Chapter 5

Imperfections in Solids

QUESTIONS AND PROBLEMS

Point Defects in Metals

W5.1 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/cm³ (at 900°C) and 196.9 g/mol, respectively.

Point Defects in Ceramics

W5.2 Would you expect Frenkel defects for anions to exist in ionic ceramics in relatively large concentrations? Why or why not?

W5.3 Calculate the number of Frenkel defects per cubic meter in silver chloride at 350°C. The energy for defect formation is 1.1 eV, while the density for AgCl is 5.50 g/cm³ (at 350°C).

W5.4 In your own words, briefly define the term “stoichiometric.”

W5.5 If cupric oxide (CuO) is exposed to reducing atmospheres at elevated temperatures, some of the Cu²⁺ ions will become Cu⁺.

(a) Under these conditions, name one crystalline defect that you would expect to form in order to maintain charge neutrality.

(b) How many Cu⁺ ions are required for the creation of each defect?

(c) How would you express the chemical formula for this nonstoichiometric material?
Impurities in Solids

W5.6 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

W5.7 Derive the following equations:

(a) Equation 5.10a

(b) Equation 5.12a

(c) Equation 5.13a

(d) Equation 5.14b

W5.8 Generate a spreadsheet that allows the user to convert the concentration of one element of a two-element metal alloy from weight percent to atom percent.

W5.9 Generate a spreadsheet that allows the user to convert the concentration of one element of a two-element metal alloy from atom percent to weight percent.

W5.10 What is the composition, in weight percent, of an alloy that consists of 5 at% Cu and 95 at% Pt?
W5.11 What is the composition, in atom percent, of an alloy that contains 33 g copper and 47 g zinc?

W5.12 What is the composition, in atom percent, of an alloy that consists of 5.5 wt% Pb and 94.5 wt% Sn?

W5.13 Calculate the number of atoms per cubic meter in lead.

W5.14 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?

W5.15 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/cm³.

W5.16 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:

\[
N_1 = \frac{N_A C_1}{\frac{C_1 A_1}{\rho_1} + \frac{A_1}{\rho_2}(100 - C_1)}
\]

(5.21)

where

\( N_A = \) Avogadro’s number
\( \rho_1 \) and \( \rho_2 \) = densities of the two elements
\( A_1 = \) the atomic weight of element 1

Derive Equation 5.21 using Equation 5.2 and expressions contained in Section 5.6.

W5.17 Generate a spreadsheet that allows the user to convert the concentration of one element of a two-element metal alloy from weight percent to number of atoms per cubic centimeter.
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/cm³, respectively.

Generate a spreadsheet that allows the user to convert the concentration of one element of a two-element metal alloy from number of atoms per cubic centimeter to weight percent.

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 $5.5 \times 10^{21}$ Au atoms per cubic centimeter. The densities of pure Au and Ag are 19.32 and 10.49 g/cm³, respectively.

Dislocations—Linear Defects

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

Interfacial Defects

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 3.44 at the end of Chapter 3.)

Briefly describe a twin and a twin boundary.

Cite the difference between mechanical and annealing twins.

Grain Size Determination

Using the intercept method, determine the average grain size, in millimeters, of the specimen whose microstructure is shown in Figure 5.19(b); use at least seven straight-line segments.

Estimate the ASTM grain size number for this material.
**W5.25** Determine the ASTM grain size number if 30 grains per square inch are measured at a magnification of 250.

**DESIGN PROBLEM**

*Specification of Composition*

**W5.D1** 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.