**UNIVERSITY OF GHANA**

(All rights reserved)

**BSc. (ENG) MATERIALS SCIENCE AND ENGINEERING**

**END OF SECOND SEMESTER EXAMINATIONS: 2016/2017**

**SCHOOL OF ENGINEERING SCIENCES**

**MATERIALS SCIENCE AND ENGINEERING DEPARTMENT**

**MTEN 322: PHYSICAL METALLURGY I (3 CREDITS)**

**TIME ALLOWED: 2.5 HOURS**

***Answer ALL Questions*** **ATTACH FIGURE 3 TO YOUR ANSWER SHEET**

1

With respect to Table 1;

a. Calculate the critical radius (in centimeters) of a homogenous nucleus that forms when pure liquid Fe solidifies. Assume $\Delta T = 0.18Tm$. Use Table 1 provided. **[5 marks]**

b. Calculate the number of atoms in the critical-sized nucleus at this undercooling if the crystal structure of Fe is BCC. (Atomic radius, $R_{Fe}$ = 0.1241 nm). **[9 marks]**

Table 1: Values of the freezing temperature, heat of fusion, surface energy, and maximum undercooling for selected metals (B Chambers, Solidification of metals, Wiley, 1964)

| Metal | Freezing temp. °C | Freezing temp. K | Heat of fusion (J/cm³) | Surface energy (J/cm²) | Maximum undercooling, observed ($\Delta T$[°C]) |
|---|---|---|---|---|---|
| Pb | 327 | 600 | 280 | $33.3 \times 10^{-7}$ | 80 |
| Al | 660 | 933 | 1066 | $93 \times 10^{-7}$ | 130 |
| Ag | 962 | 1235 | 1097 | $126 \times 10^{-7}$ | 227 |
| Cu | 1083 | 1356 | 1826 | $177 \times 10^{-7}$ | 236 |
| Ni | 1453 | 1726 | 2660 | $255 \times 10^{-7}$ | 319 |
| Fe | 1535 | 1808 | 2098 | $204 \times 10^{-7}$ | 295 |
| Pt | 1772 | 2045 | 2160 | $240 \times 10^{-7}$ | 332 |

2

Consider the copper-zinc (Cu-Zn) binary phase diagram in Figure 1. This phase diagram has six (6) points where three phases coexist. For each of these three-phase points:

a. List the coordinates of composition (weight percent) and temperature for each point.
b. Write the invariant reaction that occurs during slow cooling of the Cu – Zn alloy through each point
c. Name the type of invariant reaction which takes place at each point.

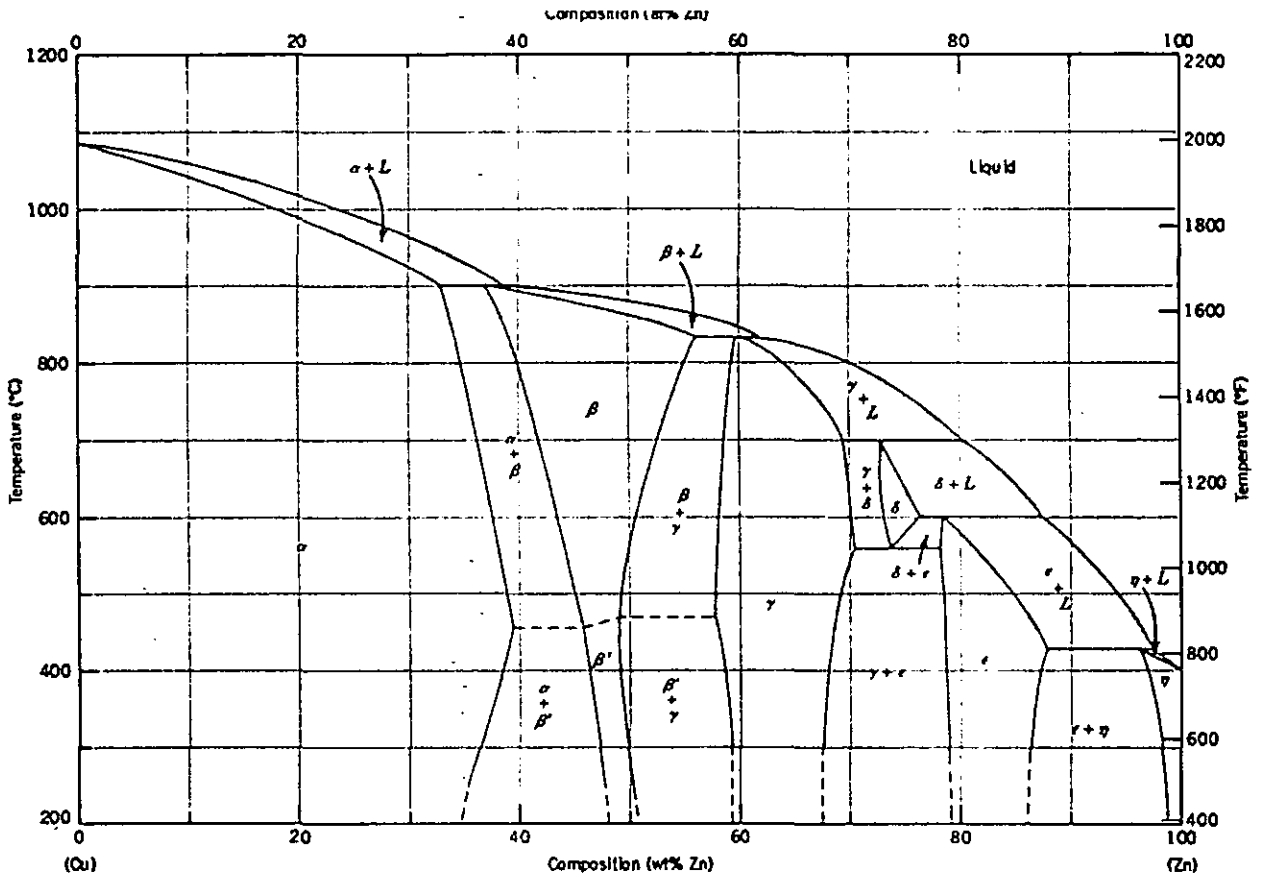


Figure 1: The copper-zinc binary phase diagram (Callister Jr & Rethwisch, 2008). **[21 marks]**

3

Consider the orthorhombic unit cell shown in Figure 2 where $a \neq b \neq c$. Let the atomic radius be 0.12 nm, a = 0.306 nm and c/a = 1.33. Calculate the lattice parameters **b** and **c** and the theoretical density. Take the atomic weight as 69 g/mol and Avogadro's constant as $6.022 \times 10^{23}$ atoms/mol.

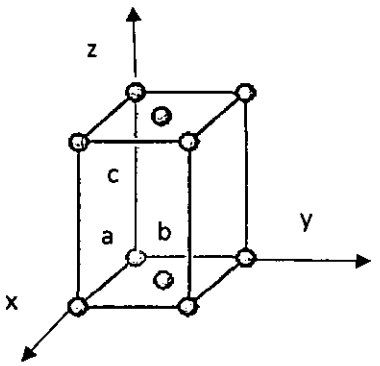


Figure 2: The orthorhombic unit cell (Callister Jr & Rethwisch, 2008). **[9 marks]**

4

a. A plate of iron is exposed to a carburizing (carbon-rich) atmosphere on one side and a decarburizing (carbon-deficient) atmosphere on the other side at 700 °C. If a condition of steady state is achieved, calculate the diffusion flux of carbon through the plate if the concentrations of carbon at positions of 5 and 10 mm beneath the carburizing surface are 1.2 and 0.8 $Kg/m^3$ respectively. Assume a diffusion coefficient of $3 \times 10^{-11}$ $m^2/s$ at this temperature. **[5 marks]**

b. Consider a steel that initially has a uniform carbon concentration of 0.25 wt% and is to be treated at 950 °C. If the concentration of carbon at the surface is suddenly brought to and maintained at 1.20 wt%, how long will it take to achieve a carbon content of 0.80 wt% at a position 0.5 mm below the surface? The diffusion coefficient for carbon in iron at this temperature is $1.6 \times 10^{-11}$ $m^2/s$; assume that the steel piece is semi-infinite. **[11 marks]**

Table 2: Tabulation of error function values (Callister Jr & Rethwisch, 2008)

| $z$ | $erf(z)$ | $z$ | $erf(z)$ | $z$ | $erf(z)$ |
|---|---|---|---|---|---|
| 0 | 0 | 0.55 | 0.5633 | 1.3 | 0.9340 |
| 0.025 | 0.0282 | 0.60 | 0.6039 | 1.4 | 0.9523 |
| 0.05 | 0.0564 | 0.65 | 0.6420 | 1.5 | 0.9661 |
| 0.10 | 0.1125 | 0.70 | 0.6778 | 1.6 | 0.9763 |
| 0.15 | 0.1680 | 0.75 | 0.7112 | 1.7 | 0.9838 |
| 0.20 | 0.2227 | 0.80 | 0.7421 | 1.8 | 0.9891 |
| 0.25 | 0.2763 | 0.85 | 0.7707 | 1.9 | 0.9928 |
| 0.30 | 0.3286 | 0.90 | 0.7970 | 2.0 | 0.9953 |
| 0.35 | 0.3794 | 0.95 | 0.8209 | 2.2 | 0.9981 |
| 0.40 | 0.4284 | 1.0 | 0.8427 | 2.4 | 0.9993 |
| 0.45 | 0.4755 | 1.1 | 0.8802 | 2.6 | 0.9998 |
| 0.50 | 0.5205 | 1.2 | 0.9103 | 2.8 | 0.9999 |

**5**

Consider the binary equilibrium phase diagram in Figure 3. Make phase analysis of the equilibrium solidification of the lead-tin (Pb-Sn) alloys at the points ***j, k, l,*** and ***m*** in the Pb-Sn. In each phase analysis, find the phases present, the compositions of the phases, the amount of phases present, and draw the microstructures. **[25 marks]**

**6**

a. List the types of second phases under equilibrium and non-equilibrium conditions.
b. Name and define the four main diffusion paths in materials
c. The application of coatings is typically done in four ways, mention them.
d. How does undercooling affects nucleation rate N? Provide a simple explanation.
e. Differentiate between homogenous nucleation and heterogenous nucleation.
f. Dendritic growth occurs in pure metals by temperature inversions. Describe temperature inversion. **[25 marks]**