

2018 FALL Semester Final Examination For General Chemistry I

Date: December 12 (Wed), **Time Limit:** 19:00 ~ 21:00

Write down your information neatly in the space provided below; print your Student ID in the upper right corner of every page.

Professor Name	Class	Student I.D. Number	Name
Problem	points	Problem	points
1	/10	7	/8
2	/4	8	/11
3	/3	9	/13
4	/6	10	/13
5	/10	11	/13
6	/4	12	/5
/100			

** This paper consists of 13 sheets with 12 problem sets (pages 11 & 12: constants & periodic table, page 13: claim form). Please check all page numbers before taking the exam. Write down your work and answers in the Answer sheet.

Please write down units in your answer when applicable. You will get 30% deduction for a missing unit.

NOTICE: SCHEDULES on RETURN and CLAIM of the MARKED EXAM PAPER.

(채점 답안지 분배 및 이의신청 일정)

1. Period, Location, and Procedure

- 1) Return and Claim Period: **December 14 (Fri, 12:00 ~ 14:00 p.m.)**
- 2) **Location: Room in Creative Learning Bldg. (E11)**

Class	Room	Class	Room	Class	Room
A	302	B	309	C	310

- 3) Procedure:

Rule 1: Students cannot bring their own writing tools into the room. (Use a pen only provided by TA)

Rule 2: With or without claim, you must submit the paper back to TA. (Do not go out of the room with it)

(During the period, you can check the marked exam paper from your TA and should hand in the paper with a FORM for claims if you have any claims on it. The claim is permitted only on the period. Keep that in mind! A solution file with answers will be uploaded on **December 14** on the web.)

2. Final Confirmation

- 1) Period: December 15 (Sat) – December 16 (Sun)
- 2) Procedure: During this period, you can check the final score of the examination *on the website*.

** For further information, please visit General Chemistry website at www.gencheminkaist.pe.kr.

1. (Total 10 pts)

Suppose that there are N molecules in a cubic box of a side length ℓ . Assume that each molecule with mass of m constantly collides elastically with the wall of the box with a speed of u . By using the ideal gas law, show that the average kinetic energy per molecule ($\bar{\epsilon}$) depends on the temperature. You should write down all the procedures to get the full points.

(Answer)

(1) **Force acted on the original wall by a molecule (+ 3 pts)**

$$\begin{aligned}\Delta p_{x,\text{mol}} &= m(-v_x) - mv_x = -2mv_x \\ \Delta p_{x,\text{wall}} &= 2mv_x \\ \Delta t &= 2\ell/v_x \\ f &= ma = m \frac{\Delta v}{\Delta t} = \frac{\Delta p_{x,\text{wall}}}{\Delta t} = \frac{mv_x^2}{\ell}\end{aligned}$$

(2) **Force acted on the original wall by N molecules (+ 1 pt)**

$$F = \frac{mv_{x1}^2}{\ell} + \frac{mv_{x2}^2}{\ell} + \frac{mv_{x3}^2}{\ell} + \dots + \frac{mv_{xN}^2}{\ell} = N \frac{m\overline{v_x^2}}{\ell}, \quad \text{where } \overline{v_x^2} = \frac{1}{N}(v_{x1}^2 + v_{x2}^2 + v_{x3}^2 + \dots + v_{xN}^2)$$

(3) **Pressure on the original wall of area A (+ 1 pt)**

$$P = \frac{F}{A} = \frac{Nm}{A\ell} v_x^2 = \frac{Nm}{V} v_x^2$$

(4) **The mean-square speed of a molecule with no preferred direction (+ 1 pt)**

$$\begin{aligned}\overline{u^2} &= \overline{v_x^2} + \overline{v_y^2} + \overline{v_z^2} = 3\overline{v_x^2} \\ PV &= Nm\overline{v_x^2} = \frac{1}{3}Nm\overline{u^2}\end{aligned}$$

(5) **Ideal gas law (+ 3 pts)**

$$nRT = \frac{1}{3}Nm\overline{u^2} \rightarrow RT = \frac{1}{3}N_A m\overline{u^2} \quad (\text{from the ideal gas law})$$

(6) **Average kinetic energy per molecule (+ 1 pt)**

$$\overline{E} = \frac{1}{2}N_A m\overline{u^2} \rightarrow \overline{\epsilon} = \frac{1}{2}m\overline{u^2} = \frac{1}{2}\left(\frac{3RT}{N_A}\right) = \frac{3}{2}k_B T$$

2. (Total 4 pts) The van der Waals equation is given as $\left(P + a \frac{n^2}{V^2}\right)(V - nb) = nRT$.

(a) List CH₄, H₂, N₂, and NH₃ in the increasing order in a with an explanation on your logic.

"a" constant depends on the strength of attractions between its component molecules



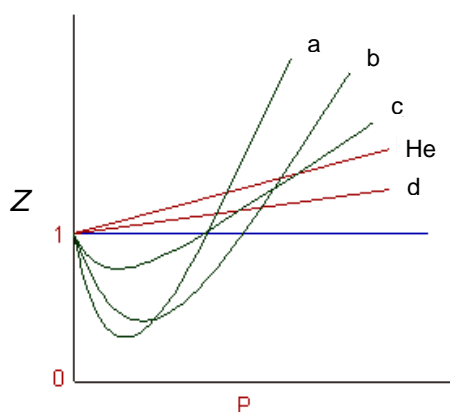
(b) List CH₄, H₂, N₂, and NH₃ in the increasing order in b with an explanation on your logic.

"b" constant reflects merely the actual volume of a mole of the molecules



3. (Total 3 pts)

The following five curves are sketches of the compressibility factors ($Z = PV / nRT$) for CH₄, CO₂, H₂, He, and NH₃ at varying pressures but at a constant temperature. The curve for He is explicitly designated for your information. For each of the remaining four curves marked with a – d, designate the gas by choosing from the remaining list (CH₄, CO₂, H₂, and NH₃).



a = NH₃ (hydrogen bonding and most deviating from ideality); b = CO₂ (larger dispersion than CH₄), c = CH₄; d = H₂ (closest to ideal)

→ 1pt for H₂, 1pt for NH₃, 1pt for getting CO₂ and CH₄ right.

4. (Total 6 pts)

State which attractive intermolecular force plays most dominantly in the following molecular pairs.

(a) Sodium ion – water : Ion – dipole force

(b) Hydroxide ion – water : Ion – dipole force

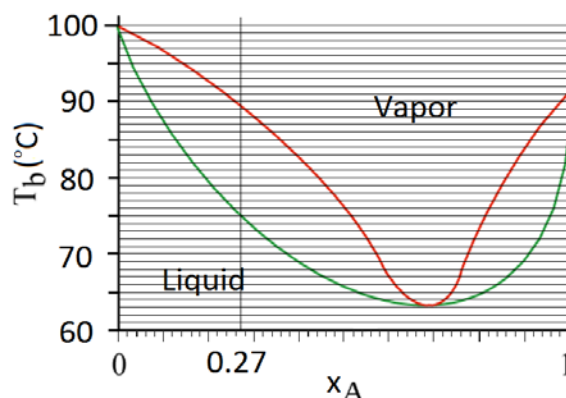
(c) Carbon dioxide gas – water : Induced dipole force (Dipole – induced dipole force)

(d) Methanol – ethanol : Hydrogen bonding

(e) Chloride ion – hexane (C₆H₁₄) : Ion – induced dipole / Charge – induced dipole force

(f) Octane (C₈H₁₈) – hexane (C₆H₁₄) : Induced dipole – induced dipole force (London dispersion force / Van der Waals force)

5. (Total 10 pts) Liquid A and B mix together as a non-ideal solution. Using the following phase diagram of boiling temperature at 1 atm as a function of the mole fraction of A (x_A), answer the following questions. (2pts each)



(a) Which of the two (namely, A or B) is more volatile at 1 atm?

Pure B boiling point: 100 deg; pure A boiling point: 91 deg → A is more volatile

(b) Estimate the boiling point of a solution with $x_A = 0.27$.

Just read it: 75 °C

(c) When an infinitesimally small amount of vapor is collected by boiling the solution in (b), what is the mole fraction of A in that vapor?

Follow the horizontal line, meet the vapor line, and then project to the x_A value: ~0.52

(d) If the vapor collected in (c) is condensed as liquid, what is its boiling point?

Do the same thing as in (b) with $x_A \sim 0.52$ to find 65 °C.

(e) Continuing the process of collecting vapor and then boiling again generates azeotrope. What is the mole fraction of A in this azeotrope?

0.68 (slight reading error is ok.)

6. (Total 4 pts: 1 pt for each right answer, -1 pt for each wrong one, and zero pt for not answering)

Answer whether the following statements are true or false. Just give the answer: no explanation is needed.

(a) When a system that is in thermal contact with a bath undergoes a spontaneous change, the entropy of the system always increases. **False, the entropy of the universe increases**

(b) The enthalpy of one mole of a monatomic ideal gas can be exactly known when its temperature but not its pressure is known. **True, $5/2 RT$**

(c) When a thermally isolated monatomic ideal gas expands freely against zero external pressure, its temperature always stays constant. **True, no work and no heat and its energy stays the same.**

(d) There is no inter-molecular interaction in an ideal solution in liquid phase. Namely, the molecules in an ideal solution do not attract or repel each other. **False, interactions are the same for each pair.**

7. (Total 8 pts) At 90°C, the vapor pressure of toluene (C₆H₅CH₃) is 0.534 atm and the vapor pressure of benzene (C₆H₆) is 1.34 atm. Now suppose that 0.400 mol of benzene is mixed with 0.900 mol of toluene to form an ideal solution at 90°C.

(a) Compute the mole fraction of benzene in the vapor that is in equilibrium with this solution.

$$P_{\text{toluene}} = x_{\text{toluene}} P_{\text{toluene}}^{\circ} = \frac{0.900}{0.400 + 0.900} \times 0.534 \text{ atm} = 0.370 \text{ atm}$$

$$P_{\text{benzene}} = x_{\text{benzene}} P_{\text{benzene}}^{\circ} = \frac{0.400}{0.400 + 0.900} \times 1.34 \text{ atm} = 0.412 \text{ atm}$$

The total pressure of the vapors above solution is 0.782 atm. Therefore, the mole fraction of benzene in the vapor is

$$x_{\text{benzene}} = \frac{0.412 \text{ atm}}{0.782 \text{ atm}} = 0.527$$

(b) Calculate the mole fraction of toluene in a mixture of benzene and toluene that boils at 90°C under atmospheric pressure.

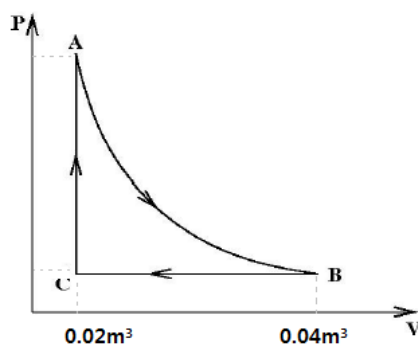
The vapor pressure of toluene is 0.534 atm at 90°C, and the vapor pressure of benzene is 1.34 atm. In order for the solution to boil, the total pressure above it must equal 1.00 atm. This total pressure is the sum of the pressures of the two components, each of which is given by Raoult's law. Letting the mole fraction of the toluene in solution as x_{toluene} , then the mole fraction of benzene is

$$x_{\text{benzene}} = 1 - x_{\text{toluene}}, \text{ and}$$

$$x_{\text{toluene}}(0.533 \text{ atm}) + (1 - x_{\text{toluene}})(0.533 \text{ atm}) = 1 \text{ atm}$$

Solving for x_{toluene} gives 0.42 as the answer.

8. (Total 11 pts) Four moles of a monatomic ideal gas goes through the cycle represented in the following figure. Process A → B is an isothermal expansion at a temperature $T_A = 300\text{K}$.



(a) Calculate P_A , P_B , and T_C , the pressures and temperature reached at A, B and C.

Process A → B is isothermal, so $T_A = T_B$

$$P_A = \frac{nRT_A}{V_A} = \frac{4 \text{ mol} \times 8.314 \text{ J K}^{-1} \text{ mol}^{-1} \times 300 \text{ K}}{0.02 \text{ m}^3} = 4.988 \times 10^5 \text{ Pa} = 4.92 \text{ atm}$$

$$P_B = \frac{nRT_B}{V_B} = \frac{4 \text{ mol} \times 8.314 \text{ J K}^{-1} \text{ mol}^{-1} \times 300 \text{ K}}{0.04 \text{ m}^3} = 2.494 \times 10^5 \text{ Pa} = 2.46 \text{ atm}$$

$$T_C = \frac{P_C V_C}{nR} = \frac{P_B V_A}{nR} = \frac{(2.494 \times 10^5 \text{ J m}^{-3}) \times (0.02 \text{ m}^3)}{4 \text{ mol} \times 8.314 \text{ J K}^{-1} \text{ mol}^{-1}} = 150 \text{ K}$$

(b) (8 pts) Fill in the following table with numerical values in Joules.

Process	ΔU	q	w
A → B	0 J	6915 J	-6915 J
B → C	-7483 J	-12471 J	4988 J
C → A	7483 J	7483 J	0 J

(1) A → B

$$\Delta U_{AB} = q + w = 0 \text{ (isothermal)}, \text{ and } dq = -dw = PdV = \left(\frac{nRT}{V}\right)dV \rightarrow$$

$$q = \int_A^B dq = -\int_A^B dw = \int_A^B PdV = \int_A^B \left(\frac{nRT}{V}\right)dV = 4 \text{ mol} \times 8.314 \text{ J K}^{-1} \text{ mol}^{-1} \times 300 \text{ K} \times \ln \frac{0.04}{0.02} \text{ J} = 6915 \text{ J}$$

and w is equal to $-q = -6915 \text{ J}$

(2) B → C

$$w_{BC} = -P\Delta V = -(2.494 \times 10^5 \text{ J m}^{-3})(0.02 \text{ m}^3 - 0.04 \text{ m}^3) = +4988 \text{ J}$$

$$q_{BC} = nc_p \Delta T = (4 \text{ mol}) \left(\frac{5}{2} R\right) (150 - 300 \text{ K}) = -12471 \text{ J}$$

$$\Delta U_{BC} = q + w = -7483 \text{ J}$$

(3) C → A: Because U is a state function, $\Delta U_{CA} = -\Delta U_{AB} - \Delta U_{BC} = 7483 \text{ J} = q_{CA}$. Or equivalently,

$$q_{CA} = nc_v \Delta T = (4 \text{ mol}) \left(\frac{5}{2} R\right) (300 - 150 \text{ K}) = 7483 \text{ J} = \Delta U_{CA}$$

9. (Total 13 pts) The equipartition theorem allows you to estimate the molar heat capacity values for various species.

(a) (4 pts) Give the equipartition values of c_v in J/mol·K for the following species.



Ar has only 3 translational degrees of freedom, so its equipartition value is $3R/2$.

N₂ has 3 translational degrees of freedom, 2 rotational degrees of freedom (linear), and 1 vibrational degree of freedom ($3 \times 2 - 5 = 1$). Its equipartition value is $7R/2$.

CO₂ has 3 translational degrees of freedom, 2 rotational degrees of freedom (linear), and 4 vibrational degrees of freedom ($3 \times 3 - 5 = 4$). Its equipartition value is $13R/2$.

CH₄ has 3 translational degrees of freedom, 3 rotational degrees of freedom (nonlinear), and 9 vibrational degrees of freedom ($3 \times 5 - 6 = 9$). Its equipartition value is $24R/2$.

Therefore, for each atom or molecule,

$$c_v(\text{Ar}) = \frac{3}{2} \times 8.314 \text{ J/K} \cdot \text{mol} = 12.47 \text{ J/K} \cdot \text{mol}$$

$$c_v(\text{N}_2) = \frac{7}{2} \times 8.314 \text{ J/K} \cdot \text{mol} = 29.10 \text{ J/K} \cdot \text{mol}$$

$$c_v(\text{CO}_2) = \frac{13}{2} \times 8.314 \text{ J/K} \cdot \text{mol} = 54.04 \text{ J/K} \cdot \text{mol}$$

$$c_v(\text{CH}_4) = \frac{24}{2} \times 8.314 \text{ J/K} \cdot \text{mol} = 99.77 \text{ J/K} \cdot \text{mol}$$

+1 pt for each correct c_v value

If the values were not converted to J/K mol units, -1 pt maximum (NOT deducting -1 pt for each!)

(b) (3 pts) The equipartition theorem predicts c_p of methane (CH₄) at 298K to be 108.08 J/mol·K, but the experimental value of c_p is only 35.31 J/mol·K. Based on the assumption that translational and rotational motions of methane are fully activated, calculate the percent of the measured c_p value at 298K that arises from vibrational motion.

From (a), CH₄ has 9 vibrational degrees of freedom. Suppose these vibrational degrees of freedom have no contribution to c_p value. That gives

$$c_v = 3R, c_p = c_v + R = 4R = 33.25 \text{ J/K} \cdot \text{mol}$$

$$\therefore \text{The vibrational contribution} = (35.31 - 33.25) \text{ J K}^{-1} \text{ mol}^{-1} = 2.06 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$\text{percent of } c_p \text{ due to vibration} = \left(\frac{2.06}{35.31} \right) \times 100\% = 5.83\%$$

+1 pt for the correct value of c_p value without vibrational contribution

+1 pt for the correct value of vibrational contribution

+1 pt for the correct answer

(c) (6 pts) Suppose 1.00 kJ of heat is transferred to 2.00 mol CH₄ at 298.0 K. During the heating process, the pressure is maintained constant at 1 atm. Calculate ΔU , q , w , ΔH , and the final temperature for this process. Use the measured value of c_p in (b). Toward calculating ΔU , assume that methane behaves with $PV = nRT$.

At constant pressure,

$$q_p = \Delta H = n c_p \Delta T = 1000 \text{ J}$$

$$1000 \text{ J} = (2.00 \text{ mol})(35.31 \text{ J K}^{-1} \text{ mol}^{-1}) \Delta T$$

$$\Delta T = 14.2 \text{ K}; \quad \therefore T_{\text{final}} = 298 + 14.2 = 312.2 \text{ K}$$

$$\Delta U = \Delta H - P\Delta V = \Delta H - nR\Delta T = 1000 \text{ J} - 2.00 \text{ mol} \times 8.314 \text{ J K}^{-1} \text{ mol}^{-1} \times 14.2 \text{ K} = 764 \text{ J}$$

$$w = \Delta U - q = 764 \text{ J} - 1000 \text{ J} = -236 \text{ J}$$

+1 pt for each correct answers for q_p , ΔH , T , and w

+2 pt for ΔU

10. (Total 13 pts)

(a) Starting from the definition of the entropy change, $\Delta S = \int_i^f \frac{dq_{\text{rev}}}{T}$, derive ΔS associated with the reversible expansion of n mol of an ideal monatomic gas, from volume V_1 to volume V_2 . Express your answer with the gas constant R together with n , V_1 , and V_2 .

$$\Delta S = \int_{V_1}^{V_2} \frac{PdV}{T} = \int_{V_1}^{V_2} \frac{nRdV}{V} = nR \ln \frac{V_2}{V_1} \quad (3\text{pts})$$

(b) Calculate the entropy change associated with the reversible expansion of 5.00 mol of an ideal monatomic gas at a constant temperature of 298.0 K from a pressure of 10.0 atm to 1.00 atm.

$$\Delta S = nR \ln \frac{V_2}{V_1} = nR \ln \frac{P_1}{P_2} = (5.00 \text{ mol})(8.314 \text{ J K}^{-1} \text{ mol}^{-1}) \ln 10 = 95.7 \text{ J K}^{-1} \quad (2\text{pts})$$

(c) Calculate the entropy change associated with the reversible adiabatic expansion of 5.00 mol of an ideal monatomic gas from a pressure of 10.0 atm to 1.00 atm.

For the adiabatic part of this path, $dq_{\text{rev}} = 0$ and entropy change is 0. (3pts)

(d) Based on the fact that the entropy is a state function, find the temperature of the expanded gas in (c). [Hint: You should use the fact that reversible heating of the gas at constant pressure back to 298.0 K will lead to the same state with the same entropy.]

Let us suppose that the temperature of the gas is T_2 , with $T_1 = 298.0$ K. For the reversible heating or cooling at constant pressure from T_2 to $T_1 = 298.0$ K, the entropy change is

$$\Delta S = \int_{T_2}^{T_1} \frac{nc_p dT}{T} = nc_p \ln \frac{T_1}{T_2} \quad (2\text{pts})$$

Because the entropy is a state function, this ΔS is the same as the entropy change in (b). Thus,

$$\Delta S = nc_p \ln \frac{T_1}{T_2} = (5.00 \text{ mol}) \left(\frac{5}{2} \times 8.314 \text{ J K}^{-1} \text{ mol}^{-1} \right) \ln \frac{T_1}{T_2} = 95.7 \text{ J K}^{-1}$$

$$\ln \frac{T_1}{T_2} = 0.921$$

$$\text{Thus, } T_2 = T_1 e^{-0.921} = 118.6 \text{ K. (3pts)}$$

[Note] -----

If $P_1 V_1^\gamma = P_2 V_2^\gamma$ and $T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$ are used to get $\left(\frac{P_1}{P_2} \right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{V_2}{V_1} \right)^{\gamma-1} = \frac{T_1}{T_2}$ and then to get

$$T_2 = T_1 \left(\frac{P_2}{P_1} \right)^{\frac{5/3-1}{5/3}} = 0.1^{0.4} \times 298.0 \text{ K} = 118.6 \text{ K, give only 3 pts.}$$

11. (Total 13 pts) For reaction $\text{PCl}_5(\text{g}) \rightleftharpoons \text{PCl}_3(\text{g}) + \text{Cl}_2(\text{g})$, the Gibbs energy change can be expressed with the reaction quotient Q as

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

(a) By assuming that the reaction enthalpy ΔH° and the reaction entropy ΔS° does not depend on temperature, derive the van't Hoff equation that relates two equilibrium constants K_1 and K_2 at two different corresponding temperatures T_1 and T_2 .

Because the reaction free energy is zero when $Q = K$, $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ = -RT \ln K$. Thus,

$$\frac{\Delta H^\circ}{T} - \Delta S^\circ = -R \ln K \quad \text{and} \quad \Delta H^\circ \left(\frac{1}{T_2} - \frac{1}{T_1} \right) = -R \ln \frac{K_2}{K_1}. \quad \text{Or equivalently,}$$

$$\ln \frac{K_2}{K_1} = -\frac{\Delta H^\circ}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right) \quad (3\text{pts for correct derivation, 1pt for just writing down the equation})$$

(b) The equilibrium constant of the above reaction at 300°C is $K_1 = 11.5$. Calculate the equilibrium constant K_2 at 400°C. The standard enthalpies of formation (ΔH_f°) are -287.0 kJ/mol for $\text{PCl}_3(\text{g})$ and -374.9 kJ/mol for $\text{PCl}_5(\text{g})$ at 25°C.

Because the formation enthalpy of Cl_2 is zero, $\Delta H^\circ = 87.9$ kJ/mol.

$$\ln \frac{K_2}{K_1} = -\frac{\Delta H^\circ}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right) = 2.74, \quad \text{and} \quad K_2 = 178. \quad (2 \text{ pts})$$

(c) Using the standard enthalpy of formation of $\text{Cl}(\text{g})$ given as $\Delta H_f^\circ[\text{Cl}(\text{g})] = 122$ kJ/mol, estimate the Cl-Cl bond enthalpy.

The bond enthalpy corresponds to the enthalpy change for one mole of bonds broken: $\text{Cl}_2(\text{g}) \rightarrow 2\text{Cl}(\text{g})$. Thus, $\Delta H^\circ = 244$ kJ/mol. (2pts; 0 pt for 122 kJ/mol or -244 kJ/mol)

(d) Estimate the average P-Cl bond enthalpy.

$$(d) \quad \Delta H^\circ \sim 5\Delta H^\circ(\text{P-Cl}) - 3\Delta H^\circ(\text{P-Cl}) - \Delta H^\circ(\text{Cl-Cl}) = 2x - 244 \text{ kJ/mol} = 87.9 \text{ kJ/mol}$$

$\rightarrow 166 \text{ kJ/mol} \quad (1\text{pt})$

(e) A weighed quantity of solid PCl_5 is sealed in a 100.0 cm³ glass bulb to which a pressure gauge is attached. The bulb is heated to 300°C, and the gauge shows that the pressure in the bulb rises to 0.895 atm. Assuming that the contents of the bulb are at equilibrium with only the three gaseous compounds (PCl_5 , PCl_3 , and Cl_2), calculate the partial pressures of the three chemical species in the vessel. Also calculate the number of moles of the initially weighed solid PCl_5 .

Let us assume that the initial pressure with only PCl_5 is P_0 . The reaction can be considered as the

following:



initial	P_0		
change	$-x$	$+x$	$+x$
final	P_0-x	x	x

Thus, $K_1 = x^2 / (P_0 - x)$. Also, the final pressure is $P_T = 0.895 \text{ atm} = P_0 + x$. Therefore, $K_1 = x^2 / (P_T - 2x) = 11.2$. Solving this quadratic equation yields $x = 0.439$ as the only meaningful solution. Thus, $P(\text{PCl}_5) = P_T - 2x = 0.017 \text{ atm}$, $P(\text{PCl}_3) = P(\text{Cl}_2) = 0.439 \text{ atm}$. (3 pts)

Initially, there was 0.456 atm of PCl_5 . Thus, its number of moles is:

$$n = P_0V/RT = 0.456\text{atm} \times 0.100 \text{ L} / (0.0820574 \text{ L atm mol}^{-1} \text{ K}^{-1} \times 573.15 \text{ K}) = 0.970 \text{ mmol. (2pts)}$$

12. (Total 5 pts) There are two isomeric hydrocarbons with the formula C_4H_{10} , butane and isobutane, which we denote here as B and I. The standard enthalpies of formation for the gaseous species are: -124.7kJ/mol for B, -131.3kJ/mol for I. In addition, the standard Gibbs free energies of formation are -15.9kJ/mol for B, -18.0kJ/mol for I.

(a) Which isomer is more dominantly existing under the standard condition? Explain why.

Let us suppose a reaction: $\text{B} \rightarrow \text{I}$. $\Delta G^\circ = -18.0 \text{ kJ/mol} + 15.9 \text{ kJ/mol} = -2.1 \text{ kJ/mol}$.

Thus, I is more preferred.

(2 pts for correct answer and correct reasoning. 1pt for giving the answer without mentioning the reason)

(b) The following reaction can occur in the presence of a catalyst:



Calculate the equilibrium constant at 298 K for this conversion.

$$\ln K = \frac{\Delta G^\circ}{-RT} = \frac{2.1 \times 10^3 \text{ J mol}^{-1}}{(8.31 \text{ J K}^{-1}\text{mol}^{-1})298 \text{ K}} = 0.85 \quad K = 2.3$$

(1 pt)

(c) Calculate the mole fraction of B in the equilibrium mixture.

Let X be the fraction of B. Then $(1 - X)$ is the fraction of I. Then

$$K = \frac{1-X}{X} = 2.3 \quad 2.3X = 1 - X \quad X = \frac{1}{3.3} = 0.30$$

(2 pts)

Physical Constants

Avogadro's number	$N_A = 6.02214179 \times 10^{23} \text{ mol}^{-1}$
Bohr radius	$a_0 = 0.52917720859 \text{ \AA} = 5.2917720859 \times 10^{-11} \text{ m}$
Boltzmann's constant	$K_B = 1.3806504 \times 10^{-23} \text{ J K}^{-1}$
Electronic charge	$e = 1.602176487 \times 10^{-19} \text{ C}$
Faraday constant	$F = 96485.3399 \text{ C mol}^{-1}$
Masses of fundamental particles:	
Electron	$m_e = 9.10938215 \times 10^{-31} \text{ kg}$
Proton	$m_p = 1.672621637 \times 10^{-27} \text{ kg}$
Neutron	$m_n = 1.674927211 \times 10^{-27} \text{ kg}$
Permittivity of vacuum	$\epsilon_0 = 8.854187817 \times 10^{-12} \text{ C}^{-2} \text{ J}^{-1} \text{ m}^{-1}$
Planck's constant	$h = 6.62606896 \times 10^{-34} \text{ J s}$
Ratio of proton mass to electron mass	$m_p / m_e = 1836.15267247$
Speed of light in a vacuum	$c = 2.99792458 \times 10^8 \text{ m s}^{-1}$ (exactly)
Standard acceleration of terrestrial gravity	$g = 9.80665 \text{ m s}^{-2}$ (exactly)
Universal gas constant	$R = 8.314472 \text{ J mol}^{-1} \text{ K}^{-1}$ $= 0.0820574 \text{ L atm mol}^{-1} \text{ K}^{-1}$

Values are taken from the 2006 CODATA recommended values, as listed by the National Institute of Standards and Technology.

Conversion factors

Ångström	$1 \text{ \AA} = 10^{-10} \text{ m}$
Atomic mass unit	$1 \text{ u} = 1.660538782 \times 10^{-27} \text{ kg}$ $1 \text{ u} = 1.492417830 \times 10^{-10} \text{ J} = 931.494028 \text{ MeV}$ (energy equivalent form $E = mc^2$)
Calorie	$1 \text{ cal} = 4.184 \text{ J}$ (exactly)
Electron volt	$1 \text{ eV} = 1.602177 \times 10^{-19} \text{ J} = 96.485335 \text{ kJ mol}^{-1}$
Foot	$1 \text{ ft} = 12 \text{ in} = 0.3048 \text{ m}$ (exactly)
Gallon (U. S.)	$1 \text{ gallon} = 4 \text{ quarts} = 3.785412 \text{ L}$ (exactly)
Liter	$1 \text{ L} = 10^{-3} \text{ m}^3 = 10^3 \text{ cm}^3$ (exactly)
Liter-atmosphere	$1 \text{ L atm} = 101.325 \text{ J}$ (exactly)
Metric ton	$1 \text{ t} = 1000 \text{ kg}$ (exactly)
Pound	$1 \text{ lb} = 16 \text{ oz} = 0.4539237 \text{ kg}$ (exactly)
Rydberg	$1 \text{ Ry} = 2.17987197 \times 10^{-18} \text{ J} = 1312.7136 \text{ kJ mol}^{-1} = 13.60569193 \text{ eV}$
Standard atmosphere	$1 \text{ atm} = 1.01325 \times 10^5 \text{ Pa} = 1.01325 \times 10^5 \text{ kg m}^{-1} \text{ s}^{-2}$ (exactly)
Torr	$1 \text{ torr} = 133.3224 \text{ Pa}$

PERIODIC TABLE OF THE ELEMENTS

KEY

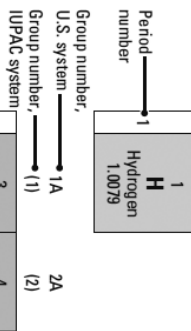
- Main group metals
- Transition metals
- Metalloids
- Nonmetals, noble gases

Legend:

- Atomic number
- Symbol
- Name
- Atomic weight

Other:

- An element



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H Hydrogen 1.0079	2 He Helium 4.0026	3 Li Lithium 6.941	4 Be Beryllium 9.0122	5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.0067	8 O Oxygen 15.9994	9 F Fluorine 18.9984	10 Ne Neon 20.1797	11 Na Sodium 22.9898	12 Mg Magnesium 24.3050	13 Al Aluminum 26.9815	14 Si Silicon 28.0855	15 P Phosphorus 30.9738	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.9559	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.9380	26 Fe Iron 55.845	27 Co Cobalt 58.9332	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.9216	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.798
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.9058	40 Zr Zirconium 91.224	41 Nb Niobium 92.9064	42 Mo Molybdenum 95.96	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.9055	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.9045	54 Xe Xenon 131.293
55 Cs Cesium 132.9055	56 Ba Barium 137.327	57 La Lanthanum 138.9055	58 Ce Cerium 140.116	59 Pr Praseodymium 140.9076	60 Nd Neodymium 144.242	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.9254	66 Dy Dysprosium 162.500	67 Ho Holmium 164.9303	68 Er Erbium 167.259	69 Tm Thulium 168.9342	70 Yb Ytterbium 173.054	71 Lu Lutetium 174.9668	
87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	90 Th Thorium 232.0381	91 Pa Protactinium 231.0359	92 U Uranium 238.0289	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (288)	102 No Nobelium (289)	103 Lr Lawrencium (262)	

Numbers in parentheses are mass numbers of radioactive isotopes.

Lanthanides		58 Ce Cerium 140.116	59 Pr Praseodymium 140.9076	60 Nd Neodymium 144.242	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.9254	66 Dy Dysprosium 162.500	67 Ho Holmium 164.9303	68 Er Erbium 167.259	69 Tm Thulium 168.9342	70 Yb Ytterbium 173.054	71 Lu Lutetium 174.9668
Actinides		90 Th Thorium 232.0381	91 Pa Protactinium 231.0359	92 U Uranium 238.0289	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (288)	102 No Nobelium (289)	103 Lr Lawrencium (262)

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By Student		By TA	
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		Yes: <input type="checkbox"/>	No: <input type="checkbox"/>
		Pts (+/-)	Reasons