



# Université d'Ottawa • University of Ottawa

Faculté des sciences  
Chimie et Sciences Biomoléculaires

Faculty of Science  
Chemistry and Biomolecular Sciences

## CHM 1301

DATE: December 20, 2016  
9:30 pm

Dr. Rashmi Venkateswaran

TIME: 3 hours

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FULL STUDENT NAME: (Print) \_\_\_\_\_

STUDENT NUMBER: \_\_\_\_\_

### INSTRUCTIONS:

1. Write your answers on the exam. Please **BOLD** or **HIGHLIGHT** your final answer.
2. You are allowed to use electronic calculators during the exam (TI 30X, TI 34, TI 36, Casio 290 or 300).
3. Equations and constants are given on pages 17 and 18. A periodic table of the elements is included (page 19).
4. **Use the correct number of significant figures at all times.**
5. Marks allotted to each question are shown in brackets. The exam is out of 100.
7. Use the back of sheets for rough work. Three extra (blank) pages (14, 15 and 16) have also been included.
8. You are advised to read through the exam paper before you begin to write. Answer first those questions that you can do right away, proceeding to more difficult questions thereafter. Allow about ten minutes near the end of the exam period to read quickly through your answers, checking for obvious errors. **Good luck!**

**READ CAREFULLY:** Cellular phones, unauthorized electronic devices or course notes (unless an open-book exam) are not allowed during this exam. Phones and devices must be turned off and put away in your bag. Do not keep them in your possession, such as in your pockets. If caught with such a device or document, the following may occur: you will be asked to leave immediately the exam, academic fraud allegations will be filed which may result in you obtaining a 0 (zero) for the exam.

**By signing below, you acknowledge that you have read and ensured that you are complying with the above statement.**

Signature: \_\_\_\_\_

Quest.	1	2	3	4	5	6	7	8	9	10	
Marks	/10	/5	/10	/5	/10	/8	/12	/10	/10	/10	/90

- (10)** 1. (a) A microwave oven uses radiation having a wavelength of 12.2 cm and has a power of 750 W (1 W= 1J/s). If  $7.84 \times 10^{25}$  photons strike a cup of tea containing 250. mL of water at 25.0 °C, does the tea boil? How long has the microwave been operating? Assume that the density of the tea and its specific heat capacity are the same as those of water.

**[5]**

- (b) Photovoltaic cells convert solar energy into electricity. Could tantalum ( $\phi = 221.6$  kJ/mol) be used to convert visible light to electricity? Assume that most of the electromagnetic energy from the sun is in the visible region near 500 nm.

**[5]**

- (5) 2. Nitromethane,  $\text{CH}_3\text{NO}_2$ , can be used as a fuel. When the liquid is burned, the (unbalanced) chemical reaction is mainly:



- a) The standard enthalpy change of reaction ( $\Delta_r H^\circ$ ) for the balanced reaction (with the LOWEST WHOLE NUMBER COEFFICIENTS) is  $-1288.5 \text{ kJ/mol}$ . Calculate the enthalpy of formation of nitromethane given that the enthalpy of formation of gaseous water and carbon dioxide are  $-242$  and  $-393.5 \text{ kJ/mol}$  respectively.

[2]

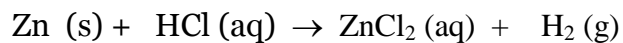
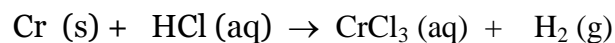
- (b) A  $15.0 \text{ L}$  flask containing a sample of nitromethane is filled with oxygen gas and the flask is heated to  $100.^\circ\text{C}$ . At this temperature, and after the reaction is complete, the total pressure of all the gases inside the flask is  $950. \text{ Torr}$ . If the mole fraction of nitrogen ( $X_{\text{nitrogen}}$ ) is  $0.134$  after the reaction is complete, what mass of nitrogen was produced?

[3]

- (10) 3. For each of the structures below, write the Lewis electron dot structure, determine the molecular geometry, the shape, the approximate bond angles and indicate if the structure is polar or not. If there are resonance structures, show them all and determine formal charges. Indicate if there is a most likely structure. Show your work.

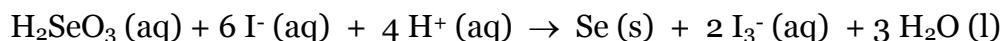


- (5) 4. A mixture of chromium and zinc has a mass of 0.362 g. The mixture is reacted with an excess of aqueous HCl and the following parallel reactions (unbalanced) occur:



225 mL of hydrogen gas was collected over water during the reaction at 750. Torr and 25 °C once the metals had reacted completely. What is the percent composition of the mixture (what mass percent Cr and Zn)? The vapour pressure of water at 25 °C is 23.8 Torr.

- (10) 5. a) The reaction below was studied at 0 °C and the data below was obtained (in the presence of an insignificant amount of  $I_3^-$ ):



Expt.	$[H_2SeO_3]_0$ (mol/L)	$[H^+]_0$ (mol/L)	$[I^-]_0$ (mol/L)	Initial Rate (mol/L·s)
1	$1.0 \times 10^{-4}$	$2.0 \times 10^{-2}$	$2.00 \times 10^{-2}$	$1.66 \times 10^{-7}$
2	$2.0 \times 10^{-4}$	$2.0 \times 10^{-2}$	$2.00 \times 10^{-2}$	$3.33 \times 10^{-7}$
3	$3.0 \times 10^{-4}$	$2.0 \times 10^{-2}$	$2.00 \times 10^{-2}$	$4.99 \times 10^{-7}$
4	$1.0 \times 10^{-4}$	$4.0 \times 10^{-2}$	$2.00 \times 10^{-2}$	$6.66 \times 10^{-7}$
5	$1.0 \times 10^{-4}$	$1.0 \times 10^{-2}$	$2.00 \times 10^{-2}$	$0.42 \times 10^{-7}$
6	$1.0 \times 10^{-4}$	$2.0 \times 10^{-2}$	$4.00 \times 10^{-2}$	$13.2 \times 10^{-7}$
7	$1.0 \times 10^{-4}$	$1.0 \times 10^{-2}$	$4.00 \times 10^{-2}$	$3.36 \times 10^{-7}$

- i) Determine the rate law expressed by this data.

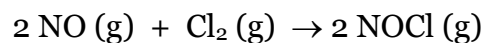
[4]

- ii) Calculate the rate constant with the CORRECT units.

- b) The decomposition of A occurs by the following unimolecular elementary reaction:  $A \rightarrow \text{products}$ . The rate constant at 273 K is  $2.3 \times 10^{-12} \text{ s}^{-1}$  and the activation energy is 111 kJ/mol. How long will it take for the concentration of A to decrease from an initial partial pressure of 2.5 bar to 1.5 bar at 500. K? You may assume that A is a gas and behaves ideally.

[3]

- c) The gas-phase reaction of nitrogen monoxide with chlorine proceeds to form nitrosyl chloride and the experimentally observed rate law is found to be:



$$\text{Rate} = k[\text{NO}]^2[\text{Cl}_2]$$

Evaluate the following proposed mechanism to determine whether it is consistent with the experimental results and identify intermediates or catalysts if any are present.

1.  $2 \text{NO (g)} \rightleftharpoons \text{N}_2\text{O}_2 \text{(g)}$  fast equilibrium
2.  $\text{N}_2\text{O}_2 \text{(g)} + \text{Cl}_2 \text{(g)} \rightarrow 2 \text{NOCl (g)}$  slow

How might you verify the mechanism?

**[3]**

- (8) 6.a) Determine the molar solubility of lead (II) fluoride in pure water.  $K_{sp}$  at 25 °C for lead (II) fluoride is  $3.7 \times 10^{-8}$ .

[4]

- b) Determine the molar solubility of lead (II) fluoride in a solution of 0.025 mol/L calcium fluoride.

[4]

(12) 7.(a) Suppose that 30.0 mL of 0.12 mol/L  $\text{C}_6\text{H}_5\text{COOH}$  (aq) (benzoic acid) is titrated with 0.20 mol/L  $\text{KOH}$  (aq). ( $K_a$  for benzoic acid is  $6.5 \times 10^{-5}$ ).

i) What is the original pH of the solution of  $\text{C}_6\text{H}_5\text{COOH}$  (aq)?

**[2]**

ii) What are the volume of  $\text{KOH}$  added AND the pH of the solution halfway through the titration?

**[2]**

iii) What is the pH at the equivalence point?

**[4]**

(b) What volume of 0.200 mol/L  $\text{K}_2\text{CO}_3$  (aq) must be added to 100 . mL of 0.100 mol/L  $\text{KHCO}_3$  (aq) in order to prepare a buffer solution with a pH of 11.0?  $K_a$  for  $\text{HCO}_3^-$  is  $5.61 \times 10^{-11}$ .

**[4]**

- (10) 8. a) The equilibrium constant  $K$  for the reaction  $\text{CCl}_4(\text{g}) \rightleftharpoons \text{C}(\text{s}) + 2 \text{Cl}_2(\text{g})$  at  $700^\circ\text{C}$  is 0.76. Determine the initial pressure of carbon tetrachloride that will produce a total equilibrium pressure of 1.20 bar at the same temperature.

[6]

- (b) A steel ball having a diameter of 2.3 cm is heated to  $412^\circ\text{C}$  and dropped into a calorimeter containing 125 mL of water at  $17.1^\circ\text{C}$ . Given that the volume of a sphere is  $\frac{4}{3} \pi r^3$ , that steel has a specific heat capacity of  $0.51 \text{ J/g}^\circ\text{C}$  and a density of  $8.03 \text{ g/cm}^3$ , what is the final temperature of the system?

[4]

- (10) 9. An organic compound contains C, H, N, and O. Combustion of 0.1023 g of the compound in excess oxygen yielded 0.2766 g of carbon dioxide and 0.0991 g of water. A sample of 0.4831 g of the compound was analyzed for nitrogen. From this sample, at STP, 27.6 mL of dry  $N_2$  was obtained. In a third experiment, the density of the compound as a gas was found to be 4.02 g/L at 127 °C and 256 Torr. What are the empirical and molecular formulae of the compound?

- (10)** 10. Your parents are visiting you so they can attend your graduation. They are so proud because you have been selected as the valedictorian for your class! You have been asked to choose the course that had the biggest impact on you as an undergraduate and, of course, you choose chemistry! Using **any one** of the topics covered during the semester, explain (in an essay of minimum length 1 page and using at least 3 chemical concepts within your chosen topic that are clearly explained and not just repeated from class) how your understanding of this topic made an impact on your life.







## Equations and Constants

### Gas Laws

$$pV = nRT$$

$$p_{\text{total}} = p_1 + p_2 + p_3 + \dots$$

$$d = \frac{m}{V} = \frac{p(MM)}{RT}$$

$$KE = (1/2)mv_{\text{av}}^2$$

$$p_A = X_A p_T$$

$$X_A = \frac{n_A}{n_T}$$

$$u_{\text{rms}} = \sqrt{\frac{3RT}{MM}}$$

$$\frac{\text{rate of effusion of A}}{\text{rate of effusion of B}} = \sqrt{\frac{MM_B}{MM_A}}$$

$$P + \frac{n^2 a}{V^2} (V - nb) = nRT$$

### Equilibrium

$$K_p = K(RT)^{\Delta n}$$

$$K = [C]^c [D]^d / [A]^a [B]^b$$

$$K_{\text{sp}} = [C]^c [D]^d$$

### Acid/Base

$$pOH = -\log [OH^-]$$

$$pH = -\log [H^+]$$

$$pH + pOH = 14$$

$$K_a \cdot K_b = K_w$$

$$pH = pK_a + \log \frac{[A^-]}{[HA]}$$

$$pH = \frac{pK_{a1} + pK_{a2}}{2}$$

$$C_1 V_1 = C_2 V_2$$

$$\ln \left( \frac{K_1}{K_2} \right) = \frac{\Delta H^\circ}{R} \left( \frac{1}{T_2} - \frac{1}{T_1} \right)$$

### Electrochemistry

$$\Delta G^\circ = -nFE^\circ$$

$$E = E^\circ - \frac{RT}{zF} \ln(Q)$$

$$\text{Or } E = E^\circ - \frac{0.059}{z} \log(Q) \quad \text{at } 25^\circ\text{C}$$

$$Q = I \cdot t$$

### Quantum Mechanics

$$\lambda \cdot \nu = c$$

$$E = h \cdot \nu$$

$$m = \frac{h}{\lambda c}$$

$$\lambda = h/\mu$$

$$\text{Energy of state} = -2.178 \times 10^{-18} \text{ J} / n^2$$

$$\Delta x \cdot \Delta p \geq h / 4\pi$$

$$E = -C(1/n^2)$$

$$KE = h\nu - \phi$$

$$KE = (1/2)mv_{\text{av}}^2$$

### Liquids and Colligative Properties

$$\ln \left( \frac{p_1}{p_2} \right) = \frac{\Delta H^\circ}{R} \left( \frac{1}{T_2} - \frac{1}{T_1} \right)$$

$$P_{\text{solution}} = X_{\text{solvent}} \cdot P_{\text{solvent}}^\circ$$

$$\Delta T_{\text{BP}} = K_{\text{BP}} \cdot m$$

$$\Delta T_{\text{FP}} = K_{\text{FP}} \cdot m$$

$$\Delta T = K \cdot m \cdot i$$

$$\Pi = cRT$$

$$\text{molality} = n(\text{solute})/m(\text{solvent (kg)})$$

### General INFORMATION

$$n = \frac{m}{MM}$$

$$d = \frac{m}{V}$$

$$c = \frac{n}{V}$$

$$1 \text{ atm} = 760 \text{ Torr} = 760 \text{ mm Hg} = 1.01325 \times 10^5 \text{ Pa} = 1.01325 \text{ bar} = 101.325 \text{ kPa}$$

<b>Thermodynamics</b>	<b>Kinetics</b>
$\Delta U = q$	Rate = $k [A]^x[B]^y[C]^z$
$w_{\text{system}} = -p\Delta V$	Rate = $k$
$\Delta E = q + w$	Rate = $k[A]$
$\Delta H = \Delta E + p\Delta V$	Rate = $k[A]^2$
$q_p = \Delta E + p\Delta V$	$[A] = -kt + [A]_0$
$\Delta E = nC_v\Delta T$	$\ln[A] = -kt + \ln[A]_0$
$\Delta H = q_p = m C_p \Delta T$	$\ln\left(\frac{[A]_t}{[A]_0}\right) = -kt$
$C_p = C_v + R$	$1/[A] = kt + 1/[A]_0$
$\Delta_r H^\circ = \Delta_r n \Delta_f H^\circ(\text{products}) -$	$t = [A]_0 / 2k$
$\Delta_r n \Delta_f H^\circ(\text{reactants})$	$\ln 2 = kt$
$q_{\text{rev}} = -w_{\text{max}} = nRT \ln(V_2/V_1)$	$k = Ae^{-E_a/RT}$
$\Delta S = q_{\text{rev}} / T$	$\ln\left(\frac{k_1}{k_2}\right) = \frac{E_a}{R} \left(\frac{1}{T_2} - \frac{1}{T_1}\right)$
$\Delta S_{T_1-T_2} = nC_p \ln(T_2/T_1)$	<b>Bonding</b>
$\Delta S_{T_1-T_2} = nC_v \ln(T_2/T_1)$	$DE = k(Q_1 Q_2 / r)$
$\Delta S_{\text{surroundings}}^0 = \frac{q_{\text{surroundings}}}{T} = \frac{-\Delta H_{\text{sys}}}{T}$	$DH_{\text{rxn}} = \sum n_p D(\text{reactants}) -$
$\Delta G^0 = \Delta H^0 - T\Delta S^0$	$\sum n_r D(\text{products})$
$\Delta G = \Delta G^0 + RT \ln(Q)$	Formal Charge = #valence $e^-$ in free atom -
$\Delta G^0 = -RT \ln(K)$	#lone pair $e^-$ - $1/2(\# \text{ bonding } e^-)$

### Data For Water and Other Constants

Density $d_{\text{water}} = 1.00 \text{ g/mL (25}^\circ\text{C)}$		$c_{\text{water}} = 4.184 \text{ J g}^{-1} \text{ }^\circ\text{C}^{-1}$ (liquid)	
Avogadro's Number	$N$	$6.022 \times 10^{23}$	$\text{mol}^{-1}$
Boltzmann's constant	$k$	$1.30866 \times 10^{-23}$	$\text{J}\cdot\text{K}^{-1}$
Faraday's constant	$F$	96,485	$\text{C}\cdot\text{mol}^{-1}$
Gas constant	$R$	8.31451	$\text{J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}$
	$R$	0.08206	$\text{L}\cdot\text{atm}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}$
	$R$	0.0831451	$\text{bar}\cdot\text{L}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}$
	$R$	8.31451	$\text{kPa}\cdot\text{L}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}$
Mass of Electron	$m_e$	$9.10938188 \times 10^{-31} \text{ kg}$	
Planck's constant	$h$	$6.62608 \times 10^{-34}$	$\text{J}\cdot\text{s}$
Speed of Light	$c$	$2.99792458 \times 10^8$	$\text{m}\cdot\text{s}^{-1}$

$$K_w = 1.00 \times 10^{-14}$$

General Information:  $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

