CHEMISTRY 202
Hour Exam II
October 31, 2024
Dr. D. DeCoste

Name KEY

Signature ______________________

T.A. ______________________

This exam contains 22 questions on 8 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
- $N_A = 6.022 \times 10^{23}$

$\Delta E = q + w$

$\Delta S = q_{rev}/T$

$H = E + PV$

$G = H - TS$

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!

$\Delta S = nR\ln(V_2/V_1)$

$\Delta S = \Delta H/T$

$C_v = (3/2)R$

$C_p = (5/2)R$

$\Delta S = nC\ln(T_2/T_1)$

$\Delta G = \Delta G° + RT\ln(Q)$

$\Delta S_{surr} = -q/T$

$E = (3/2)RT$

$w = -P\Delta V$

$q_{rev} = nRT\ln(V_2/V_1)$

$q = nC\Delta T$

$$\ln(K) = -\frac{\Delta H^\circ}{R}\left(\frac{1}{T}\right) + \frac{\Delta S^\circ}{R}$$

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

1. Given the following data, determine the value of Δ*E* (in kJ/mol) for the condensation of methanol (CH_3OH) at 25°C and 1.00 atm.

	$CH_3OH(l)$	**$CH_3OH(g)$**
ΔH_f° (kJ/mol)	–239.0	–201.0

a) –40.5 [✓ b) –35.5] c) 35.5 d) 38.0 e) 40.5

2. Consider the reaction $2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$ carried out at 25°C in a bomb calorimeter with a heat capacity of 62.3 kJ/K. A 2.00 mol sample of $SO_2(g)$ is reacted completely with 1.00 mol of $O_2(g)$ and the temperature of the calorimeter increases by 3.14°C. Calculate Δ*H* for this process.

[✓ a) –198.1 kJ] b) –195.6 kJ c) –193.1 kJ d) 193.1 kJ e) 195.6 kJ

3. Suppose that you carry out two experiments in coffee-cup calorimeters in which you add a heated metal to a sample of water and measure the final temperature of the water. In both cases you start with the metals at the same temperature, and you have the same mass of water at the same temperature. The final temperature after each experiment is the same. In one case you added zinc (Zn; c = 0.387 J/g°C) and in the other case aluminum (Al; c = 0.890 J/g°C). Determine the ratio of the mass of the zinc to the mass of the aluminum.

a) 0.413 b) 0.435 c) 1.00 [✓ d) 2.30] e) 2.42

4. 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

Determine the standard enthalpy of formation of CO(*g*).

a) –394 kJ/mol b) –344 kJ/mol [✓ c) –111 kJ/mol] d) 344 kJ/mol e) 394 kJ/mol

5. Your goal is to add enough liquid water at 25.0°C to ice at –10.0°C in a perfectly insulated Styrofoam cup calorimeter so that you end up with nothing but water. Given the following information, which statement below best describes the relative amounts of ice and water required (in terms of masses)?

- Molar heat capacity of $H_2O(s)$ = 37.5 J/mol°C
- Molar heat capacity of $H_2O(l)$ = 75.3 J/mol°C
- ΔH_{fusion} = 6.01 kJ/mol

[✓ a) You need to add at least 3.4 times as much liquid water as ice.]
b) You need to add at least 3.4 times as much ice as liquid water.
c) You need to add at least 5 times as much liquid water as ice.
d) You need to add at least 5 times as much ice as liquid water.
e) You need to add at least 21 times as much liquid water as ice.

6. Which of the following statements is **true** for an isothermal expansion of 1.00 mole of an ideal, monatomic gas?

   a) The value of ΔG is greater than zero because the expansion is spontaneous.
   b) The value of ΔG is less than zero because the expansion is spontaneous.
   c) The value of ΔG is greater than zero because the expansion is not spontaneous.
   d) The value of ΔG is less than zero because the expansion is not spontaneous.
   [✓ e) None of these statements is true.]

7. For how many of the following does the magnitude of ΔH equal the magnitude of q?

   - An isothermal free expansion of 1.00 mole of an ideal, monatomic gas.
   - An isothermal reversible expansion of 1.00 mole of an ideal, monatomic gas.
   - An isothermal one-step expansion of 1.00 mole of an ideal, monatomic gas against a constant pressure.
   - An isothermal reversible compression of 1.00 mole of an ideal, monatomic gas.

   a) 0 [✓ b) 1] c) 2 d) 3 e) 4

8. The following chemical reactions are all spontaneous at standard conditions. How many of them are predicted to be **exothermic** at standard conditions?

   - Hydrogen gas reacts with nitrogen gas to make ammonia gas (NH_3).
   - Phosphorous trichloride gas reacts with chlorine gas to produce phosphorous pentachloride gas.
   - Nitrogen dioxide gas reacts to form dinitrogen tetroxide gas.
   - Liquid hydrogen nitrate reacts with nitrogen monoxide gas to produce nitrogen dioxide gas and liquid water.

   a) 0 b) 1 c) 2 [✓ d) 3] e) 4

9-10. Use the following data for questions 9 and 10.

	ΔH_f° (kJ/mol)	**heat capacity (J/Kmol)**
$O_2(g)$	0	29.40
$O_3(g)$	143.0	39.20

9. Determine ΔH for $3O_2(g) \rightarrow 2O_3(g)$ at 125°C. Assume heat capacity values are temperature independent but do **not** assume enthalpy values are independent of temperature.

   a) –694.0 kJ [✓ b) 285.0 kJ] c) 286.0 kJ d) 694.0 kJ e) 1266 kJ

10. Which of the following statements is **true** concerning the reaction $3O_2(g) \rightarrow 2O_3(g)$?

   a) It is most likely spontaneous at room temperature (25°C).
   b) It is most likely spontaneous at very high temperatures.
   c) It is most likely spontaneous at very low temperatures.
   d) It is most likely spontaneous at any temperature.
   [✓ e) It is most likely not spontaneous at any temperature.]

11. Imagine that a 1.00 kJ sample of heat is transferred from a 1,000 kg body of water at 99°C to a 1,000 kg body of water at 1°C. Which of the following best estimates ΔS_{univ} for this?

a) –300 J/K [✓ b) 1 J/K] c) 10 J/K d) 300 J/K e) 1000 J/K

12. Suppose the volume of an ideal gas is decreased at constant temperature. Which of the following (a-c) increases in value?

[✓ a) G_{gas}]
b) H_{gas}
c) S_{gas}
d) At least two of the above (a-c) increase in value.
e) None of the above (a-c) increase in value.

13. Consider two containers, each with 0.333 mol samples of an ideal, monatomic gas at 25°C. A quantity of 83.14 J heat is added to each sample. Sample 1 is at constant volume, Sample 2 is at constant pressure. Determine ratio of final temperatures, in Celsius, for Sample 1/Sample 2.

a) 0.600 b) 0.822 c) 1.00 [✓ d) 1.22] e) 1.67

14. For which of the following is the difference between the value of $\Delta G_f°$ and the value of $\Delta H_f°$ (both in units of kJ/mol) expected to be the **largest**?

a) $NH_3(g)$ b) $H_2O(g)$ [✓ c) $N_2O_4(g)$] d) $HCl(g)$ e) $HF(g)$

15. If we use the following data and assume ΔH and ΔS are independent of temperature, what is our estimate for the boiling point of water at 1 atm?

	$\Delta G_f°$ (kJ/mol)	$\Delta H_f°$ (kJ/mol)
$H_2O(l)$	–237	–286
$H_2O(g)$	–229	–242

[✓ a) 91.2°C] b) 97.4°C c) 100.°C d) 105°C e) 111°C

16. Of $\Delta G_f°$, $\Delta H_f°$, $S°$, and c, how many have a value of zero for all elements in their standard states?

a) 0 b) 1 [✓ c) 2] d) 3 e) 4

17. For how many of the following is the value of ΔS for the reaction expected to increase if all gases (reactants and products) are at 10 atm instead of 1 atm?

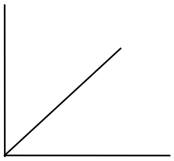
- $2CO(g) + O_2(g) \rightarrow 2CO_2(g)$
- $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$
- $2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$
- $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$

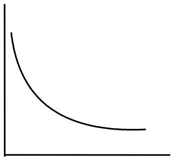
a) 0 b) 1 c) 2 [✓ d) 3] e) 4

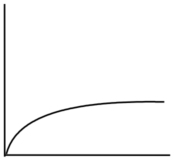
18. Consider a 1.00 mol sample of an ideal, monatomic gas in a container fitted with a frictionless, massless piston at 4.00 atm and 25°C. The gas is allowed to expand isothermally and reversibly until the final volume is two times the original volume. The gas is then compressed isothermally in one step back to the original pressure. Which of the following is true about the overall heat involved?

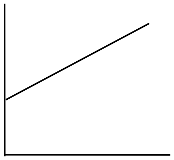
[✓ a) Overall, 760. J of heat is released into the surroundings.]
b) Overall, 760. J of heat is absorbed from the surroundings by the gas.
c) Overall, 1.24 kJ of heat is released into the surroundings.
d) Overall, 1.24 kJ of heat is absorbed from the surroundings by the gas.
e) Overall, the change in heat into or out of the surroundings is equal to zero.

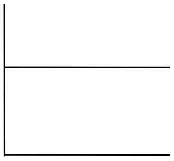
19-20. Indicate which of the graphs below best represents each plot described in questions 19 and 20. Note: the graphs may be used once, more than once, or not at all.

a)


b)


c)


d)


e)


19. The magnitude of heat transferred (y) vs. the number of steps (x) for an isothermal expansion of one mole of an ideal, monatomic gas. c

20. Internal energy, E, (y) vs. volume (x) for one mole of an ideal gas at constant temperature. e

21. Consider a calorimetry experiment in which you mix 100.0 mL of a 1.00*M* aqueous solution of HCl with 100.0 mL of a 1.00*M* aqueous solution of NaOH, both at 25.00°C, in a coffee cup calorimeter. In doing so, you note that the temperature of the product solution **increases** by 6.68°C from that of the original solutions. The reaction mixture then returns to 25.00°C.

    For this problem, assume that the density of each solution is 1.00 g/mL, and the specific heat capacity of all solutions is equal to 4.18 J/g°C.

    a. Given the following information, **determine the value of $\Delta H_f°$**, in kJ/mol, for the **hydroxide ion** in solution. **Show all work**, and briefly **explain** your **process** and any **assumptions**. **Full credit** is reserved for **deriving any equations** that you use that are not on the front of the exam. **Please limit your answer to this page.** [**18 points**]

        - $2H_2(g) + O_2(g) \rightarrow 2H_2O(g) \quad \Delta H° = -483.63$ kJ
        - Standard enthalpy of vaporization of water = 43.9 kJ/mol
        - $\Delta H_f°$ for the aqueous hydrogen ion = 0 kJ/mol

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$\Delta H_f°$ for $OH^-(aq)$ = **–230. kJ**

21. b. Given the previous calorimetry data and the following values of *S*°, **determine the value** of the **equilibrium constant**, *K*, for the reaction that occurred in the calorimeter when balanced in standard form and allowed to return to 25.00°C. **Explain the significance** of this value. Also, **is the spontaneity of the reaction temperature dependent?** If so, **determine the temperature range** when the reaction is spontaneous. If not, **explain why not**. **Please limit your answer to this page.** [**12 points**]

Show all work, and briefly **explain** your **process** and any **assumptions**. **Full credit** is reserved for **deriving any equations** that you use that are not on the front of the exam

	$H_2O(l)$	$H^+(aq)$	$OH^-(aq)$
***S*° (J/mol K)**	69.91	0	–10.54

- **$K = 9.8 \times 10^{13}$**.

22. Consider a container fitted with a frictionless, massless piston containing 1.00 mole of a monatomic, ideal gas at 1.00 atm and 323°C. You carry out two experiments.

Experiment #1: You place the container with the gas (1.00 atm, 323°C) in a room at 1.00 atm and 25.0°C. You allow the system to come to equilibrium with the environment.

Experiment #2: You lock the piston in place on the container with the gas (1.00 atm, 323°C). You place the container with the gas in a room at 1.00 atm and 25.0°C and allow the gas to reach thermal equilibrium with the room. You then unlock the piston and allow the system to come to equilibrium with the environment.

- **Show in both cases** that the gas at 323°C will **spontaneously** reach equilibrium with the environment. **Show all work**, briefly **explain your process**, and **explain** what is meant by *thermal equilibrium* and *equilibrium with the environment.*
- **Discuss the relative spontaneities of the two experiments.** Is one case more spontaneous than the other, or are they equally spontaneous? **Support your answer** with **calculations** and also **explain qualitatively** why this **makes sense**.

Full credit is reserved for **deriving any equations** that you use that are not on the front of the exam. Please use the next page, if needed. [**30 points**]

Experiment 1:

- ΔS_{univ} = **6.378 J/K**
- **$\boldsymbol{\Delta S_{\text{univ}}}$ is positive**, so the **process is spontaneous**.

Experiment 2:

- ΔS_{univ} = **6.378 J/K**
- **$\boldsymbol{\Delta S_{\text{univ}}}$ is positive**, so the **process is spontaneous**.

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