CHEMISTRY 202
Hour Exam II
October 30, 2025
Dr. D. DeCoste

Name ______________________________

Signature ___________________________

T.A. _______________________________

This exam contains 22 questions on 11 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.**

Please limit your answers to the front of the pages provided and write legibly and so that we can follow your thought process. Take some time to think these through before you start writing.

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!

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

$\Delta S = \Delta H/T$

$C_v = (3/2)R$

$C_p = (5/2)R$

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

$\Delta G = \Delta G^\circ + RT\ln(Q)$

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

$E = (3/2)RT$

$w = -P\Delta V$

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

$q = nC\Delta T$

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

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

1. Baking soda ($NaHCO_3$) and vinegar (a 0.850*M* aqueous solution of acetic acid, $HC_2H_3O_2$) react to form $NaC_2H_3O_2(aq)$, $H_2O(l)$, and $CO_2(g)$. The value of ΔH°_{rxn} for this reaction is 26.4 kJ/mol of baking soda. You react 10.0 g of baking soda with 100.0 mL of vinegar, both at 25.0°C. Determine the temperature of the solution after the reaction is complete. Assume the mass of the solution is 110.0 g and the heat capacity of the solution is 4.18 J/g°C.

   a) 18.2°C b) 20.1°C c) 29.9°C d) 31.8°C e) 36.7°C

2. Isopropyl alcohol ($(CH_3)_2CHOH$), also known as rubbing alcohol, has a boiling point of 82.6°C at 1.00 atm. Determine the enthalpy of vaporization of isopropyl alcohol at its boiling point. Assume heat capacity values are temperature independent but do **not** assume enthalpy values are independent of temperature.

	ΔH°_f (kJ/mol)	**heat capacity (J/Kmol)**
$(CH_3)_2CHOH(g)$	–272.8	89.32
$(CH_3)_2CHOH(l)$	–318.2	161.2

   a) –49.5 kJ/mol b) –45.4 kJ/mol c) –41.3 kJ/mol d) 41.3 kJ/mol e) 49.5 kJ/mol

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3, 4. Consider the following reactions:

Reaction I: Solid potassium chlorate ($KClO_3$) decomposes to form solid potassium chloride and oxygen gas.
Reaction II: Hydrogen gas reacts with nitrogen gas to make ammonia gas (NH_3).
Reaction III: Phosphorous trichloride gas reacts with chlorine gas to produce phosphorous pentachloride gas.
Reaction IV: Nitrogen dioxide gas reacts to form dinitrogen tetroxide gas.

Answer the following in terms of "moles of reaction" when considered as balanced in standard form.

3. For which of the reactions above is the **magnitude** of $\Delta H - \Delta E$ the **largest**?

   a) I b) II c) III d) IV e) At least two for I-IV are equally largest.

4. How many of the reactions above is the **value** of $\Delta H - \Delta E$ **greater than zero**?

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

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5. You have a sample of an ideal, monatomic gas and that is compressed and allowed to expand isothermally. For how many of the following cases is $\Delta S_{univ} = 0$?

   - The gas is compressed in one step and expands in one step.
   - The gas is compressed reversibly and expands in one step.
   - The gas is compressed in one step and expands reversibly.
   - The gas is compressed reversibly and expands reversibly.

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

6. Consider two containers each with 1.00 mole of a gas at 25.0°C. Container #1 is at constant volume and Container #2 is at constant pressure. A quantity of 314 J of heat is transferred to each. The gas in Container #1 changes by 15.1°C, and the gas in Container #2 changes by 11.6°C. Which of the following best describes the gas?

   a) It is not monatomic and does not behave ideally.
   b) It is not monatomic but does behave ideally.
   c) It is monatomic and behaves ideally.
   d) It is monatomic but does not behave ideally.
   e) There is no way to tell from these data.

7. Consider two containers each with 1.00 mole of an ideal, monatomic gas at 25.0°C. Container #1 is at constant volume and Container #2 is at constant pressure. Heat is transferred to each such that the change in entropy of the gas in each container is the same. If the higher temperature gas has twice the kinetic energy it had originally, determine the ratio of the final temperatures in Container 1 compared to Container 2.

   a) 0.630 b) 0.758 c) 1.00 d) 1.32 e) 1.59

8. How many of the following statements are **true**?

   - The magnitude of ΔS_{surr} is always greater than the magnitude of ΔS for a given irreversible isothermal compression of a monatomic, ideal gas.
   - The magnitude of work, w, for any irreversible, isothermal compression of a sample of an ideal gas from P_1 and V_1 to P_2 and V_2 is always greater than the magnitude of work, w, for any irreversible isothermal expansion of that sample of ideal gas from P_2 and V_2 to P_1 and V_1.
   - The overall value of ΔS for the isothermal expansion and then isothermal compression of an ideal gas back to its original state is always equal to zero, no matter how these are carried out (reversibly, irreversibly, one step, two steps, etc.).
   - ΔS_{univ} is always positive for a spontaneous process.

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

9. For how many of following is ΔG a measure of spontaneity?

   - An isothermal, irreversible expansion of an ideal, monatomic gas.
   - An isothermal, irreversible compression of an ideal, monatomic gas.
   - A phase change at a given condition of pressure and temperature.
   - The cooling of a “hot metal” as it sits in a “cold room.”

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

10. One mole of an ideal, monatomic gas is compressed isothermally against a constant pressure of 2.00 atm to a volume of 15.0 L such that the heat involved has a magnitude of 2.03 kJ. Determine the value of ΔG.

    a) –3.35 kJ b) –1.55 kJ c) 1.55 kJ d) 2.03 kJ e) 3.35 kJ

11. If we use the following data and assume that these given values are independent of temperature, what do we determine for the vapor pressure of water at 100.°C?

	$H_2O(l)$	**$H_2O(g)$**
ΔH_f° (kJ/mol)	–286.0	–242
S° (J/Kmol)	70.0	189

a) 0.883 atm b) 0.972 atm c) 1.00 atm d) 1.03 atm e) 1.13 atm

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12-17. Consider a sample of 2.00 moles of an ideal, monatomic gas. This sample is taken from its initial state (a pressure of 3.00 atm with a volume of 10.0 L) to its final state (a pressure of 7.00 atm with a volume of 25.0 L) in two "quick" steps. The intermediate step is a pressure of 3.00 atm with a volume of 65.0 L.

12. Determine the value of ΔH for the overall process (initial to final state).

a) 11.0 kJ b) 14.7 kJ c) 18.4 kJ d).22.0 kJ e) 36.7 kJ

13. Determine the value of ΔE for the overall process (initial to final state).

a) 11.0 kJ b) 14.7 kJ c) 18.4 kJ d).22.0 kJ e) 36.7 kJ

14. Determine the value of *w* for the overall process (initial to final state).

a) –10.6 kJ b) 10.6 kJ c) 11.6 kJ d) 14.7 kJ e) 45.1 kJ

15. Determine the value of *q* for the overall process (initial to final state).

a) –8.4 kJ b) 10.4 kJ c) 22.0 kJ d) 26.1 kJ e) 36.7 kJ

16. Determine the value of ΔS for the overall process (initial to final state).

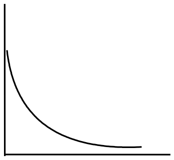
a) 15.2 J/K b) 29.6 J/K c) 44.0 J/K d) 59.2 J/K e) 73.3 J/K

17. How many of the values in 12-16 would be different if the sample was taken from the initial state to the final state in one step?

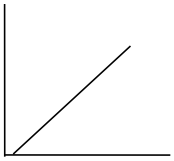
a) 0 b) 1 c) 2 d) 3 e) 4

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.

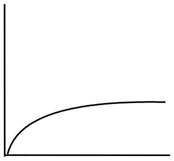
a)



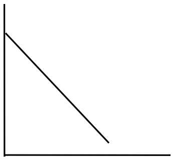
b)



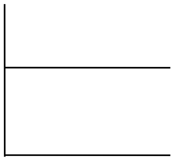
c)



d)



e)



18. The absolute value of ΔS_{surr} (y) vs. the number of steps (x) for an isothermal expansion of one mole of an ideal, monatomic gas.

19. ΔG (y) vs. the number of steps (x) for an isothermal compression of one mole of an ideal, monatomic gas.

20. ΔS_{univ} (y) vs. the number of steps (x) for an isothermal expansion of one mole of an ideal, monatomic gas.

21. You and some friends are working on chemistry problems together in preparation for the thermodynamics exam. Your friends have some misconceptions, but you are there to help! Please answer the following. Make sure to **explain** when asked and to **show all work**.

a. The first problem you discuss concerns the classic calorimetry problem of dropping a piece of “hot metal” into “cool water.” In this problem you are said to heat 50.00 g of aluminum metal (specific heat capacity = 0.8970 J/g°C) in a hot water bath (100.00°C) and then quickly transfer it to 100.0 g of water (specific heat capacity = 4.184 J/g°C) at 25.00°C in a Styrofoam calorimeter. You are to assume that there is no heat transfer with the surroundings and that the specific heat capacities are independent of temperature.

“Well,” says one of your friends. “We know the water and aluminum reach thermal equilibrium, so …” But another friend interrupts and says, “Actually, the first law of thermodynamics doesn’t say that they must reach thermal equilibrium. So why can’t some energy as heat transfer from the metal to the water but not enough to reach thermal equilibrium?” They both look to you for help.

You tell your friends to suppose the water ends up 2.00°C below the thermal equilibrium temperature. Using the data and assumptions above, provide **quantitative support** that reaching **thermal equilibrium is thermodynamically favorable** compared to water reaching a temperature 2.00°C below the thermal equilibrium temperature.

Show all work, **briefly explain** your process, and **explain the significance** of your answers. Full credit is reserved for **legible** work that **we can follow**. Please use the front of the next page if needed. [**15 pts.**]

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21. a. Continue any work on this page.

21. b. Next you work on problem 139 from Chapter 10 in your textbook. In this problem, 1.00 L of water at 90.°C is sitting open in a room at 25°C. You are to assume that the density and the heat capacity of water do not change with temperature, and their values are 1.00 g/mL and 75.3 J/Kmol, respectively.

Another friend (who ignored your last answer) says, "If thermal equilibrium doesn't need to be reached, then the water can cool below room temperature. Actually, the water releases heat to the surroundings by cooling, and releases even more by freezing, so this would increase ΔS_{univ} even more! So why isn't this thermodynamically favorable?"

- Given that the absolute value of the enthalpy of fusion of water is 6.01 kJ/mol (and using the other data above), provide mathematical support that the water will not end up as ice at 0°C in the above scenario.
- Provide mathematical support to show that while the temperature of liquid water could reach 0°C, it is more favorable to reach and stay at room temperature.

Show all work and **explain the significance** of your answers**.** Full credit is reserved for **legible** work that **we can follow**. Please use the front of next page if needed. [**15 pts.**]

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21. b. Continue any work on this page.

22. Recall from the first hour exam that a saturated hydrocarbon has the general formula C_xH_{2x+2}. Your goal in this problem is to determine the formula of an unknown saturated hydrocarbon.

Suppose a sample of gaseous saturated hydrocarbon is reacted in a **bomb calorimeter** with the stoichiometric amount of oxygen gas (no leftover reactants) to produce carbon dioxide gas and liquid water (all reactants and products at 25°C). You have access to the following data:

- The mass of the hydrocarbon sample.
- The heat capacity of the bomb calorimeter.
- The temperature change of the bomb calorimeter.
- The values of $\Delta H_f°$ for the hydrocarbon, carbon dioxide, and water.

a. **Explain** how you can use these data to determine the formula for the hydrocarbon. **Explain any assumptions**. Please limit your answer to the front of this page. [**12 points**]

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22. b. Now that you have mapped out how to solve this, it's time to solve it! A sample of gaseous saturated hydrocarbon is reacted in a bomb calorimeter with the stoichiometric amount of oxygen gas (no leftover reactants) to produce carbon dioxide gas and liquid water. You have the following data:

- The mass of the hydrocarbon sample = 1.000 g.
- The heat capacity of the bomb calorimeter = 15.72 kJ/°C
- The temperature change of the bomb calorimeter: increase of 3.14°C
- The values of $\Delta H_f°$ are:
  - $\Delta H_f°$ for the hydrocarbon(*g*) = –125.7 kJ/mol
  - $\Delta H_f°$ for $CO_2(g)$ = –393.5 kJ/mol
  - $\Delta H_f°$ for $H_2O(l)$ = –286 kJ/mol

Determine the molecular formula of the hydrocarbon. **Show all work**. Please use the front of next page if needed. [**18 points**]

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22. b. Continue any work on this page.