QUESTIONS AND PROBLEMS

Vacancies and Self-Interstitials

4.1 Calculate the fraction of atom sites that are vacant for copper at its melting temperature of 1084°C (1357 K). Assume an energy for vacancy formation of 0.90 eV/atom.

4.2 Calculate the number of vacancies per cubic meter in gold at 900°C. The energy for vacancy formation is 0.98 eV/atom. Furthermore, the density and atomic weight for Au are 18.63 g/cm^3 (at 900°C) and 196.9 g/mol, respectively.

4.3 Calculate the energy for vacancy formation in silver, given that the equilibrium number of vacancies at 800°C (1073 K) is 3.6×10^{23} m^{-3}. The atomic weight and density (at 800°C) for silver are, respectively, 107.9 g/mol and 9.5 g/cm^3.

Impurities in Solids

4.4 Below, atomic radius, crystal structure, electronegativity, and the most common valence are tabulated, for several elements; for those that are nonmetals, only atomic radii are indicated.

Element	*Atomic Radius (nm)*	*Crystal Structure*	*Electro-negativity*	*Valence*
Ni	0.1246	FCC	1.8	+2
C	0.071			
H	0.046			
O	0.060			
Ag	0.1445	FCC	1.9	+1
Al	0.1431	FCC	1.5	+3
Co	0.1253	HCP	1.8	+2
Cr	0.1249	BCC	1.6	+3
Fe	0.1241	BCC	1.8	+2
Pt	0.1387	FCC	2.2	+2
Zn	0.1332	HCP	1.6	+2

Which of these elements would you expect to form the following with nickel:

(a) A substitutional solid solution having complete solubility

(b) A substitutional solid solution of incomplete solubility

(c) An interstitial solid solution

4.5 For both FCC and BCC crystal structures, there are two different types of interstitial sites. In each case, one site is larger than the other, and is normally occupied by impurity atoms. For FCC, this larger one is located at the center of each edge of the unit cell; it is termed an octahedral interstitial site. On the other hand, with BCC the larger site type is found at $0\ \frac{1}{2}\ \frac{1}{4}$ positions—that is, lying on {100} faces, and situated midway between two unit cell edges on this face and one-quarter of the distance between the other two unit cell edges; it is termed a tetrahedral interstitial site. For both FCC and BCC crystal structures, compute the radius r of an impurity atom that will just fit into one of these sites in terms of the atomic radius R of the host atom.

Specification of Composition

4.6 Derive the following equations:

(a) Equation 4.7a

(b) Equation 4.9a

(c) Equation 4.10a

(d) Equation 4.11b

4.7 What is the composition, in atom percent, of an alloy that consists of 92.5 wt% Ag and 7.5 wt% Cu?

4.8 What is the composition, in weight percent, of an alloy that consists of 5 at% Cu and 95 at% Pt?

4.9 Calculate the composition, in weight percent, of an alloy that contains 105 kg of iron, 0.2 kg of carbon, and 1.0 kg of chromium.

4.10 What is the composition, in atom percent, of an alloy that contains 33 g copper and 47 g zinc?

4.11 What is the composition, in atom percent, of an alloy that contains 44.5 lb_m of silver, 83.7 lb_m of gold, and 5.3 lb_m of Cu?

4.12 What is the composition, in atom percent, of an alloy that consists of 5.5 wt% Pb and 94.5 wt% Sn?

4.13 Convert the atom percent composition in Problem 4.11 to weight percent.

4.14 Calculate the number of atoms per cubic meter in lead.

4.15 The concentration of silicon in an iron-silicon alloy is 0.25 wt%. What is the concentration in kilograms of silicon per cubic meter of alloy?

4.16 Determine the approximate density of a Ti-6Al-4V titanium alloy that has a composition of 90 wt% Ti, 6 wt% Al, and 4 wt% V.

4.17 Calculate the unit cell edge length for an 80 wt% Ag-20 wt% Pd alloy. All of the palladium is in solid solution, the crystal structure for this alloy is FCC, and the room-temperature density of Pd is 12.02 g/cm^3.

4.18 Some hypothetical alloy is composed of 25 wt% of metal A and 75 wt% of metal B. If the densities of metals A and B are 6.17 and 8.00 g/cm^3, respectively, whereas their respective atomic weights are 171.3 and 162.0 g/mol, determine whether the crystal structure for this alloy is simple cubic, face-centered cubic, or body-centered cubic. Assume a unit cell edge length of 0.332 nm.

4.19 For a solid solution consisting of two elements (designated as 1 and 2), sometimes it is desirable to determine the number of atoms per cubic centimeter of one element in a solid solution, N_1, given the concentration of that element specified in weight percent, C_1. This computation is possible using the following expression:

$$N_1 = \frac{N_A C_1}{\frac{C_1 A_1}{\rho_1} + \frac{A_1}{\rho_2}(100 - C_1)} \qquad (4.18)$$

where

N_A = Avogadro's number

ρ_1 and ρ_2 = densities of the two elements

A_1 = the atomic weight of element 1

Derive Equation 4.18 using Equation 4.2 and expressions contained in Section 4.4.

4.20 Molybdenum forms a substitutional solid solution with tungsten. Compute the number of molybdenum atoms per cubic centimeter for a molybdenum-tungsten alloy that contains 16.4 wt% Mo and 83.6 wt% W. The densities of pure molybdenum and tungsten are 10.22 and 19.30 g/cm^3, respectively.

4.21 Niobium forms a substitutional solid solution with vanadium. Compute the number of niobium atoms per cubic centimeter for a niobium-vanadium alloy that contains 24 wt% Nb and 76 wt% V. The densities of pure niobium and vanadium are 8.57 and 6.10 g/cm^3, respectively.

4.22 Sometimes it is desirable to be able to determine the weight percent of one element, C_1, that will produce a specified concentration in terms of the number of atoms per cubic centimeter, N_1, for an alloy composed of two types of atoms. This computation is possible using the following expression:

$$C_1 = \frac{100}{1 + \frac{N_A \rho_2}{N_1 A_1} - \frac{\rho_2}{\rho_1}} \qquad (4.19)$$

where

N_A = Avogadro's number

ρ_1 and ρ_2 = densities of the two elements

A_1 and A_2 = the atomic weights of the two elements

Derive Equation 4.19 using Equation 4.2 and expressions contained in Section 4.4.

4.23 Gold forms a substitutional solid solution with silver. Compute the weight percent of gold that must be added to silver to yield an alloy that contains 5.5×10^{21} Au atoms per cubic centimeter. The densities of pure Au and Ag are 19.32 and 10.49 g/cm^3, respectively.

4.24 Germanium forms a substitutional solid solution with silicon. Compute the weight percent of germanium that must be added to silicon to yield an alloy that contains 2.43×10^{21} Ge atoms per cubic centimeter. The densities of pure Ge and Si are 5.32 and 2.33 g/cm^3, respectively.

4.25 Iron and vanadium both have the BCC crystal structure, and V forms a substitutional solid solution for concentrations up to approximately 20 wt% V at room temperature. Compute the unit cell edge length for a 90 wt% Fe–10 wt% V alloy.

Dislocations—Linear Defects

4.26 Cite the relative Burgers vector–dislocation line orientations for edge, screw, and mixed dislocations.

Interfacial Defects

4.27 For an FCC single crystal, would you expect the surface energy for a (100) plane to be greater or less than that for a (111) plane? Why? (*Note:* You may want to consult the solution to Problem 3.53 at the end of Chapter 3.)

4.28 For a BCC single crystal, would you expect the surface energy for a (100) plane to be greater or less than that for a (110) plane? Why? (*Note:* You may want to consult the solution to Problem 3.54 at the end of Chapter 3.)

4.29 **(a)** For a given material, would you expect the surface energy to be greater than, the same as, or less than the grain boundary energy? Why?

(b) The grain boundary energy of a small-angle grain boundary is less than for a high-angle one. Why is this so?

4.30 **(a)** Briefly describe a twin and a twin boundary.

(b) Cite the difference between mechanical and annealing twins.

4.31 For each of the following stacking sequences found in FCC metals, cite the type of planar defect that exists:

(a) . . . *A B C A B C B A C B A* . . .

(b) . . . *A B C A B C B C A B C* . . .

Now, copy the stacking sequences and indicate the position(s) of planar defect(s) with a vertical dashed line.

Grain Size Determination

4.32 **(a)** Using the intercept method, determine the average grain size, in millimeters, of the specimen whose microstructure is shown in Figure 4.14(*b*); use at least seven straight-line segments.

(b) Estimate the ASTM grain size number for this material.

4.33 **(a)** Employing the intercept technique, determine the average grain size for the steel specimen whose microstructure is shown in Figure 9.25(*a*); use at least seven straight-line segments.

(b) Estimate the ASTM grain size number for this material.

4.34 For an ASTM grain size of 6, approximately how many grains would there be per square inch at

(a) a magnification of 100, and

(b) without any magnification?

4.35 Determine the ASTM grain size number if 30 grains per square inch are measured at a magnification of 250.

4.36 Determine the ASTM grain size number if 25 grains per square inch are measured at a magnification of 75.

DESIGN PROBLEMS

Specification of Composition

4.D1 Aluminum–lithium alloys have been developed by the aircraft industry to reduce the weight and improve the performance of its aircraft. A commercial aircraft skin material having a density of 2.47 g/cm^3 is desired. Compute the concentration of Li (in wt%) that is required.

4.D2 Copper and platinum both have the FCC crystal structure, and Cu forms a substitutional solid solution for concentrations up to approximately 6 wt% Cu at room temperature. Determine the concentration in weight percent of Cu that must be added to platinum to yield a unit cell edge length of 0.390 nm.