lattice parameter of 0.35167 nm, in the [100], [110], and [111] directions. Which of these directions is close packed?

**3-31** Determine the repeat distance, linear density, and packing fraction for BCC lithium, which has a lattice parameter of 0.35089 nm, in the [100], [110], and [111] directions. Which of these directions is close packed?

**3-32** Determine the planar density and packing fraction for FCC nickel in the (100), (110), and (111) planes. Which, if any, of these planes is close-packed?

**3-33** Determine the planar density and packing fraction for BCC lithium in the (100), (110), and (111) planes. Which, if any, of these planes is close packed?

**3-34** Suppose that FCC rhodium is produced as a 1-mm thick sheet, with the (111) plane parallel to the surface of the sheet. How many (111) interplanar spacings $d_{111}$ thick is the sheet? See Appendix A for necessary data.

**3-35** What are the Miller indices of the plane shown in the Figure 3-35?

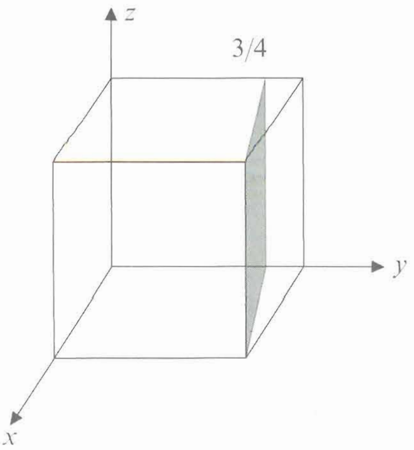


**Figure 3-35** Plane in a cubic unit cell for Problem 3-35.

## Section 3-6 Interstitial Sites

**3-36** Determine the minimum radius of an atom that will just fit into:

**(a)** the tetrahedral interstitial site in FCC nickel; and

**(b)** the octahedral interstitial site in BCC lithium.

**3-37** What are the coordination numbers for octahedral and tetrahedral sites?

## Section 3-7 Crystal Structures of Ionic Materials

**3-38** What is meant by coordination polyhedra?

**3-39** Is the radius of an atom or ion fixed? Explain.

**3-40** Explain why we consider anions to form the close-packed structures and cations to enter the interstitial sites?

**3-41** What is the coordination number for the titanium ion in the perovskite crystal structure?

**3-42** What is the radius of an atom that will just fit into the octahedral site in FCC copper without disturbing the crystal structure?

**3-43** Would you expect NiO to have the cesium chloride, sodium chloride, or zinc blende structure? Based on your answer, determine

**(a)** the lattice parameter;
**(b)** the density; and
**(c)** the packing factor.

**3-44** Would you expect $UO_2$ to have the sodium chloride, zinc blende, or fluorite structure? Based on your answer, determine

**(a)** the lattice parameter;
**(b)** the density; and
**(c)** the packing factor.

**3-45** Would you expect BeO to have the sodium chloride, zinc blende, or fluorite structure? Based on your answer, determine

**(a)** the lattice parameter;
**(b)** the density; and
**(c)** the packing factor.

**3-46** Would you expect CsBr to have the sodium chloride, zinc blende, fluorite, or cesium chloride structure? Based on your answer, determine

**(a)** the lattice parameter;
**(b)** the density; and
**(d)** the packing factor.

**3-47** Recently, gallium nitride (GaN) material has been used to make light-emitting diodes (LEDs) that emit a blue or ultraviolet light. Such LEDs are used in DVD players and other electronic devices. This material has two crystal structures. One form is the zinc-blende crystal structure (lattice constant $a_0 = 0.450$ nm), which has a density of 6.1 g/cm$^3$ at 300 K. Calculate the number of Ga and N atoms per unit cell of this form of GaN.

**3-48** The theoretical density of germanium (Ge) is 5.323 g/cm$^3$ at 300 K. Germanium has the same crystal structure as diamond. What is the lattice constant of germanium at 300 K?

**3-49** The lattice constant of zinc selenide (ZnSe) is 0.567 nm. The crystal structure is that of zinc blende. Show that the theoretical density for ZnSe should be 5.26 g/cm$^3$.

## Section 3-8 Covalent Structures

**3-50** Calculate the theoretical density of $\alpha$-Sn. Assume diamond cubic structure and obtain the radius information from Appendix B.

**3-51** What are the different polymorphs of carbon?

## Section 3-9 Diffraction Techniques for Crystal Structure Analysis

**3-52** Explain the principle of XRD.

**3-53** A sample of cubic SiC was analyzed using XRD. It was found that the (111) peak was located at $2\theta$ of 16°. The wavelength ($\lambda$) of the x-ray radiation used in this experiment was 0.6975 Å. Show that the lattice constant ($a_0$) of this form of SiC is 4.0867 Å.

**3-54** For the cubic phase of $BaTiO_3$, a diffraction peak is seen at a value of $2\theta = 45°$. What crystallographic plane does this peak correspond to if the XRD analysis was done using Cu K-$\alpha$ x-rays ($\lambda = 1.54$ Å)?

**3-55** The lattice constant of $BaTiO_3$, a ceramic material used to make capacitors, for the cubic crystal structure is 4 Å. This material is analyzed using copper K-$\alpha$ radiation of wavelength 1.54 Å. What will be the value of $2\theta$ at which the (200) reflection from the diffracted x-rays can be expected?

# Design Problems

**3-56** An oxygen sensor is to be made to measure dissolved oxygen in a large vessel containing molten steel. What kind of material would you choose for this application? Explain.

**3-57** You would like to sort iron specimens, some of which are FCC and others BCC. Design an x-ray diffraction method by which this can be accomplished.

(b) the total number of vacancies in a cubic centimeter of Pd.

**4-4** The density of a sample of HCP beryllium is 1.844 g/cm$^3$ and the lattice parameters are $a_0 =$ 0.22858 nm and $c_0 =$ 0.35842 nm. Calculate

(a) the fraction of the lattice points that contain vacancies; and
(b) the total number of vacancies in a cubic centimeter.

**4-5** BCC lithium has a lattice parameter of $3.5089 \times 10^{-8}$ cm and contains one vacancy per 200 unit cells. Calculate

(a) the number of vacancies per cubic centimeter; and
(b) the density of Li.

**4-6** FCC lead (Pb) has a lattice parameter of 0.4949 nm and contains one vacancy per 500 Pb atoms. Calculate

(a) the density; and
(b) the number of vacancies per gram of Pb.

**4-7** A niobium alloy is produced by introducing tungsten substitutional atoms in the BCC structure; eventually an alloy is produced that has a lattice parameter of 0.32554 nm and a density of 11.95 g/cm$^3$. Calculate the fraction of the atoms in the alloy that are tungsten.

**4-8** Tin atoms are introduced into a FCC copper crystal, producing an alloy with a lattice parameter of $3.7589 \times 10^{-8}$ cm and a density of 8.772 g/cm$^3$. Calculate the atomic percentage of tin present in the alloy.

**4-9** We replace 7.5 atomic percent of the chromium atoms in its BCC crystal with tantalum. X-ray diffraction shows that the lattice parameter is 0.29158 nm. Calculate the density of the alloy.

**4-10** Suppose we introduce one carbon atom for every 100 iron atoms in an interstitial position in BCC iron, giving a lattice parameter of 0.2867 nm. For the Fe-C alloy, find the density and the packing factor.

**4-11** The density of BCC iron is 7.882 g/cm$^3$ and the lattice parameter is 0.2866 nm when hydrogen atoms are introduced at interstitial positions. Calculate

(a) the atomic fraction of hydrogen atoms; and
(b) number of unit cells on average that contain hydrogen atoms.

## Section 4-2 Other Point Defects

**4-12** Suppose one Schottky defect is present in every tenth unit cell of MgO. MgO has the sodium chloride crystal structure and a lattice parameter of 0.396 nm. Calculate

(a) the number of anion vacancies per cm$^3$; and
(b) the density of the ceramic.

**4-13** ZnS has the zinc blende structure. If the density is 3.02 g/cm$^3$ and the lattice parameter is 0.59583 nm, determine the number of Schottky defects

(a) per unit cell; and
(b) per cubic centimeter.

## Section 4-3 Dislocations

**4-14** What are the Miller indices of the slip directions:

(a) on the (111) plane in an FCC unit cell?
(b) on the (011) plane in a BCC unit cell?

**4-15** What are the Miller indices of the slip planes in FCC unit cells that include the [101] slip direction?

**4-16** What are the Miller indices of the {110} slip planes in BCC unit cells that include the [111] slip direction?

**4-17** Calculate the length of the Burgers vector in the following materials:

(a) BCC niobium;
(b) FCC silver; and
(c) diamond cubic silicon.

**4-18** Determine the interplanar spacing and the length of the Burgers vector for slip on the expected slip systems in FCC aluminum. Repeat, assuming that the slip system is a (110) plane and a $[1\bar{1}1]$ direction. What is the ratio between the shear stresses required for slip for the two systems? Assume that k = 2 in Equation 4-2.

**4-19** Determine the interplanar spacing and the length of the Burgers vector for slip on the $(110)/[1\bar{1}1]$ slip system in BCC tantalum. Repeat, assuming that the slip system is a $(111)/[1\bar{1}0]$ system. What is the ratio between the shear stresses required for slip for the two systems? Assume that k = 2 in Equation 4-2.

## Section 4-4 Significance of Dislocations

**4-20** How many grams of aluminum, with a dislocation density of $10^{10}$ cm/cm$^3$, are required to give a total dislocation length that would stretch from New York City to Los Angeles (3000 miles)?

**4-21** Compare the $c/a$ ratios for the following HCP metals, determine the likely slip processes in each, and estimate the approximate critical resolved shear stress. Explain. (See data in Appendix A.)

(a) zinc (b) magnesium (c) titanium
(d) zirconium (e) rhenium (f) beryllium