

CONCEPTS TO REMEMBER

Chemical bonds. Chemical bonds are the attractive forces that hold atoms together in more complex units. Chemical bonds result from the transfer of valence electrons between atoms (ionic bond) or from the sharing of electrons between atoms (covalent bond) (Section 4.1).

Valence electrons. Valence electrons, for representative elements, are the electrons in the outermost electron shell, which is the shell with the highest shell number. These electrons are particularly important in determining the bonding characteristics of a given atom (Section 4.2).

Octet rule. In compound formation, atoms of representative elements lose, gain, or share electrons in such a way that their electron configurations become identical to those of the noble gas nearest them in the periodic table (Section 4.3).

Ionic compounds. Ionic compounds commonly involve a metal atom and a nonmetal atom. Metal atoms lose one or more electrons, producing positive ions. Nonmetal atoms acquire the electrons lost by the metal atoms, producing negative ions. The oppositely charged ions attract one another, creating ionic bonds (Section 4.4).

Charge magnitude for ions. Metal atoms containing one, two, or three valence electrons tend to lose such electrons, producing ions of

+1, +2, or +3 charge, respectively. Nonmetal atoms containing five, six, or seven valence electrons tend to gain electrons, producing ions of -3 , -2 , or -1 charge, respectively (Section 4.5).

Chemical formulas for ionic compounds. The ratio in which positive and negative ions combine is the ratio that causes the total amount of positive and negative charges to add up to zero (Section 4.7).

Structure of ionic compounds. Ionic solids consist of positive and negative ions arranged in such a way that each ion is surrounded by ions of the opposite charge (Section 4.8).

Binary ionic compound nomenclature. Binary ionic compounds are named by giving the full name of the metallic element first, followed by a separate word containing the stem of the nonmetallic element name and the suffix *-ide*. A Roman numeral specifying ionic charge is appended to the name of the metallic element if it is a metal that exhibits variable ionic charge (Section 4.9).

Polyatomic ions. A polyatomic ion is a group of covalently bonded atoms that has acquired a charge through the loss or gain of electrons. Polyatomic ions are very stable entities that generally maintain their identity during chemical reactions (Section 4.10).

KEY REACTIONS AND EQUATIONS

- Number of valence electrons for representative elements (Section 4.2)
Number of valence electrons = periodic-table group number
- Charges on metallic monatomic ions (Section 4.5)
Group IA metals form 1^+ ions.
Group IIA metals form 2^+ ions.
Group IIIA metals form 3^+ ions.
- Charges on nonmetallic monatomic ions (Section 4.5)
Group VA nonmetals form 3^- ions.
Group VIA nonmetals form 2^- ions.
Group VIIA nonmetals form 1^- ions.

EXERCISES and PROBLEMS

The members of each pair of problems in this section test similar material.

Types of Chemical Bonds (Section 4.1)

- Contrast the two general types of chemical *bonds* in terms of the mechanism by which they form.
- Contrast the two general types of chemical *compounds* in terms of their general physical properties.

Valence Electrons (Section 4.2)

- How many valence electrons do atoms with the following electron configurations have?
a. $1s^22s^2$ b. $1s^22s^22p^63s^2$
c. $1s^22s^22p^63s^23p^1$ d. $1s^22s^22p^63s^23p^64s^23d^{10}4p^2$
- How many valence electrons do atoms with the following electron configurations have?
a. $1s^22s^22p^6$ b. $1s^22s^22p^63s^23p^1$
c. $1s^22s^22p^63s^1$ d. $1s^22s^22p^63s^23p^64s^23d^{10}4p^5$
- Give the periodic-table group number and the number of valence electrons present for each of the following representative elements.
a. ${}_3\text{Li}$ b. ${}_{10}\text{Ne}$ c. ${}_{20}\text{Ca}$ d. ${}_{53}\text{I}$
- Give the periodic-table group number and the number of valence electrons present for each of the following representative elements.
a. ${}_{12}\text{Mg}$ b. ${}_{19}\text{K}$ c. ${}_{15}\text{P}$ d. ${}_{35}\text{Br}$

- Write the complete electron configuration for each of the following representative elements.

- Period 2 element with four valence electrons
- Period 2 element with seven valence electrons
- Period 3 element with two valence electrons
- Period 3 element with five valence electrons

- Write the complete electron configuration for each of the following representative elements.

- Period 2 element with one valence electron
- Period 2 element with six valence electrons
- Period 3 element with seven valence electrons
- Period 3 element with three valence electrons

Lewis Symbols for Atoms (Section 4.2)

- Draw Lewis symbols for atoms of each of the following elements.
a. ${}_{12}\text{Mg}$ b. ${}_{19}\text{K}$ c. ${}_{15}\text{P}$ d. ${}_{36}\text{Kr}$
- Draw Lewis symbols for atoms of each of the following elements.
a. ${}_{13}\text{Al}$ b. ${}_{20}\text{Ca}$ c. ${}_{17}\text{Cl}$ d. ${}_4\text{Be}$
- Each of the following Lewis symbols represents a Period 2 element. Determine each element's identity.
a. $\text{X} \cdot$ b. $:\ddot{\text{X}}:$ c. $\ddot{\text{X}} \cdot$ d. $\cdot\ddot{\text{X}}\cdot$

- 4.12 Each of the following Lewis symbols represents a Period 3 element. Determine each element's identity.



The Octet Rule (Section 4.3)

- 4.13 What is the chemical property of the noble gases that leads to the conclusion that they possess extremely stable electron arrangements?
- 4.14 What is the maximum number of valence electrons that a representative element/noble gas can possess, and which group of elements possesses this maximum number of valence electrons?
- 4.15 What does the octet rule indicate happens to elements that lack a noble-gas electron configuration?
- 4.16 Which noble gas is an exception to the rule that noble-gas elements possess eight valence electrons?

Notation for Ions (Section 4.4)

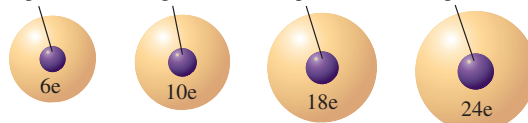
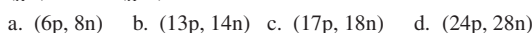
- 4.17 Give the chemical symbol for each of the following ions.
- An oxygen atom that has gained two electrons
 - A magnesium atom that has lost two electrons
 - A fluorine atom that has gained one electron
 - An aluminum atom that has lost three electrons
- 4.18 Give the chemical symbol for each of the following ions.
- A chlorine atom that has gained one electron
 - A sulfur atom that has gained two electrons
 - A potassium atom that has lost one electron
 - A beryllium atom that has lost two electrons
- 4.19 What would be the chemical symbol for an ion with each of the following numbers of protons and electrons?
- 20 protons and 18 electrons
 - 8 protons and 10 electrons
 - 11 protons and 10 electrons
 - 13 protons and 10 electrons
- 4.20 What would be the chemical symbol for an ion with each of the following numbers of protons and electrons?
- 15 protons and 18 electrons
 - 17 protons and 18 electrons
 - 12 protons and 10 electrons
 - 19 protons and 18 electrons
- 4.21 Calculate the number of protons and electrons in each of the following ions.
- P^{3-}
 - N^{3-}
 - Mg^{2+}
 - Li^+
- 4.22 Calculate the number of protons and electrons in each of the following ions.
- S^{2-}
 - F^-
 - K^+
 - H^+
- 4.23 Fill in the blanks to complete the following table.

Chemical Symbol	Ion Formed	Number of Electrons in Ion	Number of Protons in Ion
Ca	Ca^{2+}		
	Be^{2+}	2	
		54	53
Al			13

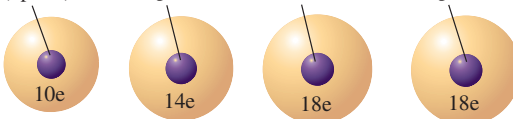
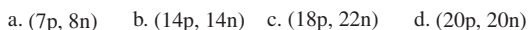
- 4.24 Fill in the blanks to complete the following table.

Chemical Symbol	Ion Formed	Number of Electrons in Ion	Number of Protons in Ion
F	F^-		
S		18	
Br			35
	Ba^{2+}		56

- 4.25 Write the complete chemical symbol for the following atoms (A_ZE) or ions (${}^A_ZE^n$).



- 4.26 Write the complete chemical symbol for the following atoms (A_ZE) or ions (${}^A_ZE^n$).



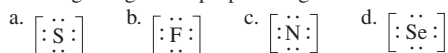
Ionic Charge Sign and Magnitude (Section 4.5)

- 4.27 What is the charge on the monatomic ion formed by each of the following elements?
- ${}_{12}Mg$
 - ${}_7N$
 - ${}_{19}K$
 - ${}_9F$
- 4.28 What is the charge on the monatomic ion formed by each of the following elements?
- ${}_3Li$
 - ${}_{15}P$
 - ${}_{16}S$
 - ${}_{13}Al$
- 4.29 Indicate the number of electrons lost or gained when each of the following atoms forms an ion.
- ${}_4Be$
 - ${}_{35}Br$
 - ${}_{38}Sr$
 - ${}_{34}Se$
- 4.30 Indicate the number of electrons lost or gained when each of the following atoms forms an ion.
- ${}_{37}Rb$
 - ${}_{53}I$
 - ${}_8O$
 - ${}_{11}Na$
- 4.31 Which noble gas has an electron configuration identical to that of each of the following ions?
- O^{2-}
 - P^{3-}
 - Ca^{2+}
 - K^+
- 4.32 Which noble gas has an electron configuration identical to that of each of the following ions?
- F^-
 - Al^{3+}
 - Si^{4+}
 - C^{4-}
- 4.33 Which noble gas is isoelectronic with each of the ions in Problem 4.31?
- 4.34 Which noble gas is isoelectronic with each of the ions in Problem 4.32?
- 4.35 In what group in the periodic table would representative elements that form ions with the following charges most likely be found?
- +2
 - 2
 - 3
 - +1
- 4.36 In what group in the periodic table would representative elements that form ions with the following charges most likely be found?
- +3
 - 4
 - +4
 - 1
- 4.37 Write the electron configuration of the following.
- An aluminum atom
 - An aluminum ion
- 4.38 Write the electron configuration of the following.
- An oxygen atom
 - An oxygen ion

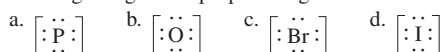
Lewis Structures for Ionic Compounds (Section 4.6)

- 4.39 Using Lewis structures, show how ionic compounds are formed by atoms of
- Be and O
 - Mg and S
 - K and N
 - F and Ca
- 4.40 Using Lewis structures, show how ionic compounds are formed by atoms of
- Na and F
 - Li and S
 - Be and S
 - P and K

4.41 The following Lewis symbols for ions have the charges omitted. Determine the number of extra electrons that each structure is showing and give the proper charge for each ion.

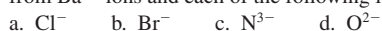


4.42 The following Lewis symbols for ions have the charges omitted. Determine the number of extra electrons that each structure is showing and give the proper charge for each ion.

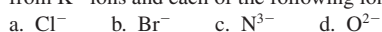


Chemical Formulas for Ionic Compounds (Section 4.7)

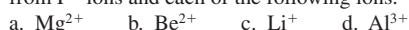
4.43 Write the chemical formula for an ionic compound formed from Ba^{2+} ions and each of the following ions.



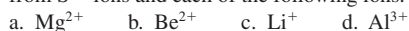
4.44 Write the chemical formula for an ionic compound formed from K^+ ions and each of the following ions.



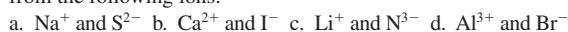
4.45 Write the chemical formula for an ionic compound formed from F^- ions and each of the following ions.



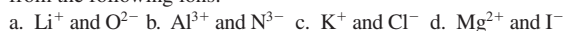
4.46 Write the chemical formula for an ionic compound formed from S^{2-} ions and each of the following ions.



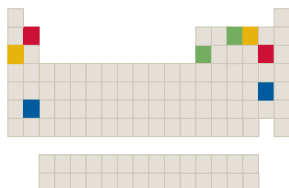
4.47 Write the chemical formula for an ionic compound formed from the following ions.



4.48 Write the chemical formula for an ionic compound formed from the following ions.



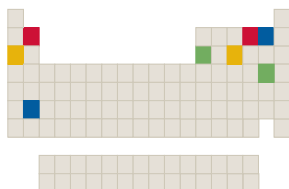
4.49 The component elements for four binary ionic compounds are shown with different colors on the following periodic table.



What is the likely chemical formula for the following?

- a. Red compound b. Blue compound
c. Yellow compound d. Green compound

4.50 The component elements for four binary ionic compounds are shown with different colors on the following periodic table.



What is the likely chemical formula for the following?

- a. Red compound b. Blue compound
c. Yellow compound d. Green compound

Structure of Ionic Compounds (Section 4.8)

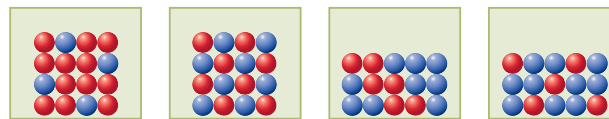
4.51 Describe the general structure of a solid-state ionic compound.

4.52 Explain why ionic compounds do not contain individual molecules.

4.53 What is a *formula unit* of an ionic compound?

4.54 In general terms, how many *formula units* are present in a crystal of an ionic compound?

4.55 The following drawings represent solid-state ionic compounds, with red spheres denoting positive ions and blue spheres denoting negative ions.



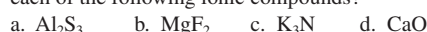
I

II

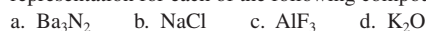
III

IV

Which of these drawings could be used as a representation for each of the following ionic compounds?



4.56 Use the solid-state ionic drawings in Problem 4.55, but with blue spheres denoting positive ions and red spheres denoting negative ions. Which of these drawings could be used as a representation for each of the following compounds?



Binary Ionic Compound Nomenclature (Section 4.9)

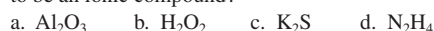
4.57 Which of the following pairs of elements would be expected to form a binary ionic compound?

- a. Sodium and oxygen b. Magnesium and sulfur
c. Nitrogen and chlorine d. Copper and fluorine

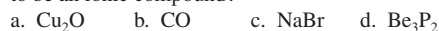
4.58 Which of the following pairs of elements would be expected to form a binary ionic compound?

- a. Potassium and sulfur b. Calcium and nitrogen
c. Carbon and chlorine d. Iron and iodine

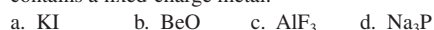
4.59 Which of the following binary compounds would be expected to be an ionic compound?



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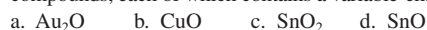
4.61 Name the following binary ionic compounds, each of which contains a fixed-charge metal.



4.62 Name the following binary ionic compounds, each of which contains a fixed-charge metal.



4.63 Calculate the charge on the metal ion in the following binary ionic compounds, each of which contains a variable-charge metal.



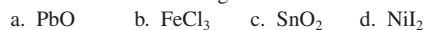
4.64 Calculate the charge on the metal ion in the following binary ionic compounds, each of which contains a variable-charge metal.



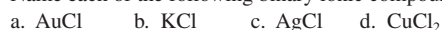
4.65 Name the following binary ionic compounds, each of which contains a variable-charge metal.



4.66 Name the following binary ionic compounds, each of which contains a variable-charge metal.



4.67 Name each of the following binary ionic compounds.



4.68 Name each of the following binary ionic compounds.



- 4.69** Write chemical formulas for the following binary ionic compounds.
- Potassium bromide
 - Silver oxide
 - Beryllium fluoride
 - Barium phosphide
- 4.70** Write chemical formulas for the following binary ionic compounds.
- Gallium nitride
 - Zinc chloride
 - Magnesium sulfide
 - Aluminum nitride
- 4.71** Write chemical formulas for the following binary ionic compounds.
- Cobalt(II) sulfide
 - Cobalt(III) sulfide
 - Tin(IV) iodide
 - Lead(II) nitride
- 4.72** Write chemical formulas for the following binary ionic compounds.
- Iron(III) oxide
 - Iron(II) oxide
 - Nickel(III) sulfide
 - Copper(I) bromide

Compounds Containing Polyatomic Ions (Sections 4.10 and 4.11)

- 4.73** With the help of Table 4.3, write chemical formulas (including charge) for each of the following polyatomic ions.
- Sulfate
 - Chlorate
 - Hydroxide
 - Cyanide
- 4.74** With the help of Table 4.3, write chemical formulas (including charge) for each of the following polyatomic ions.
- Ammonium
 - Nitrate
 - Perchlorate
 - Phosphate
- 4.75** With the help of Table 4.3, write chemical formulas (including charge) for each of the following pairs of polyatomic ions.
- Phosphate and hydrogen phosphate
 - Nitrate and nitrite
 - Hydronium and hydroxide
 - Chromate and dichromate
- 4.76** With the help of Table 4.3, write chemical formulas (including charge) for each of the following pairs of polyatomic ions.
- Chlorate and perchlorate
 - Hydrogen phosphate and dihydrogen phosphate
 - Carbonate and bicarbonate
 - Sulfate and hydrogen sulfate
- 4.77** Write chemical formulas for the compounds formed between the following positive and negative ions.
- Na^+ and ClO_4^-
 - Fe^{3+} and OH^-
 - Ba^{2+} and NO_3^-
 - Al^{3+} and CO_3^{2-}
- 4.78** Write chemical formulas for the compounds formed between the following positive and negative ions.
- K^+ and CN^-
 - NH_4^+ and SO_4^{2-}
 - Co^{2+} and H_2PO_4^-
 - Ca^{2+} and PO_4^{3-}

- 4.79** Fill in the blanks to complete the following table of chemical formulas for polyatomic-ion-containing compounds. For each compound the positive ion present is listed on the left side of the table and the negative ion present is listed at the top.

	CN^-	NO_3^-	HCO_3^-	SO_4^{2-}
NH_4^+				
Al^{3+}				
Ag^+		AgNO_3		
Ca^{2+}				

- 4.80** Fill in the blanks to complete the following table of chemical formulas for polyatomic-ion-containing compounds. For each compound the positive ion present is listed on the left side of the table and the negative ion present is listed at the top.

	OH^-	PO_4^{3-}	CO_3^{2-}	HSO_4^-
Li^+				
Cu^{2+}				
Ba^{2+}			BaCO_3	
Fe^{3+}				

- 4.81** Name the following compounds, all of which contain polyatomic ions and fixed-charge metals.
- MgCO_3
 - ZnSO_4
 - $\text{Be}(\text{NO}_3)_2$
 - Ag_3PO_4
- 4.82** Name the following compounds, all of which contain polyatomic ions and fixed-charge metals.
- LiOH
 - $\text{Al}(\text{CN})_3$
 - $\text{Ba}(\text{ClO}_3)_2$
 - NaNO_3
- 4.83** Name the following compounds, all of which contain polyatomic ions and variable-charge metals.
- $\text{Fe}(\text{OH})_2$
 - CuCO_3
 - AuCN
 - $\text{Mn}_3(\text{PO}_4)_2$
- 4.84** Name the following compounds, all of which contain polyatomic ions and variable-charge metals.
- $\text{Fe}(\text{NO}_3)_3$
 - $\text{Co}_2(\text{CO}_3)_3$
 - Cu_3PO_4
 - $\text{Pb}(\text{SO}_4)_2$
- 4.85** Write formulas for the following compounds, all of which contain polyatomic ions.
- Potassium bicarbonate
 - Gold(III) sulfate
 - Silver nitrate
 - Copper(II) phosphate
- 4.86** Write formulas for the following compounds, all of which contain polyatomic ions.
- Aluminum nitrate
 - Iron(III) sulfate
 - Calcium cyanide
 - Lead(IV) hydroxide

ADDITIONAL PROBLEMS

- 4.87** Fill in the blanks to complete the following table.

Positive Ion	Negative Ion	Chemical Formula	Name
			Magnesium hydroxide
		BaBr_2	
Zn^{2+}	NO_3^-		
			Iron(III) chlorate
		PbO_2	
Co^{2+}	PO_4^{3-}		
K^+	I^-		
		Cu_2SO_4	
			Lithium nitride
Al^{3+}	S^{2-}		

- 4.88** Fill in the blanks to complete the following table.

Chemical Symbol	Number of Protons	Number of Neutrons	Number of Electrons	Net Charge
$^{59}_{26}\text{Fe}^{3+}$				
	28	31	25	
	77	120		2+
		9	10	1-

- 4.89** What would be the chemical symbol for an ion with each of the following characteristics?
- A sodium ion with ten electrons
 - A fluorine ion with ten electrons
 - A sulfur ion with two fewer protons than electrons
 - A calcium ion with two more protons than electrons

- 4.90** Write the formula of the ionic compound that could form from the elements X and Z if
- X has two valence electrons and Z has seven valence electrons
 - X has one valence electron and Z has six valence electrons
 - X has three valence electrons and Z has five valence electrons
 - X has six valence electrons and Z has two valence electrons
- 4.91** Identify the Period 3 element that most commonly produces each of the following ions.
- X^{2-}
 - X^{2+}
 - X^{3-}
 - X^{3+}
- 4.92** Indicate whether each of the following compounds contains (1) only monatomic ions, (2) only polyatomic ions, (3) both monatomic and polyatomic ions, or (4) no ions.
- CaF_2
 - $NaNO_3$
 - NH_4CN
 - AlP
- 4.93** Write chemical formulas (symbol and charge) for both kinds of ions present in each of the following compounds.
- KCl
 - CaS
 - BeF_2
 - Al_2S_3
- 4.94** Give the chemical formula for, and the name of the compound formed from, each of the following pairs of ions.
- Na^+ and N_3^-
 - K^+ and NO_3^-
 - Mg^{2+} and O^{2-}
 - NH_4^+ and PO_4^{3-}
- 4.95** Name each compound in the following pairs of binary ionic compounds.
- $SnCl_4$ and $SnCl_2$
 - FeS and Fe_2S_3
 - Cu_3N and Cu_3N_2
 - NiI_2 and NiI_3
- 4.96** In which of the following pairs of binary ionic compounds do both members of the pair contain positive ions with the same charge?
- Co_2O_3 and $CoCl_3$
 - Cu_2O and CuO
 - K_2O and Al_2O_3
 - MgS and NaI
- 4.97** Name each compound in the following pairs of polyatomic-ion-containing compounds.
- $CuNO_3$ and $Cu(NO_3)_2$
 - $Pb_3(PO_4)_2$ and $Pb_3(PO_4)_4$
 - $Mn(CN)_3$ and $Mn(CN)_2$
 - $Co(ClO_3)_2$ and $Co(ClO_3)_3$
- 4.98** Write chemical formulas for the following compounds.
- Sodium sulfide
 - Sodium sulfate
 - Sodium sulfite
 - Sodium thiosulfate

Multiple-Choice Practice Test

- 4.99** For which of the following elements is the listed number of valence electrons *correct*?
- Mg (2 valence electrons)
 - N (3 valence electrons)
 - F (1 valence electron)
 - S (2 valence electrons)
- 4.100** Which of the following is an *incorrect* statement about the number of electrons lost or gained by a representative element during ion formation?
- The number usually does not exceed three.
 - The number is governed by the octet rule.
 - The number is related to the position of the element in the periodic table.
 - The number is the same as the number of valence electrons present.
- 4.101** Which of the following is a *correct* statement concerning the mechanism for ionic bond formation?
- Electrons are transferred from nonmetallic atoms to metallic atoms.
 - Protons are transferred from the nuclei of metallic atoms to the nuclei of nonmetallic atoms.
 - Sufficient electrons are transferred to form ions of equal but opposite charge.
 - Electron loss is always equal to electron gain.
- 4.102** In which of the following pairings is the chemical formula *not* consistent with the ions shown?
- M^{2+} and X^{3-} (M_3X_2)
 - M^{2+} and X^- (MX_2)
 - M^+ and X^{3-} (MX_3)
 - M^{2+} and X^{2-} (MX)
- 4.103** The correct chemical formula for the ionic compound formed between Mg and O is
- MgO
 - Mg_2O_2
 - MgO_2
 - Mg_2O
- 4.104** In which of the following pairs of ionic compounds do both members of the pair contain positive ions with a +1 charge?
- KCl and CaO
 - Na_3N and Li_2S
 - $AlCl_3$ and MgF_2
 - BaI_2 and $BeBr_2$
- 4.105** The correct chemical formula for the compound aluminum nitride is
- AlN
 - AlN_2
 - Al_2N_3
 - Al_3N_2
- 4.106** In which of the following pairs of metals are both members of the pair variable-charge metals?
- Na and Al
 - Au and Ag
 - Cu and Zn
 - Fe and Ni
- 4.107** In which of the following pairs of polyatomic ions do both members of the pair have the same charge?
- ammonium and phosphate
 - sulfate and nitrate
 - cyanide and hydroxide
 - hydrogen carbonate and carbonate
- 4.108** Which of the following ionic compounds contains 4 atoms per formula unit?
- Lithium nitride
 - Potassium sulfide
 - Copper(II) iodide
 - Sodium cyanide