National Exams December 2017

10-Met-A1, Metallurgical Thermodynamics

3 hours duration

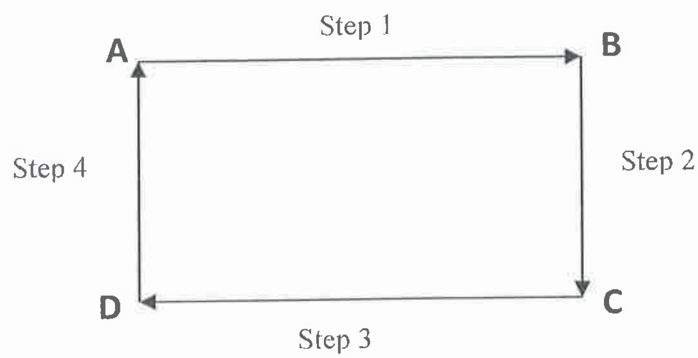
NOTES:

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) 10, (b) 10
Question 3: (a) 10, (b) 10
Question 4: (a) 8, (b) 12
Question 5: (a) 10, (b) 10
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)

One mole of a monatomic ideal gas is taken from state A to state B, then to Step C, then to Step D and finally back to Step A as shown below:



Step 1: Constant T: State A (T_A = 300 K, V_A= 10 L) to state B (T_B = 300 K, V_B= 50 L)

Step 2: Constant V: State B (T_B = 300 K, V_B= 50 L) to state C (T_C = 600 K, V_C= 50 L)

Step 3: Constant T: State C (T_C = 600 K, V_C= 50 L) to state D (T_D = 600 K, V_D= 10 L)

Step 4: Constant V: State D (T_D = 600 K, V_D= 10 L) to state A (T_A = 300 K, V_A= 10 L)

(a) Calculate P_A, P_B, P_C, and P_D. (4 marks)

(b) 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)

(c) 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)

(d) 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)

(e) 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)

Problem No. 2 (20 marks)

At room temperature (25°C), the standard entropy of Pb(s) is 64.8 J K^{-1} mol^{-1}. The melting point of Pb is 327.4°C. The heat of fusion at the melting point of lead is 4,770.0 J mol^{-1}.

(a) Calculate the standard entropy of Pb at 600°C. (10 marks)

(b) Calculate the change in enthalpy of Pb from 25°C to 600°C. (10 marks)

Given,

$$C_P\ (Pb,s) = 22.13 + 0.012\ T + 1.0 \times 10^{-5}\ T^2$$
$$C_P\ (Pb,l) = 32.51 - 0.003\ T$$

where T is in K and unit of C_P is J mol^{-1} K^{-1}.

Problem No. 3 (20 marks)

(a) 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)

(b) An ideal gas underwent reversible adiabatic expansion from 80 kPa to 60 kPa. If the initial temperature of the gas was 300 K, what was its final temperature? Assume that $C_p = 28.9\ J\ K^{-1}\ mol^{-1}$ for the ideal gas. (10 marks)

Problem No. 4 (20 marks)

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

$$C_2H_2 + 2\tfrac{1}{2}\ O_2 = 2CO_2 + H_2O$$

Standard enthalpy of formation at 25°C is given in the following table:

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

Heat capacity data is as follows:

$C_p(CO_2)$ in $J\ K^{-1}\ mol^{-1} = 18.9 + 7.9 \times 10^{-2}\ T$

$C_p(H_2O)$ in $J\ K^{-1}\ mol^{-1} = 31.4 + 0.4 \times 10^{-2}\ T$

$C_p(N_2)$ in $J\ K^{-1}\ mol^{-1} = 27.9 + 0.4 \times 10^{-2}\ T$

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)

A gaseous mixture of 25 % CO, 25 % CO_2, 25 % H_2 and 25 % H_2O is brought to a temperature T and 1 atm. Equilibrium composition of the gas mixture is determined by the following reaction:

$$CO_2 + H_2 = CO + H_2O \qquad (1)$$

(a) Calculate the equilibrium composition of the gaseous phase at 700 K. (10 marks)

(b) Calculate the equilibrium composition of the gaseous phase at 1500 K. (10 marks)

Given: ΔG° at 700 K = 14 kJ and ΔG° at 1500 K = -9.6 kJ.

Problem No. 6 (20 marks)

Consider a galvanic cell based on the following reaction:

$$Sn\ (s) + Pb^{2+}\ (aq) \longrightarrow Sn^{2+}\ (aq) + Pb\ (s) \qquad (1)$$

(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 Pb^{2+} is 0.1 M and concentration of Sn^{2+} is 1.0 M. (5 marks)

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

$Sn^{2+} + 2e^- \longrightarrow Sn\ (s)$ -0.137 V

$Pb^{2+} + 2e^- \longrightarrow Pb\ (s)$ -0.125 V

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 Ti and TiO_2 at 1600 °C? (4 marks)

b) What is the ratio of partial pressures of CO to CO_2 for equilibrium of Ca and CaO in a CO-CO_2 atmosphere at 1600 °C? (4 marks)

c) What is the ratio of partial pressures of H_2 to H_2O for equilibrium of Si and SiO_2 in a H_2-H_2O atmosphere at 1600 °C? (4 marks)

d) What is ΔG° (kJ/mol) at 400 °C for the reaction: $Ti + SiO_2 = TiO_2 + Si$? (4 marks)

e) What is the melting point of Mn? (2 marks)

f) What is the boiling point of Mg? (2 marks)

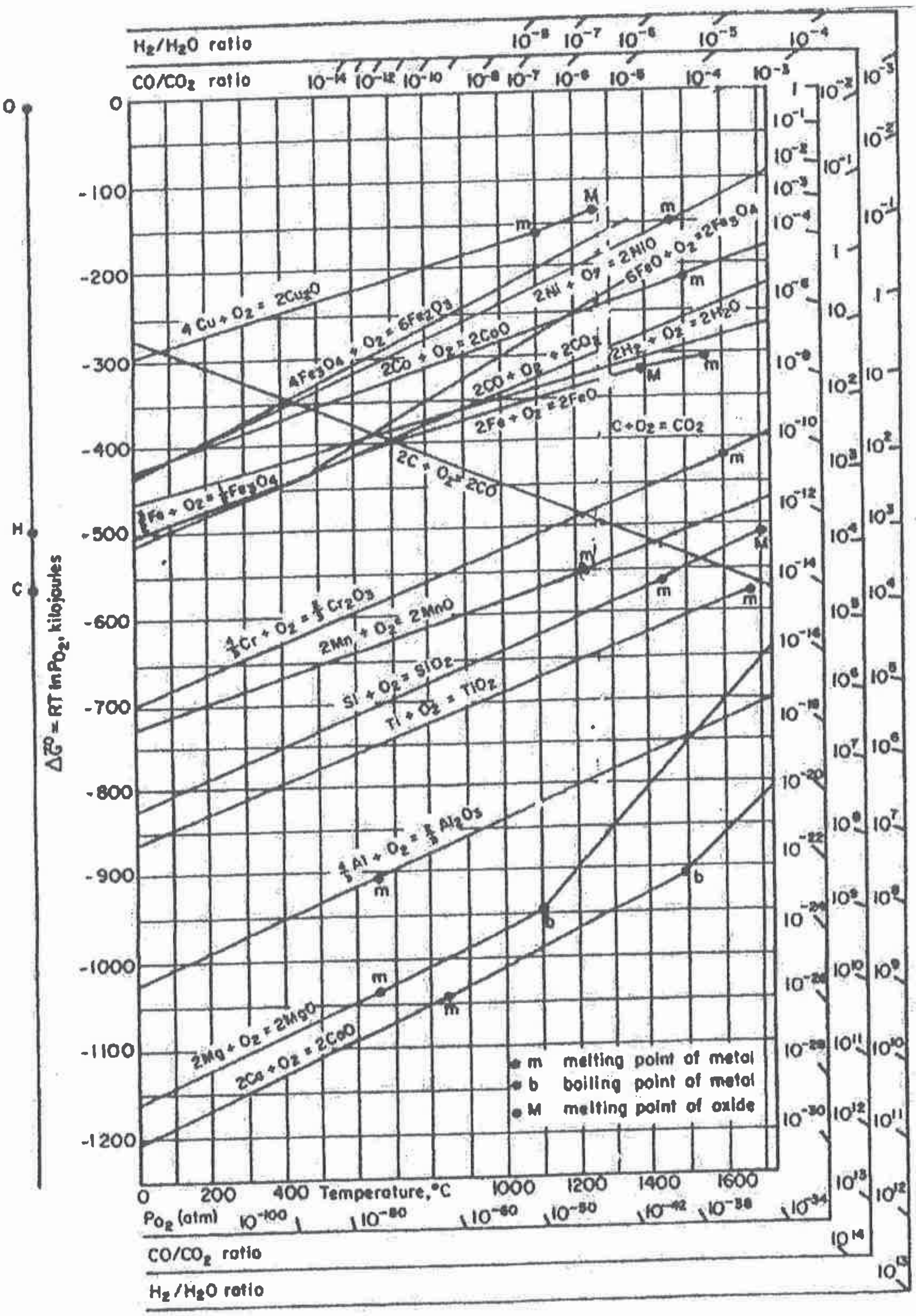


Figure 9–3. Ellingham diagram for some oxides; Richardson nomographic scales are included. (Adapted from D. R. Gaskell, *Introduction to Metallurgical Thermodynamics*, 2nd ed., Hemisphere Publishing, New York, 1981.)