This midterm exam consists of **8** consecutively numbered pages including a **formula sheet** (**the last page**). Please check that your paper is complete before starting work. **You may peel off the formula sheet.** All work must be shown on the first **7** pages in this booklet (including the back pages). Only the work written on the first **7** pages will be marked; anything written on the formula sheet will be discarded and not be marked at all.

Family Name: ____________________ First Name: ____________________

(print, surname first)

Student Number: ____________________ Signature: ____________________

University of British Columbia
CHEM 205 Mid-term Examination
27 February 2019, 6:00−7:30 PM

Time: 90 minutes
Answer all questions
ALL CALCULATORS ARE PERMITTED

READ AND OBSERVE THE FOLLOWING EXAM RULES

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    - (b) Purposely exposing written papers to the view of other examination candidates or imaging devices;
    - (c) purposely viewing the written papers of other examination candidates;
    - (d) using or having visible at the place of writing any books, papers or other memory aid devices other than those authorized by the examiner(s); and
    - (e) using or operating electronic devices including but not limited to telephones, calculators, computers, or similar devices other than those authorized by the examiner(s) — (electronic devices other than those authorized by the examiner(s) must be completely powered down if present at the place of writing).
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7. Examination candidates must follow any additional examination rules or directions communicated by the examiner(s) or invigilator(s).

Question	Max	Mark
Part A	15	
Part B	11	
Part C	9	
Part D	5	
Total	40	

Part A: [15 marks] Circle the **only one** correct answer for each of the following questions.

1. [1 mark] If a system completed a reversible cyclic process, which one of the following statements is true (assuming that the surroundings is much, much larger than the system)?

1) $q = w = 0$ 2) $q > 0$ 3) $q < 0$ 4) $\Delta S_{\text{surr}} > 0$ 5) $\Delta S > 0$

2. [1 mark] Which one of the following quantities is equal to the exact amount of all energy of an isolated system, *nothing more nothing less*?

1) S 2) G 3) U 4) H 5) PV

3. [1 mark] Under arbitrary conditions, in order to determine if a chemical reaction has achieved equilibrium we need only consider

1) $\Delta G_{\text{reaction}}$ 2) $\Delta S_{\text{universe}}$ 3) $\Delta S_{\text{reaction}}$ 4) $\Delta H_{\text{reaction}}$ 5) $\Delta G_{\text{universe}}$

4. [1 mark] For a certain process, if $w = -3$ Joules, which one of the following statements must be true for this process?

1) $q = +3$ Joules.
2) $\Delta U = -3$ Joules.
3) $\Delta H = +3$ Joules.
4) There is +3 Joules of work being done on the surroundings.
5) None of the above.

5. [1 mark] Which one of the following statements is true?

1) For pure Sulphur, the two-phase boundary line between the orthorhombic solid (stable at lower T) and monoclinic solid (stable at higher T) has positive slope in a graph of P *versus* T. Therefore, for a given T, the orthorhombic phase is found at lower P.
2) In a closed system, the entropy change of the system associated with an irreversible process is greater than the entropy change of the system associated with any reversible process performed between the same initial and final states in the same system.
3) The amount of the work w can be evaluated if we know the initial and final states.
4) During a spontaneous process, the entropy change in the surroundings must be greater than zero.
5) Nonspontaneous process can happen.

6. [1 mark] A closed system transitions from state A(T, P) to state B(T, P) – both states have the same temperature and pressure – by two different processes. In process 1, the temperature and pressure are not held constant during the process. In process 2, the temperature and pressure are held constant throughout the process. Which one of the following statements is true? Note that the subscripts refer to processes 1 and 2.

1) $\Delta G_1 \neq \Delta G_2$.

2) $\Delta S_1 \neq \Delta S_2$.

3) $\Delta G_1 = \Delta G_2$ and we can use the sign of ΔG_2 to infer the reversibility of process 1.

4) $\Delta G_1 = \Delta G_2$ and we cannot use the sign of ΔG_2 to infer the reversibility of process 1.

5) None of the above.

7. [1 mark] An isolated system undergoes an isothermal process, then

1) $\Delta S = 0$ 2) $\Delta G = 0$ 3) $\Delta V = 0$ 4) $\Delta P = 0$ 5) $q = 0$

8. [1 mark] An ideal gas is undergoing an isothermal expansion/compression process in which both the volume and pressure of the gas are to change, indicate which one of the following quantities can be used by itself to decide whether or not the process is spontaneous:

1) ΔS_{sys} 2) $\Delta S_{\text{universe}}$ 3) ΔU 4) ΔH 5) ΔG

9. [1 mark] A gas undergoes a process reversibly at a constant temperature of 298 K. In the course of the process, 298 J of heat is transferred to the surroundings. What is the ΔS for the system?

1) 1 J/K 2) 2 J/K 3) −1 J/K 4) −2 J/K 5) 0 J/K

10. [1 mark] For an isochoric process in a closed system, which one of the following statements is true?

1) $w_{\text{expansion}} = 0$ 2) $q = 0$ 3) $\Delta S = 0$ 4) $\Delta U = 0$ 5) $\Delta H = 0$

11. [1 mark] The **enthalpy** of 2 moles of a monatomic ideal gas is $3RT$. The gas atoms are

1) moving in 2 dimensions.
2) moving in 1 dimension.
3) moving in 3/2 dimensions.
4) confined to a cubical box.
5) not moving at all.

12. [1 mark] For a particular mixture, the Gibbs phase rule tells us that the maximum number of phases that can coexist is 5. How many components are in the mixture?

1) 1 2) 2 3) 3 4) 4 5) 5

13. [1 mark] For systems containing 1 mole of molecules, which one of the following systems has the highest temperature?

1) System containing the fastest moving molecule.
2) System containing a few molecules going at 90% of the speed of light.
3) System with all molecules moving very fast.
4) System with lowest mean square velocity.
5) System with highest mean square velocity.

14. [1 mark] An ideal gas is compressed adiabatically. Which one of the following statements is always true?

1) $\Delta U = w$ 2) $\Delta T = 0$ 3) $\Delta U = q$ 4) $q = w$ 5) $\Delta U = \Delta H$

15. [1 mark] The initial and final states of process 1 are the same as initial and final states of process 2. Which one of the following statements is **not** true?

1) $\Delta H_1 = \Delta H_2$ 2) $\Delta G_1 = \Delta G_2$ 3) $\Delta S_1 = \Delta S_2$ 4) $q_1 = q_2$ 5) $q_1 + w_1 = \Delta U_2$

Part B: **[11 marks]** Two moles of liquid water initially at 273 K mix with three moles of liquid water at 363 K in a perfectly insulated container. The total volume of the liquid remains constant during the mixing process. Assume that the molar heat capacity of liquid water ($C_{v,m} = 73.0$ J mol^{-1} K^{-1}) is constant independent of temperature.

(a) [2 marks] What are q and ΔU for the process?

(b) [4 marks] Calculate the final equilibrium temperature of the water after mixing.

(c) [4 marks] Calculate ΔS for the process.

(d) [1 mark] Is this process spontaneous? (circle the **only one** correct answer below)

1) Yes 2) No 3) Not enough information to know the answer.

Part C: **[9 marks]** Two moles of a monatomic ideal gas ($C_{v,m} = 3R/2$) undergo a reversible constant pressure process such that the volume expands by a factor of 3 and the temperature change $\Delta T = T_\mathrm{f} - T_\mathrm{i} = 100\ \mathrm{K}$.

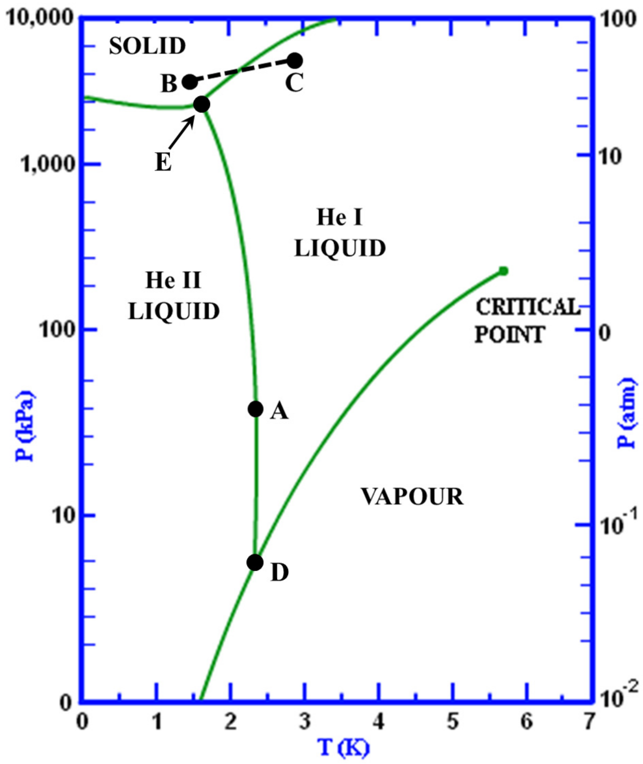
(a) [4 marks] Calculate ΔU, ΔH, q, and w for this process.

(b) [4 marks] Calculate ΔS, ΔS_surr, the initial and final temperatures T_i and T_f of the gas for this process.

(c) [1 mark] What is ΔG for this process? (circle the **only one** correct answer below)

1) $\Delta G < 0$ 2) $\Delta G > 0$ 3) $\Delta G = 0$ 4) Insufficient information to determine the sign of ΔG

Part D: **[5 marks]** Please circle the **only one** correct answer for each of the following questions. **All solid lines represent phase boundaries**. In the phase diagram for helium (He) below, there are two distinct liquid phases, "He I" and "He II", in addition to the solid phase and vapour phase.



(a) [1 mark] The broken line connecting points **B** and **C** signifies a constant-volume process between the solid (**B**) and the liquid He I (**C**) phases, **B** → **C**. Should the change in internal energy (ΔU) for **B** → **C** be positive, negative, or zero?

1) positive   2) negative   3) zero   4) cannot be determined

(b) [1 mark] At point **A** on the boundary curve separating the two liquid phases, is $\Delta S_{\text{universe}}$ positive, negative, or zero for the phase transition: He I (l) → He II (l) at constant pressure?

1) positive   2) negative   3) zero   4) cannot be determined

(c) [1 mark] At point **A** on the boundary curve separating the two liquid phases, is ΔS_{system} positive, negative, or zero for the phase transition: He I (l) → He II (l) at constant pressure?

1) positive   2) negative   3) zero   4) cannot be determined

(d) [1 mark] In the phase diagram shown above, triple points are

1) points **A**, **B**, and **C**   2) points **B**, **C**, and **D**

3) points **B**, **C**, and **E**   4) points **D** and **E**

(e) [1 mark] In the phase diagram shown above, the maximum number of degrees of freedom locates at

1) the critical point   2) the region containing point **B** or point **C**

3) points **D** and **E**   4) the boundary curve containing point **A**

Equations and Constants

(note: conditions for applying equations are **not** specified)

$R = 8.314\ \mathrm{J\ K^{-1}\ mol^{-1}} = 0.08206\ \mathrm{L\ atm\ K^{-1}\ mol^{-1}}$

$k = 1.3807 \times 10^{-23}\ \mathrm{J\ K^{-1}}$

$N_{\mathrm{A}} = 6.0221 \times 10^{23}\ \mathrm{mol^{-1}}$

$F = 96485\ \mathrm{C\ mol^{-1}}$

$0\ {}^{\circ}\mathrm{C} = 273.15\ \mathrm{K}$

$1\ \mathrm{atm} = 101325\ \mathrm{Pa}$

$1\ \mathrm{L} = 0.001\ \mathrm{m^3}$

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

$$PV = nRT$$

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

$$\Delta U = U_2 - U_1 = q + w$$

$$dw = -P_{\mathrm{ex}}dV$$

$$w = -P_{\mathrm{ex}}(V_2 - V_1)$$

$$w = -nRT\ln\left(\frac{V_2}{V_1}\right)$$

$$dq = C \cdot dT$$

$$C_V = nC_{V,m} = \frac{dq_V}{dT}$$

$$\Delta U = q_V = \int_{T_1}^{T_2} nC_{V,m}dT = \int_{T_1}^{T_2} C_V dT$$

$$H = U + PV$$

$$C_P = nC_{P,m} = \frac{dq_P}{dT}$$

$$\Delta H = q_P = \int_{T_1}^{T_2} nC_{P,m}dT = \int_{T_1}^{T_2} C_P dT$$

$$\Delta H^0_{\mathrm{rxn}} = \sum_i \nu_i \Delta H^0_{m,i}(\mathrm{products}) - \sum_j \nu_j \Delta H^0_{m,j}(\mathrm{reatants})$$

$$C_{V,m} = \frac{3}{2}R, \quad C_{P,m} = \frac{5}{2}R$$

$$dS = dq_{\mathrm{rev}}/T$$

$$\Delta S = S_2 - S_1 = \int_{\mathrm{state\,1}}^{\mathrm{state\,2}} \frac{dq_{\mathrm{rev}}}{T}$$

$$(\Delta S)_{T,P} = \Delta H/T$$

$$(\Delta S)_T = nR\ln\left(\frac{V_2}{V_1}\right) = nR\ln\left(\frac{P_1}{P_2}\right)$$

$$(\Delta S)_V = nC_{V,m}\ln\left(\frac{T_2}{T_1}\right)$$

$$(\Delta S)_P = nC_{P,m}\ln\left(\frac{T_2}{T_1}\right)$$

$$\Delta S = nC_{V,m}\ln\left(\frac{T_2}{T_1}\right) + nR\ln\left(\frac{V_2}{V_1}\right)$$

$$\Delta S = nC_{P,m}\ln\left(\frac{T_2}{T_1}\right) + nR\ln\left(\frac{P_1}{P_2}\right)$$

$$\Delta S_{\mathrm{univ}} = \Delta S_{\mathrm{sys}} + \Delta S_{\mathrm{surr}}$$

$$\ln\left(\frac{P_2}{P_1}\right) = \frac{-\Delta H^0_{\mathrm{vap},m}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

$$\ln\left(\frac{K_2}{K_1}\right) = \frac{-\Delta H^0_{\mathrm{rxn}}}{(1\,\mathrm{mol}) \cdot R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

$$\mathrm{F} = \mathrm{C} - \mathrm{P} + 2$$

$$G = H - TS$$

$$\Delta G_{T,P} = -T \cdot \Delta S_{\mathrm{univ}}$$

$$\Delta G_{\mathrm{rxn}} = \Delta G^0_{\mathrm{rxn}} + (1\,\mathrm{mol}) \cdot RT\ln Q$$

$$\Delta G^0_{\mathrm{rxn}} = -(1\,\mathrm{mol}) \cdot RT\ln K$$

$$\Delta G_{\mathrm{rxn}} = -nF\varepsilon, \quad \Delta G^0_{\mathrm{rxn}} = -nF\varepsilon^0$$

$$\varepsilon = \varepsilon^0 - \frac{(1\,\mathrm{mol}) \cdot RT}{nF}\ln Q$$

$$\Delta T_{\mathrm{b}} = T_{\mathrm{b,mix}} - T_{\mathrm{b,pure}} \approx K_{\mathrm{b}}b_B$$

$$\Delta T_{\mathrm{f}} = T_{\mathrm{f,mix}} - T_{\mathrm{f,pure}} \approx -K_{\mathrm{f}}b_B$$

$$\Pi = c_B RT$$

$$\Delta\Pi = \Delta c \cdot RT$$

$$\varepsilon \approx \frac{-RT}{z_i F}\ln\left(\frac{[i]_{\mathrm{R}}}{[i]_{\mathrm{L}}}\right)$$

$$T = \frac{I}{I_0}$$

$$A = -\log_{10} T = lc\varepsilon$$

$$v = k[\mathrm{A}]^a[\mathrm{B}]^b[\mathrm{C}]^c \cdots$$

$$a\mathrm{A} \to \mathrm{B}: \quad v = -\frac{1}{a}\frac{d[\mathrm{A}]}{dt} = k[\mathrm{A}]^n$$

$$a\mathrm{A} \to \mathrm{B}: \quad [\mathrm{A}] = [\mathrm{A}]_0 - akt, \quad t_{1/2} = \frac{[\mathrm{A}]_0}{2ak}$$

$$a\mathrm{A} \to \mathrm{B}: \quad \ln\left(\frac{[\mathrm{A}]}{[\mathrm{A}]_0}\right) = -akt, \quad t_{1/2} = \frac{\ln 2}{ak}$$

$$a\mathrm{A} \to \mathrm{B}: \quad \frac{1}{[\mathrm{A}]} - \frac{1}{[\mathrm{A}]_0} = akt, \quad t_{1/2} = \frac{1}{ak[\mathrm{A}]_0}$$

$$t = \frac{t_{1/2}}{\ln 0.5}\ln\left(\frac{[\mathrm{A}]}{[\mathrm{A}]_0}\right), \quad \frac{[\mathrm{A}]}{[\mathrm{A}]_0} = 0.5^{\frac{\mathrm{time}}{\mathrm{half\text{-}life}}}$$

$$K = \frac{k_1}{k_1'} \times \frac{k_2}{k_2'} \times \frac{k_3}{k_3'} \times \cdots$$

$$k = Ae^{\frac{-E_a}{RT}} = A\exp\left(\frac{-E_a}{RT}\right)$$

$$\ln\left(\frac{k_2}{k_1}\right) = \frac{-E_a}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

$$v = \frac{[\mathrm{S}] \cdot v_{\max}}{[\mathrm{S}] + K_{\mathrm{M}}}, \quad v_{\max} = k_b[\mathrm{E}]_{\mathrm{tot}}$$

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Answer Key

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Question	Max	Mark
Part A	15	
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Part C	9	
Part D	5	
Total	40	

Part A: [15 marks] Circle the **only one** correct answer for each of the following questions.

1. [1 mark] If a system completed a reversible cyclic process, which one of the following statements is true (assuming that the surroundings is much, much larger than the system)?

[✓ 1) $q = w = 0$]   2) $q > 0$ 3) $q < 0$ 4) $\Delta S_{\text{surr}} > 0$ 5) $\Delta S > 0$

2. [1 mark] Which one of the following quantities is equal to the exact amount of all energy of an isolated system, *nothing more nothing less*?

1) S 2) G [✓ 3) U]   4) H 5) PV

3. [1 mark] Under arbitrary conditions, in order to determine if a chemical reaction has achieved equilibrium we need only consider

1) $\Delta G_{\text{reaction}}$ [✓ 2) $\Delta S_{\text{universe}}$]   3) $\Delta S_{\text{reaction}}$ 4) $\Delta H_{\text{reaction}}$ 5) $\Delta G_{\text{universe}}$

4. [1 mark] For a certain process, if $w = -3$ Joules, which one of the following statements must be true for this process?

1) $q = +3$ Joules.

2) $\Delta U = -3$ Joules.

3) $\Delta H = +3$ Joules.

[✓ 4) There is +3 Joules of work being done on the surroundings.]

5) None of the above.

5. [1 mark] Which one of the following statements is true?

1) For pure Sulphur, the two-phase boundary line between the orthorhombic solid (stable at lower T) and monoclinic solid (stable at higher T) has positive slope in a graph of P *versus* T. Therefore, for a given T, the orthorhombic phase is found at lower P.

2) In a closed system, the entropy change of the system associated with an irreversible process is greater than the entropy change of the system associated with any reversible process performed between the same initial and final states in the same system.

3) The amount of the work w can be evaluated if we know the initial and final states.

4) During a spontaneous process, the entropy change in the surroundings must be greater than zero.

[✓ 5) Nonspontaneous process can happen.]

6. [1 mark] A closed system transitions from state A(T, P) to state B(T, P) – both states have the same temperature and pressure – by two different processes. In process 1, the temperature and pressure are not held constant during the process. In process 2, the temperature and pressure are held constant throughout the process. Which one of the following statements is true? Note that the subscripts refer to processes 1 and 2.

1) $\Delta G_1 \neq \Delta G_2$.

2) $\Delta S_1 \neq \Delta S_2$.

3) $\Delta G_1 = \Delta G_2$ and we can use the sign of ΔG_2 to infer the reversibility of process 1.

[✓ 4) $\Delta G_1 = \Delta G_2$ and we cannot use the sign of ΔG_2 to infer the reversibility of process 1.]

5) None of the above.

7. [1 mark] An isolated system undergoes an isothermal process, then

1) $\Delta S = 0$
2) $\Delta G = 0$
3) $\Delta V = 0$
4) $\Delta P = 0$
[✓ 5) $q = 0$]

8. [1 mark] An ideal gas is undergoing an isothermal expansion/compression process in which both the volume and pressure of the gas are to change, indicate which one of the following quantities can be used by itself to decide whether or not the process is spontaneous:

1) ΔS_{sys}
[✓ 2) $\Delta S_{\text{universe}}$]
3) ΔU
4) ΔH
5) ΔG

9. [1 mark] A gas undergoes a process reversibly at a constant temperature of 298 K. In the course of the process, 298 J of heat is transferred to the surroundings. What is the ΔS for the system?

1) 1 J/K
2) 2 J/K
[✓ 3) −1 J/K]
4) −2 J/K
5) 0 J/K

10. [1 mark] For an isochoric process in a closed system, which one of the following statements is true?

[✓ 1) $w_{\text{expansion}} = 0$]
2) $q = 0$
3) $\Delta S = 0$
4) $\Delta U = 0$
5) $\Delta H = 0$

11. [1 mark] The **enthalpy** of 2 moles of a monatomic ideal gas is $3RT$. The gas atoms are

1) moving in 2 dimensions.

[✓ 2) moving in 1 dimension.]

3) moving in 3/2 dimensions.

4) confined to a cubical box.

5) not moving at all.

12. [1 mark] For a particular mixture, the Gibbs phase rule tells us that the maximum number of phases that can coexist is 5. How many components are in the mixture?

1) 1 2) 2 [✓ 3) 3] 4) 4 5) 5

13. [1 mark] For systems containing 1 mole of molecules, which one of the following systems has the highest temperature?

1) System containing the fastest moving molecule.

2) System containing a few molecules going at 90% of the speed of light.

3) System with all molecules moving very fast.

4) System with lowest mean square velocity.

[✓ 5) System with highest mean square velocity.]

14. [1 mark] An ideal gas is compressed adiabatically. Which one of the following statements is always true?

[✓ 1) $\Delta U = w$] 2) $\Delta T = 0$ 3) $\Delta U = q$ 4) $q = w$ 5) $\Delta U = \Delta H$

15. [1 mark] The initial and final states of process 1 are the same as initial and final states of process 2. Which one of the following statements is **not** true?

1) $\Delta H_1 = \Delta H_2$ 2) $\Delta G_1 = \Delta G_2$ 3) $\Delta S_1 = \Delta S_2$ [✓ 4) $q_1 = q_2$] 5) $q_1 + w_1 = \Delta U_2$

Part B: [11 marks] Two moles of liquid water initially at 273 K mix with three moles of liquid water at 363 K in a perfectly insulated container. The total volume of the liquid remains constant during the mixing process. Assume that the molar heat capacity of liquid water ($C_{v,m}$ = 73.0 J mol^{-1} K^{-1}) is constant independent of temperature.

(a) [2 marks] What are q and ΔU for the process?

$$\text{Perfectly insulated} \Rightarrow q = 0$$

$$\text{Constant volume} \Rightarrow q = q_v = \Delta U = 0$$

(b) [4 marks] Calculate the final equilibrium temperature of the water after mixing.

$$\text{Total } \Delta U = q = 0,\ T_1\ (273\ \text{K}) < T_f < T_2\ (363\ \text{K})$$

$$\left.\begin{aligned} \Delta U_1 &= q_1 = n_1 C_{v,m}(T_f - T_1) \\ \Delta U_2 &= q_2 = n_2 C_{v,m}(T_f - T_2) \end{aligned}\right\} \Rightarrow \Delta U = \Delta U_1 + \Delta U_2 = q = q_1 + q_2 = 0$$

$$n_1 C_{v,m}(T_f - T_1) + n_2 C_{v,m}(T_f - T_2) = 0$$

$$T_f = \frac{n_1 \times T_1 + n_2 \times T_2}{n_1 + n_2} = \frac{2 \times 273 + 3 \times 363}{2 + 3} = 327\ \text{K}\ \ (53.85\ {}^\circ\text{C})$$

(c) [4 marks] Calculate ΔS for the process.

$$\Delta S = \Delta S_1 + \Delta S_2$$

$$\left.\begin{aligned} \Delta S_1 &= n_1 C_{v,m} \ln\frac{T_f}{T_1} = 2 \times 73 \times \ln\frac{327}{273} = 26.35\ \text{J/K} \\ \Delta S_2 &= n_2 C_{v,m} \ln\frac{T_f}{T_2} = 3 \times 73 \times \ln\frac{327}{363} = -22.87\ \text{J/K} \end{aligned}\right\}$$

$$\Delta S = n_1 C_{v,m} \ln\frac{T_f}{T_1} + n_2 C_{v,m} \ln\frac{T_f}{T_2} = 26.35 - 22.87 = 3.48\ \text{J/K}$$

(d) [1 mark] Is this process spontaneous? (circle the **only one** correct answer below)

[✓ 1) Yes]   2) No   3) Not enough information to know the answer.

$$q = 0 \Rightarrow \Delta S_{\text{surr}} = 0$$
$$\Delta S_{\text{univ}} = \Delta S_{\text{sys}} + \Delta S_{\text{surr}} = \Delta S_{\text{sys}} = 3.48\ \text{J/K} > 0$$

Part C: **[9 marks]** Two moles of a monatomic ideal gas ($C_{v,m} = 3R/2$) undergo a reversible constant pressure process such that the volume expands by a factor of 3 and the temperature change $\Delta T = T_{\mathrm{f}} - T_{\mathrm{i}} = 100\,\mathrm{K}$.

(a) [4 marks] Calculate ΔU, ΔH, q, and w for this process.

$$\Delta U = nC_{v,m}\Delta T = 2\times\frac{3}{2}R\times 100 = 300\times 8.314 = 2494.2\ \mathrm{J}\ \ (2.494\ \mathrm{kJ})$$

$$\Delta H = nC_{p,m}\Delta T = 2\times\frac{5}{2}R\times 100 = 500\times 8.314 = 4157.0\ \mathrm{J}\ \ (4.157\ \mathrm{kJ})$$

$$P\ \text{constant} \Rightarrow q = q_p = \Delta H = 4157.0\ \mathrm{J}\ \ (4.157\ \mathrm{kJ})$$

$$\Delta U = q_p + w_p \Rightarrow w = w_p = \Delta U - q_p = 2494.2 - 4157.0 = -1662.8\ \mathrm{J}\ \ (-1.663\ \mathrm{kJ})$$

(b) [4 marks] Calculate ΔS, ΔS_{surr}, the initial and final temperatures T_{i} and T_{f} of the gas for this process.

$$\left.\begin{array}{r} \left.\begin{array}{l} PV_{\mathrm{f}} = nRT_{\mathrm{f}} \\ PV_{\mathrm{i}} = nRT_{\mathrm{i}} \end{array}\right\} \Rightarrow \dfrac{V_{\mathrm{f}}}{V_{\mathrm{i}}} = \dfrac{T_{\mathrm{f}}}{T_{\mathrm{i}}} = 3 \\ \Delta T = T_{\mathrm{f}} - T_{\mathrm{i}} = 100\ \mathrm{K} \end{array}\right\} \Rightarrow \left\{\begin{array}{l} T_{\mathrm{i}} = 50\ \mathrm{K} \\ \\ T_{\mathrm{f}} = 150\ \mathrm{K} \end{array}\right.$$

$$\Delta S = \Delta S_p = nC_{p,m}\ln\frac{T_{\mathrm{f}}}{T_{\mathrm{i}}} = nC_{p,m}\ln\frac{V_{\mathrm{f}}}{V_{\mathrm{i}}} = 2\times\frac{5}{2}R\times\ln 3 = 5\times 8.314\times\ln 3 = 45.67\ \mathrm{J/K}$$

$$\text{reversible} \Rightarrow \Delta S_{\mathrm{univ}} = 0 \Rightarrow \Delta S_{\mathrm{surr}} = -\Delta S_{\mathrm{sys}} = -45.67\ \mathrm{J/K}$$

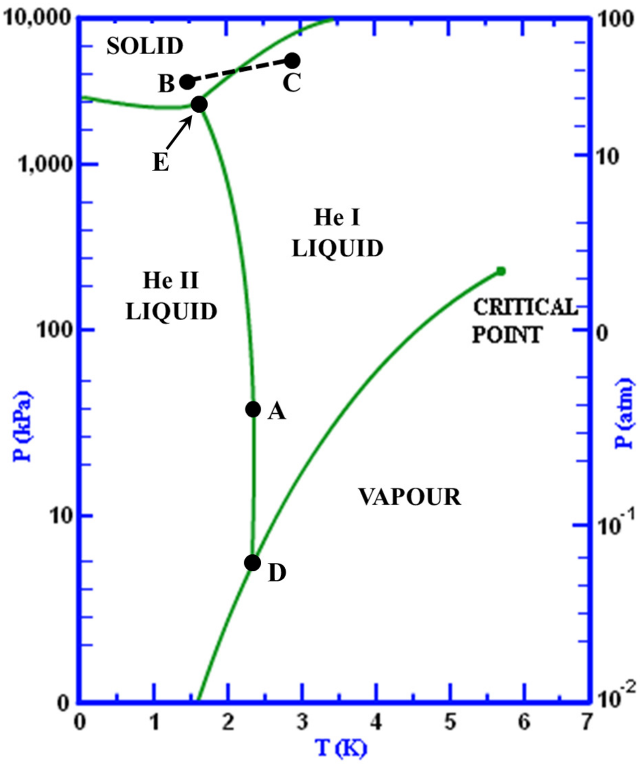
(c) [1 mark] What is ΔG for this process? (circle the **only one** correct answer below)

[✓ 1) $\Delta G < 0$]   2) $\Delta G > 0$ 3) $\Delta G = 0$ 4) Insufficient information to determine the sign of ΔG

$$\left.\begin{array}{l} G = H - T\cdot S \Rightarrow dG = dH - T\cdot dS - S\cdot dT \\ dS = \dfrac{dq^{\mathrm{rev}}}{T} \Rightarrow T\cdot dS = dq^{\mathrm{rev}} = dq_p^{\mathrm{rev}} = dH \end{array}\right\} \Rightarrow dG = -S\cdot dT$$

$$\Delta G = -\int_{T_{\mathrm{i}}}^{T_{\mathrm{f}}} S\cdot dT < 0,\ \ \text{because}\ \ S > 0\ \ \text{and}\ \ dT > 0.$$

Part D: **[5 marks]** Please circle the **only one** correct answer for each of the following questions. **All solid lines represent phase boundaries**. In the phase diagram for helium (He) below, there are two distinct liquid phases, "He I" and "He II", in addition to the solid phase and vapour phase.



(a) [1 mark] The broken line connecting points **B** and **C** signifies a constant-volume process between the solid (**B**) and the liquid He I (**C**) phases, **B** → **C**. Should the change in internal energy (ΔU) for **B** → **C** be positive, negative, or zero?

[✓ 1) positive] 2) negative 3) zero 4) cannot be determined

(b) [1 mark] At point **A** on the boundary curve separating the two liquid phases, is $\Delta S_{\text{universe}}$ positive, negative, or zero for the phase transition: He I (l) → He II (l) at constant pressure?

1) positive 2) negative [✓ 3) zero] 4) cannot be determined

(c) [1 mark] At point **A** on the boundary curve separating the two liquid phases, is ΔS_{system} positive, negative, or zero for the phase transition: He I (l) → He II (l) at constant pressure?

1) positive [✓ 2) negative] 3) zero 4) cannot be determined

(d) [1 mark] In the phase diagram shown above, triple points are

1) points **A**, **B**, and **C** 2) points **B**, **C**, and **D**
3) points **B**, **C**, and **E** [✓ 4) points **D** and **E**]

(e) [1 mark] In the phase diagram shown above, the maximum number of degrees of freedom locates at

1) the critical point [✓ 2) the region containing point **B** or point **C**]
3) points **D** and **E** 4) the boundary curve containing point **A**