

M.E. MECHANICAL ENGINEERING FIRST YEAR FIRST SEMESTER EXAMINATION, 2018

Advanced Thermodynamics

Time: 3 hours

Full Marks: 100

Use separate answer scripts for each group

Tacitly assume any data not provided

Use of steam tables and charts is allowed

Answer to all parts of a question must be together

Brief and to-the-point answer will be credited

Provide nomenclature of the symbols used

Group A

Answer any **three** questions

1. (a) Show that for an ideal gas with constant heat capacities the slope of a P - v curve for an isentropic process is negative and that it has a larger absolute value than the slope of a P - v curve for an isotherm at the same values of P and v . 10
- (b) Two bodies, A and B , with constant total heat capacities, C_{PA} and C_{PB} , and different initial temperatures, T_{A0} and T_{B0} , exchange heat with each other under isobaric conditions. No heat is transferred to or from the surroundings, and the temperatures of both bodies are assumed uniform at all times. (a) Derive an expression for the total entropy change ΔS of the two bodies as a function of T_A , the temperature of body A . (b) Demonstrate that the process is irreversible by showing that $\Delta S > 0$. (c) What is the equilibrium temperature of the system? 10
2. (a) Prove that

$$\left(\frac{\partial C_P}{\partial P}\right)_T = -T \left(\frac{\partial^2 v}{\partial T^2}\right)_P$$

where the symbols have their usual meanings. Hence prove that for ideal gases, C_P is a function of temperature only. 10

- (b) Evaluate the changes in molar enthalpy and molar entropy of methane when it is heated from 25°C to 550°C at atmospheric pressure. Methane may be considered to be behaving like an ideal gas at the stated conditions. Given for methane: 10

$$\frac{C_P^{ig}}{R} = 1.702 + 9.081 \times 10^{-3} T - 2.164 \times 10^{-6} T^2 \text{ upto } T = 1500 \text{ K}$$

3. (a) Prove that

$$\frac{g^R}{RT} = \int_0^P (Z - 1) \frac{dP}{P} \quad (\text{constant } T)$$

Where the symbols have their usual meanings.

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- (b) Prove that for any fluid obeying the van der Waals equation of state the critical compressibility factor is 0.375.

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4. Estimate the compressibility factor for air at 180 K and 100 bar. Assume air to contain 79 mole-percent nitrogen and 21 mole-percent oxygen. Use van der Waals equation of state with linear mixing rule for the parameter
- b
- and quadratic mixing rule with geometric mean combining rule for the parameter
- a
- . The following data are provided further:

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COMPONENT	CRITICAL TEMPERATURE (K)	CRITICAL PRESSURE (bar)
Nitrogen	126.2	33.9
Oxygen	154.5	50.5

5. a) Prove that

$$\bar{y}_i = y - \sum_{k \neq i} x_k \left(\frac{\partial y}{\partial x_k} \right)_{T, P, x_{l \neq k, i}}$$

Here y is some molar property of a single phase solution, \bar{y}_i is the partial molar property of component i in the solution and x_k is the mole-fraction of the component k in the solution.

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- b) Determine the mass of distilled water to be added with 2000 cm
- ³
- laboratory alcohol that contains 96 mass-percent ethanol and 4 mass percent water to produce vodka that contains 56 mass-percent ethanol and 44 mass percent water at 25°C. Find out whether total volume is conserved in the mixing process if specific volume of distilled water is 1.003 cm
- ³
- .g
- ⁻¹
- at 25°C. The following table provides the partial specific volume data.

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Partial Specific Volume of	In Laboratory alcohol (cm ³ .g ⁻¹)	In vodka (cm ³ .g ⁻¹)
H ₂ O	0.816	0.953
C ₂ H ₅ OH	1.273	1.243

Group B

Answer any two questions

1.
 - a) Derive Gouy-Stodola theorem stating assumptions for it.
 - b) Derive the expression of entropy generation due to mixing of two different ideal gases at same temperature and pressure. For what mole fraction of gases, entropy generation due to mixing will be maximum?
 - c) Show that entropy generation due to filling of a tank with air from vacuum up to atmospheric pressure is proportional to the lost work due to free expansion. 6+6+8 = 20

2.
 - a) Derive the expression of work output and heat input in a steady flow combustion device for stoichiometric combustion of the Fuel C_aH_b assuming all gases to be ideal. Why and what experimental data is required for some fuels for this energy balance?
 - b) Calculate the chemical exergy of the fuel C_4H_{10} if environment composition is defined as % by volume of O_2 , CO_2 and H_2O (g) as 20.35, 0.03 and 3.12 respectively. Assume gases to be ideal and consult attached property table. Derive the expression used. 10+10=20

3. Write short notes on the following: 5x4=20
 - a) Enthalpy of formation
 - b) Entropy generation due to heat transfer with finite temperature difference
 - c) Pressure departure term in chemical exergy calculation when all products and reactants are ideal gases.
 - d) Lost work due to irreversible heat rejection of a heat engine.

Table A-25 Thermochemical Properties of Selected Substances at 298K and 1 atm

Substance	Formula	Molar Mass, <i>M</i> (kg/kmol)	Enthalpy of Formation, \bar{h}_f° (kJ/kmol)	Gibbs Function of Formation, \bar{g}_f° (kJ/kmol)	Absolute Entropy, \bar{s}° (kJ/kmol · K)	Heating Values	
						Higher, HHV (kJ/kg)	Lower, LHV (kJ/kg)
Carbon	C(s)	12.01	0	0	5.74	32,770	32,770
Hydrogen	H ₂ (g)	2.016	0	0	130.57	141,780	119,950
Nitrogen	N ₂ (g)	28.01	0	0	191.50	—	—
Oxygen	O ₂ (g)	32.00	0	0	205.03	—	—
Carbon monoxide	CO(g)	28.01	-110,530	-137,150	197.54	—	—
Carbon dioxide	CO ₂ (g)	44.01	-393,520	-394,380	213.69	—	—
Water	H ₂ O(g)	18.02	-241,820	-228,590	188.72	—	—
Water	H ₂ O(l)	18.02	-285,830	-237,180	69.95	—	—
Hydrogen peroxide	H ₂ O ₂ (g)	34.02	-136,310	-105,600	232.63	—	—
Ammonia	NH ₃ (g)	17.03	-46,190	-16,590	192.33	—	—
Oxygen	O(g)	16.00	249,170	231,770	160.95	—	—
Hydrogen	H(g)	1.008	218,000	203,290	114.61	—	—
Nitrogen	N(g)	14.01	472,680	455,510	153.19	—	—
Hydroxyl	OH(g)	17.01	39,460	34,280	183.75	—	—
Methane	CH ₄ (g)	16.04	-74,850	-50,790	186.16	55,510	50,020
Acetylene	C ₂ H ₂ (g)	26.04	226,730	209,170	200.85	49,910	48,220
Ethylene	C ₂ H ₄ (g)	28.05	52,280	63,120	219.83	50,300	47,160
Ethane	C ₂ H ₆ (g)	30.07	-84,680	-32,890	229.49	51,870	47,480
Propylene	C ₃ H ₆ (g)	42.08	20,410	62,720	266.94	48,920	45,780
Propane	C ₃ H ₈ (g)	44.09	-103,850	-23,490	269.91	50,350	46,360
Butane	C ₄ H ₁₀ (g)	58.12	-126,150	-15,710	310.03	49,500	45,720
Pentane	C ₅ H ₁₂ (g)	72.15	-146,440	-8,200	348.40	49,010	45,350
Octane	C ₈ H ₁₈ (g)	114.22	-208,450	17,320	463.67	48,260	44,790
Octane	C ₈ H ₁₈ (l)	114.22	-249,910	6,610	360.79	47,900	44,430
Benzene	C ₆ H ₆ (g)	78.11	82,930	129,660	269.20	42,270	40,580
Methyl alcohol	CH ₃ OH(g)	32.04	-200,890	-162,140	239.70	23,850	21,110
Methyl alcohol	CH ₃ OH(l)	32.04	-238,810	-166,290	126.80	22,670	19,920
Ethyl alcohol	C ₂ H ₅ OH(g)	46.07	-235,310	-168,570	282.59	30,590	27,720
Ethyl alcohol	C ₂ H ₅ OH(l)	46.07	-277,690	174,890	160.70	29,670	26,800

Source: Based on JANAF Thermochemical Tables, NSRDS-NBS-37, 1971; Selected Values of Chemical Thermodynamic Properties, NBS Tech. Note 270-3, 1968; and API Research Project 44, Carnegie Press, 1953. Heating values calculated.