

National Exams December 2015

Met-A1, Metallurgical Thermodynamics

3 hours duration

NOTES:

1. Answer only **five** questions. Any five questions (out of seven) constitute a complete paper. Only the first five questions as they appear in your answer book will be marked.
2. All questions are of equal value (20 marks each out of 100).
3. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper a clear statement of any assumptions made.
4. Candidates may use one of two calculators, the Casio or Sharp approved models. This is a closed book exam.
5. The exam consists of 5 pages including Ellingham diagram.

Question 1: (a) 4, (b) 4, (c) 4, (d) 4, (e) 2, (f) 2

Question 2: (a) 10, (b) 10

Question 3: (a) 2, (b) 2, (c) 2, (d) 2, (e) 2, (f) 2, (g) 2, (h) 2, (i) 2, (j) 2

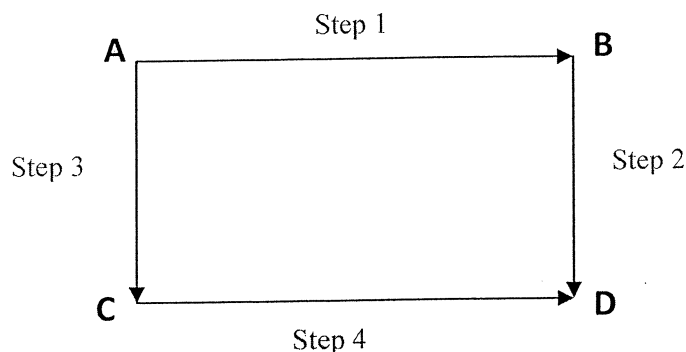
Question 4: (a) 8, (b) 12

Question 5: (a) 4, (b) 4, (c) 4, (d) 4, (e) 4

Question 6: (a) 5, (b) 5, (c) 5, (d) 5

Question 7: (a) 4, (b) 4, (c) 4, (d) 4, (e) 2, (f) 2

Problem No. 1 (20 marks): 1 mol of a monatomic ideal gas is taken from state A ($P_A = 200 \text{ kPa}$, $V_A = 10 \text{ L}$) to state D ($P_D = 50 \text{ kPa}$, $V_D = 40 \text{ L}$) by two different paths as shown below:



Path 1: Step 1: State A ($P_A = 200 \text{ kPa}$, $V_A = 10 \text{ L}$) to state B ($P_B = 200 \text{ kPa}$, $V_B = 40 \text{ L}$)
 Step 2: State B ($P_B = 200 \text{ kPa}$, $V_B = 40 \text{ L}$) to state D ($P_D = 50 \text{ kPa}$, $V_D = 40 \text{ L}$)

Path 2: Step 3: State A ($P_A = 200 \text{ kPa}$, $V_A = 10 \text{ L}$) to state C ($P_C = 50 \text{ kPa}$, $V_C = 10 \text{ L}$)
 Step 4: State C ($P_C = 50 \text{ kPa}$, $V_C = 10 \text{ L}$) to state D ($P_D = 50 \text{ kPa}$, $V_D = 40 \text{ L}$)

- Calculate heat flow in the system (q), work done on the system (w), change in internal energy of the system (ΔE) and change in enthalpy of the system (ΔH) for Step 1. (4 marks)
- Calculate heat flow in the system (q), work done on the system (w), change in internal energy of the system (ΔE) and change in enthalpy of the system (ΔH) for Step 2. (4 marks)
- Calculate heat flow in the system (q), work done on the system (w), change in internal energy of the system (ΔE) and change in enthalpy of the system (ΔH) for Step 3. (4 marks)
- Calculate heat flow in the system (q), work done on the system (w), change in internal energy of the system (ΔE) and change in enthalpy of the system (ΔH) for Step 4. (4 marks)
- Calculate heat flow in the system (q), work done on the system (w), change in internal energy of the system (ΔE) and change in enthalpy of the system (ΔH) for Path 1. (2 marks)
- Calculate heat flow in the system (q), work done on the system (w), change in internal energy of the system (ΔE) and change in enthalpy of the system (ΔH) for Path 2. (2 marks)

Problem No. 2 (20 marks):

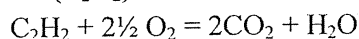
- Prove that $P_i V_i^\gamma = P_f V_f^\gamma$ for the reversible adiabatic expansion of an ideal gas. Assume that C_v is constant over temperature range and $C_p - C_v = R$. (10 marks)
- An ideal gas underwent reversible adiabatic expansion from 100 kPa to 53 kPa. If the initial temperature of the gas was 300 K, what was its final temperature? Assume that $C_p = 28.9 \text{ J K}^{-1} \text{ mol}^{-1}$ for the ideal gas. (10 marks)

Problem No. 3 (20 marks): 1 mol of a compound A is heated from $-25\text{ }^{\circ}\text{C}$ to $75\text{ }^{\circ}\text{C}$ at 1 atm pressure. Constant pressure molar heat capacities of solid A, liquid A and vapour A are 118.4, 134.8 and $82.4\text{ J mol}^{-1}\text{K}^{-1}$ respectively. The standard enthalpy change of fusion of compound A is 9.9 kJ mol^{-1} at $5.4\text{ }^{\circ}\text{C}$ and the standard enthalpy change of vaporization of compound A is 33.9 kJ mol^{-1} at $25\text{ }^{\circ}\text{C}$.

- (a) Calculate the change in entropy for solid A from $-25\text{ }^{\circ}\text{C}$ to $5.4\text{ }^{\circ}\text{C}$. (2 marks)
- (b) Calculate the change in entropy for phase transformation at $5.4\text{ }^{\circ}\text{C}$. (2 marks)
- (c) Calculate the change in entropy for liquid A from $5.4\text{ }^{\circ}\text{C}$ to $25\text{ }^{\circ}\text{C}$. (2 marks)
- (d) Calculate the change in entropy for phase transformation at $25\text{ }^{\circ}\text{C}$. (2 marks)
- (e) Calculate the change in entropy for vapour A from $25\text{ }^{\circ}\text{C}$ to $75\text{ }^{\circ}\text{C}$. (2 marks)
- (f) Calculate the total change in entropy from $-25\text{ }^{\circ}\text{C}$ to $75\text{ }^{\circ}\text{C}$. (2 marks)
- (g) Calculate the change in enthalpy for solid A from $-25\text{ }^{\circ}\text{C}$ to $5.4\text{ }^{\circ}\text{C}$. (2 marks)
- (h) Calculate the change in enthalpy for liquid A from $5.4\text{ }^{\circ}\text{C}$ to $25\text{ }^{\circ}\text{C}$. (2 marks)
- (i) Calculate the change in enthalpy for vapour A from $25\text{ }^{\circ}\text{C}$ to $75\text{ }^{\circ}\text{C}$. (2 marks)
- (j) Calculate the total change in enthalpy from $-25\text{ }^{\circ}\text{C}$ to $75\text{ }^{\circ}\text{C}$. (2 marks)

Problem No. 4 (20 marks):

Acetylene (C_2H_2) is combusted at 298 K according to the following reaction:



Standard enthalpy of formation at $25\text{ }^{\circ}\text{C}$ is given in the following table:

Compound	Standard enthalpy of formation
C_2H_2	$+226.7\text{ kJ mol}^{-1}$
CO_2	$-393.5\text{ kJ mol}^{-1}$
H_2O	$-241.8\text{ kJ mol}^{-1}$

Heat capacity data is as follows:

$$C_p(\text{CO}_2) \text{ in } \text{J K}^{-1} \text{ mol}^{-1} = 18.9 + 7.9 \times 10^{-2} T$$

$$C_p(\text{H}_2\text{O}) \text{ in } \text{J K}^{-1} \text{ mol}^{-1} = 31.4 + 0.4 \times 10^{-2} T$$

$$C_p(\text{N}_2) \text{ in } \text{J K}^{-1} \text{ mol}^{-1} = 27.9 + 0.4 \times 10^{-2} T$$

Assume that T is in K for heat capacity data.

- (a) Calculate the adiabatic flame temperature when acetylene is combusted with stoichiometric amount of oxygen. (8 marks)
- (b) Calculate the adiabatic flame temperature when acetylene is combusted in air (containing 21% O_2 , rest being N_2) containing stoichiometric amount of oxygen. (12 marks)

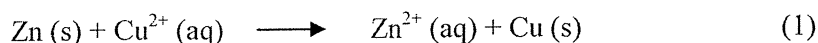
Problem No. 5 (20 marks):

Given the following data for standard enthalpy of formation at 25 °C:

Compound	Standard enthalpy of formation
CH ₄	-75 kJ/mol
CH ₄ O	-201 kJ/mol
C ₂ H ₆ O	-235 kJ/mol
C ₆ H ₁₄	-199 kJ/mol
CO ₂	-394 kJ/mol
H ₂ O	-286 kJ/mol

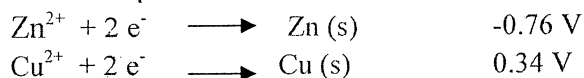
- Calculate the heat of combustion per mole of CH₄. (4 marks)
- Calculate the heat of combustion per mole of CH₄O. (4 marks)
- Calculate the heat of combustion per mole of C₂H₆O. (4 marks)
- Calculate the heat of combustion per mole of C₆H₁₄. (4 marks)
- Which fuel generates highest amount of heat per unit weight of the fuel. (4 marks)

Problem No. 6 (20 marks): Consider a galvanic cell based on the following reaction:



- Calculate the standard cell potential (E°) at 25 °C. (5 marks)
- Calculate the standard free energy (ΔG°) for the cell at 25 °C. (5 marks)
- Calculate the equilibrium constant for the redox reaction at 25 °C. (5 marks)
- Calculate the cell potential (E) at 25 °C if concentration of Cu²⁺ is 0.5 M and concentration of Zn²⁺ is 2.0 M. (5 marks)

Given: Standard reduction potentials at 25 °C for half reactions:



Problem No. 7 (20 marks): Use the attached Ellingham Diagram to answer the following questions:

- What is the partial pressure of oxygen in equilibrium with Al and Al₂O₃ at 1600 °C? (4 marks)
- What is the ratio of partial pressures of CO to CO₂ for equilibrium of Al and Al₂O₃ in a CO-CO₂ atmosphere at 1600 °C? (4 marks)
- What is the ratio of partial pressures of H₂ to H₂O for equilibrium of Al and Al₂O₃ in a H₂-H₂O atmosphere at 1600 °C? (4 marks)
- What is ΔG° (kJ/mol) at 1300 °C for the reaction: Ca + MgO = CaO + Mg? (4 marks)
- Explain why the line for reaction C(s) + O₂ (g) = CO₂ (g) runs nearly horizontally on the chart. (2 marks)
- Explain why the line for reaction 2C(s) + O₂ (g) = 2CO (g) runs downward on the chart. (2 marks)

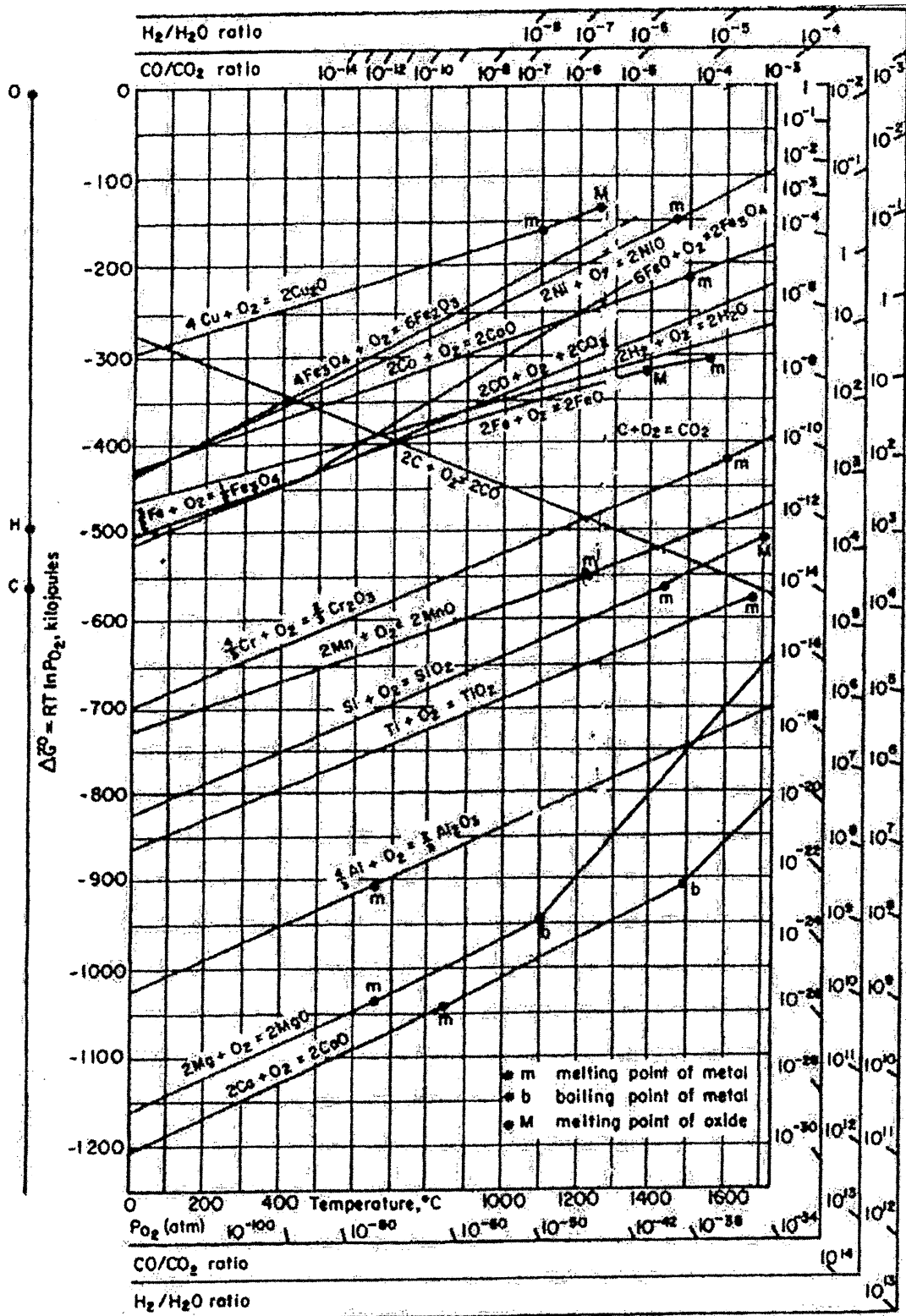


Figure 9-3. Ellingham diagram for some oxides; Richardson nomographic scales are included. (Adapted from D. R. Gaskell, *Introduction to Metallurgical Thermodynamics*, 2nd ed., Hemisphere Publishing, New York, 1981.)