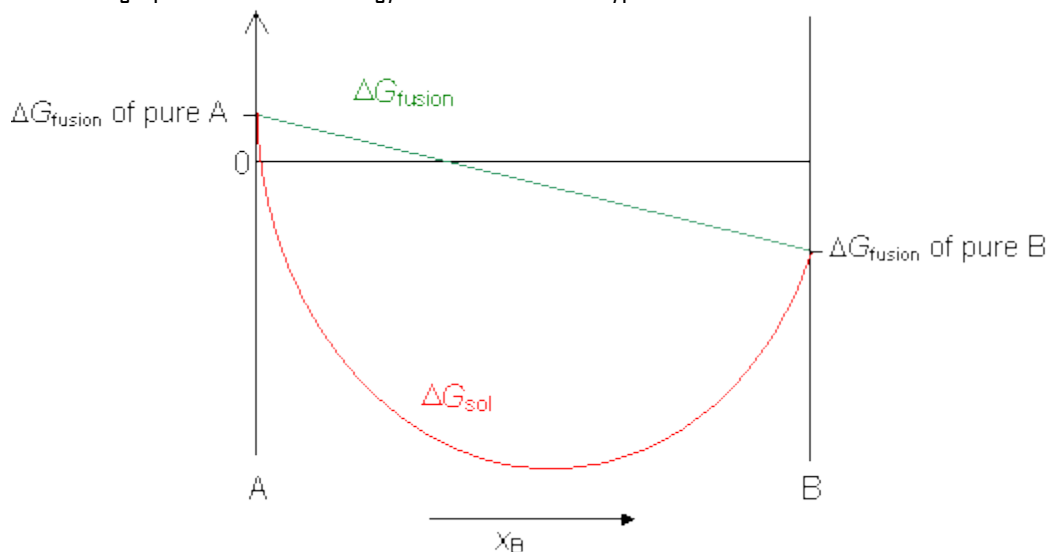


Chemistry Lab 2016-2017  
Thermodynamics and Gases

**Part 1: Thermodynamics**

Multiple Choice: (1 point each)

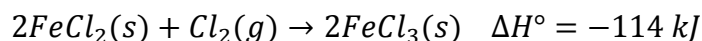
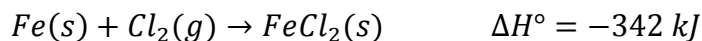
- Which of the following are state functions
  - Enthalpy
  - Work
  - Heat
  - Gibb's Free Energy
  - I and II only
  - I and III only
  - I, II, and III only
  - I and IV only
  - I, II, III, and IV
- For the reaction  $2H_2(g) + O_2(g) \rightleftharpoons 2H_2O(g)$ , which of the following must be true?
  - The reaction is endothermic
  - $\Delta E$  is greater than  $\Delta H$
  - The reaction is spontaneous
  - The transition state's geometry resembles the products more so than the reactants
- Below is a graph of Gibb's Free Energy vs. the extent of a (hypothetical) reaction.



Which of the following is true?

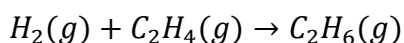
- A. Pure A is more stable than pure B
  - B. The shape of the curves are independent of temperature and pressure
  - C. The shape of the curves are independent of the composition and phases of the compounds
  - D. The minima of the red curve is the equilibrium position of the reaction
4. Which of the following is true of a coffee-cup calorimeter?
- A. The reaction occurs at constant volume and  $\Delta H = q$
  - B. The reaction occurs at constant pressure and  $\Delta H = q$
  - C. The reaction occurs at constant volume and  $\Delta H = q + w$
  - D. The reaction occurs at constant pressure and  $\Delta H = q + w$
5. Consider the hypothetical reaction  $A(g) + 2B(g) \rightarrow 2C(g)$  with  $\Delta H = -20.72 \frac{\text{kJ}}{\text{mol}}$  at standard conditions. What is  $\Delta U$  in  $\frac{\text{kJ}}{\text{mol}}$ ?
- A. -18.24
  - B. -20.72
  - C. -23.20
  - D. -16.52
  - E. -21.97

For questions 6 - 8 use the following information:



6. What principle is employed to find the enthalpy change of the reaction  $\text{Fe}(s) + \text{Cl}_2(g) \rightarrow \text{FeCl}_3(s)$ ?
- A. Conservation of Energy
  - B. The Zeroth Law of Thermodynamics
  - C. Hess's Law
  - D. Clairaut's Theorem
7. What is the standard enthalpy change for the reaction in question 6?
- A. -456 kJ
  - B. -399 kJ
  - C. -912 kJ
  - D. -798 kJ
8. What is the standard enthalpy of formation for  $\text{FeCl}_2(s)$ ?
- A. -342 kJ
  - B. -114 kJ
  - C. -456 kJ
  - D. 114 kJ

9. Given the table of average bond dissociation energies, calculate the enthalpy change, in kilojoules per mole, of the reaction:

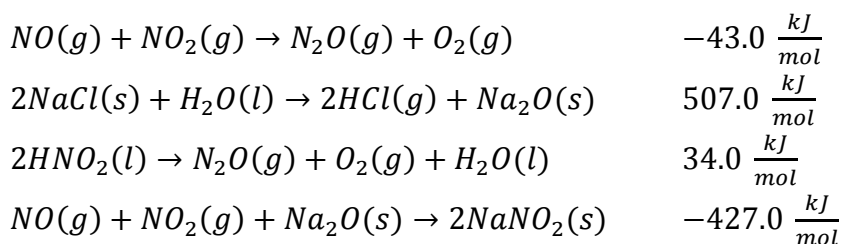


Bond	BDE ( $\frac{kJ}{mol}$ )	Bond	BDE ( $\frac{kJ}{mol}$ )
$H - H$	436	$C - C$	350
$C - H$	410	$C = C$	728

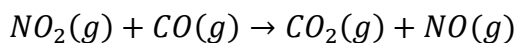
- A. -6  
B. 6  
C. -384  
D. 384
10. The standard enthalpy of formation for  $CaCO_3$  is  $-1207.6 \frac{kJ}{mol}$ . When 30.7 g of calcium is reacted with excess carbon dioxide, how much heat is transferred?  
A. 370.4 kilojoules is evolved  
B. 370.4 kilojoules is absorbed  
C. 925.0 kilojoules is evolved  
D. 925.0 kilojoules is absorbed
11. What mass of ice at  $-1.4^\circ C$  added to 74 g of liquid water at  $74^\circ C$  will result in a mixture of pure water at  $0.0^\circ C$ ?  
A. 2.05 g  
B. 42.44 g  
C. 68.05 g  
D. 82.30 g
12. Three different metals at  $75^\circ C$  with the same mass are all placed in water at  $25^\circ C$ . Which of the following is true?  
A. The metal with the greatest specific heat capacity will exhibit the greatest temperature change  
B. The metal with the highest melting point will exhibit the greatest temperature change  
C. The metal with the lowest specific heat capacity will exhibit the greatest temperature change  
D. The metal with the lowest melting point will exhibit the greatest temperature change
13. Which of the following correctly describes bond dissociation energy?  
A. The amount of energy absorbed when a bond is broken homolytically  
B. The amount of energy absorbed when a bond is broken heterolytically  
C. The amount of energy released when a bond is broken homolytically  
D. The amount of energy released when a bond is broken heterolytically
14. Which of the following processes are exothermic?  
I. The first ionization of gaseous lithium  
II. The electron affinity of gaseous fluorine

- III. The combustion of methanol
- A. I only  
B. I and III only  
C. II and III only  
D. III only
15. For a reaction with a positive  $\Delta G$ , which of the following is true?  
A.  $K < 0$   
B.  $K < 1$   
C.  $K > 1$   
D. The reaction is spontaneous
16. What is the average kinetic energy of a molecule of argon at  $30^\circ\text{C}$ ? You may assume that all gases are ideal.  
A.  $3.78 * 10^3 \text{ J}$   
B.  $3.73 * 10^1 \text{ J}$   
C.  $6.28 * 10^{-21} \text{ J}$   
D.  $6.19 * 10^{-23} \text{ J}$
17. The entropy of aqueous solutions is measured relative to a specific substance. What is this substance?  
A.  $\text{H}_2\text{O}$   
B.  $\text{H}^+$   
C.  $\text{OH}^-$   
D.  $\text{F}^-$
18. Which of the following types of processes/reactions are always spontaneous at standard conditions?  
I. Sublimation  
II. Substitution  
III. Exergonic  
A. I only  
B. III only  
C. II and III only  
D. I, II, and III
19. A reaction occurs. It releases  $30 \text{ kJ}$  of heat and does  $10 \text{ kJ}$  of expansion work. What is the overall change in internal energy?  
A.  $40 \text{ kJ}$   
B.  $20 \text{ kJ}$   
C.  $-20 \text{ kJ}$   
D.  $-40 \text{ kJ}$
20. What is the difference between Gibb's Free Energy and Helmholtz Free Energy  
A. Gibb's Free Energy is used in chemical thermodynamics while Helmholtz Free Energy is used in statistical thermodynamics  
B. Gibb's Free Energy is a macroscopic property while Helmholtz Free Energy is a microscopic property  
C. Gibb's Free Energy is an extensive property while Helmholtz Free Energy is an intensive property

- D. Gibb's Free Energy is used with processes under constant pressure while Helmholtz Free Energy is used with processes under constant volume and temperature
21. What is true of the macroscopic thermodynamic equilibrium of a chemical reaction?
- It is static
  - There is maximum entropy
  - There is nonzero heat flow
  - There are systems that have no thermodynamic equilibrium
22. What is a reaction called when the temperature remains constant?
- Isothermal
  - Adiabatic
  - Carnotic
  - Caloric
23. Calculate  $\Delta H^\circ$  for the reaction  $NaCl(s) + HNO_2(l) \rightleftharpoons HCl(g) + NaNO_2(s)$  given the following information:



- $157 \frac{kJ}{mol}$
  - $71.0 \frac{kJ}{mol}$
  - $78.5 \frac{kJ}{mol}$
  - $35.5 \frac{kJ}{mol}$
24. Compared to the value of  $\Delta H_f^\circ$  for  $H_2O(l)$ , the value of  $\Delta H_f^\circ$  for  $H_2O(g)$  is has the...
- Opposite sign and same magnitude
  - Same sign and greater magnitude
  - Opposite sign and greater magnitude
  - Same sign and smaller magnitude
  - Opposite sign and smaller magnitude
25. Given the table of standard molar entropies, find the value of  $\Delta S^\circ$  for the reaction

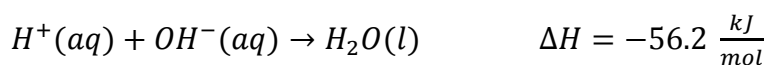


Compound	$\Delta S^\circ \left( \frac{J}{mol * K} \right)$	Compound	$\Delta S^\circ \left( \frac{J}{mol * K} \right)$
$NO(g)$	210.8	$CO(g)$	197.7
$NO_2(g)$	240.1	$CO_2(g)$	213.7

- A.  $13.3 \frac{J}{mol \cdot K}$
- B.  $-13.3 \frac{J}{mol \cdot K}$
- C.  $26.6 \frac{J}{mol \cdot K}$
- D.  $-26.6 \frac{J}{mol \cdot K}$

Short Answer:

1. A neutralization reaction is a chemical reaction in which an acid and a base react with each other. Given the following information, answer the questions below.



- a. 0.200 g of oxalic acid is reacted with 0.450 g of aluminum hydroxide. Write the balanced chemical reaction. You may assume precipitation will occur. (1 point)
  - b. What is the limiting reactant? (1 point)
  - c. How many grams of excess reactant are there? (1 point)
  - d. What is the heat produced from this reaction if there is no precipitation? (1 point)
  - e. If only 30.4 J of heat was produced, what was the percent yield? (1 point)
2. When subjected to sufficiently high temperatures and pressures, liquid benzene vaporizes into gaseous benzene. Benzene has a normal boiling point 353.2 K and exhibits a vapor pressure of 0.526 atm at 333.6 K.
- a. Calculate benzene's enthalpy of vaporization. (2 points)
  - b. Calculate  $\Delta S$  for the vaporization of benzene. (2 points)

- c. Given that  $\Delta H_f^\circ$  for gaseous benzene is  $82.9 \frac{\text{kJ}}{\text{mol}}$ , what is the standard enthalpy of formation for liquid benzene? (2 points)
3. The combustion of hydrocarbons leads to the formation of water and carbon dioxide. But when nitrogen-containing compounds are combusted, a mixture of products are obtained. Consider the combustion of ethylenediamine,  $C_2H_4(NH_2)_2$ . At high temperatures (above 500 Kelvin), a mixture of  $NO$  and  $NO_2$  is obtained.
- a. Write a balanced chemical reaction for the combustion of ethylenediamine at high temperatures. You may assume that the ethylenediamine to oxygen ratio in the reaction is 2 to 11. (1 point)

- b. Given the table of formation enthalpies, calculate  $\Delta H$  at 500 Kelvin. (2 points)

Compound	$\Delta H_f^\circ$	Compound	$\Delta H_f^\circ$
$C_2H_4(NH_2)_2$	-62.9	$H_2O(g)$	-241.8
$CO_2$	-393.5	$NO$	90.3
$H_2O(l)$	-285.8	$NO_2$	33.2

- c. If  $\Delta G^\circ$  for the reaction is  $55 \frac{\text{kJ}}{\text{mol}}$ , calculate  $\Delta S$  at 500 Kelvin. (1 point)

## Part 2: Gases

### Multiple Choice: (1 point each)

1. A 2.0 liter container contains 2.5 moles of nitrogen gas at  $600^\circ\text{C}$ . What is the pressure of the nitrogen gas in atmospheres?
- A. 3.56  
 B. 15.2  
 C. 42.3  
 D. 89.5

2. What is the pressure exerted by the nitrogen gas under real conditions? For nitrogen,  $a = 1.370 \frac{L^2 \cdot atm}{mol^2}$  and  $b = 0.0387 \frac{L}{mol}$ .
- A. 5.50 atm
  - B. 31.2 atm
  - C. 92.0 atm
  - D. 103 atm
3. For an ideal gas, what will a graph of  $P$  vs.  $V$  give you?
- A. A direct relationship
  - B. An inverse relationship
  - C. A horizontal line at a nonzero pressure value
  - D. No discernible relationship
4. The density of gas A is four that of gas B at the same temperature and pressure. How do their molar masses compare?
- A. Gas A's molar mass is four times that of gas B
  - B. Gas B's molar mass is four times that of gas A
  - C. Gas A and gas B's molar masses are equal
  - D. There is not enough information to compare their molar masses
5. Consider the hypothetical reaction  $A(g) + 3B(l) \rightleftharpoons 2C(g) + 2D(g)$ . Compounds A, B, C, D are all placed in a container and allowed to reach equilibrium. If the volume that the compounds occupy is reduced, what will happen to the partial pressure of C?
- A. It will increase
  - B. It will decrease
  - C. It will remain the same
  - D. It depends on the temperature
6. How many grams of krypton gas are in a 1.0 L container at 70°F and 2.0 atmospheres of pressure?
- A. 5.95
  - B. 6.94
  - C. 29.2
  - D. 40.2
7. A sample of fluorine gas effuses at  $300 \frac{m}{s}$  at a certain temperature. An unknown gas effuses at  $462 \frac{m}{s}$  at the same temperature. What is the identity of this unknown gas?
- A. Neon
  - B. Hydrogen
  - C. Methane
  - D. Helium
8. What is the root mean square speed of hydrogen chloride gas at 285 Kelvin?
- A.  $328 \frac{m}{s}$



- B.  $255 \frac{m}{s}$   
C.  $389 \frac{m}{s}$   
D.  $442 \frac{m}{s}$
9. Rank the following gases in order of increasing vapor pressure:  $CO_2, H_2, SO_2, HF$ .
- A.  $HF, CO_2, SO_2, H_2$   
B.  $SO_2, CO_2, HF, H_2$   
C.  $H_2, HF, CO_2, SO_2$   
D.  $HF, SO_2, CO_2, H_2$   
E.  $SO_2, H_2, HF, CO_2$
10. Given that water has an enthalpy of vaporization of  $40.7 \frac{kJ}{mol}$ , what would be its vapor pressure at  $350 K$  in atmospheres?
- A. 0.206  
B. 0.422  
C. 0.697  
D. 1.00

For questions 11 – 13, use the following information:

Equal masses of carbon dioxide and methane gases are placed into a massless jar containing a sample of an unknown gas. The total pressure in the jar is 5 atmospheres and you may assume the three do not react with each other.

11. The partial pressure of carbon dioxide is  $0.94 atm$ . What is the mole fraction of methane in the jar?
- A. 0.94  
B. 0.47  
C. 0.38  
D. 0.19
12. What is the partial pressure of the unknown gas?
- A.  $0.94 atm$   
B.  $2.00 atm$   
C.  $2.58 atm$   
D.  $4.06 atm$
13. You find out that the mass of the filled jar is three times the mass of the methane gas inside. What is the identity of the unknown gas inside?
- A. Ammonia  
B. Ethane  
C. Nitrogen  
D. Oxygen
14. What type of catalysts do catalytic converters use?
- A. Heterogeneous

- B. Homogeneous
  - C. Nonmetal oxides
  - D. Metalloids
15. Which greenhouse gas has the most direct contribution to the greenhouse effect?
- A. Ozone
  - B. Methane
  - C. Carbon dioxide
  - D. Water vapor
16. Which property is the same for two samples of two different gases at the same temperature?
- A. Conditions of triple point
  - B. Number of molecules
  - C. Average molecular velocity
  - D. Average kinetic energy
17. The molar mass of an unknown gas is 300 *g*. What is its density at STP in grams per liter, assuming ideal behavior?
- A. 13.4
  - B. 6920
  - C. 201
  - D. 26.7
18. Consider three identical sealed flasks at the same temperature and pressure all containing 0.200 moles of gas. However, one flask contains argon gas, one contains nitrogen gas, and one contains xenon gas. Which of the following is true?
- I. The mass of the flask containing the xenon is the greatest
  - II. The number of molecules in each flask is the same
  - III. The density of the constituents of each flask is the same
- A. I only
  - B. II only
  - C. I and II only
  - D. II and III only
19. In the van der Waals equation of state, what do the constants *a* and *b* symbolize?
- A. The forces of attraction between the molecules and the volume occupied by the molecules respectively
  - B. The volume occupied by the molecules and the forces of attraction between the molecules respectively
  - C. The forces of attraction between the molecules and the pressure gradient between different molecules respectively
  - D. The volume occupied by the molecules and the pressure gradient between different molecules respectively

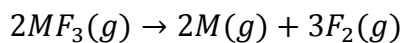
Short Answer:

- I. Iron metal reacts with acids to produce hydrogen gas and  $Fe^{3+}$  ions.
  - a. Write a balanced chemical equation for this reaction. (1 point)

b. A hypothetical sample of iron is reacted with excess acid and 100.4 mL of gas is collected over water at 670 torr and 30°C. Assuming ideal behavior, determine the mass of the sample. (1 point)

c. Assuming ideal behavior, determine the number of molecules of hydrogen gas that would be produced. (1 point)

2. A 0.055 mole sample of  $MF_3$  is added to an evacuated 2.50 liter container. The container is sealed, is heated to 300°C, and establishes the following equilibrium:



At equilibrium, the pressure in the container is 1.50 atmospheres.

a. Calculate the pressure in the container at 300°C had the reaction not occurred. (1 point)

b. Calculate the equilibrium partial pressures of all of the participant molecules. (3 points)

c. What are the values of  $K_p$  and  $\Delta G$  at 300°C? (2 points)

3. Given the following table of percent mass compositions for a molecule, answer the following questions.

Element	C	H	O
Percent Composition	40.68	5.12	54.20

- a. Determine the empirical formula of this molecule. (1 point)
- b. Given that the molar mass of the molecule is  $118.09 \frac{g}{mol}$ , determine its molecular formula. (1 point)
- c. Write a balanced chemical reaction for the combustion of this molecule. (1 point)
- d. At  $745 \text{ mm Hg}$  and  $30^\circ\text{C}$ , one mole of this compound is combusted. Determine the volume of gas produced under ideal conditions. (2 points)
- e. At  $778 \text{ mm Hg}$  and  $384 \text{ K}$ , one mole of this compound is combusted. Determine the volume of gas produced under ideal conditions. (2 points)