This midterm exam consists of **7** 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 **6** pages in this booklet (including the back pages). Only the work written on the first **6** pages will be marked; anything written on the formula sheet will be discarded and not be marked at all.

Name: ____________________ Student number: ____________________
(print, surname first)

Signature: ____________________ Lecture Section: ____________________

University of British Columbia
CHEM 205 Mid-term Examination
12 February 2015, 6:30−7:30 PM

Time: 60 minutes
Answer all questions
ALL CALCULATORS ARE PERMITTED

READ AND OBSERVE THE FOLLOWING EXAM RULES

1. Each examination candidate must be prepared to produce, upon the request of the invigilator or examiner, his or her UBCcard for identification.
2. Examination candidates are not permitted to ask questions of the examiners or invigilators, except in cases of supposed errors or ambiguities in examination questions, illegible or missing material, or the like.
3. No examination candidate shall be permitted to enter the examination room after the expiration of one-half hour from the scheduled starting time, or to leave during the first half hour of the examination. Should the examination run forty five (45) minutes or less, no examination candidate shall be permitted to enter the examination room once the examination has begun.
4. Examination candidates must conduct themselves honestly and in accordance with established rules for a given examination, which will be articulated by the examiner or invigilator prior to the examination commencing. Should dishonest behaviour be observed by the examiner(s) or invigilator(s), pleas of accident or forgetfulness shall not be received.
5. Examination candidates suspected of any of the following, or any other similar practices, may be immediately dismissed from the examination by the examiner/invigilator, and may be subject to disciplinary action:
   (a) speaking or communicating with other examination candidates, unless otherwise authorized;
   (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).
6. Examination candidates must not destroy or damage any examination material, must hand in all examination papers, and must not take any examination material from the examination room without permission of the examiner or invigilator.
7. Examination candidates must follow any additional examination rules or directions communicated by the examiner(s) or invigilator(s).

Question	Max	Mark
Part A	10	
Part B	15	
Part C	10	
Part D	5	
Total	40	

Part A: [10 marks] There is **only one** correct answer for each of the following questions. Please circle it.

1. [1 mark] An isothermal process is one in which

1) No heat is transferred.

2) No work is done.

3) The system is isolated.

4) Temperature is constant.

5) The system is closed.

2. [1 mark] If an ideal gas undergoes an isothermal irreversible process adiabatically. Which of the following is **not always** true?

1) $\Delta U = 0$ 2) $\Delta(VP) = 0$ 3) $\Delta H = 0$ 4) $\Delta S > 0$ 5) $\Delta G > 0$

3. [1 mark] During a reversible phase transition at constant T and P, which of the following is true?

1) $\Delta S_{sys} = 0$ 2) $\Delta S_{univ} > 0$ 3) $\Delta G_{sys} = 0$ 4) $\Delta H_{sys} = 0$ 5) $\Delta G_{sys} < 0$

4. [1 mark] For a system going from state A to state B through two alternative processes, one reversible and the other irreversible, which of the following is true?

1) $\Delta S^{irrev} \neq \Delta S^{rev}$

2) $w^{irrev} = w^{rev}$

3) $q^{irrev} = q^{rev}$

4) $\Delta S^{irrev} = \Delta S^{rev}$

5) None of the above.

5. [1 mark] Which of the following statements about the Second Law is true?

1) If $\Delta G < 0$, the process is certainly irreversible.

2) If $\Delta G = 0$, the process is certainly reversible.

3) If $\Delta S_{univ} < 0$, the reversibility of the process is uncertain.

4) If $\Delta S_{univ} < 0$, the process in the reverse direction is irreversible.

5) None of the above.

6. [1 mark] The equilibrium constant, *K*, involves activities of products and reactants at:

1) standard state conditions.

2) equilibrium conditions.

3) initial conditions before reaching equilibrium.

4) 1 atm and 25 °C.

5) None of the above.

7. [1 mark] An ideal gas is undergoing an isothermal expansion against a constant external pressure. Which of the following statements is true?

1) This process is reversible.

2) This process is irreversible.

3) This process is exothermic.

4) The system pressure is always in equilibrium with the external pressure.

5) The information given is insufficient to describe this process.

8. [1 mark] Which of the following equations holds for any spontaneous process?

1) $\Delta S > 0$ 2) $\Delta G < 0$ 3) $\Delta S_{surr} > 0$ 4) $\Delta G > 0$ 5) $\Delta S_{univ} > 0$

9. [1 mark] According to the Gibbs phase rule, what is the maximal number of phases that can co-exist in equilibrium for a pure substance?

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

10. [1 mark] Which of the following statements is true for chemical equilibrium?

1) At equilibrium, $Q = 0$ and $\Delta G = RT \ln K$

2) At equilibrium, $\Delta G = RT \ln Q$ and $\Delta G^0 = 0$

3) At equilibrium, $\Delta G^0 = -RT \ln K$ and $Q = K$

4) At equilibrium, $\Delta G = -RT \ln Q$

5) At equilibrium, $\Delta G = 0$ and $K = 1$

Part B: **[15 marks]** Consider ethane to be an ideal gas with $C_{V,m} = 39$ J mol^{-1} K^{-1}. Three moles of ethane gas at 300 K are compressed isothermally against a constant external pressure of 2 atm until the pressure of the gas equals the external pressure. During this compression, 3000 J of work are done on the ethane, and the temperature of the surroundings is kept at 300 K.

(a) [4 marks] Calculate the initial and final volumes (V_i and V_f).

(b) [9 marks] Calculate q, ΔU, ΔH, ΔS, ΔG, and ΔS_{surr} for this process.

(c) [2 marks] This process is: (circle on below)

1) spontaneous 2) reversible 3) spontaneous in the opposite direction

Explain your answer here:

Part C: [10 marks] The following chemical reaction, taking place at 298 K,

$$2\,\mathrm{NO}(g) + \mathrm{N_2O_3}(g) \rightleftharpoons \mathrm{N_2}(g) + \mathrm{N_2O_5}(s)$$

has a standard entropy of reaction of −366.45 J/K and a standard enthalpy of reaction of −314.88 kJ. Some standard entropies are provided below:

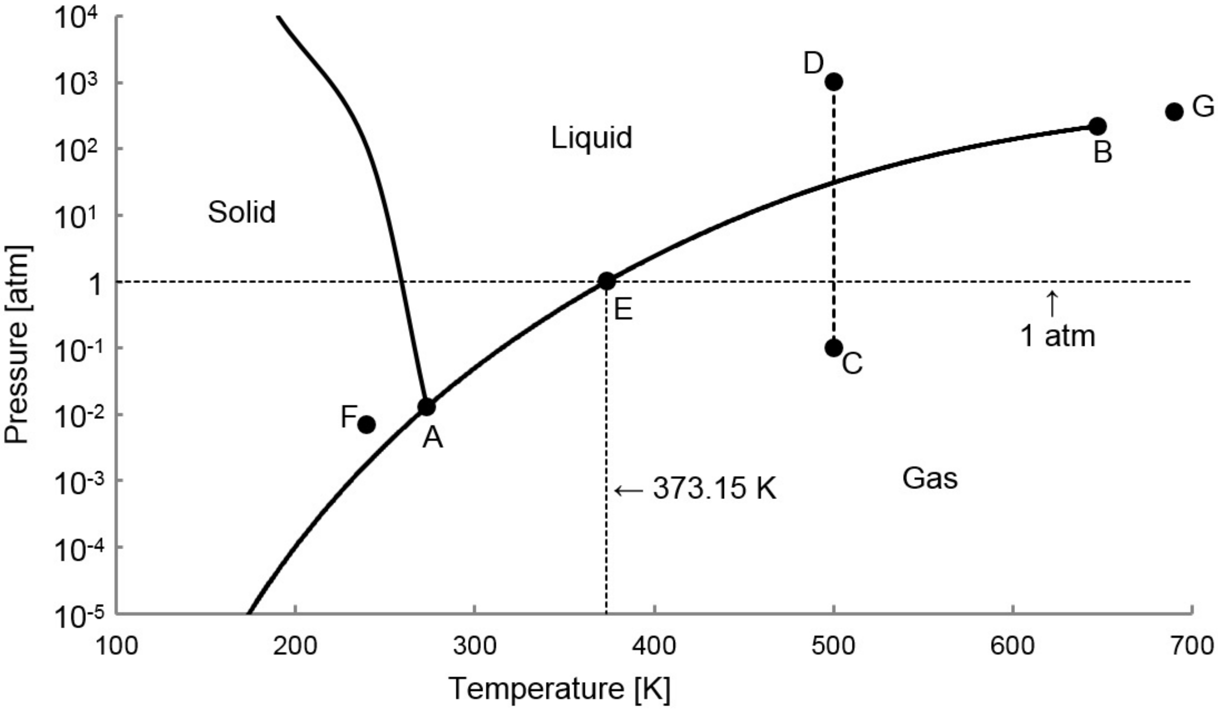
at 298 K	$N_2O_3(g)$	$N_2(g)$	$N_2O_5(s)$
S^0 [J K^{-1} mol^{-1}]	314.63	191.50	178.20

(a) [3 marks] Calculate the standard entropy of $NO(g)$ at 298 K.

(b) [5 marks] Calculate the standard Gibbs free energy of reaction and the equilibrium constant K at 298 K.

(c) [2 marks] At what temperature can the reverse reaction begin to become spontaneous under standard state conditions? **State clearly any approximations you have made**.

Part D: [5 marks] Please circle the **only** correct answer for each of the following questions regarding the phase diagram for water (H_2O) shown below.



(a) [1 mark] At point F, which of the following actions is sufficient to melt ice to liquid water?

1) Increasing only T
2) Decreasing only T
3) Increasing only P
4) Decreasing only P
5) Just wait because the melting of ice at point F is spontaneous

(b) [1 mark] The broken line connecting points C and D represents an isothermal process between liquid water and water vapour. The change in volume ΔV for $C \rightarrow D$ should be:

1) Positive
2) Negative
3) Zero

(c) [1 mark] On the phase diagram, where is the triple point?

1) At point A
2) At point G
3) At point D
4) At point E
5) At point F

(d) [1 mark] A beaker is filled with boiling water under standard conditions. Which point on the water phase diagram is the best representation of the water in this beaker?

1) A
2) B
3) D
4) E
5) F

(e) [1 mark] On the phase diagram, the broken line connecting points C and D represents an isothermal process at 500 K. At the intersection of the broken line C−D with the curve E−B, the enthalpy change of the phase transition is equal to −500 J. Which of the following describes the actual process?

1) $D \rightarrow C$ and $\Delta S = -1$ J/K
2) $D \rightarrow C$ and $\Delta S = 1$ J/K
3) $C \rightarrow D$ and $\Delta S = 1$ J/K
4) $C \rightarrow D$ and $\Delta S = -1$ J/K
5) $\Delta S = -1$ J/K and it is impossible to tell the direction.

SOME FAMILIAR EQUATIONS and CONSTANTS:
NOTE: conditions to which they apply are NOT specified here.

R = 8.314 J K^{-1} mol^{-1} = 0.08206 L atm K^{-1} mol^{-1}
k = 1.3807 × 10^{-23} JK^{-1}
e = 1.602x10^{-19} C
N_A = 6.0221x10^{23} mol^{-1}
$F = eN_A$ =96485 C mol^{-1}
c = 2.998×10^{8} m/s
h = 6.626×10^{-34} J s
1 atm = 101325 Pa

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

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

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

$$w = -p_{ex}\,(V_2 - V_1)$$

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

$$dq = C\, dT$$

$$nC_{V,m} = (dq_V / dT)$$

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

$$H = U + pV$$

$$nC_{p,m} = (dq_p / dT)$$

$$(\Delta H)_p = q_p = \int_{T_1}^{T_2} nC_{p,m}\, dT$$

$$C_{V,m} = \frac{3}{2}R \qquad C_{p,m} = \frac{5}{2}R$$

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

$$S = k \ln W$$

$$\Delta S = S_2 - S_1 = \int_{state1}^{state2} (dq_{rev}/T)$$

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

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

$$\Delta S_{univ} = \Delta S + \Delta S_{surr}$$

$$\ln\frac{p_2}{p_1} = -\frac{\Delta_{vap}H_m}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

$$G = H - TS$$

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

$$\Delta_r G = \Delta_r G^0 + RT\ln(Q)$$

$$E = -\frac{\Delta_r G^0}{n\cdot F} - \frac{R\cdot T}{n\cdot F}\cdot\ln(Q)$$

$$= E^0 - \frac{R\cdot T}{n\cdot F}\cdot\ln(Q)$$

$$\Delta T_b = T_{b,mix} - T_{b,pure} \approx K_b b_B = K_b m_B$$

$$\Delta T_f = T_{f,mix} - T_{f,pure} \approx -K_f b_B = -K_c m_B$$

$$\Pi = c_B RT$$

$$\varepsilon \approx -\frac{RT}{z_i F}\ln\left(\frac{[i]_R}{[i]_L}\right)$$

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

$$c = \lambda\nu$$

$$\Delta E = h\nu = hc/\lambda$$

$$T = I/I_0$$

$$A = \log_{10}(I_0/I) = \varepsilon c l$$

$$E_{vib} = \hbar\sqrt{\frac{k}{\mu}}\left(v + \frac{1}{2}\right)$$

$$[A] = [A]_0 - kt \quad and \quad t_{1/2} = [A]_0/(2k)$$

$$\ln\left(\frac{[A]}{[A]_0}\right) = -kt \quad and \quad t_{1/2} = (\ln 2)/k$$

$$\frac{1}{[A]} - \frac{1}{[A]_0} = kt \quad and \quad t_{1/2} = \frac{1}{k[A]_0}$$

$$k = A\exp(-E_a/(RT))$$

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

$$v = \frac{v_{\max}[S]}{[S] + K_M}$$

Part A: [10 marks] There is **only one** correct answer for each of the following questions. Please circle it.

1. [1 mark] An isothermal process is one in which

1) No heat is transferred.

2) No work is done.

3) The system is isolated.

[✓ 4) Temperature is constant.]

5) The system is closed.

2. [1 mark] If an ideal gas undergoes an isothermal irreversible process adiabatically. Which of the following is **not always** true?

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

3. [1 mark] During a reversible phase transition at constant T and P, which of the following is true?

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

4. [1 mark] For a system going from state A to state B through two alternative processes, one reversible and the other irreversible, which of the following is true?

1) $\Delta S^{irrev} \neq \Delta S^{rev}$

2) $w^{irrev} = w^{rev}$

3) $q^{irrev} = q^{rev}$

[✓ 4) $\Delta S^{irrev} = \Delta S^{rev}$]

5) None of the above.

5. [1 mark] Which of the following statements about the Second Law is true?

1) If $\Delta G < 0$, the process is certainly irreversible.

2) If $\Delta G = 0$, the process is certainly reversible.

3) If $\Delta S_{univ} < 0$, the reversibility of the process is uncertain.

[✓ 4) If $\Delta S_{univ} < 0$, the process in the reverse direction is irreversible.]

5) None of the above.

6. [1 mark] The equilibrium constant, K, involves activities of products and reactants at:

1) standard state conditions.

[✓ 2) equilibrium conditions.]

3) initial conditions before reaching equilibrium.

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5) None of the above.

7. [1 mark] An ideal gas is undergoing an isothermal expansion against a constant external pressure. Which of the following statements is true?

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8. [1 mark] Which of the following equations holds for any spontaneous process?

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

9. [1 mark] According to the Gibbs phase rule, what is the maximal number of phases that can co-exist in equilibrium for a pure substance?

1) 0 2) 1 3) 2 [✓ 4) 3] 5) unlimited

10. [1 mark] Which of the following statements is true for chemical equilibrium?

1) At equilibrium, $Q = 0$ and $\Delta G = RT \ln K$

2) At equilibrium, $\Delta G = RT \ln Q$ and $\Delta G^0 = 0$

[✓ 3) At equilibrium, $\Delta G^0 = -RT \ln K$ and $Q = K$]

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5) At equilibrium, $\Delta G = 0$ and $K = 1$

Part B: **[15 marks]** Consider ethane to be an ideal gas with $C_{V,m} = 39\ \mathrm{J\ mol^{-1}\ K^{-1}}$. Three moles of ethane gas at 300 K are compressed isothermally against a constant external pressure of 2 atm until the pressure of the gas equals the external pressure. During this compression, 3000 J of work are done on the ethane, and the temperature of the surroundings is kept at 300 K.

(a) [4 marks] Calculate the initial and final volumes (V_i and V_f).

$$\text{(a)}\ \begin{cases} p_f V_f = nRT \ \Rightarrow V_f = \dfrac{nRT}{p_f} = \dfrac{3\times 0.08206\times 300}{2} = 36.9\ \text{L}\ \ (\text{or}\ 0.0369\ \text{m}^3) \\ w = -p_{ex}\cdot(V_f - V_i) \ \Rightarrow V_i = V_f + \dfrac{w}{p_{ex}} = 36.9 + \dfrac{3000}{2\times 101.325} = 51.7\ \text{L}\ \ (\text{or}\ 0.0517\ \text{m}^3) \end{cases}$$

(b) [9 marks] Calculate q, ΔU, ΔH, ΔS, ΔG, and ΔS_{surr} for this process.

$$\text{(b)}\ \begin{cases} w = 3000\ \text{J} \\ dT = 0\ \text{for ideal gas} \ \Rightarrow\ \Delta U = 0,\ \ \Delta H = 0 \\ \Delta U = q + w = 0 \ \Rightarrow q = -w = -3000\ \text{J}\ (-3\ \text{kJ}) \\ \Delta S_T = nR\ln\dfrac{V_f}{V_i} = 3\times 8.314\times\ln\dfrac{36.9}{51.7} = -8.41\ \text{J/K} \\ \Delta G = \Delta H - T\cdot\Delta S = -T\cdot\Delta S = -300\times(-8.41) = 2523\ \text{J}\ (2.52\ \text{kJ}) \\ \Delta S_{surr} = \dfrac{-q}{T} = \dfrac{3000}{300} = 10\ \text{J/K} \end{cases}$$

(c) [2 marks] This process is: (circle on below)

[✓ 1) spontaneous] 2) reversible 3) spontaneous in the opposite direction

Explain your answer here:

$$\text{(c)}\ \begin{cases} \text{Because of non-iso-}p,\ \Delta G\ \text{cannot be used here.} \\ \Delta S_{univ} = \Delta S_{sys} + \Delta S_{surr} = -8.41 + 10 = 1.59\ \text{J/K} > 0 \end{cases}$$

Part C: [10 marks] The following chemical reaction, taking place at 298 K,

$$2\,\mathrm{NO}(g) + \mathrm{N_2O_3}(g) \rightleftharpoons \mathrm{N_2}(g) + \mathrm{N_2O_5}(s)$$

has a standard entropy of reaction of −366.45 J/K and a standard enthalpy of reaction of −314.88 kJ. Some standard entropies are provided below:

at 298 K	$N_2O_3(g)$	$N_2(g)$	$N_2O_5(s)$
S^0 [J K^{-1} mol^{-1}]	314.63	191.50	178.20

(a) [3 marks] Calculate the standard entropy of NO(*g*) at 298 K.

$$\text{(a)}\ \left\{\begin{aligned} \Delta S^0 &= S^0(\mathrm{N_2}) + S^0(\mathrm{N_2O_5}) - S^0(\mathrm{N_2O_3}) - 2\cdot S^0(\mathrm{NO}) = -366.45\ \text{J/K} \\ S^0(\mathrm{NO}) &= \frac{S^0(\mathrm{N_2}) + S^0(\mathrm{N_2O_5}) - S^0(\mathrm{N_2O_3}) - \Delta S^0}{2} \\ &= \frac{191.50 + 178.20 - 314.63 + 366.45}{2} = 210.76\ \text{J/(K}\cdot\text{mol)} \end{aligned}\right.$$

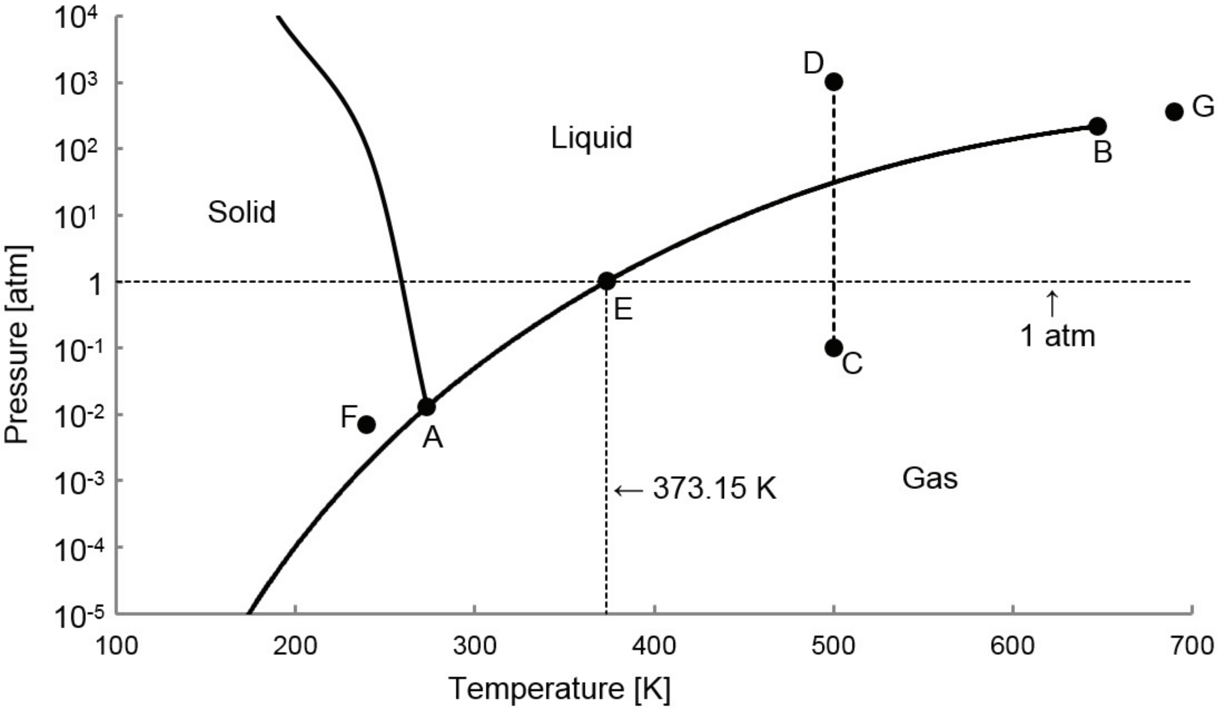
(b) [5 marks] Calculate the standard Gibbs free energy of reaction and the equilibrium constant *K* at 298 K.

$$\text{(b)}\ \left\{\begin{aligned} &\Delta G^0 = \Delta H^0 - T\cdot\Delta S^0 = -314.88 + 0.298\times 366.45 = -205.68\ \text{kJ} \\ &\Delta G^0 = -(1\,\text{mol})\cdot RT\cdot \ln K \;\Rightarrow\; \ln K = \frac{-\Delta G^0}{(1\,\text{mol})\cdot RT} = \frac{205.68}{8.314\times 0.298} = 83.02 \\ &K = e^{83.02} = 1.13\times 10^{36} \end{aligned}\right.$$

(c) [2 marks] At what temperature can the reverse reaction begin to become spontaneous under standard state conditions? **State clearly any approximations you have made**.

$$\text{(c)}\ \left\{\begin{aligned} &\text{Reverse reaction is spontaneous: } \Delta G^0_{back} = -\Delta G^0 = -(\Delta H^0 - T\cdot\Delta S^0) = T\cdot\Delta S^0 - \Delta H^0 < 0 \\ &\left.\begin{aligned} T\cdot\Delta S^0 &< \Delta H^0 \\ \Delta S^0 &< 0 \end{aligned}\right\} \Rightarrow\; T > \frac{\Delta H^0}{\Delta S^0} = \frac{-314.88}{-0.36645} = 859.3\ \text{K (or 586 °C)} \\ &\text{where } \Delta H^0 \text{ \& } \Delta S^0 \text{ are assumed to be independent of } T \end{aligned}\right.$$

Part D: [5 marks] Please circle the **only** correct answer for each of the following questions regarding the phase diagram for water (H_2O) shown below.



(a) [1 mark] At point F, which of the following actions is sufficient to melt ice to liquid water?

1) Increasing only *T*
2) Decreasing only *T*
[✓ 3) Increasing only *P*]
4) Decreasing only *P*
5) Just wait because the melting of ice at point F is spontaneous

(b) [1 mark] The broken line connecting points C and D represents an isothermal process between liquid water and water vapour. The change in volume ΔV for $C \rightarrow D$ should be:

1) Positive
[✓ 2) Negative]
3) Zero

(c) [1 mark] On the phase diagram, where is the triple point?

[✓ 1) At point A]
2) At point G
3) At point D
4) At point E
5) At point F

(d) [1 mark] A beaker is filled with boiling water under standard conditions. Which point on the water phase diagram is the best representation of the water in this beaker?

1) A
2) B
3) D
[✓ 4) E]
5) F

(e) [1 mark] On the phase diagram, the broken line connecting points C and D represents an isothermal process at 500 K. At the intersection of the broken line C−D with the curve E−B, the enthalpy change of the phase transition is equal to −500 J. Which of the following describes the actual process?

1) $D \rightarrow C$ and $\Delta S = -1$ J/K
2) $D \rightarrow C$ and $\Delta S = 1$ J/K
3) $C \rightarrow D$ and $\Delta S = 1$ J/K
[✓ 4) $C \rightarrow D$ and $\Delta S = -1$ J/K]
5) $\Delta S = -1$ J/K and it is impossible to tell the direction.