NOVEMBER 2016 SESSION

Open book examination

Non-programmable calculators: Authorized models only

Duration: 3 hours

14-MT-A1

Metallurgical Thermodynamics

Question 1 (3 points)

In a first process, 1200 moles of pure liquid aluminum (Al) at 900°C are cooled down to 720°C by the addition of solid Al ingots (pure) initially at 25°C. Calculate the number of moles of pure Al ingots to be added if the total heat losses during the entire mixing process are equal to 2.25 MJ.

In a second process, all the moles of pure liquid aluminum resulting from the first process receive a heat transfer of 800 kJ.

Calculate the final temperature of the liquid aluminum.

Data: C_p(liquid Al): 31.7 J/mol-K C_p(solid Al): 20.8 + 0.0121 T(K) J/mol-K

T^o(fusion,Al): 660 °C

Δh^o_{fusion} (Al): 10,711.0 J/mol

Question 2 (3 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 temperature at which pure liquid Zn is boiling under a total pressure ($P_{tot} = P_{Zn}$) of 0.85 bars;
b) Calculate the boiling point (at $P_{tot} = P_{Zn}$ = 1.0 bar) of a (Zn+Al) binary liquid alloy with a mole fraction of Al (x_{Al}) of 0.98. You can assume that Al does not volatilize and that the activity coefficient of Zn (γ_{Zn}) is given by: RT ln $\gamma_{Zn} = 6000X_{Al}^2$

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

1 bar = 10^5 Pa

1 J = 1 Pa·m^3

Question 3 (4 points)

At 500°C, copper (Cu) is soluble in solid aluminum (Al, fcc structure) to a few percent. Beyond the solubility limit, Cu reacts with Al to form solid Al_2Cu, according to the following reaction:

$2\ Al_{(fcc)} + Cu_{(fcc)} \longrightarrow Al_2Cu_{(s)}$ ΔG^o = -47,400.0 + 6.75T(K) J/mol

Assuming $Al_{(fcc)}$ is the solvent with a Raoultian behaviour and Cu is the solute in the fcc solution with an Henrian behaviour (activity coefficient γ_{Cu} in fcc is equal to 0.085 at 500°C), calculate the equilibrium solubility limit of Cu in $Al_{(fcc)}$ (in mole fraction X_{Cu}).

Question 4 (3 points)

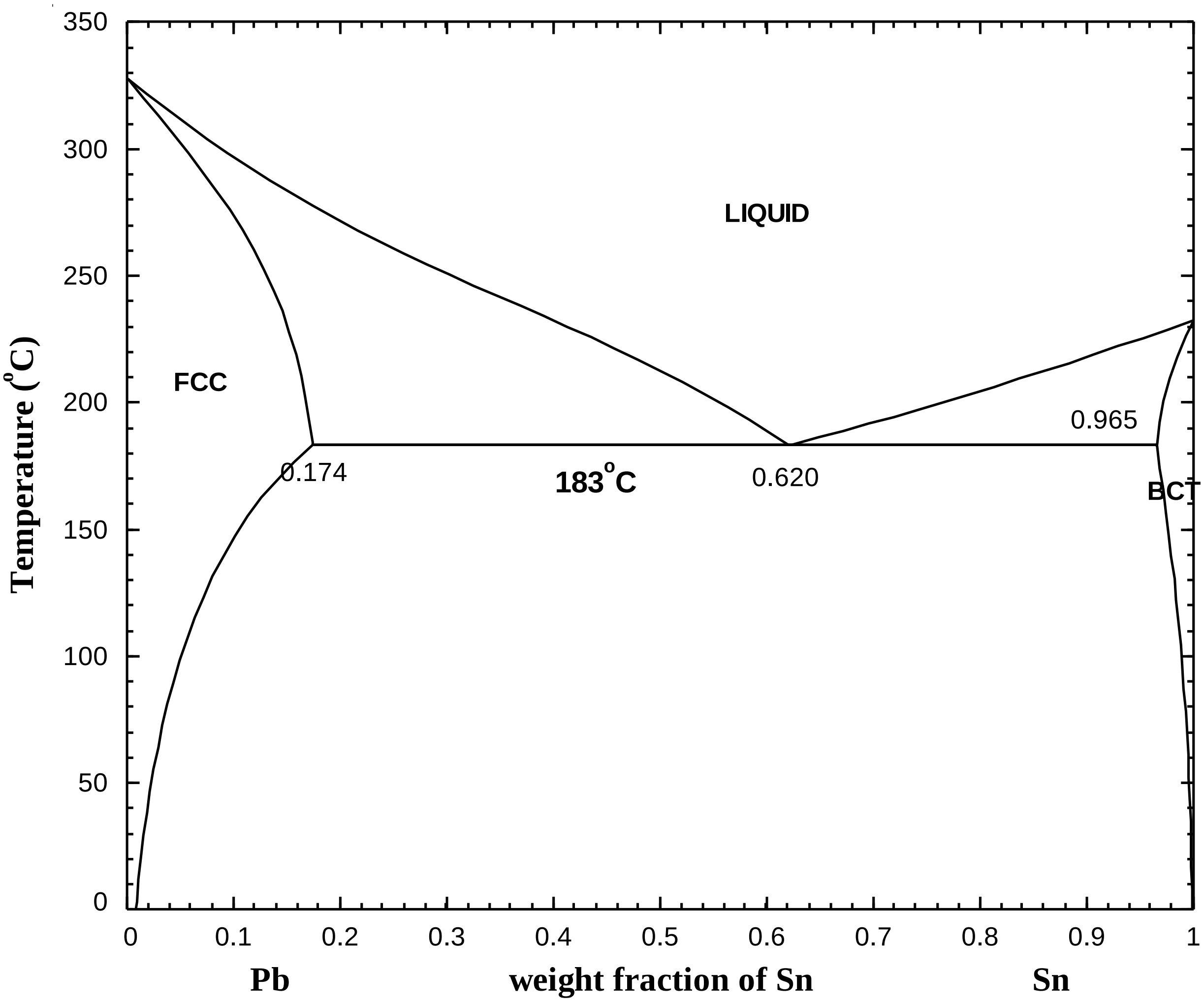

Figure 1: The Pb – Sn Phase Diagram

The Pb-Sn phase diagram (in mass fractions) is given in Figure 1. Apart from the liquid solution, two terminal solid solutions are shown: FCC-Pb and BCT-Sn.

For 120 grams of a 80 wt.% Sn – 20 wt.% Pb alloy, under equilibrium conditions:

a) Give the mass and composition (wt. fraction Sn) of the phases at equilibrium at 183.1^{o}C (i.e. just above the eutectic temperature);

b) Give the mass and composition of the phases at equilibrium at 182.9^{o}C (i.e. just below the eutectic temperature), and also give the mass of $BCT_{pro\text{-}eutectic}$, $FCC_{eutectic}$ and $BCT_{eutectic}$.

Question 5 (4 points)

An empty rigid closed container of a total volume of 1.00 m^3 is filled with 1 mole of pure $BaCO_{3(s)}$, 0.01 mole of $CO_{2(g)}$ and 0.10 mole of $Ar_{(g)}$. The container is then heated to 1100°C and equilibrium is achieved for the following reaction:

$$BaCO_{3(s)} \leftrightarrow BaO_{(s)} + CO_{2(g)} \qquad \Delta G^o(1100^oC) = 53.35 \text{ kJ/mol}$$

The equilibrium products at 1100°C in the container are pure solid $BaCO_3$, pure solid BaO and a gaseous phase containing $Ar_{(g)}$ and $CO_{2(g)}$.

a) Explain in a few words or with a simple equation why the reaction of formation of $BaO_{(s)}$ can proceed to some extent in the container under the above equilibrium conditions even though ΔG^o is positive at 1100°C.
b) Calculate the values of the partial pressures (in bar) of $Ar_{(g)}$ (P(Ar)) and $CO_{2(g)}$ ($P(CO_2)$) and the total pressure (P(total)) at equilibrium at 1100°C (assume an ideal gas behavior and that the solids occupy a negligible volume);
c) Calculate the number of moles of solid $BaO_{(s)}$ generated in the container under the same equilibrium conditions.

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

1 bar = 10^5 Pa

1 J = 1 Pa·m^3

Question 6 (3 points)

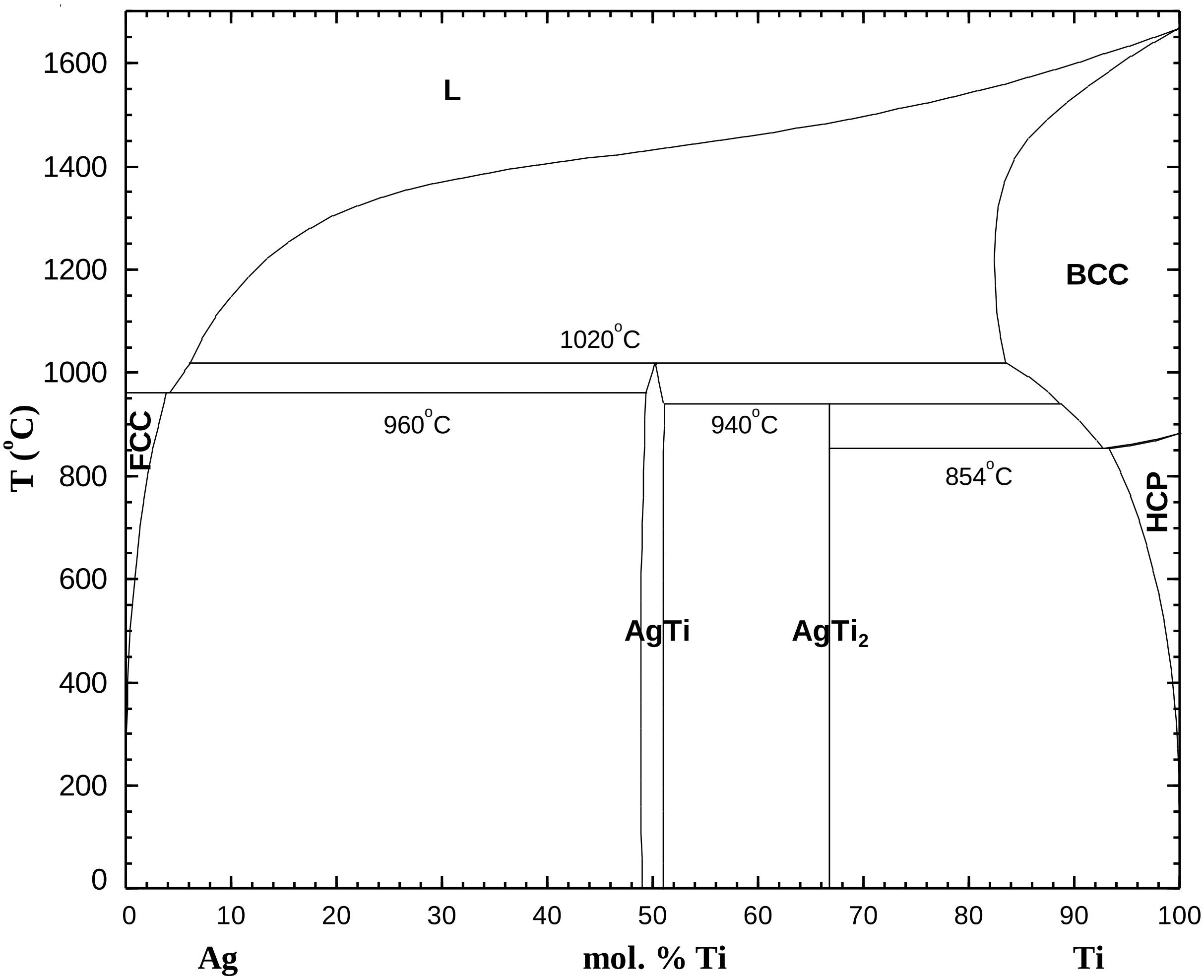

Figure 2: The Ag-Ti Phase Diagram

The silver (Ag) – titanium (Ti) 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.% Ti + 30 mol.% Ag;
   ii. 14 mol.% Ag;
   iii. 50 wt.% Ag (M_{Ag} = 107.87 g/mol; M_{Ti} = 47.87 g/mol)
b) What is the usual name of the invariant reaction at 1020°C, and write its reactant(s) and product(s) upon cooling?