ORDRE DES INGÉNIEURS DU QUÉBEC

NOVEMBER 2014 SESSION

Open-book examination Calculators : only authorized models Duration : 3 hours

14-MT-A1 Metallurgical Thermodynamics

Question 1 (3 points)

1,200 kg of liquid magnesium at 950^{o}C must be cooled to 680^{o}C by the addition of solid Mg ingots initially at 25^{o}C. Calculate the mass of Mg ingots to be added if the mixing process is assumed to be adiabatic.

Data: M_{Mg} : 24.3 g/mol

C_p(liquid Mg): 34.3 J/mol-K

C_p(solid Mg): 21.3 + 0.0118 T(K) J/mol-K

T^o(fusion,Mg): 923 K

Δh^o_{fusion} : 8,477.0 J/mol

Question 2 (4 points)

For the vaporization of pure Zn:

$Zn_{(liquid)} = Zn_{(gas)}$ ΔG^o = 115,295.0 – 97.586 T(K) J/mol

a) Calculate the standard boiling point (that is, when P_{Zn} = 1 bar) of pure Zn;
b) Calculate the standard boiling point of a (Zn+Al) binary liquid alloy with a mole fraction of Al (x_{Al}) of 0.03. You can assume that the liquid solution is ideal and that Al does not volatilize.

Question 3 (4 points)

At 550^{o}C, a liquid sodium (Na) – potassium (K) alloy is at equilibrium with an solid solution of 20 mol.% NaCl + 80 mol.% KCl (both solids are completely miscible at 550^{o}C). The activity coefficients of Na and K (γ_{Na} and γ_K) in the liquid alloy at 550^{o}C are given in Table 1. Assume that Cl is not soluble in the liquid alloy. Calculate the composition mole fraction of K (x_K) of the liquid alloy at equilibrium.

Data: $Na_{(liquid)} + KCl_{(solid)} \leftrightarrow K_{(liquid)} + NaCl_{(solid)}$ $\Delta G^o_{823.15K}$ = 22,835 J/mol

At 550°C, x_{NaCl} = 0.20 and x_{KCl} = 0.80: γ_{NaCl} = 2.99 and γ_{KCl} = 1.05

Table 1: Activity coefficients γ_{Na} and γ_K in the Na-K alloys at 550°C

$x_K = 1 - x_{Na}$	γ_{Na}	γ_K
0.01	1.000	1.674
0.05	1.003	1.513
0.1	1.011	1.377
0.2	1.030	1.229
0.4	1.067	1.126
0.6	1.124	1.071

Question 4 (3 points)

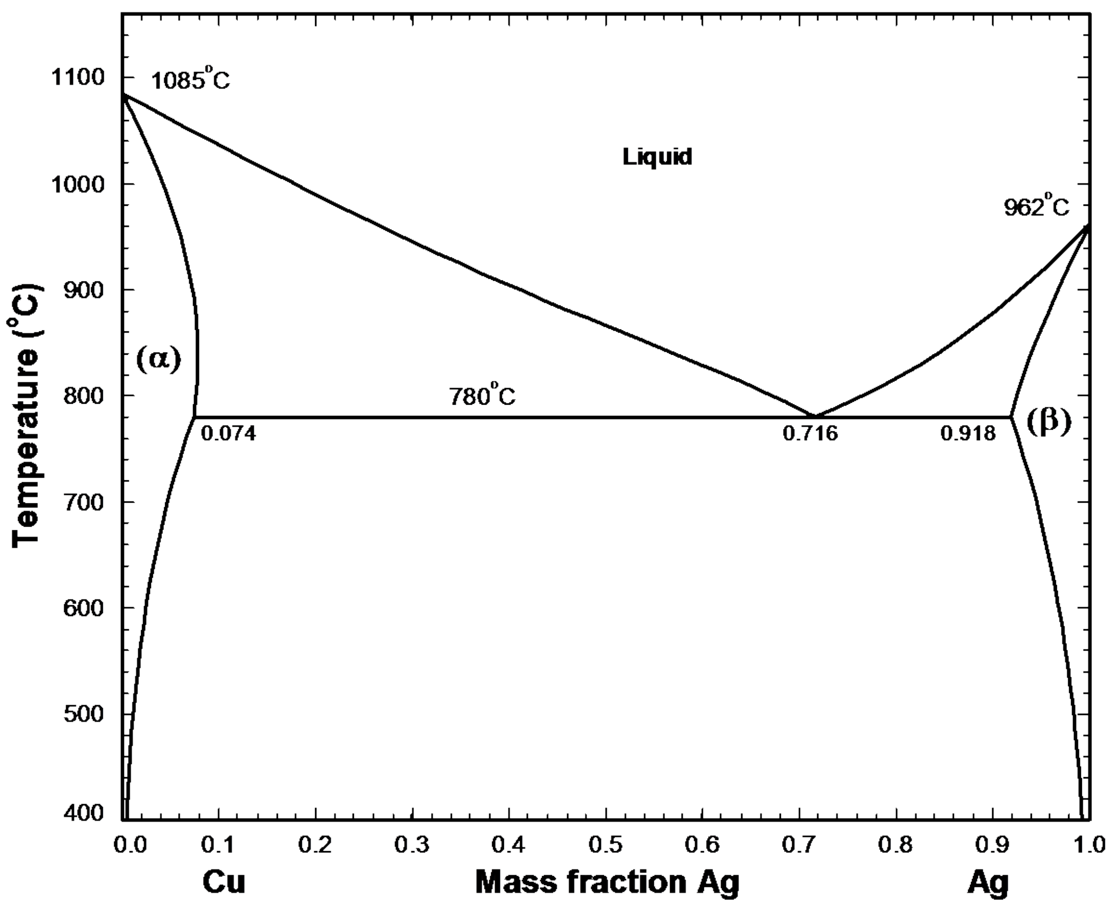

Figure 1: The Cu – Ag Phase Diagram

The Cu-Ag phase diagram (in mass fractions) is given in Figure 1. Apart from the liquid solution, two terminal solid solutions are shown: α-Cu and β-Ag, both face-centered-cubic solutions.

For 240 grams of a Cu – 12 wt.% Ag alloy, under equilibrium conditions:

a) Give the mass and composition of the phases at equilibrium at 780.1°C (i.e. just above the eutectic temperature);
b) Give the mass and composition of the phases at equilibrium at 779.9°C (i.e. just below the eutectic temperature), and also give the mass of $\alpha_{pro\text{-}eutectic}$, $\alpha_{eutectic}$ and $\beta_{eutectic}$.

Question 5 (5 points)

A closed container of a total volume of 25.0 litres (0.0250 m^3) is filled with 0.100 mol of carbon (C), 0.060 mol of diatomic oxygen (O_2) and 0.300 mol of argon (Ar).

a) Calculate (in bar) the values of the partial pressures of CO (P(CO)), CO_2 ($P(CO_2)$), O_2 ($P(O_2)$) and the total pressure (P(total)) at equilibrium at 900°C (assume an ideal gas behavior);
b) Calculate the activity of carbon (graphite reference state) in the gas phase for the previous conditions;
c) Calculate the equilibrium composition of carbon, in mole fraction x_C, of pure iron (Fe_{fcc} austenite) if equilibrated with the gas phase at 900°C (neglect the loss of carbon from the gas phase and the volume occupied by the austenite);

<u>Data</u>: R (gas constant) = 8.31451 J/mol-K

1 bar = 10^5 Pa

1 J = 1 Pa·m^3

for: $CO_{(g)} + \frac{1}{2} O_{2(g)} \leftrightarrow CO_{2(g)}$ $\quad K_{eq}(1173.15K) = 1.11 \times 10^8$

for: $C_{(graphite)} + \frac{1}{2} O_{2(g)} \leftrightarrow CO_{(g)}$ $\quad K_{eq}(1173.15K) = 3.93 \times 10^9$

γ^{o}_{C} in austenite = 12.0 (at 1173.15K)

Question 6 (4 points)

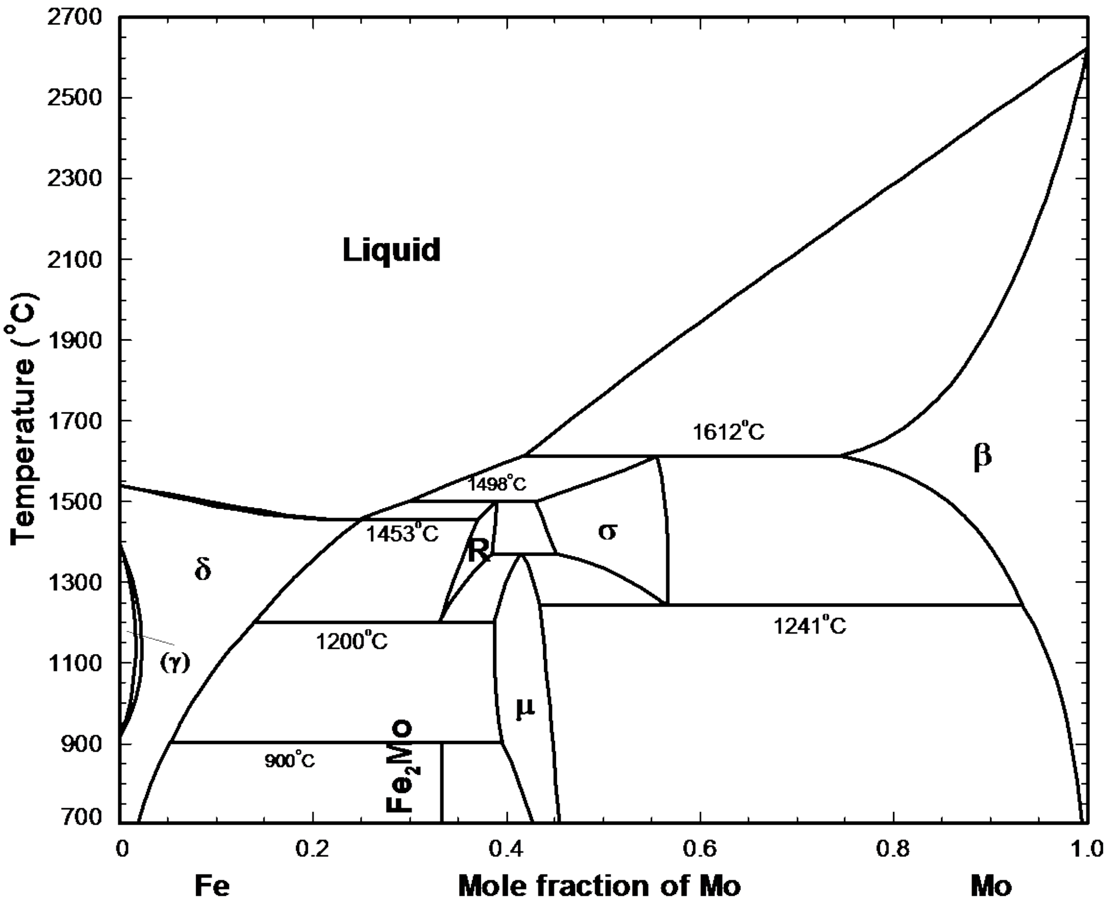

Figure 2: The Fe-Mo Phase Diagram

The Fe-Mo phase diagram is given in Figure 2.

a) What is the first melting temperature (in °C) of the following alloys when heated very slowly (i.e. near equilibrium conditions)?
   i. 70 mol.% Fe + 30 mol.% Mo;
   ii. 90 mol.% Mo;
   iii. 60 mol.% Fe;

b) What is the usual name of the invariant reaction at 1612°C, and write its reactant(s) and product(s) upon cooling?