Answers to Selected Problems

Chapter 2

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

2.13

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

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

2.14 **(c)** $r_0 = 0.279$ nm; $E_0 = -4.57$ eV

2.19 63.2% for TiO_2; 1.0% for InSb

Chapter 3

3.3 $V_C = 6.62 \times 10^{-29}$ m^3

3.9 $R = 0.136$ nm

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

3.15 Metal B: face-centered cubic

3.17 **(a)** $n = 8.0$; **(b)** $\rho = 4.96$ g/cm^3

3.20 $V_C = 8.63 \times 10^{-2}$ nm^3

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

3.31 APF = 0.73

3.35 **(a)** $a = 0.421$ nm; $a = 0.424$ nm

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

3.39 **(a)** $\rho = 4.20$ g/cm^3

3.41 Cesium chloride

3.43 APF = 0.84

3.45 APF = 0.68

3.50 **(a)** Direction 1: [012]; **(b)** Plane 1: (020)

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

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

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

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

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

3.58 Plane B: (221)

3.60 **(a)** $(1\bar{1}00)$

3.64 **(a)** (100) and $(0\bar{1}0)$

3.65 **(c)** [010]

3.66 **(a)** FCC; **(b)** tetrahedral; **(c)** one half

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

3.70* [100]: LD = 0.71

3.71* [111]: LD = 1.0

3.72* (100): PD = 0.79

3.73* (110): PD = 0.83

3.79* $2\theta = 81.38°$

3.80* $d_{110} = 0.2862$ nm

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

3.84* $d_{110} = 0.2015$ nm; $a = 0.285$ nm

Chapter 4

4.4 $n_n = 23{,}700$

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

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

4.11 $L = 1254$ nm; $r = 15.4$ nm

4.16 8530 of both styrene and butadiene mers

4.18 Propylene

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

4.28 $\rho = 0.998$ g/cm^3

4.30 **(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 $Q_v = 1.10$ eV/atom

5.4 6.02×10^{28} atoms/m^3

5.9 For FCC, $r = 0.41R$

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

5.13 $C_{Pb} = 10.0$ wt%; $C_{Sn} = 90.0$ wt%

5.15 $C'_{Sn} = 72.5$ at%; $C'_{Pb} = 27.5$ at%

5.18* $C'_{Fe} = 94.2$ at%; $C'_{Si} = 5.8$ at%

5.23 $N_{Au} = 3.36 \times 10^{21}$ atoms/cm^3

5.27 $C_{Nb} = 35.2$ wt%

5.30 **(a)** FCC: $\mathbf{b} = \frac{a}{2}[110]$;

(b) Al: $|\mathbf{b}| = 0.2862$ nm

5.35 $d \cong 0.07$ mm

5.37 **(a)** $N = 8$

5.D1* $C_{Li} = 1.537$ wt%

Chapter 6

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

6.8 $D = 3.9 \times 10^{-11}$ 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, $D_0 = 2.2 \times 10^{-5}$ m^2/s

(b) $D = 5.3 \times 10^{-15}$ m^2/s

6.24 $T = 1044$ K (771°C)

6.29 $x = 1.6$ mm

6.D1 Not possible

Chapter 7

7.4 $l_0 = 250$ mm (10 in.)

7.7 **(a)** $F = 89{,}400$ N (20,000 lb$_f$)

(b) $l_i = 115.28$ mm (4.511 in.)

7.9 $\Delta l = 0.10$ mm (0.004 in.)

7.12

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

7.14 **(a)** $\Delta l = 0.50$ mm (0.02 in.);

(b) $\Delta d = -1.62 \times 10^{-2}$ mm (-6.2×10^{-4} in.); decrease

7.15 $F = 16{,}250$ N (3770 lb$_f$)

7.16 $\nu = 0.280$

7.18 $E = 170.5$ GPa (24.7×10^6 psi)

7.21 **(a)** $\Delta l = 0.10$ mm (4×10^{-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) $\Delta l = 4.0$ mm (0.16 in.)

7.29 **(b)** $E = 62$ GPa (9×10^6 psi)

(c) $\sigma_y = 285$ MPa (41,500 psi)

(d) $TS = 370$ MPa (53,500 psi)

(e) %EL = 16%

(f) $U_r = 0.66 \times 10^6$ J/m^2 (95.7 in.-lb$_m$/in.^{3})

7.32 Figure 7.12: $U_r = 3.32 \times 10^5$ J/m^3 (47.6 in.-lb$_f$/in.^{3})

7.34 $\sigma_y = 381$ MPa (55,500 psi)

7.39 $\epsilon_T = 0.237$

7.41 $\sigma_T = 440$ MPa (63,700 psi)

7.43 Toughness $= 3.65 \times 10^9$ J/m^3 (5.29×10^5 in.-lb$_m$/in.^{3})

7.45 $n = 0.134$

7.47 **(a)** ϵ (elastic) $\cong 0.0027$; ϵ (plastic) $\cong 0.0023$

(b) $l_i = 461.1$ mm (18.05 in.)

7.49 $R = 4$ mm

7.50 $F_f = 10{,}100$ N (2165 lb$_f$)

7.52* **(a)** $E_0 = 342$ GPa; **(b)** $E = 280$ GPa

7.54* **(b)** $P = 0.186$

7.59* $E_r(10) = 4.25$ MPa (616 psi)

7.65 **(a)** 125 HB (70 HRB)

7.70 Figure 7.12: $\sigma_w = 125$ MPa (18,000 psi)

7.D2 **(a)** $\Delta x = 2.5$ mm; **(b)** $\sigma = 10$ MPa

Chapter 8

8.10* $\cos\lambda \cos\phi = 0.408$

8.12* **(b)** $\tau_{crss} = 0.80$ MPa (114 psi)

8.13* $\tau_{crss} = 0.45$ MPa (65.1 psi)

8.20 $d = 1.48 \times 10^{-2}$ mm

8.21 $d = 6.9 \times 10^{-3}$ mm

8.25 $r_d = 8.25$ mm

8.27 $r_0 = 10.6$ mm (0.424 in.)

8.29 $\tau_{crss} = 20.2$ MPa (2920 psi)

8.35 **(b)** $t \cong 150$ min

8.36 **(b)** $d = 0.085$ mm

8.45* $TS = 44$ MPa

8.54 Fraction sites vulcanized = 0.180

8.56 Fraction of mer sites crosslinked = 0.47

8.D1 Is possible

8.D6 Cold work to between 21 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

9.3 $\sigma_m = 2404$ MPa (354,000 psi)

9.7 $\rho_t = 0.39$ nm

9.8 $\sigma_c = 16.2$ MPa

9.10* **(a)** $\sigma_x = 171$ MPa (25,000 psi), $\sigma_y = 247$ MPa (35,800 psi)

(d) $\sigma_x = 41.7$ MPa (6050 psi), $\sigma_y = 126$ MPa (18,300 psi)

9.12* **(a)** $\sigma_m = 170$ MPa (24,650 psi)

9.13* **(a)** $\sigma_m = 120$ MPa (17,400 psi)

9.15* Aluminum 2024-T3: $B \geq 40.6$ mm (1.6 in.); 4340 steel (tempered at 260°C): $B \geq 2.3$ mm (0.10 in.)

9.17 Fracture will not occur

9.19 $a = 24$ mm (0.95 in.)

9.21 Is not subject to detection since $a < 4.0$ mm

9.26 **(b)** −105°C; **(c)** −95°C

9.29 **(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)

9.31 $N_f = 1 \times 10^5$ cycles

9.33 **(b)** $S = 250$ MPa; **(c)** $N_f \cong 2.2 \times 10^6$ cycles

9.34 **(a)** $\tau = 130$ MPa; **(c)** $\tau = 195$ MPa

9.36 **(a)** $t = 120$ min; **(c)** $t = 220$ h

9.47 $\Delta\epsilon/\Delta t = 7.0 \times 10^{-3}$ min^{-1}

9.48 $\Delta l = 7.1$ mm (0.29 in.)

9.50 $t_r = 36{,}000$ h

9.52* 427°C: $n = 5.3$

9.53* **(a)** $Q_c = 186{,}200$ J/mol

9.55* $\dot{\epsilon}_s = 0.118$ (h)$^{-1}$

9.D1* $K_{Ic} = 67.9$ MPa$\sqrt{\text{m}}$ (62.3 ksi$\sqrt{\text{in.}}$)

9.D3* $W \geq 4.4$ mm

9.D7* $\sigma_{max} = 178$ MPa

9.D9* $a_c = 0.25$ in.

9.D14* $T = 991$ K (718°C)

9.D16* For 5 years: $\sigma = 260$ MPa (37,500 psi)

Chapter 10

10.5 **(a)** $\epsilon + \eta$; $C_\epsilon = 87$ 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, $C_\gamma = 57$ wt% Zn-43 wt% Cu;

(g) α; $C_\alpha = 63.8$ wt% Ni-36.2 wt% Cu

10.7 **(a)** $W_\epsilon = 0.70$, $W_\eta = 0.30$;

(c) $W_L = 1.0$;

(e) $W_\beta = 0.50$, $W_\gamma = 0.50$;

(g) $W_\alpha = 1.0$

10.9 **(a)** $V_\epsilon = 0.70$, $V_\eta = 0.30$

10.11 **(a)** $T = 300$°C (570°F)

10.12 **(a)** $m_s = 5022$ g;

(b) $C_L = 64$ wt% sugar;

(c) $m_s = 2355$ g

10.13 **(a)** The pressure must be raised to approximately 570 atm

10.18 Is possible

10.21 **(a)** $T = 550$°C (1020°F);

(b) $C_\alpha = 22$ wt% Pb-78 wt% Mg;

(c) $T = 465$°C (870°F);

(d) $C_L = 66$ wt% Pb-34 wt% Mg

10.24 **(a)** $T \cong 230$°C (445°F);

(b) $C_\alpha = 15$ wt% Sn; $C_L = 42$ wt% Sn

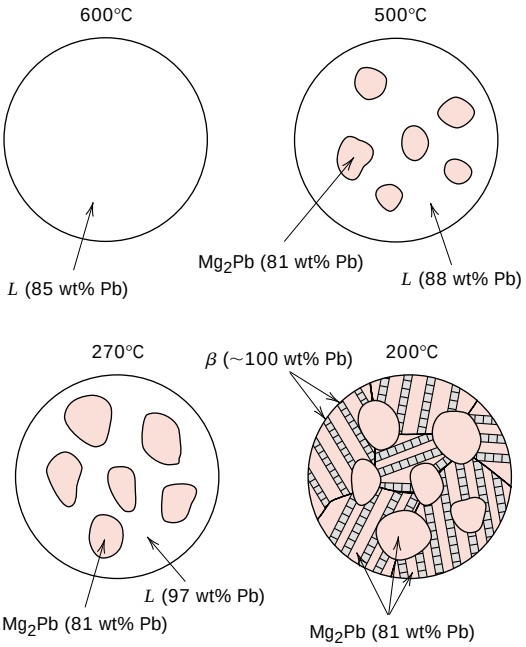
10.25* **(a)** $C = 45.9$ wt% Al_2O_3–54.1 wt% SiO_2

10.26 $C_\alpha = 90$ wt% A-10 wt% B; $C_\beta = 20.2$ wt% A-79.8 wt% B

10.28 Not possible

10.32* Is possible

10.35* C_0 = 82.4 wt% Sn-17.6 wt% Pb

10.38* 

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.

10.45* **(a)** 8.1% of Mg^{2+} vacancies

10.47* For point B, $F = 2$

10.54 $C_0' = 0.42$ wt% C

10.57 **(a)** α-ferrite; **(b)** 2.26 kg of ferrite, 0.24 kg of Fe_3C;

(c) 0.38 kg of proeutectoid ferrite, 2.12 kg of pearlite

10.59 C_0 = 0.55 wt% C

10.61 C_0 = 0.61 wt% C

10.64 Possible

10.67 Two answers are possible: C_0 = 1.11 wt% C and 0.72 wt% C

10.70 HB (alloy) = 128

10.73* **(a)** T (eutectoid) = 650°C (1200°F); **(b)** ferrite; **(c)** $W_{\alpha'} = 0.68$, $W_p = 0.32$

Chapter 11

11.2 t = 305 s

11.4 $r = 4.42 \times 10^{-3}$ min^{-1}

11.6 y = 0.51

11.7 **(c)** $t \cong 250$ days

11.10 **(b)** 265 HB (27 HRC)

11.14 **(a)** 50% coarse pearlite and 50% martensite; **(d)** 100% martensite; **(e)** 40% bainite and 60% martensite; **(g)** 100% fine pearlite

11.16 **(a)** martensite; **(c)** bainite; **(e)** ferrite, medium pearlite, bainite, and martensite; **(g)** proeutectoid ferrite, pearlite, and martensite

11.19* **(a)** martensite

11.24* **(a)** martensite; **(c)** martensite, proeutectoid ferrite, and bainite

11.34 **(b)** 180 HB (87 HRB); **(g)** 265 HB (27 HRC)

11.36* **(c)** TS = 915 MPa (132,500 psi)

11.37 **(a)** Rapidly cool to about 675°C (1245°F), hold for at least 200 s, then cool to room temperature

11.D1 Not possible

11.D5 Temper at between 400 and 450°C (750 and 840°F) for 1 h

11.D8 For about 10 h at 149°C, or between about 35 and 400 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; $\mathscr{E} = 2.5 \times 10^{-2}$ V/m

12.12 $\sigma = 0.096\ (\Omega\text{-m})^{-1}$

12.13 **(a)** $n = 1.25 \times 10^{29}$ m^{-3};

(b) 1.48 free electrons/atom

12.16 **(a)** $\rho_0 = 1.58 \times 10^{-8}$ Ω-m, $a = 6.5 \times 10^{-11}$ Ω-m/°C;
(b) $A = 1.12 \times 10^{-6}$ Ω-m;
(c) $\rho = 4.26 \times 10^{-8}$ Ω-m

12.18 $\sigma = 7.3 \times 10^{6}\ (\Omega\text{-m})^{-1}$

12.21 **(b)** for Si, 2.7×10^{-13}; for Ge, 5.6×10^{-10}

12.30 **(a)** $n = 8.9 \times 10^{21}\ \text{m}^{-3}$; **(b)** *p*-type extrinsic

12.33 $\mu_e = 0.50\ \text{m}^2/\text{V-s}$; $\mu_h = 0.02\ \text{m}^2/\text{V-s}$

12.38 $E_g = 1.46$ eV

12.39 **(b)** $\sigma = 3.8 \times 10^{-5}\ (\Omega\text{-m})^{-1}$

12.40 **(a)** $\sigma = 61.4\ (\Omega\text{-m})^{-1}$; **(b)** $n = p = 1.16 \times 10^{21}\ \text{m}^{-3}$

12.45* $B_z = 0.58$ tesla

12.52* $l = 1.6$ mm

12.56* $p_i = 2.26 \times 10^{-30}$ C-m

12.58* **(a)** $V = 17.3$ V; **(b)** $V = 86.5$ V;
(e) $P = 1.75 \times 10^{-7}\ \text{C/m}^2$

12.60* Fraction of ϵ_r due to $P_i = 0.67$

12.D2 $\sigma = 2.44 \times 10^{7}(\Omega\text{-m})^{-1}$

12.D3 Possible; 30 wt% $< C_{\text{Ni}} <$ 32.5 wt%

Chapter 13

13.5 $V_{\text{Gr}} = 11.1$ vol%

13.21* **(a)** $T = 2000$°C (3630°F)

13.23* **(a)** $W_L = 0.86$; **(c)** $W_L = 0.66$

13.24* **(a)** 1890°C (3435°F); between ~77 and 100 wt% Al_2O_3

Chapter 14

14.11 **(a)** 890–920°C (1635–1690°F)

14.12 **(b)** 790–815°C (1450–1500°F)

14.26 **(b)** $Q_{\text{vis}} = 362$ kJ/mol

14.43 **(a)** m(adipic acid) = 117.7 kg
(b) m(polyester) = 153.2 kg

14.D5 Maximum diameter = 75 mm (3 in.)

14.D7 Maximum diameter = 70 mm (2.75 in.)

Chapter 15

15.4 $k_{\text{max}} = 33.3$ W/m-K; $k_{\text{min}} = 29.7$ W/m-K

15.9 $\tau_c = 34.5$ MPa

15.12 Possible

15.14 $E_f = 70.4$ GPa (10.2×10^6 psi); $E_m = 2.79$ GPa (4.04×10^5 psi)

15.17 **(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) $\epsilon = 3.4 \times 10^{-3}$

15.19 $\sigma_{cl}^{*} = 633$ MPa (91,700 psi)

15.21 $\sigma_{cd}^{*} = 1340$ MPa (194,400 psi)

15.28 $E_{cl} = 69.1$ GPa (10.0×10^6 psi)

15.D1 Carbon (PAN standard-modulus) and aramid

15.D2 Not possible

Chapter 16

16.5 **(a)** $\Delta V = +0.031$ V;
(b) $Fe^{2+} + Cd \longrightarrow Fe + Cd^{2+}$

16.7 $[Pb^{2+}] = 2.5 \times 10^{-2}\ M$

16.13 $t = 10$ yr

16.16 CPR = 5.24 mpy

16.20 **(a)** $r = 8.0 \times 10^{-14}\ \text{mol/cm}^2\text{-s}$;
(b) $V_C = -0.019$ V

16.34 Sn: P-B ratio = 1.33; protective

16.36 **(a)** Parabolic kinetics; **(b)** $W = 1.51\ \text{mg/cm}^2$

Chapter 17

17.2 $T_f = 49$°C (120°F)

17.4 **(a)** $c_v = 139$ J/kg-K; **(b)** $c_v = 925$ J/kg-K

17.9 $\Delta l = -9.2$ mm (−0.36 in.)

17.14 $T_f = 129.5$°C

17.16 **(b)** $dQ/dt = 9.3 \times 10^8$ J/h

17.24 k(upper) = 26.4 W/m-K

17.28 **(a)** $\sigma = 150$ MPa (21,800 psi); compression

17.29 $T_f = 39$°C (102°F)

17.30 $\Delta d = 0.0251$ 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

18.6 **(a)** $\mu = 1.26 \times 10^{-6}$ H/m;
(b) $\chi_m = 6 \times 10^{-3}$

18.8 **(a)** $M_s = 1.45 \times 10^{6}$ A/m

18.16 4.6 Bohr magnetons/Mn^{2+} ion

18.24 $M_s = 1.69 \times 10^{6}$ A/m

18.27 **(b)** $\mu_i = 3.0 \times 10^{-3}$ H/m, $\mu_{ri} = 2400$;
(c) $\mu(\text{max}) \cong 9 \times 10^{-3}$ H/m

18.29 **(b)** **(i)** $\mu \cong 1.0 \times 10^{-2}$ H/m; **(iii)** $\chi_m \cong 7954$

18.32 **(a)** 2.5 K: 1.33×10^{4} A/m; **(b)** 5.96 K

Chapter 19

19.9 $v = 2.09 \times 10^{8}$ m/s

19.10 Silica: 0.53; soda-lime glass: 0.33

19.11 Fused silica: $\epsilon_r = 2.13$; polyethylene: $\epsilon_r = 2.28$

19.19 $I_T'/I_0' = 0.81$

19.21 $l = 67.3$ mm

19.30 $\Delta E = 1.78$ eV

Chapter 20

20.D2 Stiffness: $P = \dfrac{\sqrt{G}}{\rho}$

20.D3 Stiffness $P = \dfrac{\sqrt{E}}{\rho}$; strength: $P = \dfrac{\sigma_y^{2/3}}{\rho}$

20.D6 **(a)** $F = 21.5$ N (4.8 lb_f);
(b) $F = 53.6$ N (12.0 lb_f)