Answers to Selected Problems

Chapter 2

2.3 **(a)** 1.66×10^{-24} g/amu; **(b)** 2.73×10^{26} atoms/lb · mol

2.14 $r_0 = \left(\dfrac{A}{nB}\right)^{1/(1-n)}$

$$E_0 = -\frac{A}{\left(\dfrac{A}{nB}\right)^{1/(1-n)}} + \frac{B}{\left(\dfrac{A}{nB}\right)^{n/(1-n)}}$$

2.15 **(c)** $r_0 = 0.279$ nm, $E_0 = -4.57$ eV

2.21 63.2% for TiO_2; 1.0% for InSb

Chapter 3

3.2 $V_C = 6.62 \times 10^{-29}\ m^3$

3.8 $R = 0.136$ nm

3.11 **(a)** $V_C = 1.40 \times 10^{-28}\ m^3$; **(b)** $a = 0.323$ nm; $c = 0.515$ nm

3.14 Metal B: face-centered cubic

3.16 **(a)** $n = 8$ atoms/unit cell; **(b)** $\rho = 4.96\ g/cm^3$

3.19 $V_C = 8.63 \times 10^{-2}\ nm^3$

3.24 **(a)** Cesium chloride; **(c)** sodium chloride

3.26 APF = 0.79

3.27 APF = 0.755

3.28 APF = 0.684

3.30 **(a)** $a = 0.421$ nm; **(b)** $a = 0.424$ nm

3.32 **(a)** $\rho = 4.21\ g/cm^3$

3.34 Cesium chloride

3.39 **(a)** ρ(calculated) = 4.11 g/cm^3; **(b)** ρ(measured) = 4.10 g/cm^3

3.43 000, 100, 110, 010, 001, 101, 111, 011, $\frac{1}{2}\frac{1}{2}0$, $\frac{1}{2}\frac{1}{2}1$, $1\frac{1}{2}\frac{1}{2}$, $0\frac{1}{2}\frac{1}{2}$, $\frac{1}{2}0\frac{1}{2}$, and $\frac{1}{2}1\frac{1}{2}$

3.51 Direction 1: [012]

3.53 Direction A: $[0\bar{1}\bar{1}]$; direction C: [112]

3.54 Direction B: $[2\bar{3}2]$; direction D: $[13\bar{6}]$

3.55 **(b)** $[\bar{1}\bar{1}0]$, $[\bar{1}10]$, and $[1\bar{1}0]$

3.57 **(a)** $[10\bar{1}1]$

3.62 Plane B: $(\bar{1}\bar{1}2)$ or $(11\bar{2})$

3.63 Plane A: $(32\bar{2})$

3.64 Plane B: (221)

3.65 **(c)** [010] or $[0\bar{1}0]$

3.68 **(a)** (010) and $(\bar{1}00)$

3.72 **(b)** $(10\bar{1}0)$

3.74 **(a)** $LD_{100} = \dfrac{1}{2R\sqrt{2}}$

3.75 **(b)** $LD_{111}(W) = 3.65 \times 10^9\ m^{-1}$

3.76 **(a)** $PD_{111} = \dfrac{1}{2R^2\sqrt{3}}$

3.77 **(b)** $PD_{110}(V) = 1.522 \times 10^{19}\ m^{-2}$

3.79 **(a)** FCC; **(b)** tetrahedral; **(c)** one-half

3.81 **(a)** octahedral; **(b)** all

3.85 $d_{110} = 0.2862$ nm

3.86 $2_\theta = 81.38°$

3.88 **(a)** $d_{321} = 0.1523$ nm; **(b)** $R = 0.2468$ nm

Chapter 4

4.3 $DP = 23{,}760$

4.5 **(a)** $\overline{M}_n = 33{,}040$ g/mol; **(c)** $DP = 785$

4.8 **(a)** $C_{Cl} = 20.3$ wt%

4.9 $L = 1254$ nm; $r = 15.4$ nm

4.16 8530 of both styrene and butadiene repeat units

4.18 Propylene

4.21 f(isoprene) = 0.88, f(isobutylene) = 0.12

4.25 **(a)** $\rho_a = 2.000\ g/cm^3$, $\rho_c = 2.301\ g/cm^3$; **(b)** % crystallinity = 87.9%

Chapter 5

5.1 $N_v/N = 2.41 \times 10^{-5}$

5.3 $Q_v = 0.75$ eV/atom

5.5 $N_s/N = 4.03 \times 10^{-6}$

5.10 **(a)** O^{2-} vacancy; one O^{2-} vacancy for every two Li^+ added

5.16 $C'_{Zn} = 29.4$ at%, $C'_{Cu} = 70.6$ at%

5.17 $C_{Pb} = 10.0$ wt%, $C_{Sn} = 90.0$ wt%

5.19 $C'_{Sn} = 72.5$ at%, $C'_{Pb} = 27.5$ at%

5.23 $N_{Al} = 6.05 \times 10^{28}\ atoms/m^3$

5.26 $a = 0.289$ nm

5.29 $N_{Au} = 3.36 \times 10^{21}\ atoms/cm^3$

5.33 $C_{Nb} = 35.2$ wt%

5.41 **(a)** $d \cong 0.066$ mm

5.43 $N_M = 1{,}280{,}000\ grains/in.^2$

5.D1 $C_{Li} = 1.540$ wt%

Chapter 6

6.6 $M = 2.6 \times 10^{-3}$ kg/h

6.8 $D = 3.95 \times 10^{-11}\ m^2/s$

6.11 $t = 19.7$ h

6.15 $t = 40$ h
6.18 $T = 1152$ K (879°C)
6.21 **(a)** $Q_d = 252.4$ kJ/mol, $D_0 = 2.2 \times 10^{-5}$ m²/s; **(b)** $D = 5.4 \times 10^{-15}$ m²/s
6.24 $T = 1044$ K (771°C)
6.29 $x = 1.6$ mm
6.33 $t_p = 47.4$ min
6.35 $P_M = 4.57 \times 10^{-13} \dfrac{(\text{cm}^3\ \text{STP})(\text{cm})}{\text{cm}^2 \cdot \text{s} \cdot \text{Pa}}$
6.D1 Not possible

Chapter 7

7.4 $l_0 = 255$ mm (10 in.)
7.7 **(a)** $F = 89{,}375$ N (20,000 lb_f); **(b)** $l = 115.28$ mm (4.51 in.)
7.10 $\Delta l = 0.090$ mm (0.0036 in.)
7.13

$$\left(\frac{dF}{dr}\right)_{r_0} = -\frac{2A}{\left(\frac{A}{nB}\right)^{3/(1-n)}} + \frac{(n)(n+1)B}{\left(\frac{A}{nB}\right)^{(n+2)/(1-n)}}$$

7.15 **(a)** $\Delta l = 0.50$ mm (0.02 in.); **(b)** $\Delta d = -1.6 \times 10^{-2}$ mm (-6.2×10^{-4} in.), decrease
7.16 $F = 16{,}250$ N (3770 lb_f)
7.17 $\nu = 0.280$
7.19 $E = 170.5$ GPa (24.7×10^6 psi)
7.22 **(a)** $\Delta l = 0.10$ mm (4.0×10^{-3} in.); **(b)** $\Delta d = -3.6 \times 10^{-3}$ mm (-1.4×10^{-4} in.)
7.24 Steel
7.27 **(a)** Both elastic and plastic; **(b)** $\Delta l = 3.4$ mm (0.135 in.)
7.29 **(b)** $E = 62.5$ GPa (9.1×10^6 psi); **(c)** $\sigma_y = 285$ MPa (41,000 psi); **(d)** $TS = 370$ MPa (54,000 psi); **(e)** %EL = 16%; **(f)** $U_r = 0.65 \times 10^6$ J/m³ (93.8 in.·lb_f/in.³)
7.36 Figure 7.12: $U_r = 3.32 \times 10^5$ J/m³ (48.2 in.·lb_f/in.³)
7.38 $\sigma_y = 381$ MPa (55,500 psi)
7.42 $\varepsilon_T = 0.237$
7.44 $\sigma_T = 440$ MPa (63,700 psi)
7.46 Toughness = 3.65×10^9 J/m³ (5.29×10^5 in.·lb_f/in.³)
7.48 $n = 0.136$
7.50 **(a)** ε(elastic) $\cong 0.00226$, ε(plastic) $\cong 0.00774$; **(b)** $l_i = 463.6$ mm (18.14 in.)
7.52 $R = 4.0$ mm (0.16 in.)
7.53 $F_f = 10{,}100$ N (2165 lb_f)
7.55 **(a)** $E_0 = 342$ GPa (49.6×10^6 psi); **(b)** $E = 280$ GPa (40.6×10^6 psi)
7.57 **(b)** $P = 0.19$
7.64 $E_r(10) = 4.25$ MPa (616 psi)
7.70 **(a)** 125 HB (70 HRB)
7.75 Figure 7.12: $\sigma_w = 125$ MPa (18,000 psi)
7.D2 **(a)** $\Delta x = 2.5$ mm; **(b)** $\sigma = 10$ MPa

Chapter 8

8.9 Al: $|\mathbf{b}| = 0.2862$ nm
8.11 $\cos\lambda \cos\phi = 0.408$
8.13 **(b)** $\tau_{crss} = 0.80$ MPa (114 psi)
8.14 $\tau_{crss} = 0.45$ MPa (65.1 psi)
8.15 For $(111)-[10\bar{1}]$: $\sigma_y = 4.29$ MPa
8.24 $d = 1.48 \times 10^{-2}$ mm
8.25 $d = 6.94 \times 10^{-3}$ mm
8.28 $r_d = 8.25$ mm
8.30 $r_0 = 10.6$ mm (0.424 in.)
8.32 $\tau_{crss} = 20.2$ MPa (2920 psi)
8.37 **(b)** $t \cong 150$ min
8.38 **(b)** $d = 0.085$ mm
8.47 $TS = 44$ MPa
8.55 Fraction of sites vulcanized = 0.180
8.57 Fraction of repeat unit sites crosslinked = 0.470
8.D1 Is possible
8.D6 Cold work to between 21% CW and 23% CW [to $d'_0 \cong 12.8$ mm (0.50 in.)], anneal, then cold work to give a final diameter of 11.3 mm (0.445 in.).

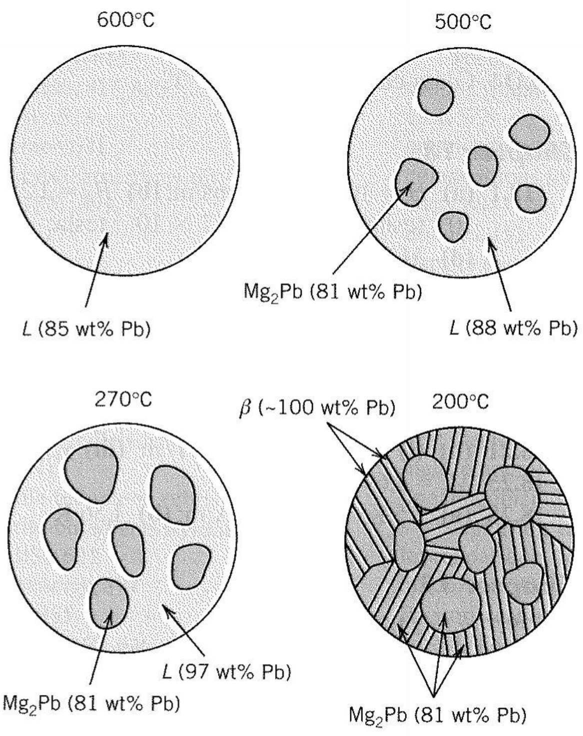
Chapter 9

9.1 $\sigma_m = 2404$ MPa (354,000 psi)
9.3 $\sigma_c = 16.2$ MPa
9.6 Fracture will not occur
9.8 $a_c = 24$ mm (0.95 in.)
9.10 Is not subject to detection because $a < 4.0$ mm
9.12 $\rho_t = 0.39$ nm
9.15 **(b)** −105°C; **(c)** −95°C
9.17 **(a)** $\sigma_{max} = 275$ MPa (40,000 psi), $\sigma_{min} = -175$ MPa (−25,500 psi); **(b)** $R = -0.64$; **(c)** $\sigma_r = 450$ MPa (65,500 psi)
9.19 $N_f > 1 \times 10^5$ cycles
9.21 **(b)** S = 250 MPa; **(c)** $N_f \cong 2 \times 10^6$ cycles
9.22 **(a)** $\tau = 130$ MPa; **(c)** $\tau = 195$ MPa
9.24 **(a)** $t = 120$ min; **(c)** $t = 222$ h
9.31 $\Delta\varepsilon/\Delta t = 7.0 \times 10^{-3}\ \text{min}^{-1}$
9.32 $\Delta l = 22.1$ mm (0.87 in.)
9.34 $t_r = 600$ h
9.36 650°C: $n = 11.2$
9.37 **(a)** $Q_c = 480{,}000$ J/mol
9.39 $\dot{\varepsilon}_s = 0.118\ \text{s}^{-1}$
9.D4 $T = 991$ K (718°C)
9.D6 For 5 years: $\sigma = 260$ MPa (37,500 psi)

Chapter 10

10.1 **(a)** $m_s = 5022$ g; **(b)** $C_L = 64$ wt% sugar; **(c)** $m_s = 2355$ g
10.5 **(a)** The pressure must be raised to approximately 570 atm
10.8 **(a)** $\varepsilon + \eta$; $C_\varepsilon = 87$ wt% Zn–13 wt% Cu, $C_\eta = 97$ wt% Zn–3 wt% Cu; **(c)** liquid; $C_L = 55$ wt% Ag–45 wt% Cu; **(e)** $\beta + \gamma$, $C_\beta = 49$ wt% Zn–51 wt% Cu, $C_\gamma = 58$ wt% Zn–42 wt% Cu; **(g)** a; $C_\alpha = 63.8$ wt% Ni–36.2 wt% Cu

10.9 Is not possible
10.12 **(a)** $T = 560°C$ (1040°F); **(b)** $C_\alpha = 21$ wt% Pb–79 wt% Mg; **(c)** $T = 465°C$ (870°F); **(d)** $C_L = 67$ wt% Pb–33 wt% Mg
10.14 **(a)** $W_\varepsilon = 0.70$, $W_\eta = 0.30$; **(c)** $W_L = 1.0$; **(e)** $W_\beta = 0.56$, $W_\gamma = 0.44$; **(g)** $W_\alpha = 1.0$
10.15 **(a)** $T = 295°C$ (560°F)
10.18 **(a)** $T \cong 230°C$ (445°F); **(b)** $C_\alpha = 15$ wt% Sn; $C_L = 43$ wt% Sn
10.19 $C_\alpha = 90$ wt% A–10 wt% B; $C_\beta = 20.2$ wt% A–79.8 wt% B
10.21 Not possible
10.24 **(a)** $V_\varepsilon = 0.70$, $V_\eta = 0.30$
10.30 Is possible
10.33 $C_0 = 82.4$ wt% Sn–17.6 wt% Pb
10.35 Schematic sketches of the microstructures called for are shown here.



10.42 Eutectics: (1) 12 wt% Nd, 632°C, $L \rightarrow Al + Al_{11}Nd_3$; (2) 97 wt% Nd, 635°C, $L \rightarrow AlNd_3 + Nd$
Congruent melting point: 73 wt% Nd, 1460°C, $L \rightarrow Al_2Nd$
Peritectics: (1) 59 wt% Nd, 1235°C, $L + Al_2Nd \rightarrow Al_{11}Nd_3$; (2) 84 wt% Nd, 940°C, $L + Al_2Nd \rightarrow AlNd$; (3) 91 wt% Nd, 795°C, $L + AlNd \rightarrow AlNd_2$; (4) 94 wt% Nd, 675°C, $L + AlNd_2 \rightarrow AlNd_3$.
No eutectoids are present.
10.46 **(a)** 8.1% of Mg^{2+} vacancies
10.47 **(a)** $C = 45.9$ wt% Al_2O_3–54.1 wt% SiO_2
10.48 For point B, $F = 2$
10.51 $C_0' = 0.42$ wt% C
10.54 **(a)** α-ferrite; **(b)** 2.27 kg of ferrite, 0.23 kg of Fe_3C; **(c)** 0.38 kg of proeutectoid ferrite, 2.12 kg of pearlite
10.56 $C_0' = 0.55$ wt% C
10.58 $C_0' = 0.61$ wt% C
10.61 Is possible
10.64 Two answers are possible: $C_0 = 1.11$ wt% C and 0.72 wt% C
10.67 HB (alloy) = 128
10.69 **(a)** T(eutectoid) = 650°C (1200°F); **(b)** ferrite; **(c)** $W_{\alpha'} = 0.68$, $W_p = 0.32$

Chapter 11

11.3 $r^* = 1.30$ nm
11.6 $t = 305$ s
11.8 rate = 4.42×10^{-3} min^{-1}
11.10 $y = 0.51$
11.11 **(c)** $t_{0.5} \cong 250$ days
11.15 **(b)** 265 HB (27 HRC)
11.18 **(a)** 50% coarse pearlite and 50% martensite; **(d)** 100% martensite; **(e)** 40% bainite and 60% martensite; **(g)** 100% fine pearlite
11.20 **(a)** martensite; **(c)** bainite; **(e)** ferrite, medium pearlite, bainite, and martensite; **(g)** proeutectoid ferrite, pearlite, and martensite
11.23 **(a)** martensite
11.27 **(a)** martensite; **(c)** martensite, proeutectoid ferrite, and bainite
11.36 **(b)** 87 HRB; **(g)** 27 HRC
11.38 **(c)** $TS = 915$ MPa (132,500 psi)
11.D1 Not possible
11.D5 Temper at between 400°C and 450°C (750°F and 840°F) for 1 h
11.D8 Heat for between 3 and 10 h at 149°C, or between about 35 and 500 h at 121°C

Chapter 12

12.2 $d = 1.88$ mm
12.5 **(a)** $R = 4.7 \times 10^{-3}\ \Omega$; **(b)** $I = 10.6$ A; **(c)** $J = 1.5 \times 10^6$ A/m^2; **(d)** $\mathscr{E} = 2.5 \times 10^{-2}$ V/m
12.11 **(a)** $n = 1.25 \times 10^{29}$ m^{-3}; **(b)** 1.48 free electrons/atom
12.14 **(a)** $\rho_0 = 1.58 \times 10^{-8}\ \Omega \cdot m$, $a = 6.5 \times 10^{-11}\ (\Omega \cdot m)/°C$; **(b)** $A = 1.18 \times 10^{-6}\ \Omega \cdot m$; **(c)** $\rho = 4.25 \times 10^{-8}\ \Omega \cdot m$
12.16 $\sigma = 7.31 \times 10^6\ (\Omega \cdot m)^{-1}$
12.18 **(a)** For Si, 1.40×10^{-12}; for Ge, 1.13×10^{-9}
12.25 $\sigma = 0.096\ (\Omega \cdot m)^{-1}$
12.29 **(a)** $n = 1.44 \times 10^{16}$ m^{-3}; **(b)** p-type extrinsic

12.31 $\mu_e = 0.50\ m^2/V\cdot s$; $\mu_h = 0.02\ m^2/V\cdot s$
12.33 $\sigma = 61.6\ (\Omega\cdot m)^{-1}$
12.37 $\sigma = 224\ (\Omega\cdot m)^{-1}$
12.39 $\sigma = 272\ (\Omega\cdot m)^{-1}$
12.42 $B_z = 0.58$ tesla
12.49 $l = 1.6$ mm
12.53 $p_i = 2.26 \times 10^{-30}$ C·m
12.55 **(a)** $V = 17.3$ V; **(b)** $V = 86.5$ V; **(e)** $P = 1.75 \times 10^{-7}\ C/m^2$
12.58 Fraction of ε_r due to P_i is 0.67
12.D2 $\sigma = 2.44 \times 10^7\ (\Omega\cdot m)^{-1}$
12.D3 Is possible; 30 wt% < C_{Ni} < 32.5 wt%

Chapter 13

13.4 $V_{Gr} = 11.1$ vol%
13.16 **(a)** $T = 2000°C$ (3630°F)
13.18 **(a)** $W_L = 0.86$; **(c)** $W_L = 0.66$
13.19 **(b)** $T = 2800°C$; pure MgO

Chapter 14

14.9 **(a)** At least 905°C (1660°F)
14.10 **(b)** 830°C (1525°F)
14.22 **(b)** $Q_{vis} = 364{,}000$ J/mol
14.36 **(a)** m(ethylene glycol) = 17.673 kg; **(b)** m[poly(ethylene terephthalate)] = 59.843 kg
14.D5 Maximum diameter = 83 mm (3.3 in.)
14.D6 Maximum diameter = 75 mm (3 in.)

Chapter 15

15.2 $k_{max} = 33.3$ W/m·K; $k_{min} = 29.7$ W/m·K
15.6 $\tau_c = 34.5$ MPa
15.9 Is possible
15.10 $E_f = 70.4$ GPa (10.2×10^6 psi); $E_m = 2.79$ GPa (4.04×10^5 psi)
15.13 **(a)** $F_f/F_m = 23.4$; **(b)** $F_f = 42{,}676$ N (9590 lb_f), $F_m = 1824$ N (410 lb_f); **(c)** $\sigma_f = 445$ MPa (63,930 psi); $\sigma_m = 8.14$ MPa (1170 psi); **(d)** $\varepsilon = 3.39 \times 10^{-3}$
15.15 $\sigma^*_{cl} = 633$ MPa (91,700 psi)
15.17 $\sigma^*_{cd} = 1340$ MPa (194,400 psi)
15.26 **(b)** $E_{cl} = 69.1$ GPa (10.0×10^6 psi)
15.D2 Carbon (PAN standard-modulus) and aramid
15.D3 Not possible

Chapter 16

16.4 **(a)** $\Delta V = 0.031$ V; **(b)** $Fe^{2+} + Cd \rightarrow Fe + Cd^{2+}$
16.6 $[Pb^{2+}] = 2.5 \times 10^{-2}$ M
16.11 $t = 10$ yr
16.14 CPR = 5.24 mpy
16.17 **(a)** $r = 8.03 \times 10^{-14}\ mol/cm^2\cdot s$; **(b)** $V_C = -0.019$ V
16.28 Sn: P–B ratio = 1.33; protective
16.30 **(a)** Parabolic kinetics; **(b)** $W = 1.51\ mg/cm^2$

Chapter 17

17.2 $T_f = 49°C$ (120°F)
17.4 **(a)** $c_v = 139$ J/kg·K; **(b)** $c_v = 923$ J/kg·K
17.7 $\Delta l = -9.2$ mm (−0.36 in.)
17.13 $T_f = 129.5°C$
17.14 **(b)** $dQ/dt = 9.3 \times 10^8$ J/h (8.9×10^5 Btu/h)
17.21 k(upper) = 26.4 W/m·K
17.25 **(a)** $\sigma = -150$ MPa (−21,800 psi); compression
17.26 $T_f = 39°C$ (101°F)
17.27 $\Delta d = 0.0251$ mm
17.D1 $T_f = 42.2°C$ (108°F)
17.D4 Glass-ceramic: $\Delta T_f = 317°C$

Chapter 18

18.1 **(a)** $H = 10{,}000$ A·turns/m; **(b)** $B_0 = 1.257 \times 10^{-2}$ tesla; **(c)** $B \cong 1.257 \times 10^{-2}$ tesla; **(d)** $M = 1.81$ A/m
18.5 **(a)** $\mu = 1.2645 \times 10^{-6}$ H/m; **(b)** $\chi_m = 6.0 \times 10^{-3}$
18.7 **(a)** $M_s = 1.45 \times 10^6$ A/m
18.13 4.6 Bohr magnetons/Mn^{2+} ion
18.19 **(b)** $\mu_i \cong 3 \times 10^{-3}$ H/m, $\mu_{ri} = 2387$; **(c)** $\mu(\max) \cong 8.70 \times 10^{-3}$ H/m
18.21 **(b)** **(i)** $\mu = 1.10 \times 10^{-2}$ H/m, **(iii)** $\chi_m \cong 8750$
18.25 $M_s = 1.69 \times 10^6$ A/m
18.28 **(a)** 2.5 K: 1.33×10^4 A/m; **(b)** 1.56 K

Chapter 19

19.7 $v = 2.09 \times 10^8$ m/s
19.8 Fused silica: 0.53; soda–lime glass: 0.33
19.9 Borosilicate glass: $\varepsilon_r = 2.16$; polypropylene: $\varepsilon_r = 2.22$
19.16 $I'_T/I'_0 = 0.81$
19.18 $l = 67.3$ mm
19.27 $\Delta E = 1.78$ eV