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 2017, 6:00−7:30 PM

**Time: 90 minutes**
**Answer all questions**
ALL CALCULATORS ARE PERMITTED

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   (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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| Question | Max | Mark |
|---|---|---|
| Part A | 15 | |
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| Part D | 5 | |
| Total | 40 | |

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

**1.** [1 mark] A system goes through an adiabatic irreversible process from the initial state A to the final state B. Alternatively, the same system goes through an adiabatic reversible process from the same initial state A to the final state C. Which one of the following statements is true?

1) State B can be the same as state C.

2) State B can never be the same as state C.

3) $q^{irrev}(A \rightarrow B) < q^{rev}(A \rightarrow C)$

4) $\Delta S^{irre\ v}(A \rightarrow B) = \Delta S^{rev}(A \rightarrow C) = 0$

5) None of the above

**2.** [1 mark] At 25 °C and 2 atm, which one of the following statements is true for a chemical reaction?

1) If $\Delta G°_{\mathrm{rxn}} > 0$, this chemical reaction cannot proceed forward spontaneously.

2) If $\Delta G°_{\mathrm{rxn}} < 0$ and initially there are only products and no reactants, the products will not react to produce any reactants at all, because the forward reaction is spontaneous.

3) After reaching chemical equilibrium, if the concentrations of the chemicals involved in the reaction are changed, the equilibrium constant $K$ of this chemical reaction will also undergo necessary changes accordingly.

4) When the reaction quotient $Q > K$, this chemical reaction shall proceed backward spontaneously.

5) None of the above

**3.** [1 mark] An ideal gas expands reversibly and isothermally at a temperature of 300 K. During this process the system does 300 J of **work on the surroundings**. Which one of the following equations is true?

1) $\Delta S_{surr} = 1$ J/K  2) $\Delta S_{sys} = -1$ J/K  3) $\Delta S_{sys} = 1$ J/K  4) $\Delta S_{univ} = -1$ J/K  5) $\Delta S_{surr} = 0$ J/K

**4.** [1 mark] Which one of the following statements about the Second Law is true?

1) Because the entropy of the whole universe is always increasing, it is impossible to create order out of disorder anywhere in the universe.

2) Any spontaneous process can never increase the order of the system.

3) Any spontaneous process can never decrease the entropy of the surroundings.

4) Any spontaneous process must decrease the value of the Gibbs free energy of the system.

5) The value of the Gibbs free energy of the system can increase even for spontaneous processes.

**5.** [1 mark] According to the Gibbs phase rule, a mixture of three different components can have at most how many degrees of freedom?

1) 0  2) 1  3) 2  4) 3  5) 4

**6.** [1 mark] At 2000 K and 200000 atm, the conversion of graphite to diamond is spontaneous. For the reaction under the stated conditions: $\Delta G = -10$ kJ/mol, and $\Delta S = -10$ J $\text{K}^{-1}$ $\text{mol}^{-1}$. Which of the following is a good **approximation** of the equilibrium temperature for this reaction at 200000 atm?

1) $T_{eq} = 2000$ K  2) $T_{eq} = 3000$ K  3) $T_{eq} = 1000$ K  4) $T_{eq} = 4000$ K  5) $T_{eq} = 300$ K

**7.** [1 mark] For an irreversible isothermal compression of an ideal gas, which one of the following statements is true?

1) $\Delta V > 0$  2) $\Delta S > 0$  3) $\Delta G > 0$  4) $\Delta U > 0$  5) $\Delta H > 0$

**8.** [1 mark] Which one of the following statements is true for a chemical reaction at constant pressure and constant temperature?

1) At equilibrium, $\Delta G° = 0$

2) At equilibrium, $\Delta G = (1\ \text{mol})\ RT{\cdot}\ln Q$

3) At equilibrium, $\Delta G° = -(1\ \text{mol})\ RT{\cdot}\ln K$

4) At equilibrium, $\Delta G = -(1\ \text{mol})\ RT{\cdot}\ln Q$

5) At equilibrium, $\Delta G° = (1\ \text{mol})\ RT{\cdot}\ln K$

**9.** [1 mark] For the isothermal expansion of an ideal gas in a vacuum, which one of the following statements is **not** true?

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

**10.** [1 mark] The internal energy of 2 moles of a monatomic ideal gas is $RT$. 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.

**11.** [1 mark] If a system undergoes an adiabatic **cyclic** process, which one of the following statements is true?

1) $w \neq 0$
2) $\Delta S > 0$, because all adiabatic processes are always irreversible.
3) $\Delta S_{univ} > 0$, because the adiabatic cyclic process can be irreversible.
4) $\Delta S_{univ} = 0$, because the adiabatic cyclic process must be reversible.
5) $\Delta G \neq 0$, because the adiabatic cyclic process can be irreversible.

**12.** [1 mark] A famous formula in chemistry is $\Delta G° = -(1\text{ mol})\, RT{\cdot}\ln K$. In this formula, $\Delta G°$ refers to

1) The difference in free energy between the products and reactants at equilibrium.
2) The difference in free energy between the products and reactants before the reaction has started.
3) The difference in free energy between the products and reactants in their standard states.
4) The difference in free energy between reactants and products after the reaction has finished.
5) None of the above.

**13.** [1 mark] For the adiabatic expansion of an ideal gas against a constant external pressure, which one of the following statements is always true?

1) $\Delta S_{surr} = 0$ 2) $\Delta S_{sys} = 0$ 3) $\Delta S_{univ} = 0$ 4) $\Delta S_{surr} = \Delta S_{univ}$ 5) $\Delta S_{surr} = \Delta S_{sys}$

**14.** [1 mark] Suppose that you are considering a chemical reaction to be carried out under conditions of constant temperature and constant pressure. The reaction will only be spontaneous if

1) $Q/K < 1$ 2) $\Delta H < 0$ 3) $\Delta S > 0$ 4) $Q/K = 1$ 5) $Q/K > 1$

**15.** [1 mark] The thermodynamic definition of entropy is $dS = dq_{rev}/T$. Which one of the following statements is correct?

1) This means that the entropy change cannot be found for any system undergoing an irreversible process.
2) This implies that entropy is not a state function.
3) Entropy must be calculated using a reversible path between the initial and final states of a system.
4) Between an initial state A and a final state B, the entropy change of a reversible path cannot be the same as the entropy change of an irreversible path.
5) The entropy change for a spontaneous chemical reaction cannot be calculated.

**Part B: [10 marks]** Iodine is the heaviest of the stable halogens and exists as a lustrous, purple-black metallic solid at room temperature and under atmospheric pressure. Iodine has a normal boiling point 184.3 °C and its enthalpy of vaporization is 41.57 kJ/mol.

(a) [4 marks] It has been found that the triple point of iodine occurs at 113.6 °C. Estimate the vapour pressure of iodine at the triple point. **Clearly state any approximations you have made**.

(b) [6 marks] The molar heat capacities at constant pressure, $C_{p,m}$, of the liquid and gasous states of iodine are 80.67 J $K^{-1}$ $mol^{-1}$ and 37.41 J $K^{-1}$ $mol^{-1}$, respectively. Use **Kirchhoff's law** to calculate the entropy of vaporization $\Delta S^0{}_{\text{vap},m}$ at 120.5 °C.

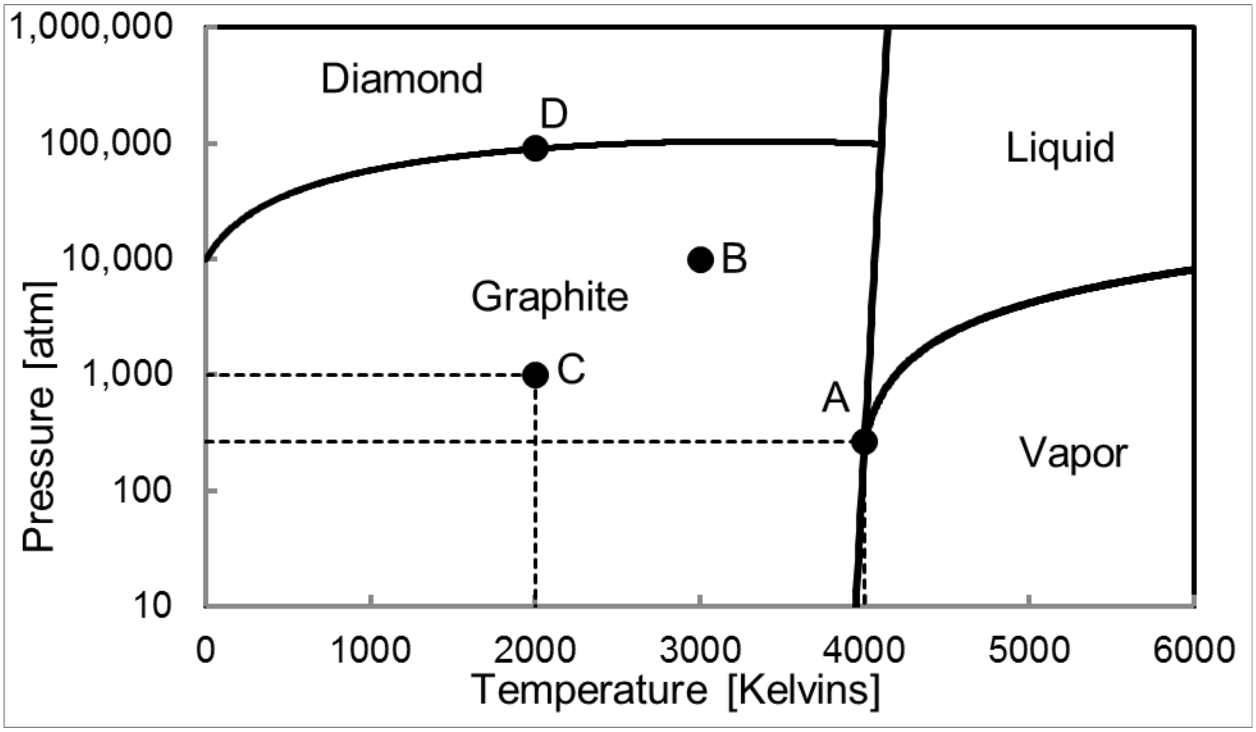
**Part C:** **[10 marks]** 0.5 moles of an ideal gas undergoes an isothermal process at 300 K against a constant external pressure of 2 atm, such that the entropy of the gas increases by 5.76 J/K. The final volume of the gas is 2 L. The temperature of the surroundings is also constant at 300 K.

(a) [8 marks] Calculate $w$, $q$, $\Delta U$, $\Delta H$, $\Delta G$, $\Delta S_{surr}$, and the initial volume of the gas for this process.

(b) [2 marks] Is this process spontaneous? (circle the **only one** correct answer below) **Explain your answer**.

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

**Part D:** **[5 marks]** Please circle the **only one** correct answer for each of the following questions regarding the phase diagram of carbon shown below.



(a) [1 mark] At the temperature and pressure indicated by point B, diamond is turned into graphite. Which one of the following equations is true?
1) $\Delta G > 0$ 2) $\Delta G = 0$ 3) $\Delta S_{univ} = 0$ 4) $\Delta G < 0$ 5) $\Delta S_{univ} < 0$

(b) [1 mark] At the temperature and pressure indicated by point D, graphite is turned into diamond. Which one of the following equations is true?
1) $\Delta G > 0$ 2) $\Delta G = 0$ 3) $\Delta S_{surr} = 0$ 4) $\Delta G < 0$ 5) $\Delta S_{univ} < 0$

(c) [1 mark] 4000 J of heat are transferred into the system to vaporize a sample of graphite. The system remains at point A throughout the transfer process. Which one of the following equations is true?
1) $\Delta G = 1$ J 2) $\Delta S = -1$ J/K 3) $\Delta S = 0$ 4) $\Delta G = -1$ J 5) $\Delta S = 1$ J/K

(d) [1 mark] 2000 J of heat are released from the system to turn a sample of diamond into graphite. The entropy of the diamond is 1 J/K lower than the entropy of the graphite. The system remains at point C throughout the transfer process. Which one of the following equations is true?
1) $\Delta G = 4$ kJ 2) $\Delta G = -4$ kJ 3) $\Delta G = 0$ 4) $\Delta G = 2$ kJ 5) $\Delta G = -2$ kJ

(e) [1 mark] At point A, which of the Gibbs phase rule parameters C, P, and F has the correct value?
1) F = 1 2) P = 0 3) P = 1 4) P = 2 5) P = 3

# Equations and Constants

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

$R = 8.314\ \mathrm{J\ K^{-1}\ mol^{-1}} = 0.08206\ \mathrm{L\ atm\ K^{-1}\ mol^{-1}}$
$k = 1.3807 \times 10^{-23}\ \mathrm{J\ K^{-1}}$
$N_A = 6.0221 \times 10^{23}\ \mathrm{mol^{-1}}$
$F = 96485\ \mathrm{C\ mol^{-1}}$
$0\ °\mathrm{C} = 273.15\ \mathrm{K}$
$1\ \mathrm{atm} = 101325\ \mathrm{Pa}$
$1\ \mathrm{L} = 0.001\ \mathrm{m^3}$
$1\ \mathrm{L\ atm} = 101.325\ \mathrm{J}$

$$PV = nRT$$

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

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

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

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

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

$$dq = C \cdot dT$$

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

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

$$H = U + PV$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$G = H - TS$$

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

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

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

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

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

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

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

$$\Pi = c_B RT$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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Answer Key

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

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1) State B can be the same as state C.

[✓ 2) State B can never be the same as state C.]

3) $q^{irrev}(A \rightarrow B) < q^{rev}(A \rightarrow C)$

4) $\Delta S^{irre\ v}(A \rightarrow B) = \Delta S^{rev}(A \rightarrow C) = 0$

5) None of the above

**2.** [1 mark] At 25 °C and 2 atm, which one of the following statements is true for a chemical reaction?

1) If $\Delta G^\circ_{\text{rxn}} > 0$, this chemical reaction cannot proceed forward spontaneously.

2) If $\Delta G^\circ_{\text{rxn}} < 0$ and initially there are only products and no reactants, the products will not react to produce any reactants at all, because the forward reaction is spontaneous.

3) After reaching chemical equilibrium, if the concentrations of the chemicals involved in the reaction are changed, the equilibrium constant $K$ of this chemical reaction will also undergo necessary changes accordingly.

[✓ 4) When the reaction quotient $Q > K$, this chemical reaction shall proceed backward spontaneously.]

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**3.** [1 mark] An ideal gas expands reversibly and isothermally at a temperature of 300 K. During this process the system does 300 J of **work on the surroundings**. Which one of the following equations is true?

1) $\Delta S_{surr} = 1$ J/K 2) $\Delta S_{sys} = -1$ J/K [✓ 3) $\Delta S_{sys} = 1$ J/K] 4) $\Delta S_{univ} = -1$ J/K 5) $\Delta S_{surr} = 0$ J/K

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1) 0 2) 1 3) 2 4) 3 [✓ 5) 4]

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1) $\Delta V > 0$ 2) $\Delta S > 0$ [✓ 3) $\Delta G > 0$] 4) $\Delta U > 0$ 5) $\Delta H > 0$

**8.** [1 mark] Which one of the following statements is true for a chemical reaction at constant pressure and constant temperature?

1) At equilibrium, $\Delta G° = 0$

2) At equilibrium, $\Delta G = (1 \text{ mol}) RT{\cdot}\ln Q$

[✓ 3) At equilibrium, $\Delta G° = -(1 \text{ mol}) RT{\cdot}\ln K$]

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[✓ 4) $\Delta S_{univ} = 0$, because the adiabatic cyclic process must be reversible.]

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(a) [4 marks] It has been found that the triple point of iodine occurs at 113.6 °C. Estimate the vapour pressure of iodine at the triple point. **Clearly state any approximations you have made**.

Assuming that $\Delta H^0_{\text{vap},m}$ is independent of $T$.

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

$$\ln\left(\frac{P_2}{1}\right) = \frac{-41.57\times10^3}{8.314}\left(\frac{1}{386.75} - \frac{1}{457.45}\right) = -1.9981$$

$$P_2 = e^{-1.9981} = 0.1356 \text{ atm } (13.74 \text{ kPa})$$

(b) [6 marks] The molar heat capacities at constant pressure, $C_{p,m}$, of the liquid and gasous states of iodine are 80.67 J $K^{-1}$ $mol^{-1}$ and 37.41 J $K^{-1}$ $mol^{-1}$, respectively. Use **Kirchhoff's law** to calculate the entropy of vaporization $\Delta S^0_{\text{vap},m}$ at 120.5 °C.

At the normal boiling point $T_b = 184.3\,°\text{C}$ (457.45 K), the phase change is reversible: $\Delta G^0_{\text{vap},m} = 0$

$$\Delta G^0_{\text{vap},m} = \Delta H^0_{\text{vap},m} - T_b \cdot \Delta S^0_{\text{vap},m} = 0 \;\Rightarrow\; \Delta S^0_{\text{vap},m} = \frac{\Delta H^0_{\text{vap},m}}{T_b}$$

$$\Delta S^0_{\text{vap},m(184.3°\text{C})} = \frac{\Delta H^0_{\text{vap},m}}{T_b} = \frac{41.57\times10^3}{457.45} = 90.873 \text{ J/(K}\cdot\text{mol)}$$

$$\Delta S^0_{\text{vap},m(120.5°\text{C})} = \Delta S^0_{\text{vap},m(184.3°\text{C})} + \int_{184.3°\text{C}}^{120.5°\text{C}} \frac{(C_{p,m,\text{gas}} - C_{p,m,\text{liquid}})}{T}dT$$

$$\Delta S^0_{\text{vap},m(120.5°\text{C})} = 90.873 + (37.41 - 80.67)\times\ln\left(\frac{120.5+273.15}{184.3+273.15}\right) = 97.37 \text{ J/(K}\cdot\text{mol)}$$

$$\begin{cases} \text{Heating of the liquid}: \Delta S^0_{\text{heating,liquid}} = \displaystyle\int_{120.5°\text{C}}^{184.3°\text{C}} \frac{C_{p,m,\text{liquid}}}{T}dT = 80.67\times\ln\left(\frac{457.45}{393.65}\right) = 12.117 \text{ J/(K}\cdot\text{mol)} \\ \text{Cooling of the gas}: \Delta S^0_{\text{cooling, gas}} = \displaystyle\int_{184.3°\text{C}}^{120.5°\text{C}} \frac{C_{p,m,\text{gas}}}{T}dT = 37.41\times\ln\left(\frac{393.65}{457.45}\right) = -5.619 \text{ J/(K}\cdot\text{mol)} \\ \Delta S^0_{\text{vap},m(120.5°\text{C})} = \Delta S^0_{\text{heating,liquid}} + \Delta S^0_{\text{vap},m(184.3°\text{C})} + \Delta S^0_{\text{cooling, gas}} = 12.117 + 90.873 - 5.619 = 97.37 \text{ J/(K}\cdot\text{mol)} \end{cases}$$

**Part C:** **[10 marks]** 0.5 moles of an ideal gas undergoes an isothermal process at 300 K against a constant external pressure of 2 atm, such that the entropy of the gas increases by 5.76 J/K. The final volume of the gas is 2 L. The temperature of the surroundings is also constant at 300 K.

(a) [8 marks] Calculate *w*, *q*, $\Delta U$, $\Delta H$, $\Delta G$, $\Delta S_{surr}$, and the initial volume of the gas for this process.

$$\text{For isothermal ideal gas process:}\ \Delta T = 0 \ \Rightarrow\ \Delta U = 0,\ \Delta H = 0$$

$$\Delta S_T = nR\ln\left(\frac{V_2}{V_1}\right) \Rightarrow \ln\left(\frac{V_2}{V_1}\right) = \frac{\Delta S_T}{nR} \Rightarrow \frac{V_2}{V_1} = \exp\left(\frac{\Delta S_T}{nR}\right) \Rightarrow V_1 = V_2\exp\left(\frac{-\Delta S_T}{nR}\right)$$

$$V_1 = V_2\exp\left(\frac{-\Delta S_T}{nR}\right) = 2\times\exp\left(\frac{-5.76}{0.5\times 8.314}\right) = 0.5\ \text{L}$$

$$w = -P_{\text{ex}}\cdot\Delta V = -P_{\text{ex}}(V_2 - V_1) == -2\times(2-0.5) = -3\ \text{L}\cdot\text{atm}\ (-304\ \text{J})$$

$$\Delta U = q + w = 0 \ \Rightarrow\ q = -w = 304\ \text{J}\ (3\ \text{L}\cdot\text{atm})$$

$$\Delta G = \Delta H - T\cdot\Delta S = 0 - 300\times 5.76 = -1728\ \text{J}\ (1.73\ \text{kJ})$$

$$\Delta S_{\text{surr}} = \frac{-q}{T_{\text{surr}}} = \frac{-304}{300} = -1.013\ \text{J/K}$$

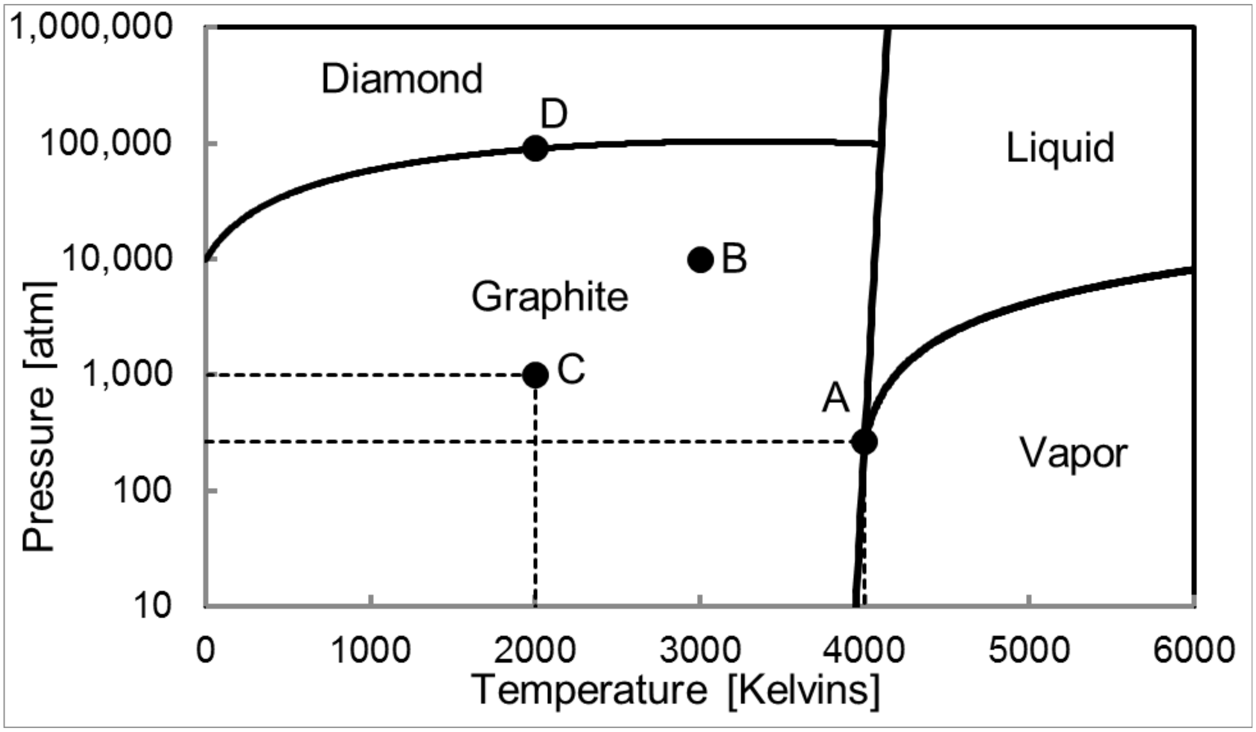
(b) [2 marks] Is this process spontaneous? (circle the **only one** correct answer below)
**Explain your answer**.

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

$$\Delta S_{\text{univ}} = \Delta S_{\text{sys}} + \Delta S_{\text{surr}} = 5.76 - 1.013 = 4.75\ \text{J/K} > 0$$

$\Delta G$ cannot be used here because it is not an isobaric, isothermal process.

**Part D:** **[5 marks]** Please circle the **only one** correct answer for each of the following questions regarding the phase diagram of carbon shown below.



(a) [1 mark] At the temperature and pressure indicated by point B, diamond is turned into graphite. Which one of the following equations is true?

1) $\Delta G > 0$    2) $\Delta G = 0$    3) $\Delta S_{univ} = 0$    [✓ 4) $\Delta G < 0$]    5) $\Delta S_{univ} < 0$

(b) [1 mark] At the temperature and pressure indicated by point D, graphite is turned into diamond. Which one of the following equations is true?

1) $\Delta G > 0$    [✓ 2) $\Delta G = 0$]    3) $\Delta S_{surr} = 0$    4) $\Delta G < 0$    5) $\Delta S_{univ} < 0$

(c) [1 mark] 4000 J of heat are transferred into the system to vaporize a sample of graphite. The system remains at point A throughout the transfer process. Which one of the following equations is true?

1) $\Delta G = 1$ J    2) $\Delta S = -1$ J/K    3) $\Delta S = 0$    4) $\Delta G = -1$ J    [✓ 5) $\Delta S = 1$ J/K]

(d) [1 mark] 2000 J of heat are released from the system to turn a sample of diamond into graphite. The entropy of the diamond is 1 J/K lower than the entropy of the graphite. The system remains at point C throughout the transfer process. Which one of the following equations is true?

1) $\Delta G = 4$ kJ    [✓ 2) $\Delta G = -4$ kJ]    3) $\Delta G = 0$    4) $\Delta G = 2$ kJ    5) $\Delta G = -2$ kJ

(e) [1 mark] At point A, which of the Gibbs phase rule parameters C, P, and F has the correct value?

1) F = 1    2) P = 0    3) P = 1    4) P = 2    [✓ 5) P = 3]