

2056
B.E. (Biotechnology) Fourth Semester
BIO-412: Thermodynamics

Time allowed: 3 Hours

Max. Marks: 50

NOTE: Attempt five questions in all, including Question No. 1 which is compulsory and selecting two questions from each Section. Assume missing data, if any.

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- Q.1.a) One mole of an ideal gas is expanded isothermally and reversibly at 27°C from a volume of 2.28 m³ to 4.56 m³. Calculate Q, W and ΔE. (2)
- b) Explain dry compression and wet compression in a vapor compression refrigeration system. (2)
- c) Define fugacity and explain its physical meaning. (2)
- d) The molar composition of a binary solution is 65% benzene and 35% toluene. The vapor pressure of pure benzene is 13.33 kPa while that of toluene is 6.67 kPa. Calculate the vapor pressure of solution using Raoult's Law. (2)
- e) A system initially containing 3 mol H₂S and 5 mol O₂ and undergoes the reaction:
$$2\text{H}_2\text{S}(g) + 3\text{O}_2(g) \rightarrow 2\text{H}_2\text{O}(g) + 2\text{SO}_2(g)$$

Develop expressions for the mole fractions of reacting species as functions of ε. (2)

SECTION-A

- Q.2. An ideal gas initially at 300 K and 1 bar undergoes a three-step mechanically reversible cycle in a closed system. In step 12, pressure increases isothermally to 5 bar; in step 23, pressure increases at constant volume; and in step 31, the gas returns adiabatically to its initial state. Calculate Q, W, ΔU, and ΔH for each step and the whole process. Take $C_p = \frac{7}{2}R$ and $C_v = \frac{5}{2}R$. (10)
- Q.3. Two reversible heat engines, A and B, operate in series such that the heat rejected by engine A is supplied to engine B. Engine A receives 200 kJ of heat from a hot reservoir at 400°C. Engine B rejects heat to a cold reservoir at 5°C. The work output of engine A is twice the work output of engine B. Determine (a) the intermediate temperature between engines A and B (b) the efficiency of each engine (c) the amount of heat rejected to the cold reservoir. (10)

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(2)

- Q.4a). Estimate the pressure of CO_2 at 500 K using van der Waals equation of state. The van der Waals constants for CO_2 are $a = 0.364 \text{ Nm}^4/\text{mol}^2$ and $b = 4.267 \times 10^{-5} \text{ m}^3/\text{mol}$ and the molar volume of CO_2 is $0.39 \times 10^{-3} \text{ m}^3/\text{mol}$. (5)
- b). What is the Joule-Thompson effect? Explain the principle and its industrial application. (5)

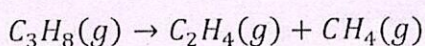
SECTION-B

- Q.5. The vapor pressure of Methanol (1) and Ethanol (2) can be evaluated by the following Antoine equations

$$\ln P_1^s (\text{kPa}) = 16.58 - \frac{3638.27}{T(\text{K}) - 34.29} \quad \ln P_2^s (\text{kPa}) = 16.90 - \frac{3795.17}{T(\text{K}) - 42.85}$$

Assuming methanol and ethanol form an ideal solution, calculate

- (a) x_1 and y_1 at 340 K and 80 kPa (b) P and y_1 at 340 K and $x_1 = 0.6$
 (c) P and x_1 at 340 K and $y_1 = 0.5$ (10)
- Q.6a). For the water gas shift reaction, the standard enthalpy change and standard Gibbs free change are -40.16 kJ/mol and -28.52 kJ/mol at 298K. Calculate the equilibrium constant at 800 K. Assume ΔH^0 is constant in this temperature range. (4)
- b). Ammonia synthesis reaction $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3$ is carried out at a temperature of 675 K and 20 bar pressure. The feed contains 1 mol N_2 , 3 mol H_2 and 2 mol argon. The equilibrium constant for the reaction is 2×10^{-4} . Determine how the conversion of nitrogen is affected by the presence of argon. (6)
- Q.7. For the cracking reaction given below the standard heat of reaction and Gibbs standard free energy change at 298 K is 82.7 kJ/mol and 42.3 kJ/mol respectively.



Estimate the standard free energy change and equilibrium constant at 500 K. The specific heat data as a function of temperature is given below.

$$C_{p_{\text{C}_3\text{H}_8}} (\text{J/mol K}) = 14.15 + 7.56 \times 10^{-2} T - 17.63 \times 10^{-6} T^2$$

$$C_{p_{\text{C}_2\text{H}_4}} (\text{J/mol K}) = 3.95 + 15.50 \times 10^{-2} T - 69.0 \times 10^{-6} T^2$$

$$C_{p_{\text{CH}_4}} (\text{J/mol K}) = 19.89 + 5.024 \times 10^{-2} T - 12.69 \times 10^{-6} T^2 \quad (10)$$