

National Exams May 2017

10-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) 4

Question 2: (a) (i) 4, (ii) 4, (iii) 2, (b) (i) 4, (ii) 4, (iii) 2

Question 3: 20

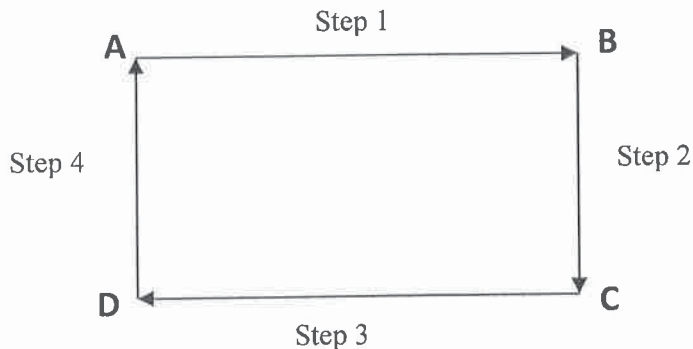
Question 4: (a) 3, (b) 3, (c) 3, (d) 3, (e) 2, (f) 2, (g) 2, (h) 2

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) 4

Problem No. 1 (20 marks): 1 mol of a monatomic ideal gas is taken from state A ($P_A = 200 \text{ kPa}$, $V_A = 20 \text{ L}$) to state B, then to Step C, then to Step D and finally back to Step A as shown below:



- Step 1: State A ($P_A = 200 \text{ kPa}$, $V_A = 20 \text{ L}$) to state B ($P_B = 200 \text{ kPa}$, $V_B = 50 \text{ L}$)
 Step 2: State B ($P_B = 200 \text{ kPa}$, $V_B = 50 \text{ L}$) to state C ($P_C = 100 \text{ kPa}$, $V_C = 50 \text{ L}$)
 Step 3: State C ($P_C = 100 \text{ kPa}$, $V_C = 50 \text{ L}$) to state D ($P_D = 100 \text{ kPa}$, $V_D = 20 \text{ L}$)
 Step 4: State D ($P_D = 100 \text{ kPa}$, $V_D = 20 \text{ L}$) to state A ($P_A = 200 \text{ kPa}$, $V_A = 20 \text{ L}$)

- 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 the complete path consisting of all four steps. (4 marks)

Problem No. 2 (20 marks):

- (a) 1 mol of an ideal gas at 325 K is reversibly and isothermally compressed from 50 L to 10 L.

- Calculate the change in the entropy of the system. (4 marks)
- Calculate the change in the entropy of the surroundings. (4 marks)
- Calculate the total change in the entropy of the system and surroundings. (2 marks)

- (b) 1 mol of an ideal gas at 325 K is isothermally compressed by a constant external pressure of 250,000 Pa from 50 L to 10 L.

- Calculate the change in the entropy of the system. (4 marks)
- Calculate the change in the entropy of the surroundings. (4 marks)
- Calculate the total change in the entropy of the system and surroundings. (2 marks)

Problem No. 3 (20 marks):

Calculate ΔS°_R for the reaction $3\text{H}_2(\text{g}) + \text{N}_2(\text{g}) = 2\text{NH}_3(\text{g})$ at 700 K given the following data:

$$S^{\circ}_{298\text{K}}(\text{H}_2, \text{g}) = 197.7 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$S^{\circ}_{298\text{K}}(\text{N}_2, \text{g}) = 191.6 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$S^{\circ}_{298\text{K}}(\text{NH}_3, \text{g}) = 130.7 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$C_p(\text{H}_2, \text{g}) \text{ in } \text{J K}^{-1} \text{ mol}^{-1} = 22.7 + 4.4 \times 10^{-2} T - 1.1 \times 10^{-4} T^2$$

$$C_p(\text{N}_2, \text{g}) \text{ in } \text{J K}^{-1} \text{ mol}^{-1} = 30.8 - 1.2 \times 10^{-2} T + 2.4 \times 10^{-5} T^2$$

$$C_p(\text{NH}_3, \text{g}) \text{ in } \text{J K}^{-1} \text{ mol}^{-1} = 29.3 + 1.1 \times 10^{-2} T + 4.2 \times 10^{-5} T^2$$

Assume that T is in K for heat capacity data.

Problem No. 4 (20 marks): Consider the formation of sulfuric acid at 25 °C and 1 atm by the following reactions:



Given the following data for standard enthalpy of formation and standard entropy:

Compound	Standard enthalpy of formation (ΔH_f°)	Standard entropy of formation (S°)
S	0 kJ mol ⁻¹	32 J K ⁻¹ mol ⁻¹
O ₂	0 kJ mol ⁻¹	205 J K ⁻¹ mol ⁻¹
SO ₂	-297 kJ mol ⁻¹	248 J K ⁻¹ mol ⁻¹
SO ₃	-396 kJ mol ⁻¹	257 J K ⁻¹ mol ⁻¹
H ₂ O	-286 kJ mol ⁻¹	70 J K ⁻¹ mol ⁻¹
H ₂ SO ₄	-814 kJ mol ⁻¹	157 J K ⁻¹ mol ⁻¹

- (a) Calculate ΔH° for reactions (1), (2) and (3). (3 marks)
- (b) Calculate ΔS° for reactions (1), (2) and (3). (3 marks)
- (c) Calculate ΔG° for reactions (1), (2) and (3). (3 marks)
- (d) Calculate equilibrium constant (K) for reactions (1), (2) and (3). (3 marks)
- (e) Write a balanced reaction for the formation of H₂SO₄ from S, O₂ and H₂O. (2 marks)
- (f) Calculate ΔH° for the balanced reaction in Part (e). (2 marks)
- (g) Calculate ΔS° for the balanced reaction in Part (e). (2 marks)
- (h) Calculate ΔG° for the balanced reaction in Part (e). (2 marks)

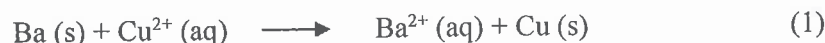
Problem No. 5 (20 marks):

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

Compound	Standard enthalpy of formation
CH ₃ OH	-201 kJ/mol
C ₃ H ₈	-105 kJ/mol
C ₇ H ₁₆	-224 kJ/mol
C ₈ H ₁₈	-259 kJ/mol
CO ₂	-394 kJ/mol
H ₂ O	-286 kJ/mol

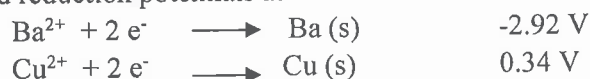
- (a) Calculate the heat of combustion per mole of CH₃OH. (4 marks)
- (b) Calculate the heat of combustion per mole of C₃H₈. (4 marks)
- (c) Calculate the heat of combustion per mole of C₇H₁₆. (4 marks)
- (d) Calculate the heat of combustion per mole of C₈H₁₈. (4 marks)
- (e) Which fuel generates highest 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:



- (a) Calculate the standard cell potential (E°) at 25°C (5 marks)
- (b) Calculate the standard free energy (ΔG°) for the cell at 25°C. (5 marks)
- (c) Calculate the equilibrium constant for the redox reaction at 25°C. (5 marks)
- (d) Calculate the cell potential (E) at 25°C if concentration of Cu²⁺ is 0.5 M and concentration of Ba²⁺ 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:

- a) What is the partial pressure of oxygen in equilibrium with Si and SiO₂ at 1100 °C? (4 marks)
- b) What is the ratio of partial pressures of CO to CO₂ for equilibrium of Si and SiO₂ in a CO-CO₂ atmosphere at 1100 °C? (4 marks)
- c) What is the ratio of partial pressures of H₂ to H₂O for equilibrium of Si and SiO₂ in a H₂-H₂O atmosphere at 1100 °C? (4 marks)
- d) What is ΔG° (kJ/mol) at 1100 °C for the reaction: Ti + SiO₂ = TiO₂ + Si? (4 marks)
- e) Explain why there is no discontinuity in the Ellingham diagram at points where phase transformations take place? (4 marks)

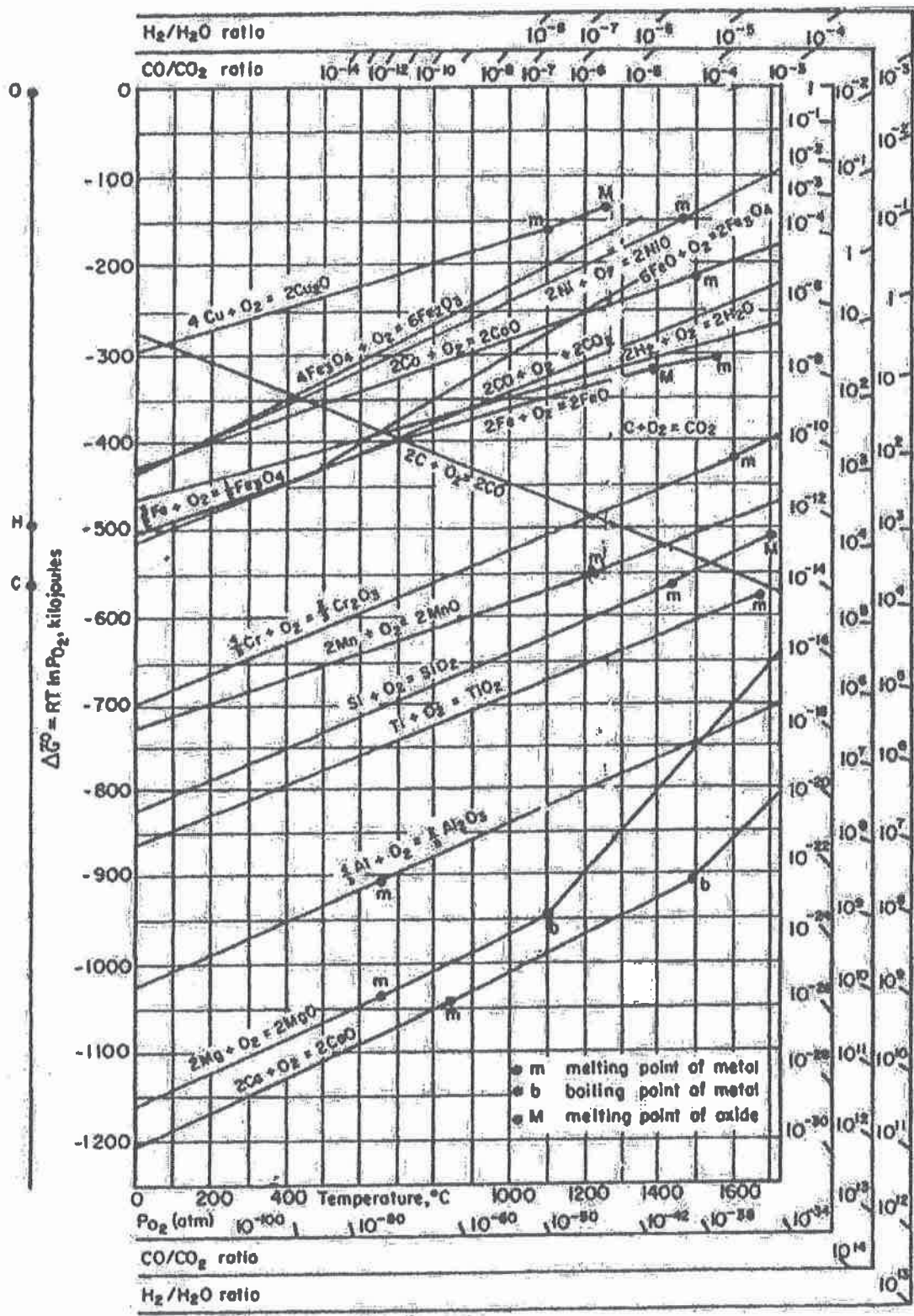


Figure 9-3. Ellingham diagram for some oxides; Richardson nomographic scales are included. (Adapted from D. R. Gaskell, *Introduction to Metallurgical Thermodynamics*, 2nd ed., Hemisphere Publishing, New York, 1981.)