# National Exams May 2014

## 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 4 pages including Ellingham diagram.

Question 1: (a) 8, (b) 8, (c) 4
Question 2: (a) 10, (b) 10
Question 3: (a) (i) 4, (ii) 4, (iii) 2, (b) (i) 4, (ii) 4, (iii) 2
Question 4: (a) 4, (b) 4, (c) 4, (d) 4, (e) 4
Question 5: (a) 5, (b) 5, (c) 5, (d) 5
Question 6: (a) 8, (b) 8, (c) 4
Question 7: (a) 4, (b) 4, (c) 4, (d) 4, (e) 4

**Problem No. 1 (20 marks):**

**(a)** 1 mol of an ideal gas at 300 K and $10^5$ Pa is expanded isothermally against a constant pressure of $10^4$ Pa till its volume doubles. Calculate q, w, ΔH and ΔU for the process. (8 marks)

**(b)** At the end of the process in Part (a), the gas is cooled at constant volume from 300 K to 250 K. Calculate q, w, ΔH and ΔU for the process. (8 marks)

**(c)** Calculate q, w, ΔH and ΔU for the complete process in Parts (a) and (b). (4 marks)

**Problem No. 2 (20 marks):**

Assume that $(\partial U/\partial V)_T = 0$ and $(\partial H/\partial P)_T = 0$ for an ideal gas.

**(a)** Prove that $C_v$ is independent of volume at constant temperature. (10 marks)

**(b)** Prove that $C_p$ is independent of pressure at constant temperature. (10 marks)

**Problem No. 3 (20 marks):**

**(a)** 1 mol of an ideal gas at 300 K is reversibly and isothermally compressed from 20 L to 10 L.

(i) Calculate the change in the entropy of the system. (4 marks)

(ii) Calculate the change in the entropy of the surroundings. (4 marks)

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

**(b)** 1 mol of an ideal gas at 300 K is isothermally compressed by a constant external pressure of 200,000 Pa from 20 L to 10 L.

(i) Calculate the change in the entropy of the system. (4 marks)

(ii) Calculate the change in the entropy of the surroundings. (4 marks)

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

**Problem No. 4 (20 marks):**

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

| Compound | Standard enthalpy of formation |
|---|---|
| $C_2H_6$ | -85 kJ/mol |
| $C_2H_5OH$ | -277 kJ/mol |
| $C_3H_8$ | -105 kJ/mol |
| $C_4H_{10}$ | -126 kJ/mol |
| $CO_2$ | -394 kJ/mol |
| $H_2O$ | -286 kJ/mol |

(a) Calculate the heat of combustion per mole of $C_2H_6$. (4 marks)

(b) Calculate the heat of combustion per mole of $C_2H_5OH$. (4 marks)

(c) Calculate the heat of combustion per mole of $C_3H_8$. (4 marks)

(d) Calculate the heat of combustion per mole of $C_4H_{10}$. (4 marks)

(e) Which fuel generates highest amount of heat per unit weight of the fuel. (4 marks)

**Problem No. 5 (20 marks):**
One mole of $NO_2$ gas is placed in a sealed container at $10^5$ Pa and allowed to come to equilibrium according to the following reaction:

$$NO_2\,(g) = NO\,(g) + \tfrac{1}{2}\,O_2\,(g) \qquad (1)$$

After attaining equilibrium, the resulting gas mixture is analyzed to give the following results:

| T | $P_{NO}/P_{NO_2}$ |
|---|---|
| 500 K | 0.6 |
| 1000 K | 3.6 |

(a) Calculate the equilibrium constant at 500 K. (5 marks)
(b) Calculate the equilibrium constant at 1000 K. (5 marks)
(c) Assuming $\Delta H^o$ for the reaction is independent of temperature, find $\Delta H^o$ for the reaction. (5 marks)
(d) Calculate $\Delta G^o$ for the reaction at 300 K. (5 marks)

**Problem No. 6(20 marks):**
Calculate the $\Delta G$ of mixing at 298 K and 1 atm pressure for the following cases:

(a) Mixing of 1 mole of $O_2$ and 1 mole of $N_2$. (8 marks)
(b) Mixing of 1 mole of $O_2$ and 2 mole of $N_2$. (8 marks)
(c) Mixing of 1 mole of $O_2$ to a mixture of 1 mole of $O_2$ and 1 mole of $N_2$. (4 marks)

**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 1500 °C? (4 marks)
b) What is the ratio of partial pressures of CO to $CO_2$ for equilibrium of Ti and $TiO_2$ in a CO-$CO_2$ atmosphere at 1000 °C? (4 marks)
c) What is the ratio of partial pressures of $H_2$ to $H_2O$ for equilibrium of Ti and $TiO_2$ in a $H_2$-$H_2O$ atmosphere at 1000 °C? (4 marks)
d) What is $\Delta G^o$ (kJ/mol) at 1000 °C for the reaction: $Ti + SiO_2 = TiO_2 + Si$? (4 marks)
e) Explain why there is no discontinuity in the Ellingham diagram at points where phase transformations take place? (4 marks)

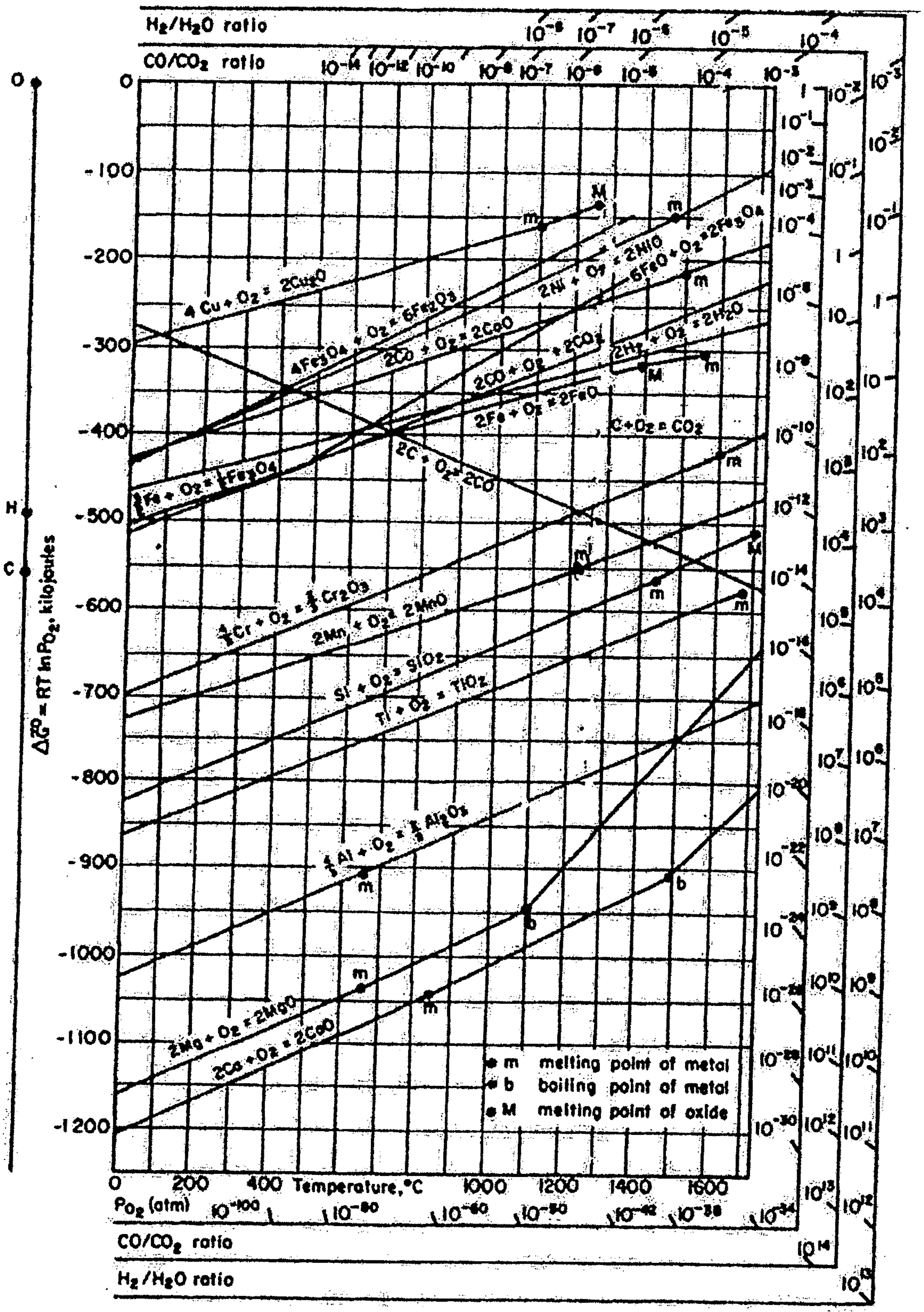


Figure 9–3. Ellingham diagram for some oxides; Richardson nomographic scales are included. (Adapted from D. R. Gaskell, *Introduction to Metallurgical Thermodynamics*, 2nd ed., Hemisphere Publishing, New York, 1981.)