Formulas for Ionic Compounds

The simplest ratio of the ions represented in an ionic compound is called a **formula unit**. For example, the formula KBr represents a formula unit for potassium bromide because potassium and bromide ions are in a one-to-one ratio in the compound. A formula unit of magnesium chloride is $MgCl_2$ because two chloride ions exist for each magnesium ion in the compound.

Because the total number of electrons gained by the nonmetallic atoms must equal the total number of electrons lost by the metallic atoms, the overall charge of the formula unit is zero. The formula unit for $MgCl_2$ contains one Mg^{2+} ion and two Cl^- ions, for a total charge of zero.

Determining Charge

Binary ionic compounds are composed of positively charged monatomic ions of a metal and negatively charged monatomic ions of a nonmetal. A monatomic ion is a one-atom ion, such as Mg^{2+} or Br^-. The table below indicates the charges of common monatomic ions according to their location on the periodic table:

Group	Atoms that commonly form ions	Charge on Ions
1	H, Li, Na, K, Rb, Cs	1+
2	Be, Mg, Ca, Sr, Ba	2+
15	N, P, As	3–
16	O, S, Se, Te	2–
17	F, Cl, Br, I	1–

The charge of a monatomic ion is its **oxidation number**, or **combining capacity**. Most transition metals and group 13 and 14 metals have more than one oxidation number, as shown in the table below:

Group	Common Ions
3	Sc^{3+}, Y^{3+}, La^{3+}
4	Ti^{2+}, Ti^{3+}
5	V^{2+}, V^{3+}
6	Cr^{2+}, Cr^{3+}
7	Mn^{2+}, Mn^{3+}, Tc^{2+}
8	Fe^{2+}, Fe^{3+}
9	Co^{2+}, Co^{3+}
10	Ni^{2+}, Pd^{2+}, Pt^{2+}, Pt^{4+}
11	Cu^{+}, Cu^{2+}, Ag^{+}, Au^{+}, Au^{3+}
12	Zn^{2+}, Cd^{2+}, Hg^{+}, Hg^{2+}
13	Al^{3+}, Ga^{2+}, Ga^{3+}, In^{+}, In^{2+}, In^{3+}, Tl^{+}, Tl^{3+}
14	Sn^{2+}, Sn^{4+}, Pb^{2+}, Pb^{4+}

The oxidation numbers given in the table are the most common ones for many of the elements listed, but might not be the only ones possible.

The oxidation numbers of ions are used to determine the chemical formulas for the ionic compounds they form. Recall that in ionic compounds, oppositely charged ions combine chemically in definite ratios to form a compound that has no charge. If you add the oxidation number of each ion multiplied by the number of these ions in a formula unit, the total must be zero.

The following method can be used to write the formula for an ionic compound.

Step 1
Write the symbols of the atoms, with the metal first.

Step 2
Write the oxidation numbers for the elements.

Step 3
Balance the oxidation numbers to give a neutral compound (they should add up to zero).

Step 4
Write the formula using subscripts to indicate the number of atoms of each element in the compound.

Example 1
The ionic compound formed from potassium and oxygen is used as a dehydrating agent because it reacts readily with water. Determine the correct formula for this ionic compound.

Example 2
Determine the correct formula for the yellowish-gray compound formed from aluminum ions and sulfide ions. This compound decomposes in moist air.

Compounds That Contain Polyatomic Ions

Many ionic compounds contain **polyatomic ions**, which are ions made up of more than one atom. The table below lists the formulas and the charges for several polyatomic ions.

Ion	Name	Ion	Name
NH_4^+	ammonium	IO_4^-	periodate
NO_2^-	nitrite	$C_2H_3O_2^-$	acetate
NO_3^-	nitrate	$H_2PO_4^-$	dihydrogen phosphate
HSO_4^-	hydrogen sulfate	CO_3^{2-}	carbonate
OH^-	hydroxide	SO_3^{2-}	sulfite
CN^-	cyanide	SO_4^{2-}	sulfate
MnO_4^-	permanganate	$S_2O_3^{2-}$	thiosulfate
HCO_3^-	hydrogen carbonate	O_2^{2-}	peroxide
ClO^-	hypochlorite	CrO_4^{2-}	chromate
ClO_2^-	chlorite	$Cr_2O_7^{2-}$	dichromate
ClO_3^-	chlorate	HPO_4^{2-}	hydrogen phosphate
ClO_4^-	perchlorate	PO_4^{3-}	phosphate
BrO_3^-	bromate	AsO_4^{3-}	arsenate
IO_3^-	iodate		

The charge given to a polyatomic ion applies to the entire group of atoms. The polyatomic ion acts as a single ion. Thus, the formula for the compound can be written using the same method used for a binary compound.

Because a polyatomic ion exists as a unit, never change the subscripts of the atoms within the ion. If more than one polyatomic ion is needed, place brackets around the ion and write the appropriate subscript outside the brackets.

Example 3
The ionic compound formed from the calcium ion and the phosphate ion is a common ingredient in fertilizers. Write the formula for this compound.

Naming Ionic Compounds

The following rules can be used to name an ionic compound.

1. Write the name of the metal first and the nonmetal second.

2. The metal ion uses the element name.

3. The nonmetal ion uses the root of the element name, but the ending is changed to –ide.

4. For metals that have more than one oxidation number, place brackets at the end of their name and write the oxidation number of the metal in the brackets. The oxidation number is written in roman numerals.

Example 4
Write the formulas and names for the compounds formed by Fe^{2+} and Fe^{3+} with O^{2-}

5. If the compound contains a polyatomic ion, simply use the ion name given in the table.

Example 5
Name the compound $NaOH$.

Names and Formulas for Ionic Compounds

1. How does the sum of the charges on the positive ions compare to the sum of the charges on the negative ions in ionic compounds?

2. Calculate the sum of the ionic charges in the compound Al_2O_3. Show your calculation.

3. Draw a Bohr diagram to show the electron transfer that occurs when magnesium and fluorine form the compound magnesium fluoride.

4. Write the formulas for the compounds formed by the following combinations of elements:

   a) lithium and fluorine
   b) calcium and bromine
   c) sodium and nitrogen
   d) aluminum and nitrogen

5. Name each of the compounds in question 4.

6. Write the formulas for the following compounds:

   a) sodium iodide
   b) beryllium fluoride
   c) magnesium oxide
   d) aluminum sulfide

7. Write the names for the following compounds:

   a) KCl
   b) Na_3P
   c) CaF_2

8. Write the formulas for the following compounds:

   a) copper(I) bromide
   b) copper(II) bromide
   c) iron(II) sulfide

9. Write the names for the following compounds:

   a) $SnCl_2$
   b) $SnCl_4$
   c) $PbBr_2$

10. Write the formula and name of the compound formed by each of the following combinations of ions. (Note that some of these ions will require the use of Roman numerals in the names.)

    a) Fe^{+3} and O^{-2}
    b) Ca^{+2} and F^{-}
    c) Cu^{+} and S^{-2}

11. In mining, some minerals are referred to as ferrous. What metallic element is present in these compounds? (Hint: Look at the letters that begin the word.)

12. In your own words, explain what is meant by the term "polyatomic ion." Give two examples.

13. Write the formulas for the following compounds:

    a) sodium phosphate
    b) calcium sulfate
    c) potassium chlorate
    d) aluminum hydroxide
    e) beryllium nitrate
    f) magnesium hydrogen carbonate (magnesium bicarbonate)
    g) nickel carbonate

14. Write the names for the following compounds:

    a) K_2CO_3
    b) Na_2SO_4
    c) $Al(HCO_3)_3$
    d) $AgNO_3$

15. Why is ammonium nitrate (NH_4NO_3) not written as $N_2H_4O_3$?

16. Give the names and formulas of the compounds formed by an ammonium ion and

    a) a chloride ion.
    b) a sulfate ion.