CHAPTER 13 IN REVIEW

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CONCEPTS

Crystalline Structures (13.2–13.4)
- X-ray crystallography uses the diffraction pattern of X-rays to determine the crystal structure of solids.
- The crystal lattice is represented by a unit cell, a structure that reproduces the entire lattice when repeated in all three dimensions.
- Three basic cubic unit cells are the simple cubic, the body-centered cubic, and the face-centered cubic.
- Some crystal lattices can also be depicted as closest-packed structures, including the hexagonal closest-packing structure (not cubic) and the cubic closest-packing structure (which has a face-centered cubic unit cell).
- The basic types of crystal solids are molecular, ionic, and atomic solids. We divide atomic solids into three different types: nonbonded, metallic, and network covalent.

Ionic Solids (13.5)
- Unit cells in the structures of ionic solids are charge neutral. The unit cells must also accommodate the difference in size between the anion and cation.
- Common unit cells for ionic compounds include the sodium chloride unit cell, the zinc blende unit cell, and the calcium fluoride unit cell.

Network Covalent Atomic Solids (13.6)
- Network covalent solids are composed of extended arrays of atoms held together by covalent bonds.
- Well known network covalent solids include diamond, graphite, graphene, and silica.

Ceramics, Cement, and Glass (13.7)
- Ceramics are inorganic nonmetallic solids that are prepared from powders typically mixed with water, formed into the desired shape, and then heated. Ceramics are usually hard, strong, nonconductive, and brittle.
- Cement is a powdered mixture consisting mostly of limestone ($CaCO_3$) and silica (SiO_2), with smaller amounts of other substances. When cement is mixed with water, it reacts to form a hard, stone-like substance.
- Glass is primarily amorphous SiO_2 or silica. Silicate glass is transparent, impervious to water, and an outstanding material for making windows and drinking vessels.

Semiconductors and Band Theory (13.8)
- Band theory is a model for bonding in solids in which the atomic orbitals of the atoms are combined and delocalized over the entire crystal solid. In band theory, solids form energy bands that are occupied by electrons.
- In metals, the valence band (composed of bonding molecular orbitals) is continuous with the conduction band (composed of antibonding molecular orbitals).
- Semiconductors have a small energy gap—called the band gap—between the valence band and the conduction band.
- Semiconductors can be doped with small amounts of impurities to modify their conductivity.

Polymers and Plastics (13.9)
- Polymers are long, chainlike molecules that consist of repeating units called monomers. They can be natural or synthetic.
- Polyethylene is an addition polymer, a polymer formed without the elimination of any atoms.
- Condensation polymers, such as nylon, are formed by the elimination of small groups of atoms.

EQUATIONS AND RELATIONSHIPS

Bragg's Law: Relationship between Light Wavelength (λ), Angle of Reflection (θ), and Distance (d) between the Atomic Layers (**13.2**) $n\lambda = 2d \sin \theta$ (n = integer)

LEARNING OUTCOMES

Chapter Objectives	Assessment		
Perform X-ray diffraction calculations using Bragg's law (**13.2**)	Example 13.1	**For Practice** 13.1	**Exercises** 27–28
Analyze crystalline solids in terms of unit cell type, coordination number, and packing efficiency (**13.3**)	Example 13.2	**For Practice** 13.2	**Exercises** 29–32
Relate unit cell volume, edge length, and atomic radius (**13.3**)	Example 13.3	**For Practice** 13.3	**Exercises** 33–34
Solve problems involving the density of crystalline solids (**13.3**)	Example 13.4	**For Practice** 13.4	**Exercises** 35–38
Classify crystalline solids by type (molecular, ionic, or atomic) (**13.4**)	Example 13.5	**For Practice** 13.5	**Exercises** 39–40
Predict relative melting points of crystalline solids (**13.4**)	**Exercises** 41–44		
Analyze atomic solids in terms of structure and properties (**13.6**)	**Exercises** 45–52		
Describe the properties of silicates and silicate-based materials (**13.7**)	**Exercises** 53–58		
Analyze semiconductors in terms of band theory and type (n or p) (**13.8**)	**Exercises** 59–68		
Analyze polymers and plastics in terms of structure and properties (**13.9**)	**Exercises** 69–76		

EXERCISES

Mastering Chemistry provides end-of-chapter exercises, feedback-enriched tutorial problems, animations, and interactive activities to encourage problem-solving practice and deeper understanding of key concepts and topics.

REVIEW QUESTIONS

1. What is graphene? Why is graphene unique?

2. Explain the basic principles involved in X-ray crystallography. Include Bragg's law in your explanation.

3. What is a crystalline lattice? How is the lattice represented with the unit cell?

4. Make a drawing of each unit cell: simple cubic, body-centered cubic, and face-centered cubic.

5. For each of the cubic cells in the previous problem, give the coordination number, edge length in terms of r, and number of atoms per unit cell.

6. What is the difference between hexagonal closest packing and cubic closest packing? What are the unit cells for each of these structures?

7. What are the three basic types of solids and the composite units of each? What types of forces hold each type of solid together?

8. What are the three categories of atomic solids?

9. What kinds of forces hold each of the three basic categories of atomic solids together?

10. What is a polymorph?

11. In an ionic compound, how are the relative sizes of the cation and anion related to the coordination number of the crystal structure?

12. Show how the cesium chloride, sodium chloride, and zinc blende unit cells each contain a cation-to-anion ratio of 1:1.

13. Show how the fluorite structure accommodates a cation-to-anion ratio of 1:2.

14. Name and describe the different allotropes of carbon.

15. What are silicates? What is quartz?

16. What is the definition of a *ceramic*? What are the three categories of ceramics?

17. List the major and minor components of Portland cement. What is the difference between the hardening process of Portland cement and the hardening process of clays?

18. How is concrete made from Portland cement? What advantage does concrete have for building compared to the construction methods that predated the development of concrete?

19. Describe what happens on the molecular level when silica is heated and then cooled to make glass.

20. Describe the difference between vitreous silica and soda-lime glass. What are some advantages and disadvantages of each of these types of glass?

21. In band theory of bonding for solids, what is a *band*? What is the difference between the *valence band* and the *conduction band*?

22. In band theory of bonding for solids, what is a band gap? How does the band gap differ in metals, semiconductors, and insulators?

23. Explain how doping can increase the conductivity of a semiconductor. What is the difference between an n-type semiconductor and a p-type semiconductor?

24. What is the trend in the size of the band gap as you move down the column of the group 4A elements?

25. What is a polymer? What is the difference between a polymer and a copolymer?

26. How do an addition polymer and a condensation polymer differ from each other?

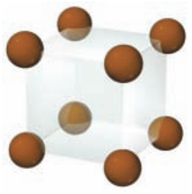
PROBLEMS BY TOPIC

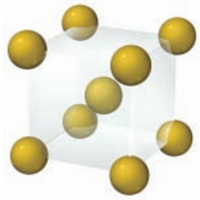
Types of Solids and Their Structures

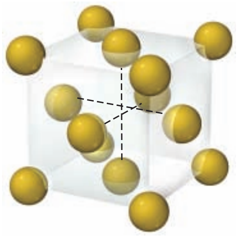
27. An X-ray beam with $\lambda = 154$ pm incident on the surface of a crystal produced a maximum reflection at an angle of $\theta = 28.3°$. Assuming $n = 1$, calculate the separation between layers of atoms in the crystal.
MISSED THIS? *Read Section 13.2*

28. An X-ray beam of unknown wavelength is diffracted from a NaCl surface. If the interplanar distance in the crystal is 286 pm, and the angle of maximum reflection is found to be 7.23°, what is the wavelength of the X-ray beam? (Assume $n = 1$.)

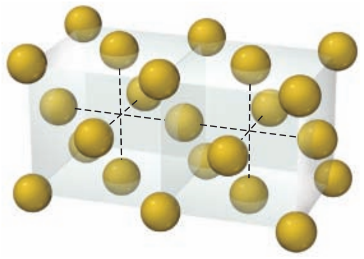
29. Determine the number of atoms per unit cell for each metal.
MISSED THIS? *Read Section 13.3; Watch KCV 13.3*

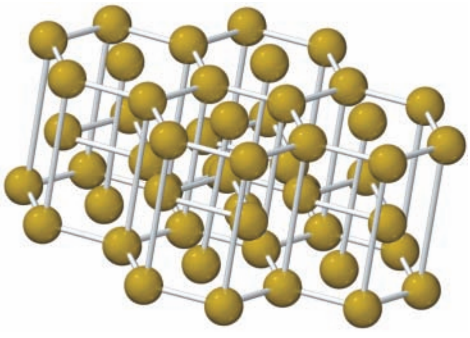

(a) Polonium

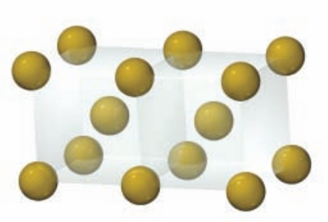

(b) Tungsten


(c) Nickel

30. Determine the coordination number for each structure.


(a) Gold


(b) Ruthenium


(c) Chromium

31. Calculate the packing efficiency of the body-centered cubic unit cell. Show your work.
MISSED THIS? *Read Section 13.3; Watch KCV 13.3*

32. Calculate the packing efficiency of the face-centered cubic unit cell. Show your work.

33. Platinum crystallizes with the face-centered cubic unit cell. The radius of a platinum atom is 139 pm. Calculate the edge length of the unit cell and the density of platinum in g/cm^3.
MISSED THIS? *Read Section 13.3; Watch KCV 13.3, IWE 13.3, 13.4*

34. Molybdenum crystallizes with the body-centered unit cell. The radius of a molybdenum atom is 136 pm. Calculate the edge length of the unit cell and the density of molybdenum.

35. Rhodium has a density of 12.41 g/cm^3 and crystallizes with the face-centered cubic unit cell. Calculate the radius of a rhodium atom. **MISSED THIS?** *Read Section 13.3; Watch KCV 13.3, IWE 13.3, 13.4*

36. Barium has a density of 3.59 g/cm^3 and crystallizes with the body-centered cubic unit cell. Calculate the radius of a barium atom.

37. Polonium crystallizes with a simple cubic structure. It has a density of 9.3 g/cm^3, a radius of 167 pm, and a molar mass of 209 g/mol. Use these data to calculate Avogadro's number (the number of atoms in one mole).
MISSED THIS? *Read Section 13.3; Watch KCV 13.3, IWE 13.4*

38. Palladium crystallizes with a face-centered cubic structure. It has a density of 12.0 g/cm^3, a radius of 138 pm, and a molar mass of 106.42 g/mol. Use these data to calculate Avogadro's number.

39. Identify each solid as molecular, ionic, or atomic.
MISSED THIS? *Read Section 13.4*

a. $Ar(s)$
b. $H_2O(s)$
c. $K_2O(s)$
d. $Fe(s)$

40. Identify each solid as molecular, ionic, or atomic.

a. $CaCl_2(s)$
b. $CO_2(s)$
c. $Ni(s)$
d. $I_2(s)$

41. Which solid has the highest melting point? Why?

$Ar(s)$, $CCl_4(s)$, $LiCl(s)$, $CH_3OH(s)$

MISSED THIS? *Read Section 13.4*

42. Which solid has the highest melting point? Why?

$C(s, \text{diamond})$, $Kr(s)$, $NaCl(s)$, $H_2O(s)$

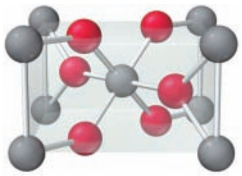
43. Which solid in each pair has the higher melting point and why?
MISSED THIS? *Read Section 13.4*

a. $TiO_2(s)$ or $HOOH(s)$
b. $CCl_4(s)$ or $SiCl_4(s)$
c. $Kr(s)$ or $Xe(s)$
d. $NaCl(s)$ or $CaO(s)$

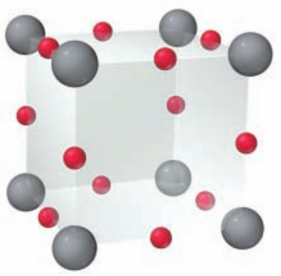
44. Which solid in each pair has the higher melting point and why?

a. $Fe(s)$ or $CCl_4(s)$
b. $KCl(s)$ or $HCl(s)$
c. $Ti(s)$ or $Ne(s)$
d. $H_2O(s)$ or $H_2S(s)$

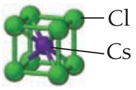
45. An oxide of titanium crystallizes with the unit cell shown here (titanium = gray; oxygen = red). What is the formula of the oxide? **MISSED THIS?** *Read Section 13.5; Watch KCV 13.5*



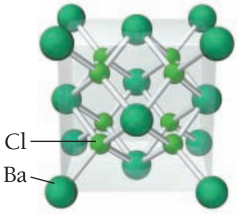
46. An oxide of rhenium crystallizes with the unit cell shown here (rhenium = gray; oxygen = red). What is the formula of the oxide?



47. The unit cells for cesium chloride and barium chloride are shown here. Show that the ratio of cations to anions in each unit cell corresponds to the ratio of cations to anions in the formula of each compound.
MISSED THIS? *Read Section 13.5; Watch KCV 13.3*

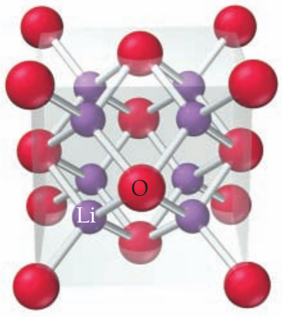


Cesium chloride

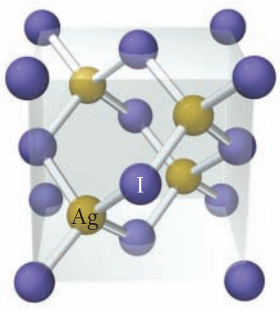


Barium chloride

48. The unit cells for lithium oxide and silver iodide are shown here. Show that the ratio of cations to anions in each unit cell corresponds to the ratio of cations to anions in the formula of each compound.



Lithium oxide



Silver iodide

49. Identify the structure of each of the two unit cells shown in Problem 47 as the rock salt structure, zinc blende structure, fluorite structure, antifluorite structure, or none of these.
MISSED THIS? *Read Section 13.5*

50. Identify the structure of each of the two unit cells shown in Problem 48 as the rock salt structure, zinc blende structure, fluorite structure, antifluorite structure, or none of these.

51. Consider the rock salt structure in Figure 13.15. What type of structure would result if all the anions were somehow removed, leaving only cations?
MISSED THIS? *Read Section 13.5; Watch KCV 13.3*

52. Consider the zinc blende structure in Figure 13.16. What type of structure would result if the remaining tetrahedral sites in the unit cell were also filled with cations?

Ceramics, Cement, and Glass

53. Classify each of the following as a component of a silicate ceramic, an oxide ceramic, or a nonoxide ceramic.
MISSED THIS? *Read Section 13.7*

a. B_4C
b. Mg_2SiO_4
c. $MoSi_2$

54. Classify each of the following as a component of a silicate ceramic, an oxide ceramic, or a nonoxide ceramic.

a. TiB_2
b. ZrO_2
c. $NaAlSi_3O_8$

55. What are the name and formula of the compound commonly used in the manufacture of glass to reduce its tendency to crack or shatter under thermal shock?
MISSED THIS? *Read Section 13.7*

56. What are the name and formula of the compound commonly used in the manufacture of glass to increase the index of refraction?

57. One of the key components in the manufacture of Portland cement is Ca_3SiO_5, a compound that is obtained by firing the reactants in a kiln at 1400–1500 °C. Assign an oxidation state to each element in this compound.
MISSED THIS? *Read Section 5.9, 13.7; Watch KCV 5.13*

58. Replacement of aluminum ions in kaolinite with magnesium ions yields a compound with the formula $Mg_3Si_2O_5(OH)_4$. Assign an oxidation state to each element in this compound.

Semiconductors and Band Theory

59. Which solid would you expect to have little or no band gap?
MISSED THIS? *Read Section 13.8*

a. Zn(*s*)
b. Si(*s*)
c. As(*s*)

60. Which solid would you expect to have the largest band gap?

a. As(*s*)
b. Sb(*s*)
c. Bi(*s*)

61. How many molecular orbitals are present in the conduction band of a lithium crystal with a mass of 11.2 g?
MISSED THIS? *Read Section 13.8*

62. How many molecular orbitals are present in the valence band of a sodium crystal with a mass of 5.45 g?

63. A substance has a band gap of 6.9 eV at 273 K. Is this substance best classified as an insulator, a semiconductor, or a metal?
MISSED THIS? *Read Section 13.8*

64. A substance has a band gap of 0.85 eV at 273 K. Is this substance best classified as an insulator, a semiconductor, or a metal?

65. Indicate if each solid forms an n-type or a p-type semiconductor. **MISSED THIS?** *Read Section 13.8*

a. germanium doped with gallium
b. silicon doped with arsenic

66. Indicate if each solid forms an n-type or a p-type semiconductor.

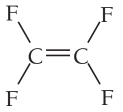
a. silicon doped with gallium
b. germanium doped with antimony

67. Does a photon of red light with a frequency of 4.29×10^{14} Hz have sufficient energy to promote an electron from the valence band to the conduction band in a sample of silicon (the band gap in silicon is 1.11 eV)? **MISSED THIS?** *Read Section 13.8*

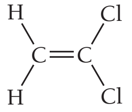
68. Which wavelength of light (in nm) is emitted if an electron moves from the conduction band to the valence band in a sample of diamond (diamond has a band gap of 5.5 eV)?

Polymers

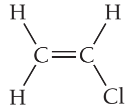
69. Teflon is an addition polymer formed from the monomer shown here. Draw the structure of the polymer. **MISSED THIS?** *Read Section 13.9*



70. Saran, the polymer used to make Saran Wrap, is an addition polymer formed from two monomers—vinylidene chloride and vinyl chloride. Draw the structure of the polymer. (*Hint:* The monomers alternate.)

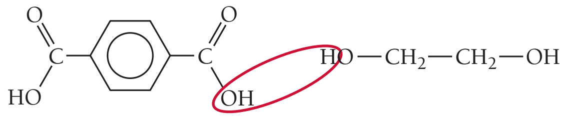


Vinylidene chloride



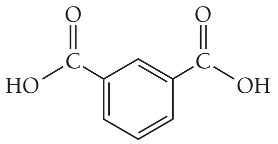
Vinyl chloride

71. One kind of polyester is a condensation copolymer formed from terephthalic acid and ethylene glycol. Draw the structure of the dimer. [*Hint:* Water (circled) is eliminated when the bond between the monomers forms.] **MISSED THIS?** *Read Section 13.9*

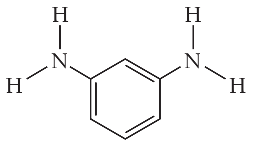


Terephthalic acid Ethylene glycol

72. Nomex, a condensation copolymer used by firefighters because of its flame-resistant properties, forms from isophthalic acid and *m*-aminoaniline. Draw the structure of the dimer. (*Hint:* Water is eliminated when the bond between the monomers forms.)

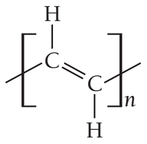


Isophthalic acid

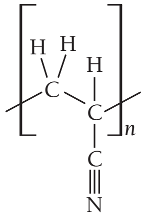


m-Aminoaniline

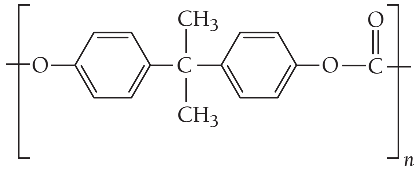
73. Polyacetylene is an addition polymer with the structure shown here. Draw the structure of the monomer. **MISSED THIS?** *Read Section 13.9*



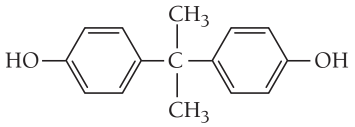
74. Polyacrylonitrile (PAN) is an addition polymer with the structure shown here. Draw the structure of the monomer.



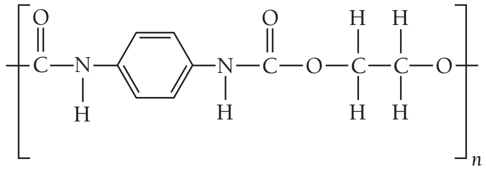
75. The polycarbonate Lexan is a condensation polymer and has the structure shown here: **MISSED THIS?** *Read Section 13.9*



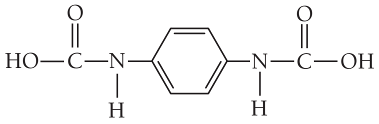
Assuming this polymer was formed from the monomer shown here plus another monomer, provide a possible structure for the other monomer that would be required to form Lexan.



76. Consider the condensation polymer with the structure shown here:



Assuming this polymer was formed from the monomer shown here plus another monomer, provide the structure of the other monomer that would be required to form this polymer.

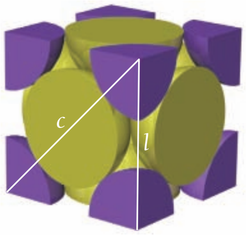


CUMULATIVE PROBLEMS

77. Silver iodide crystallizes in the zinc blende structure. The separation between nearest-neighbor cations and anions is approximately 325 pm, and the melting point is 558 °C. Cesium chloride, by contrast, crystallizes in the structure shown in Figure 13.14. Even though the separation between nearest-neighbor cations and anions is greater (348 pm), the melting point of cesium chloride is higher (645 °C). Explain.

78. Copper iodide crystallizes in the zinc blende structure. The separation between nearest-neighbor cations and anions is approximately 311 pm, and the melting point is 606 °C. Potassium chloride, by contrast, crystallizes in the rock salt structure. Even though the separation between nearest-neighbor cations and anions is greater (319 pm), the melting point of potassium chloride is higher (776 °C). Explain.

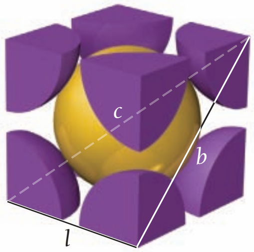
79. Consider the face-centered cubic structure shown here:



a. What is the length of the line (labeled c) that runs diagonally across one of the faces of the cube in terms of r (the atomic radius)?

b. Use the answer to part a and the Pythagorean theorem to derive the expression for the edge length (l) in terms of r.

80. Consider the body-centered cubic structure shown here:



a. What is the length of the line (labeled c) that runs from one corner of the cube diagonally through the center of the cube to the other corner in terms of r (the atomic radius)?

b. Use the Pythagorean theorem to derive an expression for the length of the line (labeled b) that runs diagonally across one of the faces of the cube in terms of the edge length (l).

c. Use the answer to parts a and b along with the Pythagorean theorem to derive the expression for the edge length (l) in terms of r.

81. The volume of a unit cell of diamond is 0.0454 nm^3, and the density of diamond is 3.52 g/cm^3. Find the number of carbon atoms in a unit cell of diamond.

82. The density of an unknown metal is 12.3 g/cm^3, and its atomic radius is 0.134 nm. It has a face-centered cubic lattice. Find the atomic mass of this metal.

83. An unknown metal is found to have a density of 7.8748 g/cm^3 and to crystallize in a body-centered cubic lattice. The edge of the unit cell is 0.28664 nm. Calculate the atomic mass of the metal.

84. When spheres of radius r are packed in a body-centered cubic arrangement, they occupy 68.0% of the available volume. Use the fraction of occupied volume to calculate the value of a, the length of the edge of the cube, in terms of r.

85. Potassium chloride crystallizes in the rock salt structure. Estimate the density of potassium chloride using the ionic radii provided in Chapter 9.

86. Calculate the fraction of empty space in cubic closest packing to five significant figures.

87. A tetrahedral site in a closest-packed lattice is formed by four spheres at the corners of a regular tetrahedron. This is equivalent to placing the spheres at alternate corners of a cube. In such a closest-packed arrangement the spheres are in contact, and if the spheres have a radius r, the diagonal of the face of the cube is $2r$. The tetrahedral hole is inside the middle of the cube. Find the length of the body diagonal of this cube and then find the radius of the tetrahedral hole.

88. X-ray diffractometers often use metals that have had their core electrons excited as a source of X-rays. Consider the $2p \longrightarrow 1s$ transition for copper, which is called the $K\alpha$ transition. Calculate the wavelength of X-rays (in Å) given off by the $K\alpha$ transition if the energy given off by a mole of copper atoms is 7.77×10^5 kJ. ($1\ \text{Å} = 10^{-10}$ m)

89. Why is it necessary to use the $K\alpha$ transition ($2p \longrightarrow 1s$) in copper (see Problem 88) to generate X-rays? Why not use, for example, the $4s \longrightarrow 3p$ transition?

90. In certain cases where X-ray diffraction is unsuitable for determining the structure of a crystal, *neutron diffraction* can be used. Instead of X-rays, a beam of neutrons is used to analyze the sample. Calculate the velocity of a beam of neutrons with a wavelength of 2.00 Å.

CHALLENGE PROBLEMS

91. The structure of the addition polymer polypropylene is shown in Table 13.3.

a. Draw the structure of the monomer.

b. Show how an alternate version of the polypropylene polymer (with a different arrangement) could be formed from the monomer you found in part a.

92. Perovskite is a compound with a cubic unit cell and has a strontium atom at the center of the cell, titanium atoms at the corners of the unit cell, and oxygen atoms at the centers of each face of the unit cell.

a. What is the formula of perovskite?

b. What is the coordination number of strontium in the perovskite structure?

c. If the edge length of the unit cell is 3.905 Å, calculate the density of perovskite in g/cm^3.

93. A compound with the formula Rb_3C_{60} has been shown to demonstrate superconductivity below 30.0 K. Given that the C_{60} molecules have a face-centered cubic arrangement, which of the tetrahedral and octahedral sites are occupied by Rb atoms?

94. Despite Dalton's laws, it is now known that many ionic compounds do not always contain atoms in small integer ratios. For example, a sample of iron(II) oxide may, in fact, contain a significant amount of Fe^{3+} in addition to Fe^{2+}. This is an example of a *nonstoichiometric* compound. A sample of iron(II) oxide is found to be 75.65% iron by mass. Determine the percentage of Fe^{3+} ions in the sample.

CONCEPTUAL PROBLEMS

95. During the glass manufacturing process, the liquid must be cooled relatively quickly to form the glass. Why?

96. Why are X-rays used for crystallography? Why not use some other, more accessible type of electromagnetic radiation such as ultraviolet light?

97. Compare the crystal structure of diamond (C) and zinc blende (ZnS). What are the key similarities and differences between the two structures?

98. In X-ray crystallography, a small amount of oil is often used to mount the crystal sample on a glass fiber. Explain why neither the oil nor the glass fiber interferes with the diffraction pattern of the crystal.

99. Which is not likely to lead to an increase in electrical conductivity?

a. Increasing the temperature of a semiconductor

b. Choosing a semiconductor with a smaller band gap

c. Doping the semiconductor

d. All of the above would likely lead to an increase in electrical conductivity.

QUESTIONS FOR GROUP WORK

Active Classroom Learning

Discuss these questions with the group and record your consensus answer.

100. Have each group member select one of the cubic crystalline lattices. Learn everything you can about your lattice and present it to the group.

101. Using group members to play the role of atoms or molecules, demonstrate the main structural features of the following categories of crystalline solids: molecular solid, ionic solid, nonbonded solid, metallic solid, network covalent solid. Clearly identify what you represent and how you are representing various interactions between particles (e.g., covalent bond, ionic bond).

102. Make a list of questions you would need to ask in order to classify a solid into one of the categories of crystalline solids (molecular solid, ionic solid, nonbonded solid, metallic solid, and network covalent solid). Determine a good order to ask them. (You may need a branching decision tree.) Once you have agreed on a good set of questions, have each group member choose a substance from the chapter and then have the other group members ask the questions in turn until the correct classification is reached. You may agree to edit your questions if you discover ways to improve them when you are using your decision tree.

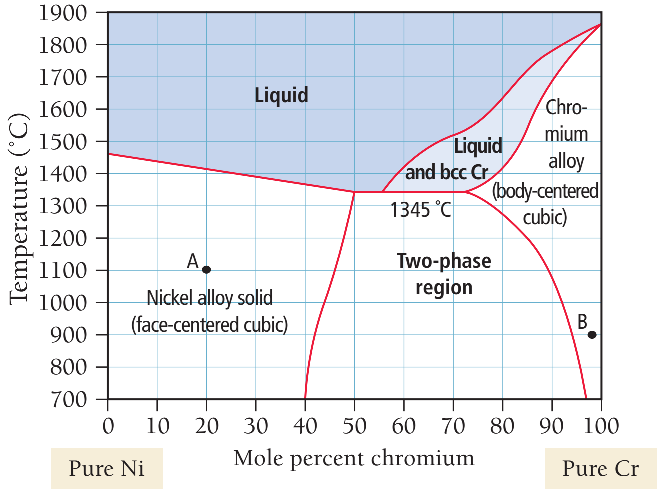
103. Have each group member select and study a material from the section on ceramics, cement, and glass. Take turns describing your material to the group, and see if they can identify the type of material based on your description (without consulting the text).

104. Describe how a common object or toy (e.g., a train, building blocks, or beads on a string) could represent the structure of a polymer. Describe how the following terms would be represented using your model: monomer, dimer, addition polymer, condensation polymer, branching.

DATA INTERPRETATION AND ANALYSIS

Alloy Composition and Phase

105. An *alloy* is a metallic mixture composed of two or more elements. As is the case in all mixtures, the relative amounts of the elements in an alloy can vary. In some cases, the components of an alloy can have different crystal structures. For example, a nickel–chromium alloy consists of nickel, which has face-centered cubic structure, and chromium, which has a body-centered cubic structure. Which structure does the alloy adopt? It depends on the relative compositions. The phase diagrams for alloys such as these reveal the structure as a function of the alloy composition and temperature. For example, the nickel and chromium phase diagram from 700 °C to 1900 °C is shown here:



▲ Cr-Ni Phase Diagram

Notice that the diagram has two different solid phases: face-centered cubic and body-centered cubic. From pure nickel (0 mol % chromium) to about 40–50 mol % chromium, the structure is face-centered cubic. In this structure, Cr atoms substitute for Ni atoms in the face-centered cubic structure of nickel. However, when an amount of chromium beyond a certain percentage (which depends on temperature) is added, that structure is no longer stable. At the other end of the diagram, from pure chromium to about 75% chromium (depending on temperature), the structure is body-centered cubic, with nickel substituting into the body-centered cubic structure of the chromium. The region in between the two phases is called the *two-phase region*. At these compositions, the two phases (nickel-rich face-centered cubic and chromium-rich body-centered cubic) exist together (the solution is not homogeneous in this region). Use the phase diagram to answer the following questions.

a. What is the relative composition of the mixture at point A? At what temperature does a solid mixture having this composition melt?

b. Is it possible to have a homogeneous solid mixture that is 50% Ni and 50% Cr? If so, what crystalline structure would it have?

c. What is the relative composition at point B? What is the crystalline structure at point B?

d. At what temperature does the solid present at point B begin to melt?

ANSWERS TO CONCEPTUAL CONNECTIONS

Edge Length and Atomic Radius

13.1 **(c)** 255 pm The relationship between the edge length and the radius for the body-centered cubic unit cell is $l = 4r\sqrt{3}$. Therefore, $r = l\sqrt{3}/4$.

Cubic Structures

13.2 **(c)** The face-centered cubic structure has four atoms per unit cell.

Crystalline Solid Types and Melting Points

13.3 **(a)** MgO, an ionic compound, has the highest melting point because the solid is held together by ionic bonds. I_2 is a molecular compound with only dispersion forces, and Kr is a nonbonding atomic solid with only dispersion forces. As a result, these two substances have much lower melting points.

Ionic Crystalline Solid Unit Cells

13.4 **(c)** The zinc blende structure occurs in ionic compounds with a one-to-one cation-to-anion ratio in which the cation is much smaller than the anion.

Phase Changes and Pressure

13.5 **(a)** An increase in pressure favors the denser phase, in this case diamond.

Semiconductor Type

13.6 **(a)** Since indium has three valence electrons and germanium has four, the presence of indium would introduce holes into the valence band, resulting in a p-type semiconductor.