

Department of Chemistry
Memorial University of Newfoundland
Chemistry 1050

FINAL EXAMINATION

Fall 2018

TIME: 3 hours

READ THE FOLLOWING CAREFULLY

1. This examination consists of 14 pages including a Data Sheet. Ensure that this examination paper is complete, *i.e.* that all **14 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	6	
3	8	
4	8	
5	9	
6	8	
7	11	
8	11	
9	12	
10	9	
11	10	
12	7	
13	9	
	Total Marks	/108

1. In alcohol fermentation, yeast converts glucose to ethanol and carbon dioxide:



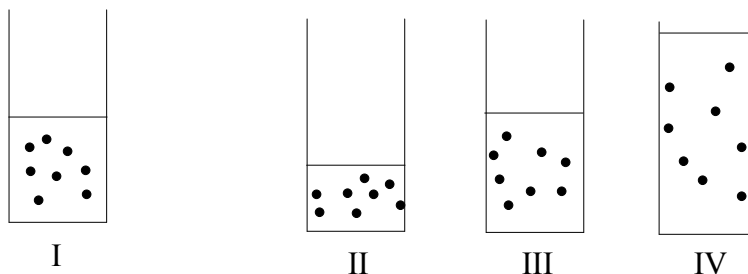
If 5.97 g of glucose reacts, and 1.44 L of CO_2 gas is collected at 293 K and 0.997 bar, then what is the percent yield of the reaction? **[4 marks]**

$$\text{MM} (\text{C}_6\text{H}_{12}\text{O}_6) = 180.1572 \text{ g mol}^{-1}$$

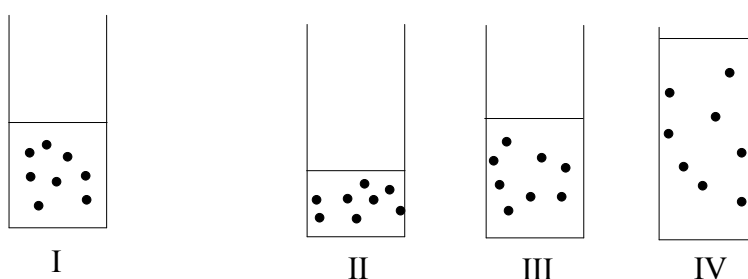
$$\text{MM} (\text{CO}_2) = 44.0098 \text{ g mol}^{-1}$$

2. Diagram I in each example depicts gas, in a cylinder of variable volume, under particular conditions. **[2 marks]**

- (a) Circle the diagram, II through IV, that correctly depicts the same amount of gas at the same temperature but double the pressure compared to that in diagram I.



- (b) Circle the diagram, II through IV, that correctly depicts the same amount of gas at twice the pressure and twice the absolute temperature (in K) compared to that in diagram I.



3. Three 5 L flasks are each filled with 4.0 g of gas at 298 K. Flask A is filled with H_2 (2.0159 g/mol), Flask B is filled with CH_4 (16.0426 g/mol) and Flask C is filled with CS_2 (76.1407 g/mol).

(a) i) With reference to the information given for Flasks A, B, and C, identify the gas having the particles with the greatest root mean square velocity. [1 mark]

ii) Calculate the root mean square velocity for CH_4 , methane (in m/s). [3 marks]

(b) In one hour, 0.315 mol of CH_4 effuses through a tiny hole. How many moles of CS_2 will effuse through the same hole in the same amount of time? [2 marks]

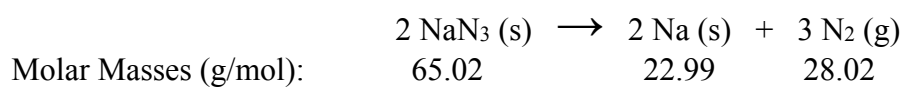
(c) (i) Assume the above gases are now placed in individual containers at STP. Rank the relative densities of the individual gases from smallest to largest. (No calculations are required). [1 mark]

_____ < _____ < _____
Smallest Largest

(ii) Explain your reasoning for the ranking of the gases. [1 mark]

4. A compound has an empirical formula of SF₄. At 20.0 °C, 0.100 g of the gaseous compound occupies a volume of 22.1 mL and exerts a pressure of 1.02 atm. What is the molecular formula of the gas? **[3 marks]**

5. Automobile air bags produce nitrogen gas from the reaction:



- (a) If 125 g NaN₃ reacts to fill an air bag, how much P-V work (in kJ) will the N₂ do against an external pressure of 101 kPa at 293 K?
[3 marks]

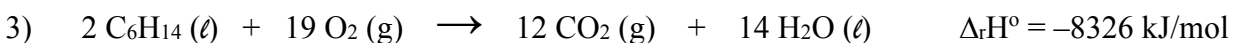
- (b) If the process releases 2.34 kJ of heat at constant pressure, then what is the change in internal energy, ΔU, for the system?
[1 mark]

- (c) What does the sign in **Part b** of this question indicate with respect to the relative energy flow between the system and its surroundings? **[1 mark]**

6. Consider the following information.

1) $\Delta_f H^\circ (\text{H}_2\text{O} (\ell)) = -285.8 \text{ kJ/mol}$

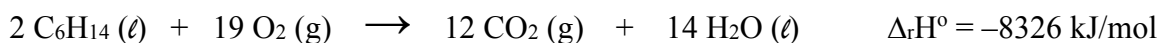
2) $\Delta_f H^\circ (\text{CO}_2 (\text{g})) = -393.5 \text{ kJ/mol}$



(a) Write the reaction equation for the standard molar enthalpy of formation for hexane, $\text{C}_6\text{H}_{14} (\ell)$, at 25°C . **[1 mark]**

(b) Using the information given above, calculate the standard heat of formation of $\text{C}_6\text{H}_{14} (\ell)$ at 25°C . **[3 marks]**

(c) Calculate the heat of reaction under constant pressure (ie. heat released) when 32.61 g of $\text{C}_6\text{H}_{14} (\ell)$ (86.1766 g/mol) reacts according to the following reaction. **[1 mark]**



7. (a) Distinguish between specific heat capacity and heat capacity. **[1 mark]**

(b) In comparing specific heat capacity and heat capacity, which is the extensive property and which is the intensive property. **[1 mark]**

(c) A 27.7 g sample of the radiator coolant ethylene glycol releases 688 J of heat. What is the initial temperature of the sample if the final temperature is 32.5°C ? (Specific heat capacity of ethylene glycol is $2.42 \text{ J/g}\cdot^\circ\text{C}$). **[2 marks]**

8. Isooctane is a component of gasoline and is used as a reference standard in determining the “octane rating” of a fuel mixture. Suppose 0.6950 g isooctane, C_8H_{18} (MM = 114.2302 g/mol), undergoes combustion in a bomb calorimeter and a temperature change from 25.000 °C to 28.310 °C is observed. The heat capacity of the bomb calorimeter is 9.980 kJ °C⁻¹.

(a) Write a balanced chemical equation for the combustion of one mole of isooctane, $C_8H_{18}(\ell)$, at 298.15 K. **[1 mark]**

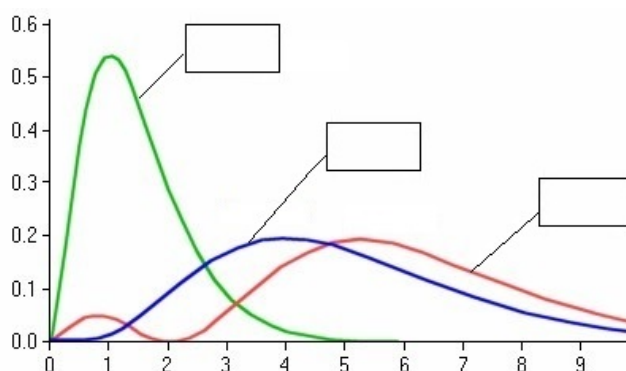
(b) Determine $\Delta_r U$ for the combustion of isooctane at 298.15 K. **[3 marks]**

(c) Determine $\Delta_r H$ for the combustion of isooctane at 298.15 K. **[1 mark]**

9. (a) What is the Aufbau principle? **[0.5 marks]**

(b) Below is a plot of the total radial probability diagram for the 1s, 2s and 2p orbitals.

On the plot, identify the curve that best represents the total radial probabilities for the 1s, 2s and 2p orbitals. **[1.5 marks]**



(c) Briefly explain why the 2s orbital is generally lower in energy than the 2p orbital. **[1 mark]**

10. (a) What is the energy (in kJ/mol) associated with light of wavelength of 330 nm? **[2 marks]**
- (b) (i) How many 4p orbitals are there in an atom? Explain, in terms of quantum numbers, how you came to your answer. **[2 marks]**
- (ii) What is the maximum number of electrons possible in the 4p orbitals of an atom? **[1 mark]**
- (c) Write a **full** electron configuration for a sodium atom. **[1 mark]**
- (d) Write the set of four quantum numbers that describe the valence electron(s) in sodium. **[1 mark]**
- (e) Is sodium diamagnetic or paramagnetic? **[1 mark]**
- (f) Write a **full** electron configuration for the +1 cation of sodium. **[1 mark]**
- (g) How would you expect the size of the sodium atom to compare to its +1 ion? Briefly explain your answer. **[2 marks]**

11. The following questions are related to the expected electron configurations in multielectron atoms and ions.

- (a) Identify the atom with the condensed ground state electron configuration of $[\text{Xe}]4f^{14}5d^{10}6s^26p^3$. [1 mark]
- (b) Write the condensed ground state electron configuration for zirconium, Zr. [1 mark]
- (c) Write a condensed ground state electron configuration and condensed orbital box diagram for cobalt, Co. [1 mark]
- (d) Write the charge and condensed ground state electron configuration for the most stable monoatomic ion formed by selenium, Se. [1 mark]
- (e) Using condensed ground-state electron orbital box diagrams, explain briefly why the two most common ions of tin are Sn^{2+} and Sn^{4+} . [2 marks]

12. Consider the following and provide the requested information. [1 mark each]

- (a) Order the following elements according to increasing Z_{eff} : Ca, Se, Kr, K

_____ < _____ < _____ < _____
Lowest Highest

- (b) Circle the element with the lowest electronegativity.

Pb C Sn Si

- (c) Circle the element with the largest atomic radius.

Au W S Fr Ne Zn

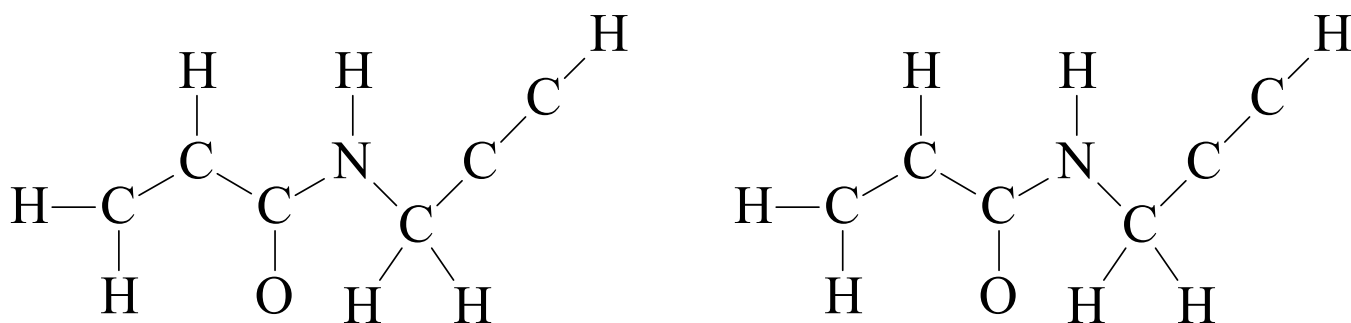
- (d) Arrange the following in order of increasing first ionization energy: F, K, P, Ca, Ne.

_____ < _____ < _____ < _____ < _____
Lowest Highest

- (e) Identify the Period 3 element with the following successive ionization energies, IE. (in kJ/mol).

$\text{IE}_1 = 1012$, $\text{IE}_2 = 1903$, $\text{IE}_3 = 2910$, $\text{IE}_4 = 4956$, $\text{IE}_5 = 6278$, $\text{IE}_6 = 22,230$

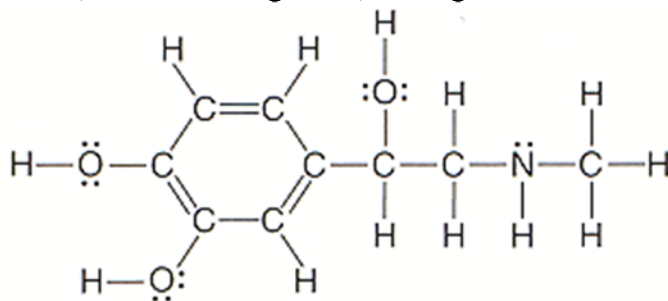
13. Write the balanced equations for the following. **[1 mark each]**
- (a) Write a balanced chemical equation to demonstrate the reaction between solid calcium and bromine gas.
- (b) Write a balanced chemical equation to demonstrate the reaction between solid magnesium and liquid water.
- (c) Write a balanced chemical equation to demonstrate the reaction between solid iodine and hydrogen gas.
14. Below is the skeletal structure for n-propargylacrylamide, C_6H_7NO . Complete the Lewis structure for n-propargylacrylamide by placing lone pairs and multiple bonds where required. Two skeletal structures are given (use one for practice, if necessary), circle the one you want graded. **[2 marks]**



15. Complete the following table to provide the missing data. For Lewis structures, the final structures should consider minimizing formal charge.

	Sulfur dibromide, SBr_2	Xenon tetrafluoride, XeF_4
Lewis Structure (1 mark each)		
Sketch of VSEPR predicted shape including bond angles (1 mark each)		
Name the molecular shape. (1 mark each)		
Is it polar or nonpolar? (0.5 mark each)		

16. Epinephrine (or adrenaline) is a naturally occurring hormone that is also manufactured commercially for use as a heart stimulant, a nasal decongestant, and a glaucoma treatment.



- (a) For the N atom in epinephrine, what is its shape and hybridization? [1 mark]

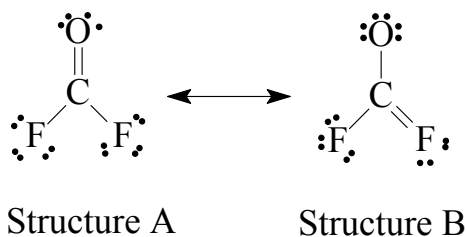
Shape: _____ Hybridization: _____

- (b) For the ring C atoms, what is their shape and hybridization? [1 mark]

Shape: _____ Hybridization: _____

- (c) How many π electrons are delocalized in the ring? [1 mark] _____

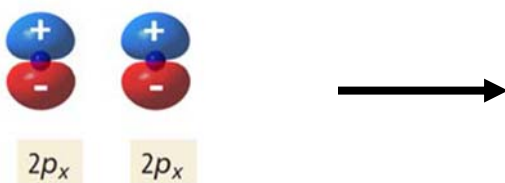
17. Consider the following resonance structures for COF_2 .



- (a) Assign formal charges to the atoms in the structures above by placing all nonzero formal charges next to the atom in the respective structures. [1 mark]
- (b) Identify the major contributor to the resonance hybrid and explain your reasoning. [1 mark]
- (c) For **Structure A** above, use valence bond and orbital hybridization theories to describe the bonding in this molecule. In doing so, you are required to provide a sketch illustrating and labelling the types of all the bonds in the molecule, sigma (σ) or pi (π) bonds, and the atomic and/or hybrid orbitals that overlap to form these bonds. [4 marks]

18. Answer the following questions:

- (a) Explain the main difference between molecular orbital theory and valence bond theory. **[1 mark]**
- (b) What is an antibonding orbital? **[1 mark]**
- (c) Sketch and correctly label any 3d orbital. In your drawing include orbital phases (+ or -) and appropriately label xyz axes. **[1 mark]**
- (d) Below are two $2p_x$ orbitals. Sketch and label the phases (+ and -) of the *antibonding* π^*_{2p} molecular orbital they would generate. **[1 mark]**



19. Using molecular orbital theory, provide the following:

- (a) Draw molecular orbital energy level diagrams for the following two species: He_2 and HHe . (Treat HHe as a diatomic molecule with three electrons.) In your diagrams, remember to label all atomic and molecular orbitals and place the correct number of electrons in the MOs. **[2 marks each]**

Molecular Orbital Diagram for He_2

Molecular Orbital Diagram for HHe

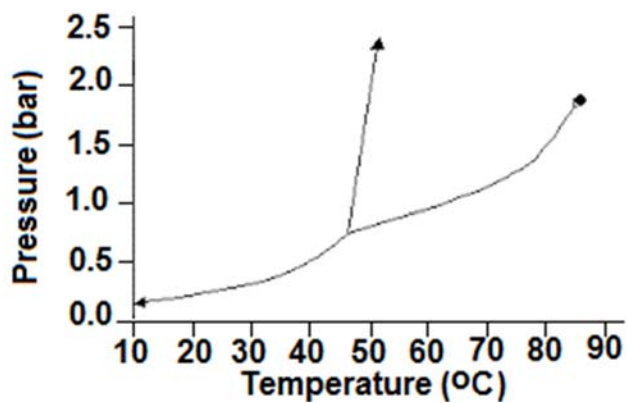
- (b) Determine the bond order for each of He_2 and HHe . **[1 mark each]**

Bond order for He_2

Bond order for HHe

21. The vapour pressure of benzene, C_6H_6 , is 0.053 bar at 281 K. What is its vapor pressure at 334 K? The molar heat of vaporization of benzene is 31.0 kJ/mol. **[3 marks]**

22. Consider the following phase diagram for hexane below.



- (a) On the phase diagram above, label the following: **[0.5 mark each]**
- (i) Solid
 - (ii) Liquid
 - (iii) Gas
 - (iv) Triple point
 - (v) Critical Point
 - (vi) Supercritical fluid
- (b) What does the term “triple point” mean with respect to a phase diagram? **[1 mark]**
- (c) Using the diagram above, determine the **normal boiling point** (in °C) of hexane. **[1 mark]**
- (d) Determine the phase change that takes place as the pressure of hexane is reduced from 1.0 bar to 0.5 bar at 40 °C. **[1 mark]**

The End

Periodic Table of the Elements

1 H 1.01																	18 He 4.00																														
3 Li 6.94	4 Be 9.01											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18																														
11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95																														
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 51.99	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.63	33 As 74.92	34 Se 78.97	35 Br 79.90	36 Kr 83.80																														
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.95	43 Tc 98.91	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.6	53 I 126.90	54 Xe 131.29																														
55 Cs 132.91	56 Ba 137.33	57-71 Lanthanides	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.09	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po [208.98]	85 At 209.99	86 Rn 222.02																														
87 Fr 223.02	88 Ra 226.03	89-103 Actinides	104 Rf [261]	105 Db [262]	106 Sg [266]	107 Bh [264]	108 Hs [269]	109 Mt [278]	110 Ds [281]	111 Rg [280]	112 Cn [285]	113 Nh [286]	114 Fl [289]	115 Mc [289]	116 Lv [293]	117 Ts [294]	118 Og [294]																														
<table border="1"> <tr> <td>57 La 138.91</td> <td>58 Ce 140.12</td> <td>59 Pr 140.91</td> <td>60 Nd 144.24</td> <td>61 Pm 144.91</td> <td>62 Sm 150.36</td> <td>63 Eu 151.96</td> <td>64 Gd 157.25</td> <td>65 Tb 158.93</td> <td>66 Dy 162.50</td> <td>67 Ho 164.93</td> <td>68 Er 167.26</td> <td>69 Tm 168.93</td> <td>70 Yb 173.06</td> <td>71 Lu 174.97</td> </tr> <tr> <td>89 Ac 227.03</td> <td>90 Th 232.04</td> <td>91 Pa 231.04</td> <td>92 U 238.03</td> <td>93 Np 237.05</td> <td>94 Pu 244.06</td> <td>95 Am 243.06</td> <td>96 Cm 247.07</td> <td>97 Bk 247.07</td> <td>98 Cf 251.08</td> <td>99 Es [254]</td> <td>100 Fm 257.10</td> <td>101 Md 258.1</td> <td>102 No 259.10</td> <td>103 Lr [262]</td> </tr> </table>																		57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm 144.91	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.06	71 Lu 174.97	89 Ac 227.03	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np 237.05	94 Pu 244.06	95 Am 243.06	96 Cm 247.07	97 Bk 247.07	98 Cf 251.08	99 Es [254]	100 Fm 257.10	101 Md 258.1	102 No 259.10	103 Lr [262]
57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm 144.91	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.06	71 Lu 174.97																																	
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Constants

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

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

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

$$\text{specific heat of } \text{H}_2\text{O}(l) = 4.184 \text{ J g}^{-1} \text{ K}^{-1}$$

$$\text{specific heat of } \text{H}_2\text{O}(s) = 1.960 \text{ J g}^{-1} \text{ K}^{-1} \text{ at } 0^\circ \text{C}$$

$$\text{density of } \text{H}_2\text{O}(l) \text{ near } 0^\circ \text{C} = 1.000 \text{ g mL}^{-1}$$

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

$$R_H = 1.0973 \times 10^7 \text{ m}^{-1}$$

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

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

$$R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$$

$$= 0.08314 \text{ L bar mol}^{-1} \text{ K}^{-1}$$

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

Some Useful Equations

$$PV = nRT \quad E_n(\text{J}) = -2.179 \times 10^{-18} \times \frac{Z^2}{n^2}$$

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

$$\Delta E(\text{J}) = -Z^2 \times 2.179 \times 10^{-18} \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$$

$$\Delta_r H^\circ = \sum \nu_p \Delta_f H_{\text{products}}^\circ - \sum \nu_r \Delta_f H_{\text{reactants}}^\circ$$

$$\ln \left(\frac{P_2}{P_1} \right) = \frac{-\Delta_{\text{vap}} H}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right) \quad E_k = \frac{1}{2} mv^2$$

$$\Delta_r H = \Delta_r U + \Delta n RT$$

$$E_n = h\nu \quad \lambda \nu = c \quad \lambda = \frac{h}{m\nu}$$

$$r_n = \frac{n^2 a_0}{Z^2} \quad u_{\text{rms}} = \sqrt{\frac{3RT}{M}} \quad \frac{\text{rate}_A}{\text{rate}_B} = \sqrt{\frac{M_B}{M_A}}$$

Conversion Factors

$$1 \text{ bar L} = 100 \text{ J}$$

$$1 \text{ atm L} = 101.325 \text{ J}$$

$$1 \text{ cal} = 4.184 \text{ J (exactly)}$$

$$1 \text{ L} = 1 \text{ dm}^3$$

$$1 \text{ mL} = 1 \text{ cm}^3$$

$$1 \text{ J} = 1 \text{ kg m}^2 \text{ s}^{-2}$$

$$1 \text{ bar} = 10^5 \text{ Pa} = 100 \text{ kPa} = 750.1 \text{ torr} = 0.9869 \text{ atm}$$