 minutes

Put the first letter of your family/last name in this box.

Family/Last Name (printed):_____

First Name: _____

Signature:_____

Student Number:_____

Please check √ your lecture section:
___101 (MWF 1:00) Kunz
___102 (MWF 2:00) Wolf
___103 (MWF 3:00) Wolf
___110 (MWF 10:00) Mehrkhodavandi
___111 (MWF 11:00) Lekhi
___122 (T,Th 2:00) Burnell
___133 (T,Th 3:30) Burnell
___188 (T,Th 8:00) Rodriguez-Nunez
___199 (T,Th 9:30) Krems

INSTRUCTIONS

1. Write all answers on this examination paper, and show full details of your solutions for Part 2.
2. Read each question carefully.
3. Check that this examination consists of **12 PAGES PRINTED ON BOTH SIDES.** The last sheet (pages 11 and 12), containing Supplementary Information and the Periodic Table, may be detached for ease of use.
4. The only calculator allowed is the Sharp EL-510RB. All other calculators will be confiscated. Cell phones or other electronic communication devices are not permitted.
5. Unassembled molecular model kits may be used.

RULES GOVERNING FORMAL EXAMINATIONS

1. Each candidate must be prepared to produce, upon request, a UBCcard for identification.
2. Candidates are not permitted to ask questions of the invigilators, except in cases of supposed errors or ambiguities in examination questions.
3. No candidate shall be permitted to enter the examination room after the expiration of 15 minutes from the scheduled starting time, or to leave during the first 15 minutes of the examination.
4. Candidates suspected of any of the following, or similar, dishonest practices shall be immediately dismissed from the examination and shall be liable to disciplinary action:
   - having at the place of writing any books, papers or memoranda, calculators, computers, sound or image players/recorders/transmitters (including telephones), or other memory aid devices, other than those authorized by the examiners;
   - speaking or communicating with other candidates; and
   - purposely exposing written papers to the view of other candidates or imaging devices. The plea of accident or forgetfulness shall not be received.
5. Candidates must not destroy or mutilate any examination material; must hand in all examination papers; and must not take any examination material from the examination room without permission of the invigilator.
6. Candidates must follow any additional examination rules or directions communicated by the instructor or invigilator.

Marks

Part	Question	Possible Marks	Marks
1		14	
2	1	6	
	2	7	
	3	7	
	4	8	
	5	5	
	6 + 7	7	
	8	6	
Total		60	

Part 1. Multiple Choice (14 marks total)
For each numbered statement below, write the letter that corresponds to the best answer. There is only one correct answer per question. Each question is worth 2 marks.

1. What is the formal charge on carbon in the bicarbonate ion $[HOCO_2]^-$? (The central atom is C).

   (a) +2
   (b) +1
   (c) 0
   (d) −1
   (e) −2

   Answer: **C**

2. Arrange the following in order of increasing electronegativity: Ba, F, As, Cl

   (a) Ba < As < Cl < F
   (b) Cl < Ba < F < As
   (c) Ba < F < As < Cl
   (d) Ba < Cl < As < F
   (e) As < Ba < Cl < F

   Answer: **A**

3. Which one of the following statements best explains the trend in atomic radii from left to right across a period?

   (a) Larger atomic numbers result in larger radii.
   (b) Electrons are held less tightly because ionization energy decreases, resulting in larger radii.
   (c) The effective nuclear charge felt by the valence electrons increases, resulting in smaller radii.
   (d) The shielding of valence electrons decreases resulting in smaller radii.
   (e) Z_{eff} decreases resulting in an increase in the number of valence electrons and larger radii.

   Answer: **C**

4. Complete the following statement. The <u>best</u> Lewis structure for the molecule NSF (S is the central atom) has

   (a) a formal negative charge on S and a formal positive charge on N.
   (b) a formal negative charge on fluorine.
   (c) an octet of electrons on each atom.
   (d) a sulfur-nitrogen triple bond.
   (e) a sulfur-nitrogen single bond.

   Answer: **D**

5. Barium has six stable isotopes (^{132}Ba, ^{134}Ba, ^{135}Ba, ^{136}Ba, ^{137}Ba and ^{138}Ba) with natural abundances ranging from 0.1 % for the least abundant to 71.7 % for the most abundant. Which isotope of barium is the most abundant?

(a) ^{132}Ba
(b) ^{134}Ba
(c) ^{135}Ba
(d) ^{136}Ba
(e) ^{138}Ba

Answer: **E**

6. Which of the following has a trigonal pyramidal molecular shape? (the central atom is underlined)

(a) $[\underline{Cl}O_4]^-$
(b) $[\underline{Cl}O_3]^-$
(c) $[\underline{Cl}O_2]^-$
(d) $\underline{Cl}O_2$
(e) $Cl_2\underline{O}$

Answer: **B**

7. Which of the following molecules is non-polar?

(a) ClF_3
(b) XeO_3
(c) SeO_2
(d) $SOCl_2$
(e) XeF_4

Answer: **E**

Part 2. Short Answer Questions

6 marks 1. Circle the species which has:

(a) the smallest ionization energy	(Cs)	Ge	Ar
(b) the smallest radius	(O^+)	O	O^-
(c) the largest radius	(Sr)	Se	Te
(d) $Z_{eff} \sim 3$	Na	Mg	(Al)
(e) the largest (most negative) electron affinity	Cl	I	(F)
(f) been demonstrated in the lecture to burn in CO_2	Na	(Mg)	Al

7 marks 2. (a) Write a balanced equation for the reaction of sodium oxide with water.

$$Na_2O + H_2O \longrightarrow 2NaOH$$

(b) Write a balanced equation for the reaction of barium metal with bromine.

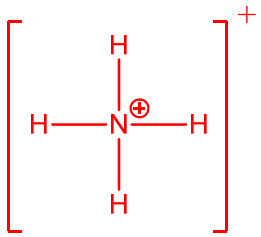
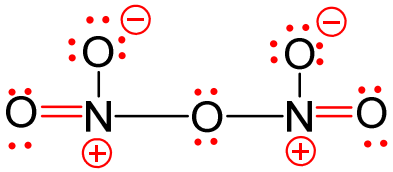
$$Ba + Br_2 \longrightarrow BaBr_2$$

(c) Sodium superoxide (NaO_2) reacts with water to give three products: a gas, a neutral compound with mass 34 g mol^{-1}, and a base. Write a balanced equation for the reaction of sodium superoxide with water.

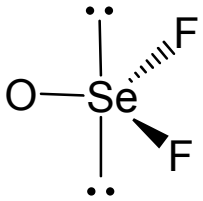
$$4NaO_2 + 6H_2O \longrightarrow 4H_2O_2 + 4NaOH + O_2$$

7 marks

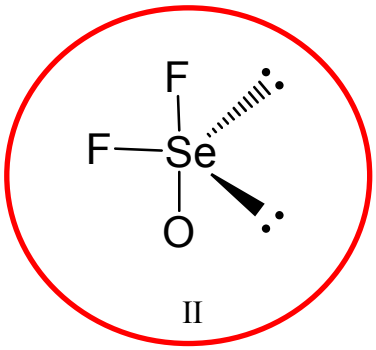
3. (a) Draw the best Lewis structure for each of the following ions. Draw only one structure when resonance is possible. Write any non-zero formal charges on the appropriate atoms, show all lone pairs of electrons as pairs of dots and all bond pairs as lines.

$[NH_4]^+$	N_2O_5 (atom connectivity shown)
	

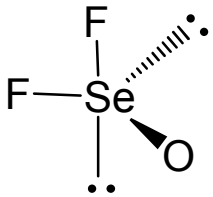
(b) Circle the correct perspective diagram of $[SeOF_2]^{2-}$ below.



I



II



III

(c) Explain briefly how you selected your choice in part (b).

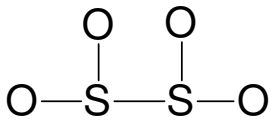
Diagram I has six 90° lone pair-bond pair interactions, diagram II has four 90° lone pair-bond pair interactions, and diagram III has one 90° lone pair-lone pair interaction and three 90° lone pair-bond pair interactions.

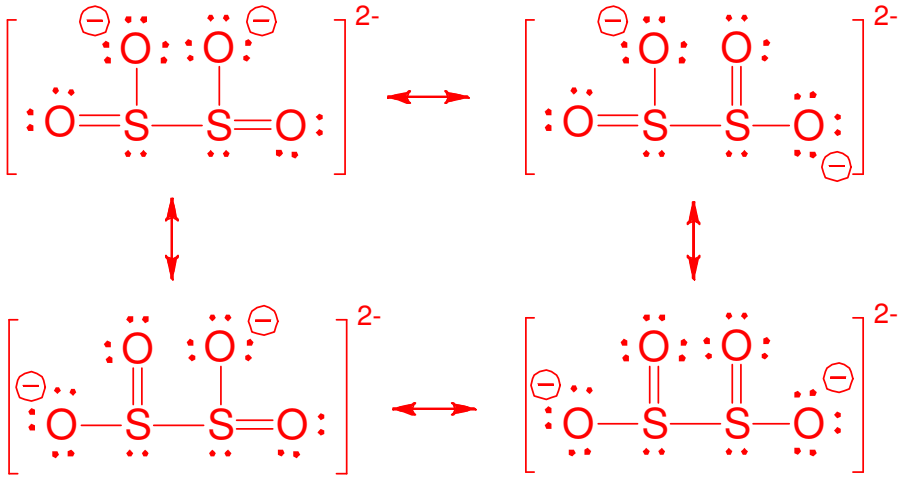
Lone pair-lone pair repulsion is stronger than lone pair-bond pair repulsion.

Thus, diagram II has the least repulsion interactions of the three.

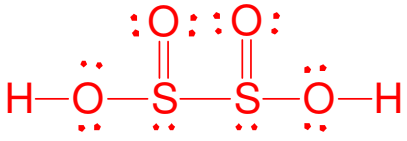
8 marks

4. (a) Draw Lewis structures for the FOUR BEST resonance structures of the dithionate ion, $[S_2O_4]^{2-}$. Show all lone pairs of electrons as pairs of dots and all additional bonds as lines. Write any non-zero formal charges on the appropriate atoms. The atom connectivity in the dithionate ion is shown below:

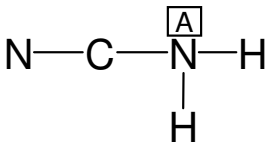




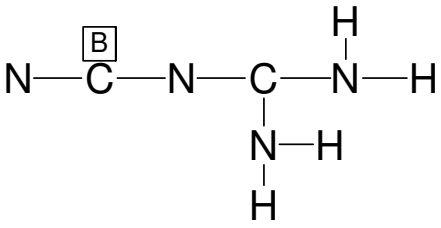
(b) Draw the best Lewis structure for dithionous acid, $H_2S_2O_4$. Show all lone pairs of electrons as pairs of dots and all additional bonds as lines. Write any non-zero formal charges on the appropriate atoms.



5 marks 5. Cyanamide and dicyanamide are two important industrial chemicals. The following diagrams show the atom connectivity of the two compounds. Answer parts (a) – (e) concerning these molecules below by circling the best answer.



Cyanamide



Dicyanamide

a) The formal charge on the atom labeled **A** in the best Lewis structure of cyanamide is

(i) −2
(ii) −1
(iii) 0
(iv) +1
(v) +2

b) The estimated C-N-H bond angle in the best Lewis structure of cyanamide is

(i) 90°
(ii) 109°
(iii) 120°
(iv) 145°
(v) 180°

c) The estimated C-N-C bond angle in the best Lewis structure of dicyanamide is

(i) 90°
(ii) 109°
(iii) 120°
(iv) 145°
(v) 180°

d) The number of atoms with trigonal planar molecular shape in the best Lewis structure of dicyanamide is

(i) 1
(ii) 2
(iii) 3
(iv) 4
(v) 5

e) The molecular shape at the atom labeled **B** in the best Lewis structure of dicyanamide is

(i) tetrahedral
(ii) linear
(iii) trigonal planar
(iv) bent
(v) trigonal pyramidal

2 marks 6. A rare earth manganite containing La, Mn and O has a crystal structure with a cubic unit cell, where the La cations occupy the corners of the cube, the oxide anions occupy the centers of the faces, and the Mn cation occupies the center of the cube. In the box below, write the empirical formula for this compound.

Answer: **$LaMnO_3$**

5 marks 7. (a) The crystal structure of tungsten (Z = 74) has a body-centered cubic unit cell. How many atoms are there in the unit cell of tungsten?

Answer: **2**

(b) Given that the density of tungsten is 19.25 g/cm^3, find the radius of the tungsten atom. Show your work and write your answer in Å.

Answer: **1.37** Å

$$density = \frac{mass}{volume}$$

$$volume = (edge\,length, a)^3$$

$$For\ a\ BCC\ unit\ cell, a = \frac{4}{\sqrt{3}} r\ where\ r\ is\ the\ radius\ of\ the\ atom$$

$$volume = a^3 = \frac{mass}{density} = \frac{(2 atoms)(183.85 g\ mol^{-1})(\frac{1 mol}{6.02\times10^{23} atoms})}{19.25 g\ cm^{-3}}$$

$$a^3 = 3.1719\times10^{-23} cm^3$$

$$a = 3.1654\times10^{-8} cm \Rightarrow 3.1654\ \overset{o}{A}$$

$$r = \frac{\sqrt{3}}{4}(3.1654\ \overset{o}{A}) = 1.37\ \overset{o}{A}$$

6 marks

8. A chemist is asked to determine the identity of two metallic elements, one from Group 1 of the periodic table, the other from Group 2. The chemist conducted several experiments to determine the identity of the two elements.

   (a) The chemist determined that the product of the reaction of **X** and chlorine is a white solid with a lattice energy of 2253 kJ/mol, while the product of the reaction of **Y** and chlorine is a white solid with a lattice energy of 715 kJ/mol.

   (b) The chemist took 1.00 g of unknown **X** and reacted it with excess bromine resulting in the formation of 4.99 g of a white solid (100% yield).

   (c) The chemist took 1.00 g of unknown **Y** and reacted it with excess oxygen, forming 1.41 g of a white solid (100% yield).

   Based on this information, what are **X** and **Y?** Show your work in the space below.

X =	**Y =**
Ca	**K**

From the information given in (a), X is a group 2 metal and Y is a group 1 metal.

The reactions in parts (b) and (c) are as follows:

$$X + Br_2 \rightarrow XBr_2$$

$$2Y + O_2 \rightarrow Y_2O_2$$

There are a few ways of doing the math to identify X and Y. One method is to equate the number of mols of reactant with the number of mols of product according to the stoichiometry of each reaction:

From part (b):

$$\frac{1.00\,g}{MW_x} = \frac{4.99\,g}{(MW_x + (2)(79.904\,g\,mol^{-1})}$$

Solving for MW_x:

$$MW_x \cong 40\,g\,mol^{-1}$$

From part (c):

$$(\frac{1.00\,g}{MW_Y}) = 2(\frac{1.41\,g}{(2)(MW_Y) + (2)(15.994\,g\,mol^{-1})})$$

Solving for MW_Y:

$$MW_Y \cong 39\,g\,mol^{-1}$$

Supplementary Sheet

Potentially Useful Information

1 Hertz = 1 Hz = 1 s^{-1} = 10^{-6} MHz 1 J = 1 kg m^2 s^{-2}
1 m = 10^6 µm =10^9 nm = 10^{12} pm = 10^{10} Å

h = Planck's constant = 6.626×10^{-34} J s
N_A = Avogadro's number = 6.022×10^{23} mol^{-1}
c = speed of light = 3.00×10^8 m s^{-1}
1 amu = 1 u = atomic mass unit = 1.66×10^{-27} kg
electron mass = 9.11×10^{-31} kg
proton mass = 1.67×10^{-27} kg
a_o = Bohr radius = 0.53 Å
R_H = Rydberg constant = 2.18×10^{-18} J
1eV = 1.60×10^{-19} J

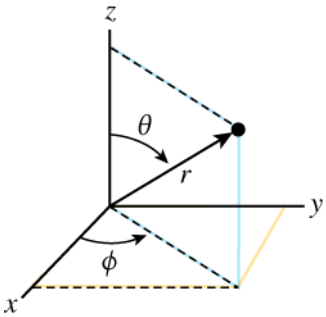
For one-electron species:

$$E_n = -2.18 \times 10^{-18} \frac{Z^2}{n^2} \text{ J}$$

Particle in a one dimensional box:

$$E_n = \frac{h^2 n^2}{8mL^2} \quad (n = 1, 2, 3, \text{etc.})$$

Cartesian and Spherical Polar Coordinates:



PERIODIC TABLE OF THE ELEMENTS

Group 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H 1.008																1 H 1.008	2 He 4.003
3 Li 6.941	4 Be 9.012											5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.179
11 Na 22.99	12 Mg 24.305											13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.064	17 Cl 35.453	18 Ar 39.948
19 K 39.098	20 Ca 40.08	21 Sc 44.956	22 Ti 47.9	23 V 50.941	24 Cr 51.996	25 Mn 54.938	26 Fe 55.847	27 Co 58.933	28 Ni 58.7	29 Cu 63.546	30 Zn 65.38	31 Ga 69.72	32 Ge 72.59	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.8
37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.22	41 Nb 92.906	42 Mo 95.94	43 Tc "(98)"	44 Ru 101.07	45 Rh 102.9	46 Pd 106.4	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.6	53 I 126.9	54 Xe 131.3
55 Cs 132.9	56 Ba 137.33	57 La* 138.91	72 Hf 178.49	73 Ta 180.95	74 W 183.85	75 Re 186.21	76 Os 190.2	77 Ir 192.22	78 Pt 195.09	79 Au 196.97	80 Hg 200.59	81 Tl 204.37	82 Pb 207.2	83 Bi 208.98	84 Po "(209)"	85 At "(210)"	86 Rn "(222)"
87 Fr 223	88 Ra 226.03	89 Ac# 227.03	104 Rf	105 Db [261]	106 Sg	107 Bh	108 Hs	109 Mt									

*	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm 145	62 Sm 150.4	63 Eu 151.96	64 Gd 157.25	65 Tb 158.92	66 Dy 162.5	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97
#	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np 237.05	94 Pu 244	95 Am 243	96 Cm 247	97 Bk 247	98 Cf 251	99 Es 252	100 Fm 257	101 Md 258	102 No 259	103 Lr 260