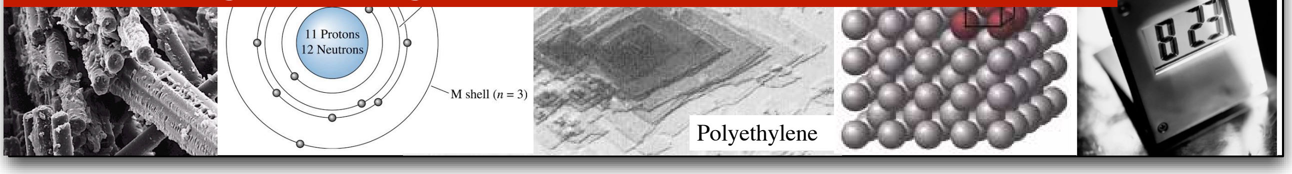
Spring 2007 Engineering Material



Exam I

Wednesday, 21 March, 2007

Duration: 50 minutes
Closed Book Exam
Write clearly your derivations and answers on the question sheet

Name:

ID#:

I Diffusion [30 points]

a. Calculate the diffusion coefficient of carbon in (i) Austenite and (ii) Ferrite (of steel) at 920˚C. User your knowledge to explain the difference between the two values.

b. A mild steel component (carbon content 0.2%) is to be case-hardened by placing it in a furnace in an atmosphere rich in hydrocarbon gas so that the surface concentration is 0.8% carbon. The design of the component requires that at the completion of this process, the carbon concentration at 1 mm below the surface will be 0.55%. The furnace is set at 1050˚C. Determine the time required for the heat treatment.

EXAM I SOLUTION:

I] a) $D = D_0 e^{\left(-\frac{Q_d}{RT}\right)}$

i) (γ Fe) T = 920°C $\quad Q_d = 148$ kJ/mol

$D_0 = 2.3 \times 10^{-5}$ m²/s

T = 1173 K

$D_1 = 2.3 \times 10^{-5} e^{-\left(\frac{148 \times 10^3}{8.31 \times 1173}\right)} = 5.858 \times 10^{-12}$ m²/s

ii) α (Fe) T = 920°C $\quad Q_d = 80 \times 10^3$

$D_0 = 6.2 \times 10^{-7}$ m²/s

T = 1173

$\Rightarrow D_2 = 6.2 \times 10^{-7} e^{-\left(\frac{80 \times 10^3}{8.31 \times 1173}\right)} = 1.65 \times 10^{-10}$ m²/s

$D_1 < D_2 \Rightarrow$ diffusion occurs at a lower rate in γFe because it has FCC that is more packed that BCC.

b) $C_0 = 0.2$ wt%

$C_S = 0.8$ wt%

$x = 1.0 \times 10^{-3}$ m $\quad C_x = 0.55$ wt%

T = 1323 K

$\frac{C_x - C_0}{C_S - C_0} = 1 - erf\left(\frac{x}{2\sqrt{Dt}}\right) \Rightarrow 1 - \left(\frac{0.55 - 0.2}{0.8 - 0.2}\right) = erf\left(\frac{x}{2\sqrt{Dt}}\right)$

$\Rightarrow 0.4161 = erf\left(\frac{x}{2\sqrt{Dt}}\right)$

Using tables $\Rightarrow D \times t = 1.661 \times 10^{-6}$

At T = 1323 K $\quad D = 2.3 \times 10^{-5} e^{-\left(\frac{148 \times 10^3}{1323 \times 8.31}\right)}$

$\Rightarrow$ (γ) Fe $\quad = 3.276 \times 10^{-11}$

$\Rightarrow t = 14.08$ h

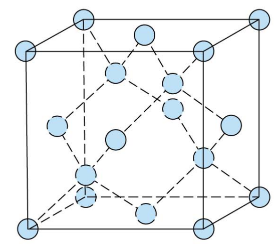
II Microstructures [40 points]

a. Draw the following directions and planes in a FCC unit cell
(110) (112) [121] [-121]
List all the members in the <122> family

b. Calculate the planar packing density of the (110) plane in FCC structure

c. Pure iron undergoes an allotropic phase transformation from FCC (austenite) to BCC (ferrite) on cooling at 910°C. Calculate the percent change in volume accompanying this transformation assuming that the atom diameter is the same in both structures

d. Calculate the density of silicon given that its atomic mass is 28.086 amu, its lattice parameter, a, is 0.543 nm, its crystal structure is diamond cubic.



diamond cubic crystal structure

III Microstructures [30 points]

a. One of the tetrahedral interstitial sites in the BCC structure locates at position (1/2, 1/4,0).
Using a sketch to identify all the tetrahedral interstitial sites in a BCC unit cell. How many (whole) tetrahedral sites are in this unit cell?

b. What is the atom-to-interstitial site ratio for the tetrahedral interstitial sites in the BCC structure?

c. What is the size, relative to that of the atoms, of the tetrahedral interstitial sites in BCC?

Data and Formula

Avogadro's number: 6.023×10^{23} /mol

Gas Constant: 8.31 J/mol•K, 1.987 cal/mol•K

Boltzmann's constant: 1.38×10^{-23} J/atom•K, 8.62×10^{-5} eV/atom•K

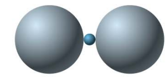
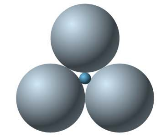
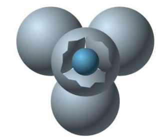
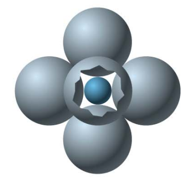
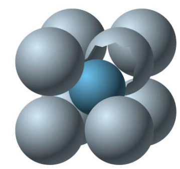
Coordination Number	*Cation-Anion Radius Ratio*	*Coordination Geometry*
2	< 0.155	
3	0.155–0.225	
4	0.225–0.414	
6	0.414–0.732	
8	0.732–1.0	

Table 5.1 Tabulation of Error Function Values

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

Table 5.2 A Tabulation of Diffusion Data

Diffusing Species	*Host Metal*	D_0 *(m²/s)*	*Activation Energy* Q_d		*Calculated Values*	
			kJ/mol	*eV/atom*	*T(°C)*	*D(m²/s)*
Fe	α-Fe (BCC)	2.8×10^{-4}	251	2.60	500 900	3.0×10^{-21} 1.8×10^{-15}
Fe	γ-Fe (FCC)	5.0×10^{-5}	284	2.94	900 1100	1.1×10^{-17} 7.8×10^{-16}
C	α−Fe	6.2×10^{-7}	80	0.83	500 900	2.4×10^{-12} 1.7×10^{-10}
C	γ-Fe	2.3×10^{-5}	148	1.53	900 1100	5.9×10^{-12} 5.3×10^{-11}
Cu	Cu	7.8×10^{-5}	211	2.19	500	4.2×10^{-19}
Zn	Cu	2.4×10^{-5}	189	1.96	500	4.0×10^{-18}
Al	Al	2.3×10^{-4}	144	1.49	500	4.2×10^{-14}
Cu	Al	6.5×10^{-5}	136	1.41	500	4.1×10^{-14}
Mg	Al	1.2×10^{-4}	131	1.35	500	1.9×10^{-13}
Cu	Ni	2.7×10^{-5}	256	2.65	500	1.3×10^{-22}

Source: E. A. Brandes and G. B. Brook (Editors), *Smithells Metals Reference Book,* 7th edition, Butterworth-Heinemann, Oxford, 1992.