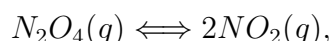


Q.1 Question 1

In the design of a new process, nitrogen dioxide (NO_2) is produced through the decomposition of nitrogen tetroxide (N_2O_4),



The Gibbs energy of formation at 25°C of both species are:

$$(\Delta G_{f,298}^\circ)_{\text{N}_2\text{O}_4} = 97.89 \text{ kJ mol}^{-1} \text{ and } (\Delta G_{f,298}^\circ)_{\text{NO}_2} = 51.31 \text{ kJ mol}^{-1}.$$

The standard enthalpy of this reaction at 25°C is $56.189 \text{ kJ mol}^{-1}$. For such decomposition, three scenarios are considered to assess overall conversion:

- A. Decomposition of N_2O_4 at 25°C ;
- B. Initial dilution with inert N_2 prior to the decomposition of N_2O_4 at 25°C ;
- C. Decomposition of N_2O_4 at 126.85°C .

Calculate the composition of the species in equilibrium for:

a) Scenario A;

[5 marks]

Solution:

The equilibrium constant is

$$K = \exp\left(-\frac{\Delta G_{r,298}^\circ}{RT}\right) = \frac{a_{\text{NO}_2}^2}{a_{\text{N}_2\text{O}_4}} = \frac{\left(\frac{y_{\text{NO}_2}P}{P_{\text{NO}_2}^\circ}\right)^2}{\left(\frac{y_{\text{N}_2\text{O}_4}P}{P_{\text{N}_2\text{O}_4}^\circ}\right)} = \frac{(y_{\text{NO}_2})^2}{(y_{\text{N}_2\text{O}_4})},$$

[1/5] *where the standard Gibbs energy of reaction is*

$$\begin{aligned} \Delta G_{r,298}^\circ &= \sum_i \nu_i \Delta G_{f,298}^\circ \\ &= (+2) \cdot (\Delta G_{f,298}^\circ)_{\text{NO}_2} + (-1) \cdot (\Delta G_{f,298}^\circ)_{\text{N}_2\text{O}_4} \\ &= 4730 \text{ J/mol}, \end{aligned}$$

and the equilibrium constant,

$$K = \exp\left(-\frac{\Delta G_{r,298}^\circ}{RT}\right) = 0.1484 = \frac{(y_{\text{NO}_2})^2}{(y_{\text{N}_2\text{O}_4})}$$

Composition and reaction coordinate are related through

$$y_i = \frac{n_{i,0} + \nu_i \epsilon}{n_0 + \nu \epsilon},$$

[1/5]

where, assuming that the initial number of moles are $n_{N_2O_4,0} = 1$ and $n_{NO_2,0} = 0$, and $\nu = 2 - 1 = 1$,

$$y_{N_2O_4} = \frac{1 - \varepsilon}{1 + \varepsilon} \quad \text{and} \quad y_{NO_2} = \frac{2\varepsilon}{1 + \varepsilon},$$

[1/5]

leading to

$$K = \frac{(y_{NO_2})^2}{(y_{N_2O_4})} = \frac{\left(\frac{2\varepsilon}{1 + \varepsilon}\right)^2}{\left(\frac{1 - \varepsilon}{1 + \varepsilon}\right)} = 0.1484 \quad \Rightarrow \quad \varepsilon = 0.1891$$

[2/5]

Thus: $y_{NO_2} = 0.3181$ and $y_{N_2O_4} = 0.6819$.

- b) Scenario B, where the initial concentration of N_2O_4 in the $N_2O_4 - N_2$ mixture before the dissociation is 20 mol%. Assume that the equilibrium constant at 25°C is 0.1484; [5 marks]

Solution:

Here, nitrogen is an inert species, i.e., it is used to dilute the reactant gas, N_2O_4 , but does not participate in the decomposition reaction, thus $\nu_{N_2} = 0$. The equilibrium constant is $K = 0.1484$ and

$$y_i = \frac{n_{i,0} + \nu_i \varepsilon}{n_0 + \nu \varepsilon},$$

The overall molar stoichiometric coefficient is $\nu = 2 - 1 - 0 = 1$, however the initial reactive composition is (assuming 1 mol of the reactant mixture) $n_{N_2O_4,0} = 0.2$, $n_{N_2,0} = 0.8$ and $n_{NO_2,0} = 0$.

[1/5]

$$y_{N_2O_4} = \frac{0.2 - \varepsilon}{1 + \varepsilon}, \quad y_{N_2} = \frac{0.8}{1 + \varepsilon} \quad \text{and} \quad y_{NO_2} = \frac{2\varepsilon}{1 + \varepsilon}.$$

[1/5]

Leading to

$$K = \frac{(y_{NO_2})^2}{(y_{N_2O_4})} = \frac{\left(\frac{2\varepsilon}{1 + \varepsilon}\right)^2}{\left(\frac{0.2 - \varepsilon}{1 + \varepsilon}\right)} = 0.1484 \quad \Rightarrow \quad \varepsilon = 0.0715,$$

[3/5]

with equilibrium compositions of $y_{NO_2} = 0.1335$, $y_{N_2O_4} = 0.1199$ and $y_{N_2} = 0.7466$.

- c) Scenario C. Assume that the equilibrium constant at 25°C is 0.1484; [8 marks]

Solution:

In order to calculate composition at equilibrium, we need to calculate the equilibrium constant, K , at 126.85°C (= 400 K) through the Van't Hoff equation,

[1/8]

$$\frac{d(\ln K)}{dT} = \frac{\Delta H_r^\circ}{RT^2} \quad \Rightarrow \quad \ln \left(\frac{K(T)}{K(298.15 \text{ K})} \right) = \int_{298.15 \text{ K}}^T \frac{\Delta H_r^\circ}{RT^2} dT,$$

[1/8]

with $K_{298.15\text{ K}} = 0.1484$. The standard heat of reaction is obtained from the fundamental enthalpy relation, $dH = C_p dT$, and

$$\Delta H_r^\circ = \sum_i \nu_i \Delta H_{i,f}^\circ \implies \int_{\Delta H_{r,298.15}^\circ}^{\Delta H_{r,T}^\circ} d(\Delta H_r^\circ) = \int_{298.15\text{ K}}^T \sum_i \nu_i C_{p,i} dT.$$

[1/8]

The first stage in this calculation is to obtain an expression for the right-hand side integration, i.e., the summation term $\Delta C_p^\circ = \sum_i \nu_i C_{p,i}$, using (for simplicity in the notation) $\text{NO}_2:1$ and $\text{N}_2\text{O}_4:2$,

$$\begin{aligned} \Delta C_p^\circ &= \sum_i \nu_i C_{p,i} = (+2)(a_1 + b_1 T + c_1 T^2 + d_1 T^3) + (-1)(a_2 + b_2 T + c_2 T^2 + d_2 T^3) \\ &= 12.804 - 7.239 \times 10^{-2} T + 4.301 \times 10^{-5} T^2 + 15.732 \times 10^{-9} T^3 \end{aligned}$$

[1/8]

And the integration becomes (with $\Delta H_{r,298.15}^\circ = 56189\text{ J.mol}^{-1}$)

$$\begin{aligned} \Delta H_r^\circ(T) - \Delta H_{r,298.15}^\circ &= \int \Delta C_p^\circ dT \\ \Delta H_r^\circ(T) &= 56189 + 12.804T - \frac{7.239 \times 10^{-2}}{2} T^2 + \frac{4.301 \times 10^{-5}}{3} T^3 + \frac{15.732 \times 10^{-9}}{4} T^4 \end{aligned}$$

[1/8]

Now, using the Van't Hoff equation,

$$\begin{aligned} \ln \left(\frac{K(T)}{K_{298.15\text{ K}}} \right) &= \int_{298.15\text{ K}}^T \frac{\Delta H_r^\circ}{RT^2} dT \\ &= \frac{1}{R} \int_{298.15\text{ K}}^T \left[\frac{56189}{T^2} + \frac{12.804}{T} - \frac{7.239 \times 10^{-2}}{2} + \frac{4.301 \times 10^{-5}}{3} T + \right. \\ &\quad \left. \frac{15.732 \times 10^{-9}}{4} T^2 \right] dT \\ &= \frac{1}{R} \left[-\frac{56189}{T} + 12.804 \ln T - \frac{7.239 \times 10^{-2}}{2} T + \frac{4.301 \times 10^{-5}}{6} T^2 + \right. \\ &\quad \left. \frac{15.732 \times 10^{-9}}{12} T^3 \right]_{298.15\text{ K}}^T \end{aligned}$$

[1/8]

Solving this integral for $T = 400\text{ K}$ leads to $K_{400\text{ K}} = 51.4338$, with

$$y_{\text{N}_2\text{O}_4} = \frac{1 - \varepsilon}{1 + \varepsilon} \quad \text{and} \quad y_{\text{NO}_2} = \frac{2\varepsilon}{1 + \varepsilon},$$

and

$$K = \frac{(y_{\text{NO}_2})^2}{(y_{\text{N}_2\text{O}_4})} = \frac{\left(\frac{2\varepsilon}{1 + \varepsilon} \right)^2}{\left(\frac{1 - \varepsilon}{1 + \varepsilon} \right)}$$

[2/8]

Leading to

$$K_{400\text{ K}} = 51.4331 \quad \implies \varepsilon = 0.9632 \quad \implies y_{\text{NO}_2} = 0.9813 \text{ and } y_{\text{N}_2\text{O}_4} = 0.0187$$

Note that at such high temperature (400 K) the forward reaction becomes dominant with nearly 98.1% of NO_2 being produced.

- d) Which scenario will lead to larger NO_2 production? Why? [2 marks]

Solution:

At room temperature conditions (A and B), the equilibrium constant is 0.1484 with reaction coordinate ranging from 0.0715 (B) to 0.1891 (A). At 400 K (C), equilibrium constant reaches 51.4331 (with $\varepsilon = 0.9632$), i.e., , nearly all N_2O_4 is decomposed to produce NO_2 . Thus, the best scenario is C.

[2/2]

Given:

$$\Delta M_r^\circ = \sum_{i=1}^c \nu_i \Delta M_{f,i}^\circ,$$

where $M = \{U, H, G, S, A\}$, ν is the molar stoichiometric coefficient, and

$$\Delta H_r^\circ(T) - \Delta H_{r,25^\circ\text{C}}^\circ = \int \Delta C_p^\circ dT \quad \text{with } \Delta C_p^\circ = \sum_{i=1}^c \nu_i C_{p,i},$$

where the molar heat capacity at constant pressure for both gases is expressed in polynomial form as,

$$C_p = a + bT + cT^2 + dT^3, \quad (\text{in J mol}^{-1} \text{ K}^{-1})$$

where

	a (J mol ⁻¹ K ⁻¹)	$b \times 10^{-2}$ (J mol ⁻¹ K ⁻²)	$c \times 10^{-5}$ (J mol ⁻¹ K ⁻³)	$d \times 10^{-9}$ (J mol ⁻¹ K ⁻⁴)
NO_2	22.929	5.711	-3.519	7.866
N_2O_4	33.054	18.661	-11.339	—

Total Question Marks:20

Q.2 Question 2

- a) Calculate the molar volume (in $\text{m}^3 \text{mol}^{-1}$) and compressibility factor (Z) for gaseous ammonia at 450 K and 56 atm using the van der Waals (vdW) equation of state. Critical temperature and pressure of ammonia are 405.5 K and 111.3 atm, respectively. [12 marks]

Solution:

[1/12] *The generic form of cubic equations of state is defined as,*

$$Z = 1 + \beta - q\beta \frac{Z - \beta}{(Z + \epsilon\beta)(Z + \sigma\beta)}$$

where

$$\beta = \Omega \frac{P_r}{T_r} \quad \text{and} \quad q = \frac{\Psi\alpha}{\Omega T_r}$$

[1/12] *For vdW-EOS:*

$$\Omega = \frac{1}{8}, \quad \Psi = \frac{27}{64}, \quad \alpha = 1, \quad \epsilon = 0 \quad \text{and} \quad \sigma = 0$$

[2/12] *Reduced pressure and temperature are :*

$$P_r = \frac{P}{P_c} = 0.5031, \quad \text{and} \quad T_r = \frac{T}{T_c} = 1.1097$$

[2/12] *β and q are :*

$$\beta = 5.6671 \times 10^{-2} \quad \text{and} \quad q = 3.0414$$

We can simplify the generic form of cubic EOS as,

$$Z = 1 + \beta - q\beta \frac{Z - \beta}{Z^2}$$

[3/12] *And solving it (calculator), we can obtain $Z = 0.8718$. Molar volume can be obtained through*

$$V = \frac{ZRT}{P} = 5.7482 \times 10^{-4} \text{ m}^3 \cdot \text{mol}^{-1}$$

- b) Using the definitions of volume expansivity (β) and isothermal compressibility (κ) coefficients,

$$\beta = \frac{1}{V} \left(\frac{\partial V}{\partial T} \right)_P \quad \text{and} \quad \kappa = -\frac{1}{V} \left(\frac{\partial V}{\partial P} \right)_T,$$

and the cyclic rule applied to PVT relations,

$$\left(\frac{\partial P}{\partial T} \right)_V \left(\frac{\partial V}{\partial P} \right)_T \left(\frac{\partial T}{\partial V} \right)_P = -1,$$

show that

$$\left(\frac{\partial P}{\partial T} \right)_V = \frac{\beta}{\kappa}.$$

[3 marks]

Solution:

From the cyclic rule applied to PVT relations,

$$\left(\frac{\partial P}{\partial T}\right)_V \left(\frac{\partial V}{\partial P}\right)_T \left(\frac{\partial T}{\partial V}\right)_P = -1.$$

[3/3]

Thus,

$$\left(\frac{\partial P}{\partial T}\right)_V = \frac{-1}{\left(\frac{\partial V}{\partial P}\right)_T \left(\frac{\partial T}{\partial V}\right)_P} = \frac{-\left(\frac{\partial V}{\partial T}\right)_P}{\left(\frac{\partial V}{\partial P}\right)_T} = \frac{-V\beta}{-V\kappa} = \frac{\beta}{\kappa}$$

c) Using the cyclic rule definition

$$\left(\frac{\partial P}{\partial T}\right)_V \left(\frac{\partial V}{\partial P}\right)_T \left(\frac{\partial T}{\partial V}\right)_P = -1,$$

obtain an algebraic expression for $\left(\frac{\partial V}{\partial T}\right)_P$ for the van der Waals equation of state.

[5 marks]

Solution:

The vdW-EOS is,

$$P = \frac{RT}{V-b} - \frac{a}{V^2},$$

where V is the molar volume and a and b are constants that depends only on critical properties, P_c and T_c . Due to the non-linearity of this EOS, obtaining $\left(\frac{\partial V}{\partial T}\right)_P$ from a direct differentiation would be difficult, thus

[5/5]

$$\left(\frac{\partial V}{\partial T}\right)_P = -\frac{\left(\frac{\partial P}{\partial T}\right)_V}{\left(\frac{\partial P}{\partial V}\right)_T} = -\frac{\frac{R}{V-b}}{-\frac{RT}{(V-b)^2} + \frac{2a}{V^3}}$$

Total Question Marks:20

Q.3 Question 3

- (a) What is the change in entropy when 0.7 m³ of CO₂ and 0.3 m³ of N₂ form a gas mixture at 1 bar and 25°C? Assume ideal gases, and given

$$\Delta S = -nR \sum_{i=1}^n y_i \ln y_i,$$

where S , n and y are entropy, number of moles and mole fraction, respectively. R is the molar gas constant. [10 marks]

Solution:

[2/10] For CO₂ (1) and N₂ (2) at 1 bar and 25°C with ideal gas behaviour, mole fraction (x_i) = volume fraction (y_i) as,

$$x_i = \frac{n_i}{n}, \text{ and } y_i = \frac{V_i}{V}$$

$$x_i = \frac{n_i}{n} = \frac{PV_i/(RT)}{PV/(RT)} = \frac{V_i}{V}$$

[2/10] Therefore,

$$y_1 = 0.7 \implies V_1^t = 0.7 \text{ m}^3$$

$$y_2 = 0.3 \implies V_2^t = 0.3 \text{ m}^3$$

[2/10] At $P = 1 \text{ bar}$ and $T = 298.15 \text{ K}$, the number of moles, n , is

$$n = \frac{P}{RT} \sum V_i^t = 40.34 \text{ moles}$$

[4/10] The entropy change is

$$\Delta S = -nR \sum_{i=1}^n y_i \ln y_i = 204.88 \text{ J/K}$$

- (b) Calculate the bubble point pressure and vapour composition for a liquid mixture of 41.2 mol% of ethanol (1) and n-hexane (2) at 331 K. Given,

$$\ln \gamma_1 = \frac{A}{\left(1 + \frac{Ax_1}{Bx_2}\right)^2}, \quad \ln \gamma_2 = \frac{A}{\left(1 + \frac{Bx_2}{Ax_1}\right)^2} \text{ and}$$

$$\ln P_i^{\text{sat}} = C_i + \frac{D_i}{T + E_i}$$

where

$$\begin{cases} A = 2.409, & B = 1.970 \\ C_1 = 16.1952, & C_2 = 14.0568, \\ D_1 = -3423.53, & D_2 = -2825.42, \\ E_1 = -55.7152, & E_2 = -42.7089 \end{cases}$$

$[P] = \text{kPa}$ and $[T] = [D_i] = [E_i] = \text{K}$.

[10 marks]

Solution:

[2/10] *At 331 K, the saturation pressures are $P_1^{sat} = 42.90 \text{ kPa}$ and $P_2^{sat} = 7054 \text{ kPa}$.*

[2/10] *The liquid solution with $x_1 = 0.412$ and $x_2 = 0.588$ results in the following activity coefficient $\gamma_1 = 2.011$ and $\gamma_2 = 1.521$.*

[2/10] *The partial pressure of ethanol and n-hexane are,*

$$P_1 = x_1 \gamma_1 P_1^{sat} = 35.55 \text{ kPa}$$

$$P_2 = x_2 \gamma_2 P_2^{sat} = 63.09 \text{ kPa}$$

[2/10] *The bubble pressure is*

$$P = P_1 + P_2 = 98.64 \text{ kPa}$$

[2/10] *And the composition of the vapour phase is*

$$y_1 = \frac{P_1}{P} = 0.360 \quad \text{and} \quad y_2 = 0.640$$

Total Question Marks:20

Q.4 **Question 4**

- a) Figure 1 shows a $P - xy$ phase diagram for an arbitrary binary mixture that is vaporised at constant temperature (M-z). Determine (i) to (ix) from Table 1. [10 marks]

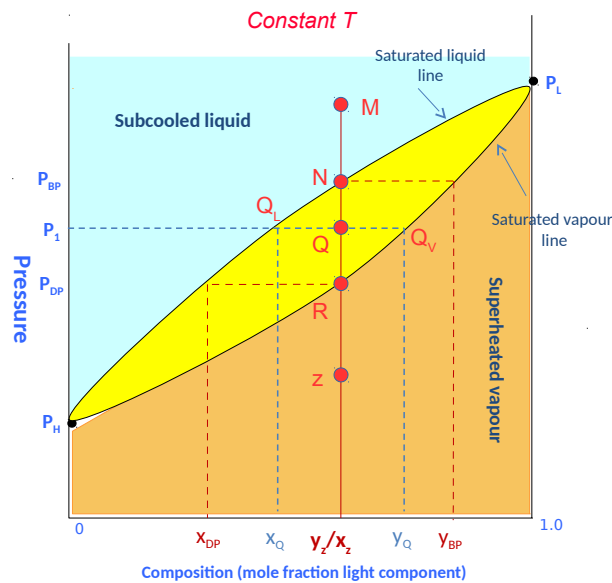


Figure 1: VLE for binary mixture: P - xy diagram at constant temperature.

Coordinate	Pressure	Fluid State	x_1	y_1
M	—	subcooled liquid	$x_1 = x_z$	$y_1 = 0$
N	bubble point (P_{BP})	—	(i)	(ii)
Q	—	(iii)	(iv)	(v)
R	(vi)	—	(vii)	(viii)
Z	—	(ix)	(x)	—

Table 1: Properties of $P - xy$ phase diagram

Solution:

- [1/10] (i) $x_1 = x_z$;
 [1/10] (ii) $y_1 = y_{BP}$;
 [1/10] (iii) vapour-liquid mixture;
 [1/10] (iv) $x_1 = x_Q$;
 [1/10] (v) $y_1 = y_Q$;
 [1/10] (vi) dew point (P_{DP});

[1/10] (vii) $x_1 = x_{DP}$;

[1/10] (viii) $y_1 = y_z$;

[1/10] (ix) *superheated vapour*;

[1/10] (x) $x_1 = 0$;

- b) Using the Redlich-Kwong equation of state, develop algebraic expressions for changes in specific entropy ($s_2 - s_1$) and internal energy ($u_2 - u_1$) of a gas between two states at the same temperature (i.e., $T_1 = T_2$) and pressures P_1 and P_2 . [10 marks]

Solution:

The RK EOS is explicit in pressure,

$$P = \frac{RT}{v - b} - \frac{a}{v\sqrt{T}(v + b)},$$

and in order to obtain $u_2 - u_1$, $s_2 - s_1$ we should integrate

$$\begin{cases} ds = \frac{C_v}{T} dT + \left(\frac{\partial P}{\partial T} \right)_v dv \\ du = C_v dT + \left[T \left(\frac{\partial P}{\partial T} \right)_v - P \right] dv \end{cases}$$

[2/10] At the isotherm $T_1 = T_2$,

$$\begin{cases} s_2 - s_1 = \int_{v_1}^{v_2} \left(\frac{\partial P}{\partial T} \right)_v dv, \\ u_2 - u_1 = \int_{v_1}^{v_2} \left[T \left(\frac{\partial P}{\partial T} \right)_v - P \right] dv. \end{cases}$$

The limits for the integrals are the specific volumes v_1 and v_2 at the two states under consideration. Using P_1 and P_2 and the known temperature, $T_1 = T_2 = T$, these specific volumes should be readily obtained from the RK EOS. Before integrating, we need to solve the partial differential $\left(\frac{\partial P}{\partial T} \right)_v$ for the RK EOS,

$$\left(\frac{\partial P}{\partial T} \right)_v = \frac{R}{v - b} + \frac{a}{2v(v + b)T^{3/2}}.$$

[3/10] Now solving for the change in entropy,

$$\begin{aligned} s_2 - s_1 &= \int_{v_1}^{v_2} \left[\frac{R}{v - b} + \frac{a}{2v(v + b)T^{3/2}} \right] dv \\ &= R \ln \left(\frac{v_2 - b}{v_1 - b} \right) + \frac{a}{2bT^{3/2}} \left[\ln \frac{v_2}{v_1} - \ln \frac{v_2 + b}{v_1 + b} \right] \\ &= R \ln \left(\frac{v_2 - b}{v_1 - b} \right) + \frac{a}{2bT^{3/2}} \ln \frac{v_2(v_1 + b)}{v_1(v_2 + b)}. \end{aligned}$$

[2/10] *For the change in internal energy, the term in bracket*

$$\left[T \left(\frac{\partial P}{\partial T} \right)_v - P \right] = \frac{3a}{2v(v+b)T^{1/2}},$$

[3/10] *need to be integrated from v_1 to v_2 ,*

$$\begin{aligned} u_2 - u_1 &= \int_{v_1}^{v_2} \frac{3a}{2v(v+b)T^{1/2}} dv \\ &= \frac{3a}{2bT^{1/2}} \left[\ln \frac{v_2}{v_1} - \ln \frac{v_2+b}{v_1+b} \right] \\ &= \frac{3a}{2bT^{1/2}} \left[\ln \frac{v_2(v_1+b)}{v_1(v_2+b)} \right]. \end{aligned}$$

Total Question Marks:20

Q.5 Question 5

- a) A process stream contains light species 1 and heavy species 2. A relatively pure liquid stream containing mostly 2 is obtained through a single-stage liquid/vapour separator. Equilibrium mole fractions are $x_1 = 0.002$ and $y_1 = 0.950$. Assuming that the modified Raoult's law applies,

$$y_i P = x_i \gamma_i P_i^{\text{sat}},$$

determine T and P for the separator. Activity coefficients for the liquid phase are given by,

$$\ln \gamma_1 = 0.93x_2^2 \quad \text{and} \quad \ln \gamma_2 = 0.93x_1^2,$$

and the saturated vapour pressure is given by,

$$\ln P^{\text{sat}} = A - \frac{B}{T} \quad \text{with } [P] = \text{bar and } [T] = [B] = \text{K},$$

with $A_1 = 10.08$, $B_1 = 2572.0$, $A_2 = 11.63$ and $B_2 = 6254.0$. [13 marks]

Solution:

Given,

$$x_1 = 0.002 \implies x_2 = 0.998$$

$$y_1 = 0.950 \implies y_2 = 0.050$$

[2/13] *Calculating the activity coefficient, ,*

$$\ln \gamma_1 = 0.93x_2^2 \implies \gamma_1 = 2.5251$$

$$\ln \gamma_2 = 0.93x_1^2 \implies \gamma_2 = 1.0000$$

[4/13] *The modified Raoult's law,*

$$y_i P = x_i \gamma_i P_i^{\text{sat}} \implies P = \frac{x_i \gamma_i P_i^{\text{sat}}}{y_i}$$

$$\frac{P_1^{\text{sat}}}{P_2^{\text{sat}}} = \frac{x_2 \gamma_2 y_1}{x_1 \gamma_1 y_2} = 3754.7028 = \frac{\exp\left(A_1 - \frac{B_1}{T}\right)}{\exp\left(A_2 - \frac{B_2}{T}\right)}$$

[3/13] *Solving this equation results in $T = 376.45 \text{ K}$. The pressure can now be obtained,*

[4/13]

$$P = \frac{x_1 \gamma_1 P_1^{\text{sat}}}{y_1} = 0.1368 \text{ bar}$$

- b) Determine the temperature and composition of the first bubble created from a saturated liquid mixture of benzene and toluene containing 45 mol% percent of benzene at 200 kPa. Benzene and toluene mixtures may be considered as ideal. Given, [7 marks]

$$\ln P^{sat} = A - \frac{B}{T + C} \quad \text{with } [P] = \text{kPa and } [T] = [B] = [C] = \text{K},$$

and

	A	B	C
Benzene	14.1603	2948.78	-44.5633
Toluene	14.2514	3242.38	-47.1806

Solution:

From Raoult's law,

$$y_i = \frac{x_i P_i^{sat}}{P}$$

[1/7] with benzene (1) and toluene (2),

$$P = x_1 P_1^{sat} + x_2 P_2^{sat}$$

[3/7] leading to the bubble point temperature of the mixture benzene-toluene

$$P = x_1 \exp \left(A_1 - \frac{B_1}{T + C_1} \right) + x_2 \exp \left(A_2 - \frac{B_2}{T + C_2} \right) \implies T = 391.73 \text{ K}$$

[3/7] Calculating the saturation pressure and mole fraction of benzene in the vapour phase,

$$P_1^{sat} = \exp \left(A_1 - \frac{B_1}{T + C_1} \right) = 289.01 \text{ kPa}$$

$$y_1 = \frac{x_1 P_1^{sat}}{P} = 0.6503 \quad \text{and} \quad y_2 = 1 - y_1 = 0.3497$$

Total Question Marks:20

END OF PAPER

Total Paper Marks:100