Department of Chemistry

Memorial University of Newfoundland

Chemistry 1050

FINAL EXAMINATION **Fall 2017** **TIME: 3 hours**

READ THE FOLLOWING CAREFULLY

1. This examination consists of 13 pages including a Data Sheet. Ensure that this examination paper is complete, *i.e.* that all **13 pages** are present.

2. A Data Sheet with a periodic table, equations and physical constants is provided. These are on the last sheet of the exam and may be detached for use during the examination.

3. DO NOT REMOVE ANY PART OF THIS EXAM FROM THE EXAM ROOM

4. Answer each question in the space provided. Should you require more space, use the back of the previous page and **indicate clearly** where this has been done.

5. **Show all relevant calculations and justify all simplifying assumptions.**

6. Numerical answers must be reported to the **appropriate number of significant digits with the correct units (if any)**.

Do not write in the table below.

Good Luck!

Page	Value	Mark
2	9	
3	10	
4	8	
5	10	
6	13	
7	9	
8	8	
9	12	
10	9	
11	11	
12	6	
	Total Marks	**/105**

1. A rigid 3.00 L container was found in a lab. The label reads "pure hydrocarbon gas", and it was determined to be one of methane (CH_4, M_w = 16.04 g mol^{-1}), ethane, (C_2H_6, M_w = 30.07 g mol^{-1}), propane (C_3H_8, M_w = 44.10 g mol^{-1}) or butane (C_4H_{10}, M_w = 55.08 g mol^{-1}). At 20.0 °C the pressure of the gas is 3.80 bar. When cooled, the gas condenses to give 20.4 g of liquid. What is the unknown gas? **(3 marks)**

2. If it takes 1.25 minutes for 0.010 mol of He to effuse through a small hole, how long will it take for the same amount of ethane (C_2H_6) to effuse? **(3 marks)**

3. Calculate the density of oxygen gas, O_2(g), at 0 °C and at 745 torr (745 mmHg). **(3 marks)**

4. A mixture of argon and xenon contains 30% argon by mass and has a total pressure of 0.940 bar. Calculate the partial pressure of argon in the container. **(2 marks)**

5. A sample of $NH_4NO_3(s)$ is placed in a 3.60 L container where it completely decomposes at 195 °C according to the following reaction:

$$NH_4NO_3(s) \rightarrow N_2O(g) + 2\ H_2O(g)$$

The total pressure of the gases in the container produced from the decomposition is 100 kPa. Calculate the mass of NH_4NO_3 (M_w = 80.0 g mol^{-1}) that was placed in the container. **(4 marks)**

6. The following reaction occurs with "Magic Baking Powder", a mixture of sodium bicarbonate ($NaHCO_3$) and an acid such as tartaric acid ($C_4H_6O_6$). When dissolved in water the reaction produces $CO_2(g)$ (M_w = 44.01 g mol^{-1}), which helps bread rise.

$$2\ NaHCO_3(aq) + C_4H_6O_6(aq) \rightarrow Na_2C_4H_4O_6(aq) + 2\ H_2O(l) + 2\ CO_2(g)\quad \Delta H = -45.3\ kJ\ mol^{-1}$$

How much heat is produced in the reaction when 12.0 g of CO_2 are formed? **(4 marks)**

7. A 5.00 mL volume of a 0.60 M solution of phosphoric acid, $H_3PO_4(aq)$, reacts with 45.00 mL of 0.25 M NaOH(aq) according to the reaction below. The temperature of the solution rises from 26.0 °C to 28.0 °C. Assume the volumes of the solutions are additive, the density of the final solution is 1.10 g mL^{-1}, the heat capacity of the solution is the same as water and the water produced by the reaction does not affect the volume of the resulting solution. Calculate the *molar enthalpy change for the reaction*. **(5 marks)**

$$H_3PO_4(aq) + 3\ NaOH(aq) \rightarrow Na_3PO_4(aq) + 3\ H_2O(l) \qquad \Delta H_{rxn} = ?$$

8. Determine the standard molar enthalpy of formation of diborane, $B_2H_6(g)$ using the following thermochemical information: **(3 marks)**

$$4\ B(s) + 3\ O_2(g) \rightarrow 2\ B_2O_3(s) \qquad \Delta H^{o} = -2509.1\ \text{kJ mol}^{-1}$$
$$2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(l) \qquad \Delta H^{o} = -571.7\ \text{kJ mol}^{-1}$$
$$B_2H_6(g) + 3\ O_2(g) \rightarrow B_2O_3(s) + 3\ H_2O(l) \qquad \Delta H^{o} = -2147.5\ \text{kJ mol}^{-1}$$

9. A tray holding 100 g of water at 22 °C was placed into a freezer to make ice cubes. If the temperature of the freezer is kept constant at –20 °C, calculate the amount of heat absorbed by the freezer for this process. Use the data provided on the Periodic Table and Data page. **(4 marks)**

10. Nitrous oxide, $N_2O(g)$, reacts with carbon disulfide, $CS_2(g)$ according to the equation below. When performed in a constant volume bomb calorimeter with a heat capacity of 8.775 kJ $°C^{-1}$, the temperature of the calorimeter rises from 22.5 °C to 29.1 °C and forms 2.48 g of sulfur, S_8. Determine the molar internal energy, ΔU, and the molar enthalpy, ΔH (both in kJ mol^{-1}) of the following reaction at 25.0 °C.
(6 marks)

$$3\ N_2O(g) + CS_2(l) \rightarrow 3\ N_2(g) + CO(g) + 1/8\ S_8(s)$$

11. Provide the condensed ground state electron configuration and condensed orbital diagram (as shown in the example using nitrogen) for the following: **(4 marks)**

N $[He]2s^2 2p^3$ [He] ⇅ (2s) ↑ ↑ ↑ (2p)

Cr

Te

Co^{3+}

Sn^{2+}

12. Provide responses to the following questions on atomic structure and periodic trends **(1 mark each, 9 marks total)**.

(a) How many electrons have quantum number $n = 2$?

(b) How many electrons have quantum numbers $n = 3$ and $l = 2$.

(c) How many electrons have quantum numbers $n = 3$, $l = 2$, $m_l = 1$, $m_s = +½$?

(d) Circle the atom with the largest radius from the following set

Al S Cl

(e) Circle the atom with the largest first ionization energy from the following sets:

i. Na Mg Ca

ii. Al P Cl

(f) Circle the ionic compound having the highest lattice enthalpy from the following sets:

i. NaCl $MgCl_2$ LiF

ii. NaCl Na_2O $CaBr_2$

(g) Which **period 3** element has the following successive ionization energies (in kJ/mol)?

786.3 1,580 3,230 4,360 16,000 20,000

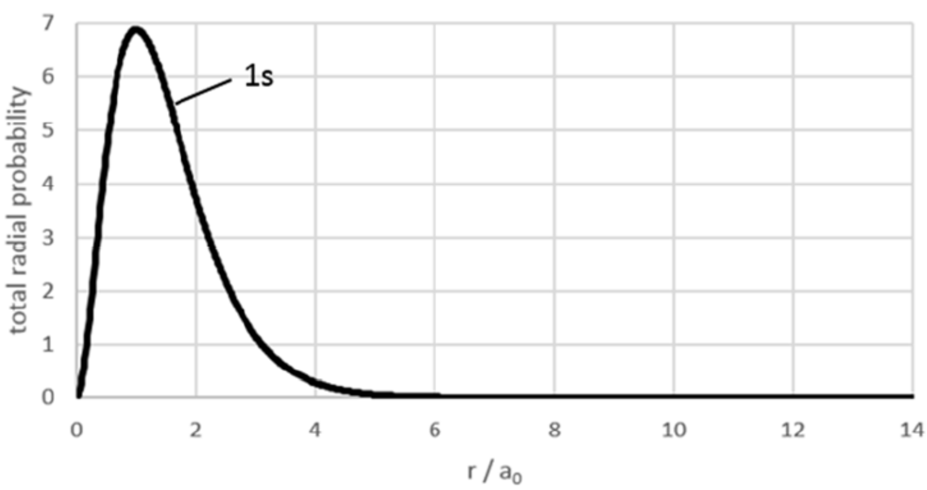
13. Write balanced equations for the following: **(3 marks)**

(a) _____ $Li(s)$ + _____ $O_2(g)$ →

(b) _____ $F_2(g)$ + _____ $H_2(g)$ →

(c) _____ $Ca(s)$ + _____ $H_2O(l)$ →

14. a) Sketch the radial probability diagrams for the 2s and 2p orbitals on the set of axes below. The probability diagram for the 1s orbital is given as an example. **(2 marks)**



b) Draw a $2p_x$ orbital indicating any radial or angular nodes if they exist. Show the correct Cartesian (xyz) axes and correct phases. **(1 mark)**

15. Write balanced chemical equations to describe the following: **(3 marks)**

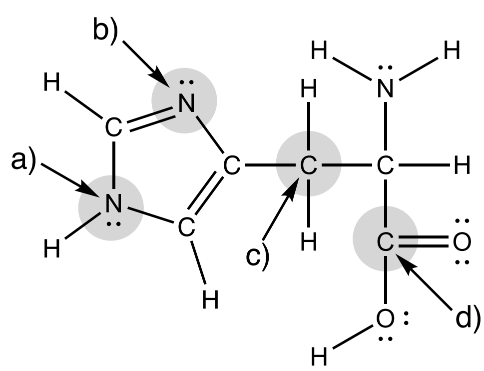
(a) The enthalpy of formation of $NaCl(s)$

(b) The enthalpy of combustion of propane, $C_3H_8(g)$

(c) The lattice enthalpy of $KBr(s)$

16. The first ionization energy of nitrogen (N) is 1402 kJ mol^{-1} and that of oxygen (O) is 1319 kJ mol^{-1} despite the general trend for ionization energies to increase going from left to right across the periodic table. Use the electron configurations for N and O to explain why O has the lower ionization energy. **(2 marks)**

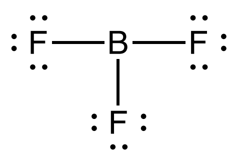
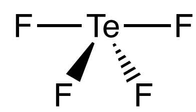
17. The following is the Lewis structure for the amino acid histidine. In the table below it, provide the molecular geometry and hybridization of the atoms labeled a) to d). **(4 marks)**



Atom	Molecular Geometry	Hybridization
a)		
b)		
c)		
d)		

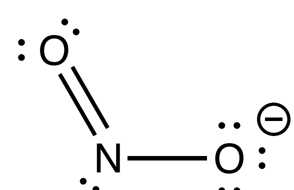
18. Explain why using pure atomic orbitals alone to describe the bonding geometry of NH_3 gives an inaccurate prediction of bond angles compared to those that are observed. **(2 marks)**

19. Complete the following table to provide the missing data. For Lewis Structures, use the expanded octet/minimized formal charge model if applicable. **(8 marks)**

	Boron trifluoride, BF_3	Chlorine pentafluoride, ClF_5	Tellurium tetrafluoride, TeF_4
Total valence electron count **(0.5 mark each)**			
Lewis structure **(1 mark each)**			
Sketch of VSEPR predicted shape including ideal **bond angles (1 mark each)**			 90° and 120°
Name of shape **(0.5 mark each)**		Square pyramidal	
Is it polar or non-polar? **(0.5 mark each)**			

20. The Lewis structure of the nitrite anion is given at right.

(a) Calculate the average N-O bond order in the nitrite anion. **(1 mark)**



(b) Using valence bond and orbital hybridization theories, draw the atomic or hybrid orbitals that overlap to form the sigma (σ) or pi (π) bonds in the nitrite ion shown. In your drawing **clearly label the orbitals and the bonds formed**. **(3 marks)**

21. Using molecular orbital theory, provide the following:

a) Draw the molecular orbital diagram for the He_2^+ cation. Don't forget to label the atomic and molecular orbitals and populate the MOs with the correct number of electrons. **(2 marks)**

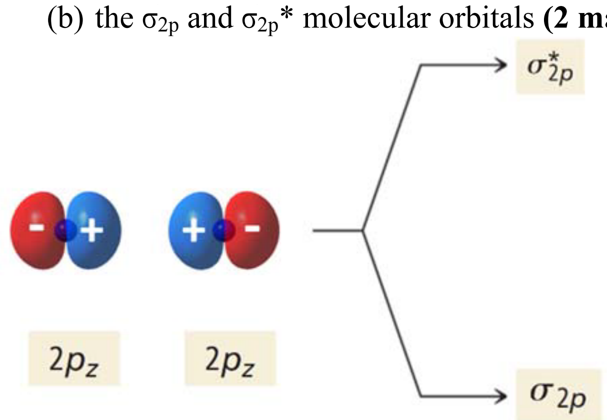
b) What is the bond order for He_2^+? **(1 mark)**

c) What is the bond order for He_2? **(1 mark)**

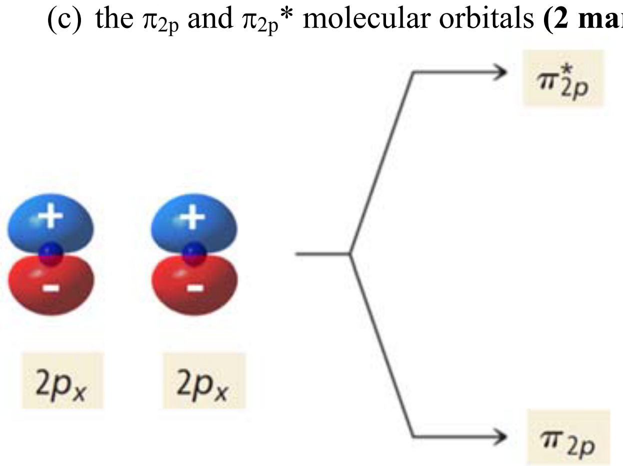
22. Sketch and **correctly label** the orbitals indicated below showing the phases (+ or -), the position of the nucleus (or nuclei) and the appropriate xyz axes.

(a) any 3d orbital and correctly name it **(1 mark)**

(b) the σ_{2p} and σ_{2p}* molecular orbitals **(2 marks)**



(c) the π_{2p} and π_{2p}* molecular orbitals **(2 marks)**



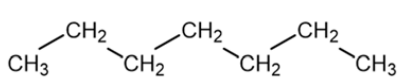
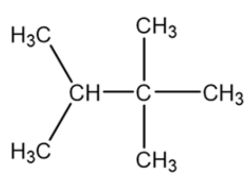
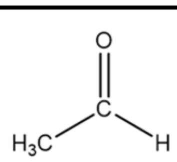
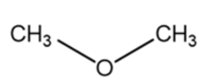
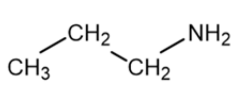
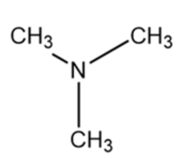
23. Two possible Lewis structures can be given for the sulfate anion, SO_4^{2-}. Draw the Lewis structure in which S obeys the octet rule, and the other where the formal charge on S is zero. Assign formal charges to all atoms in both structures. **(4 marks)**

24. The following questions concern intermolecular forces.

(a) Briefly explain, in terms of the relevant intermolecular forces, why H_2O has a higher boiling point than H_2S. **(1 mark)**

(b) Define the term "normal boiling point". **(1 mark)**

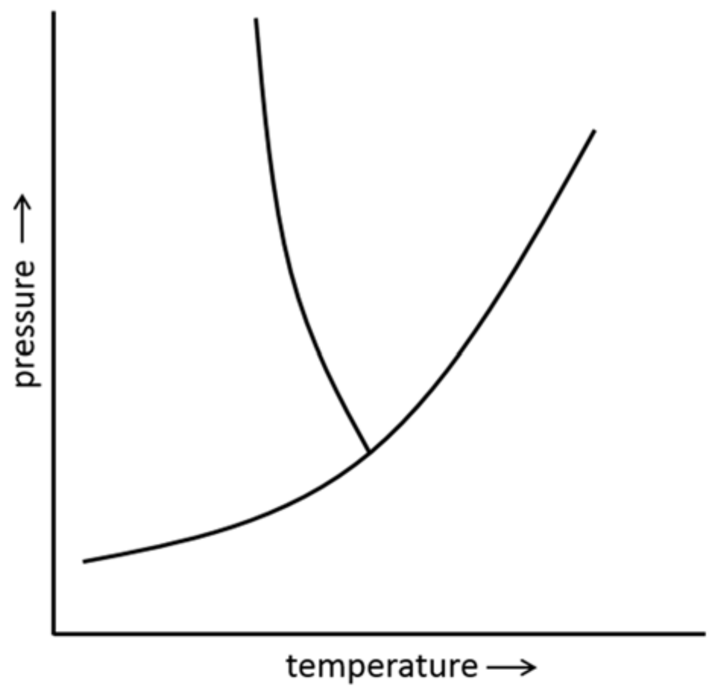
(c) For the following pairs of compounds, **circle** the one with the highest boiling point and briefly **explain** your choice for full marks. **(5 marks)**

i.	$CH_3{-}SH$ or $CH_3{-}SeH$
ii.	 or 
iii.	 or 
iv.	 or 
v.	HCl or NaCl

25. Determine the *normal* boiling point of ethanol, CH_3CH_2OH, if it has a vapour pressure of 340 torr (45.33 kPa) at 60.0 °C, given that ΔH_{vap} for ethanol is 38.56 kJ mol^{-1}. **(3 marks)**

26. On the phase diagram to the right, label the following six (6) regions or points: **(3 marks)**

(a) Liquid
(b) Solid
(c) Gas
(d) Supercritical Fluid
(e) Triple point
(f) Critical point



The End

KEY: atomic number 6, C, atomic mass 12.0107

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 **H** 1.0079																	2 **He** 4.0026
3 **Li** 6.941	4 **Be** 9.0122											5 **B** 10.811	6 **C** 12.0107	7 **N** 14.0067	8 **O** 15.9994	9 **F** 18.9984	10 **Ne** 20.1797
11 **Na** 22.9898	12 **Mg** 24.3050											13 **Al** 26.9815	14 **Si** 28.0855	15 **P** 30.9738	16 **S** 32.065	17 **Cl** 35.453	18 **Ar** 39.948
19 **K** 39.0983	20 **Ca** 40.078	21 **Sc** 44.9559	22 **Ti** 47.867	23 **V** 50.9415	24 **Cr** 51.9961	25 **Mn** 54.9380	26 **Fe** 55.8475	27 **Co** 58.9332	28 **Ni** 58.6934	29 **Cu** 63.546	30 **Zn** 65.409	31 **Ga** 69.723	32 **Ge** 72.61	33 **As** 74.9216	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.798
37 **Rb** 85.4678	38 **Sr** 87.62	39 **Y** 88.9059	40 **Zr** 91.224	41 **Nb** 92.9064	42 **Mo** 95.94	43 **Tc** (99)	44 **Ru** 101.07	45 **Rh** 102.9055	46 **Pd** 106.42	47 **Ag** 107.8682	48 **Cd** 112.411	49 **In** 114.818	50 **Sn** 118.710	51 **Sb** 121.75	52 **Te** 127.60	53 **I** 126.9045	54 **Xe** 131.29
55 **Cs** 132.9054	56 **Ba** 137.327	57 **La** 139.9055	72 **Hf** 178.49	73 **Ta** 180.9479	74 **W** 183.84	75 **Re** 186.207	76 **Os** 190.23	77 **Ir** 192.217	78 **Pt** 195.078	79 **Au** 196.9665	80 **Hg** 200.59	81 **Tl** 204.3833	82 **Pb** 207.2	83 **Bi** 208.9804	84 **Po** (210)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** (226)	89 **Ac** (227)	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (266)	107 **Bh** (264)	108 **Hs** (269)	109 **Mt** (268)									

Lanthanides	58 **Ce** 140.116	59 **Pr** 140.9077	60 **Nd** 144.24	61 **Pm** (147)	62 **Sm** 150.36	63 **Eu** 151.964	64 **Gd** 157.25	65 **Tb** 158.925	66 **Dy** 162.50	67 **Ho** 164.9303	68 **Er** 167.259	69 **Tm** 168.9342	70 **Yb** 173.04	71 **Lu** 174.967
Actinides	90 **Th** 232.0381	91 **Pa** 231.0359	92 **U** 238.0289	93 **Np** (237)	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** (262)

Parenthesis indicates the most stable isotope

Constants

$\Delta_{\text{fus}}H^{\circ}_{\text{H}_2\text{O}(s)} = 6.01 \text{ kJ mol}^{-1}$ at 273 K

$\Delta_{\text{vap}}H^{\circ}_{\text{H}_2\text{O}(l)} = 40.7 \text{ kJ mol}^{-1}$ at 373 K

$\Delta_{\text{vap}}H^{\circ}_{\text{H}_2\text{O}(l)} = 44.0 \text{ kJ mol}^{-1}$ at 298 K

specific heat of $H_2O(l) = 4.184 \text{ J g}^{-1} \text{ K}^{-1}$

specific heat of $H_2O(s) = 1.960 \text{ J g}^{-1} \text{ K}^{-1}$ at 0 °C

density of $H_2O(l)$ near 0 °C = 1.000 g mL^{-1}

$c = 2.998 \times 10^{8} \text{ m s}^{-1}$

$R_H = 1.0793 \times 10^{7} \text{ m}^{-1}$

$h = 6.626 \times 10^{-34} \text{ J s}$

$N_A = 6.022 \times 10^{23} \text{ mol}^{-1}$

$R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$
$\quad = 0.08314 \text{ L bar mol}^{-1} \text{ K}^{-1}$

$F = 9.6485 \times 10^{4} \text{ C mol}^{-1}$

Some Useful Equations

$$PV = nRT \qquad E_n(\text{J}) = -2.179\times10^{-18}\times\frac{Z^2}{n^2}$$

$$\left(P+\frac{n^2a}{V^2}\right)(V-nb) = nRT \qquad \Delta U = q + w$$

$$\Delta E(\text{J}) = -Z^2\times2.179\times10^{-18}\left(\frac{1}{n_{\text{f}}^2} - \frac{1}{n_{\text{i}}^2}\right)$$

$$\Delta_{\text{r}}H^{\circ} = \Sigma\nu_{\text{p}}\Delta_{\text{f}}H^{\circ}_{\text{products}} - \Sigma\nu_{\text{r}}\Delta_{\text{f}}H^{\circ}_{\text{reactants}}$$

$$\ln\left(\frac{P_2}{P_1}\right) = \frac{-\Delta_{\text{vap}}H}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

$$\Delta_{\text{r}}H = \Delta_{\text{r}}U + \Delta nRT \qquad E_k = \frac{1}{2}m\text{v}^2$$

$$E_n = h\nu \qquad \lambda\nu = c$$

$$r_n = \frac{n^2a_{\text{o}}}{Z^2} \qquad u_{\text{rms}} = \sqrt{\frac{3RT}{M}} \qquad \lambda = \frac{h}{m\text{v}}$$

Conversion Factors

1 bar L = 100 J
1 atm L = 101.325 J

1 cal = 4.184 J (exactly)

1 L = 1 dm^3
1 mL = 1 cm^3

1 J = 1 kg m^2 s^{-2}

1 bar = 10^5 Pa = 100 kPa = 750.1 torr = 0.9869 atm