CHEMISTRY 202   Name _____KEY_____

Hour Exam II
October 26, 2023   Signature _____
Dr. D. DeCoste

                                                 T.A. _____

This exam contains 22 questions on 10 numbered pages. Check now to make sure you have a complete exam. You have two hours to complete the exam. Determine the **best** answer to the first 20 questions and enter these on the special answer sheet. Also, circle your responses in this exam booklet. **Show all of your work and/or provide complete answers to questions 21 and 22.**

1-20	(60 pts.)	_____
21	(30 pts.)	_____
22	(30 pts.)	_____
Total	(120 pts.)	_____

Useful Information:
- Always assume ideal behavior for gases (unless explicitly told otherwise).
- 760 torr = 1.00 atm
- R = 0.08206 Latm/molK = 8.314 J/Kmol
- K = °C + 273
- $N_A = 6.022 \times 10^{23}$

$\Delta E = q + w$ $H = E + PV$
$\Delta S = q_{rev}/T$ $G = H - TS$

Here are some of the formulas we used/derived in studying thermodynamics. An individual formula may or may not apply to a specific problem. This is for you to decide!

$\Delta S = nR\ln(V_2/V_1)$ $\Delta S = \Delta H/T$ $C_v = (3/2)R$ $C_p = (5/2)R$

$\Delta S = nC\ln(T_2/T_1)$ $\Delta G = \Delta G° + RT\ln(Q)$ $\Delta S_{surr} = -q/T$

$w = -P\Delta V$ $q_{rev} = nRT\ln(V_2/V_1)$ $q = nC\Delta T$

$\ln(K) = -\dfrac{\Delta H°}{R}\left(\dfrac{1}{T}\right) + \dfrac{\Delta S°}{R}$ $\ln\left(\dfrac{K_2}{K_1}\right) = -\dfrac{\Delta H°}{R}\left(\dfrac{1}{T_2} - \dfrac{1}{T_1}\right)$

---

1. The enthalpy of vaporization for a liquid at 298K is 100.0 kJ/mol. Determine ΔE for this process at 298K.

    a) 75.5 kJ/mol   b) 97.5 kJ/mol   c) 100.0 kJ/mol   d) 102.5 kJ/mol   e) 124.5 kJ/mol

2. In a coffee-cup calorimeter, a 3.14-g sample of a sodium hydroxide is dissolved in 100.0 g of water at an initial temperature of 25.0°C. Use the data below to determine the final temperature of the solution. Assume the specific heat capacity of the solution is constant at 4.18 J/g°C, that enthalpy values are independent of temperature, and that there is no heat transfer to or out of the calorimeter.

	NaOH(s)	NaOH(aq)
ΔH_f° (kJ/mol)	–427.0	–470.0

    a) 16.9°C   b) 17.2°C   c) 25.0°C   d) 32.8°C   e) 33.1°C

3. Given: $2CO(g) \rightarrow 2C(graphite) + O_2(g)$ $\Delta H^\circ = +222$ kJ
             $2CO(g) + O_2(g) \rightarrow 2CO_2(g)$ $\Delta H^\circ = -566$ kJ

    Calculate the standard enthalpy of formation of $CO_2(g)$.

    a) –172 kJ/mol   b) –344 kJ/mol   c) –394 kJ/mol   d) 172 kJ/mol   e) 344 kJ/mol
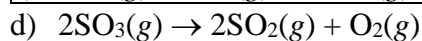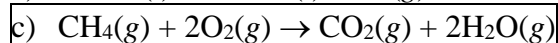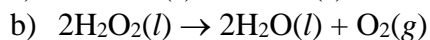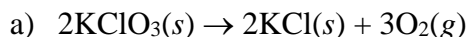
4. As we will see when we discuss electrochemistry in Chemistry 204 next semester, the value of ΔH_f° for $H^+(aq)$ is given as 0 (zero). The value of ΔH_{rxn}° for the reaction between magnesium metal and HCl(aq), which produces $MgCl_2$(aq) and hydrogen gas, is –462 kJ/mol. With this information, determine the value of ΔH_f° for $Mg^{2+}(aq)$.

    a) –924 kJ/mol   b) –462 kJ/mol   c) –231 kJ/mol   d) 462 kJ/mol   e) 924 kJ/mol

5. Suppose we use ΔH_f° values for a substance as a liquid and a vapor to estimate the value of $\Delta H_{vaporization}$ (that is we assume that the enthalpy values are temperature independent). How does the value of $\Delta H_{vaporization}$ for a substance at its boiling point without this assumption compare? Note: generally, the heat capacity of a substance as a liquid is greater than the heat capacity of that substance as a vapor.

    a) If the boiling point of the substance is below 25.0°C, the value of $\Delta H_{vaporization}$ at the boiling point is greater than the value we get if we assume temperature independence. If the boiling point of the substance is above 25.0°C, the value at the boiling point is smaller.

    b) If the boiling point of the substance is below 25.0°C, the value of $\Delta H_{vaporization}$ at the boiling point is smaller than the value we get if we assume temperature independence. If the boiling point of the substance is above 25.0°C, the value at the boiling point is greater.

    c) The value of $\Delta H_{vaporization}$ at the boiling point is always greater than the value we get if we assume temperature independence, no matter the boiling point.

    d) The value of $\Delta H_{vaporization}$ at the boiling point is always smaller than the value we get if we assume temperature independence, no matter the boiling point.

6. For which of the following reactions, at constant temperature and pressure, is the value of $\Delta H°$ closest to the value of $\Delta E°$?

a) $2KClO_3(s) \rightarrow 2KCl(s) + 3O_2(g)$
b) $2H_2O_2(l) \rightarrow 2H_2O(l) + O_2(g)$
c) $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$
d) $2SO_3(g) \rightarrow 2SO_2(g) + O_2(g)$
e) For a chemical reaction the values of $\Delta H°$ and $\Delta E°$ are always the same.

7. Use the following data to determine the value of $S°$ for $H_2O(s)$. Assume ΔH and ΔS are temperature independent.

	$H_2O(l)$	$H_2O(s)$
$\Delta H_f°$ (kJ/mol)	−286	−292
$S°$ (J/Kmol)	70.0	?

a) −22.0 J/K   b) 20.0 J/K   c) 22.0 J/K   d) 48.0 J/K   e) 92.0 J/K

8. Consider the one-step isothermal expansion and then one-step isothermal compression of 1.00 mole of an ideal, monatomic gas such that volume of the gas is the same before and after the process. For how many of the following: q, ΔH, ΔS, and ΔG, are the magnitudes of the values the same in the expansion and compression?

a) 0   b) 1   c) 2   d) 3   e) 4

---

9 – 12. Consider a 1.000 mole sample of an ideal, monatomic gas in a steel rigid container at 1.000 atm that is currently at 250.0°C. The container with the gas is moved outside and allowed to come to equilibrium with the new environment (1.000 atm and 25.0°C). Assume the container is a perfect conductor of heat.

9. Determine ΔH for the process that occurs.

a) −4.677 kJ   b) −2.806 kJ   c) 1.871 kJ   d) 2.806 kJ   e) 4.677 kJ

10. Determine ΔS for the process that occurs.

a) −11.69 JK   b) −7.015 J/K   a) 4.677 J/K   d) 7.015 J/K   e) 11.69 J/K

11. Determine ΔS_{surr} for the process that occurs.

a) −8.943 J/K   b) 0 J/K   c) 8.943 J/K   d) 9.416 J/K   e) 15.69 J/K

12. Determine ΔG for the process that occurs. Note: at 25.0°C, $S° = 65.0$ J/K for the gas.

a) −2.586 kJ   b) −715.5 J   c) 0 kJ   d) 2.586 kJ   e) 13.62 kJ

13. For which of the following is the difference between the value of ΔG_f° and the value of ΔH_f° (both in units of kJ/mol) closest to zero?

    a) $NH_3(g)$　　　　 b) $N_2H_4(l)$　　　　 c) $H_2O(g)$　　　　 d) $H_2O(l)$　　　　 e) $HF(g)$

----

14 – 15. At constant pressure and temperature, the reaction $2HF(g) \rightarrow H_2(g) + F_2(g)$ is **not spontaneous at any temperature**.

14. Given that ΔH_f° for $HF(g) = -271$ kJ/mol, which of the following is true about the value of ΔG_f° for $HF(g)$ in units of kJ/mol?

    a) The sign of ΔG_f° for $HF(g)$ is negative and the magnitude (absolute value) is greater than 271.
    b) The sign of ΔG_f° for $HF(g)$ is positive and the magnitude (absolute value) is greater than 271.
    c) The sign of ΔG_f° for $HF(g)$ is negative and the magnitude (absolute value) is less than 271.
    d) The sign of ΔG_f° for $HF(g)$ is positive and the magnitude (absolute value) is less than 271.
    e) We cannot tell anything from this information about ΔG_f° for $HF(g)$.

15. Given that the values of S° for $H_2(g)$ and $F_2(g)$ are 131 J/K and 203 J/K, respectively, which of the following is true about the value of S° for $HF(g)$?

    a) The minimum possible value of S° for $HF(g)$ is +167 J/K.
    b) The maximum possible value of S° for $HF(g)$ is +167 J/K.
    c) The only possible value of S° for $HF(g)$ is exactly +167 J/K.
    d) We cannot determine the magnitude of S° for $HF(g)$, but the sign must be negative.
    e) We cannot tell anything from this information about S° for $HF(g)$.

----

16 – 17. You are filling a balloon with helium, and you inflate it to 31.4 L at 1.00 atm and 25°C. You are filling it from a 100.0-L tank that is initially at 25.0 atm and 25°C. Determine:
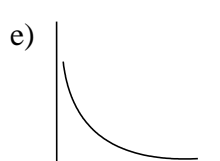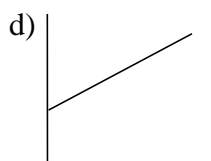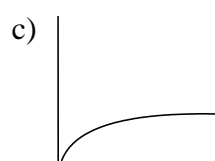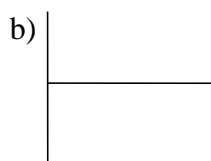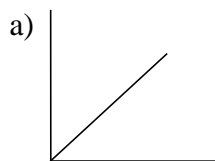
16. ΔS for the helium filling the balloon.

    a) 0 J/K　　　　 b) 26.8 J/K　　　　 c) 34.4 J/K　　　　 d) 51.5 J/K　　　　 e) 66.9 J/K

17. ΔS for the helium remaining in the tank.

    a) –23.3 J/K　　　　 b) 0 J/K　　　　 c) 10.6 J/K　　　　 d) 23.3 J/K　　　　 e) 26.8 J/K

18-20.   Indicate which of the graphs below best represents each plot described in questions 18, 19, and 20. Note: the graphs may be used once, more than once, or not at all.

a)   b)   c)

d)   e)

18. Magnitude of work (y) vs. the number of steps (x) for the isothermal compression of one mole of an ideal, monatomic gas.   e

19. Enthalpy, H, (y) vs. pressure, P, (x) for one mole of an ideal monatomic gas at constant temperature, T.   b

20. ln(K) (y) vs. 1/T (x) for an exothermic chemical reaction.   d

21. We discussed solubility rules when studying solutions (Chapter 4) and you probably recall the one that states "Most chloride salts are soluble. Exceptions: silver, (etc.)" This, of course, tells us what happens, but doesn't provide any support for why it happens. Thermodynamics to the rescue!

Use the following data (courtesy of Appendix 4 from the textbook) when answering the questions below. As always, **explain your answers** and **show all work**. Use the next page if needed.

	AgCl(*s*)	NaCl(*s*)	Ag⁺(*aq*)	Na⁺(*aq*)	Cl⁻(*aq*)
ΔH_f° **(kJ/mol)**	−127	−411	105	−240	−167
S° **(J/mol K)**	96	72	73	59	57

Consider the process of the ionic solids silver chloride and sodium chloride dissolving into their respective ions (called dissolution) in separate beakers of water.

• Use the data above to show that it is reasonable to label NaCl as soluble and AgCl as insoluble. **Show all work** and **explain your answers**.
• Are these labels (soluble and insoluble) **temperature dependent**? If they are not, **explain** why not and **support** your answer. If they are, **for what temperature ranges** do they apply? **Show all work** and **explain any assumptions**.
• Determine the **ratio** of the concentration of the chloride ion in a saturated solution of NaCl(*aq*) to the concentration of the chloride ion in a saturated solution of AgCl(*aq*). **Show all work** and **explain the significance** of your answer.
• Suppose you add enough NaCl(*s*) to water at 25.0°C to make 1.00 L of a saturated solution. Given that the heat capacity of a saturated solution of NaCl(*aq*) is 2.48J/g°C and has a density equal to 1.2 g/mL, **determine the final temperature** of the saturated NaCl(*aq*) solution. **Show all work** and **explain any assumptions.**

• **Ratio = 4.05 x 10⁵**. There is over 400,000 times as much chloride ion in the NaCl solution than the AgCl solution, showing us that it is much, much more soluble.

• **16.5°C**.

21.   Continue work on this problem below, if needed.

22. When we first started studying thermodynamics, I stated that we will be able to explain observations; that is the "*why*". We all know *what* will happen in many situations, but by studying thermodynamics we are able to support this both qualitatively (conceptually) and quantitatively (with numbers and equations). In this problem you will consider two scenarios. Please provide answers for everything addressed in the bullet points.

   a. **Thermal equilibrium.** What we know to be true: If we place two objects that are initially at different temperatures in contact with each other, they will eventually reach the same temperature.

      • Use the ideas of the **kinetic molecular theory** to **explain why** two objects placed in contact with each other will reach the same temperature.

      Suppose we have a 200.0 g block of copper (Cu) metal at 20.0°C and put it in contact with a 100.0 g block of copper metal that has a temperature of 80.0°C. Assume the heat capacity of copper has a value of 0.385 J/g°C and is temperature independent.

      • Provide **quantitative support** (using equations we have discussed in our studies) that reaching the same final temperature is spontaneous for the two blocks of copper. **Show and explain all work** and **list any assumptions**.
      • We discussed how the first law of thermodynamics allows for the hot object to get hotter (increase in temperature) and the cold object to get colder (decrease in temperature) as long as energy is conserved. For the 100.0 g block of copper to reach 90.0°C, determine the final temperature of the 200.0 g block of copper. **Show all work**. Is this process spontaneous? Provide **quantitative support** and **explain your answer**.

      Show all work and **explain your answers**. Use the next page if needed. **[15 pts.]**

   • ΔS_{univ} = 0.4542 J/K, which is positive, so it is spontaneous.

   • ΔS_{univ} = –0.2498 J/K, which is negative, so it is not spontaneous.

22.   a.   Continue work on this problem below, if needed.

22.   b.   **Evaporation.** What we know to be true: A liquid left open to the atmosphere will eventually evaporate completely.

- For the evaporation of any liquid, **explain** which factor makes the process more thermodynamically favorable, and which factor makes the process less thermodynamically favorable. Make sure to **discuss why**.

Consider acetone (CH_3COCH_3) which is often used in fingernail polish remover. If you've ever been in the same room with somebody applying fingernail polish remover, you can smell the acetone pretty quickly, letting us know that it is evaporating readily. Here are the relevant thermodynamic data for acetone:

	CH_3COCH_3 (*l*)	CH_3COCH_3 (*g*)
ΔH_f° **(kJ/mol)**	–249	–218
S° **(J/mol K)**	201	294

- Use the data in the table above to show that acetone exists as a liquid at room conditions (25°C and 1 atm). **Explain** your work and **discuss and justify** any assumptions.
- Use the data in the table above to show that the evaporation of acetone is indeed spontaneous at room conditions (25°C and 1 atm). **Show all work** and **explain your answer**.

Show all work and **explain your answers**. Use the next page if needed. **[15 pts.]**

- $T_{boil} = 333K = 60°C$, meaning at room temperature (about 25°C), acetone is a liquid.

- As long as the partial pressure of acetone vapor is at or greater than 1 atm (which it cannot do in a large room), it will condense. Less than this (see below for the number), it will evaporate completely (eventually).
- Could also determine K (K_p) which is 0.265 at 25°C, meaning the vapor pressure of acetone at this temperature is 0.265 atm. So as long as the partial pressure stays below this, it will evaporate.

22.   b.   Continue work on this problem below, if needed.