

## 6.18: Ionic Compounds Containing Polyatomic Ions

When polyatomic ions are included, the number of ionic compounds increases significantly. Indeed, most ionic compounds contain polyatomic ions. Well-known examples are sodium hydroxide (NaOH) with  $\text{OH}^-$  as the polyatomic anion, calcium carbonate ( $\text{CaCO}_3$ ), and ammonium nitrate ( $\text{NH}_4\text{NO}_3$ ), which contains two polyatomic ions:  $\text{NH}_4^+$  and  $\text{NO}_3^-$ .

A list of the more important polyatomic ions is given in the following table, which can be used for reference while learning the charges of polyatomic ions. A great many of them are oxyanions (polyatomic ions that contain oxygen).

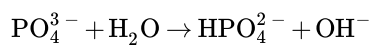
**Table 6.18.1 Ions**

Ions		
Charge	Name	Formula
-3	Phosphate	$\text{PO}_4^{3-}$
	Arsenate	$\text{AsO}_4^{3-}$
-2	Carbonate	$\text{CO}_3^{2-}$
	Peroxide	$\text{O}_2^{2-}$
	Sulfate	$\text{SO}_4^{2-}$
	Sulfite	$\text{SO}_3^{2-}$
	Chromate	$\text{CrO}_4^{2-}$
	Dichromate	$\text{Cr}_2\text{O}_7^{2-}$
	Hydrogen phosphate	$\text{HPO}_4^{2-}$
	Hydrogen carbonate (bicarbonate)	$\text{HCO}_3^-$
-1	Superoxide	$\text{O}_2^-$
	Hydrogen sulfate	$\text{HSO}_4^-$
	Dihydrogen phosphate	$\text{H}_2\text{PO}_4^-$
	Hydroxide	$\text{OH}^-$
	Nitrate	$\text{NO}_3^-$
	Nitrite	$\text{NO}_2^-$
	Acetate	$\text{C}_2\text{H}_3\text{O}_2^-$ or $\text{CH}_3\text{COO}^-$
	Cyanide	$\text{CN}^-$
	Permanganate	$\text{MnO}_4^-$
	Perchlorate	$\text{ClO}_4^-$
	Chlorate	$\text{ClO}_3^-$
	Chlorite	$\text{ClO}_2^-$
	Hypochlorite	$\text{ClO}^-$
	Ammonium	$\text{NH}_4^+$
	Hydronium	$\text{H}_3\text{O}^+$

The properties of compounds containing polyatomic ions are very similar to those of binary ionic compounds. The ions are arranged in a regular lattice and held together by coulombic forces of attraction. The resulting crystalline solids usually have high melting points (1500 °F for  $\text{CaCO}_3$ ) and all conduct electricity when molten.

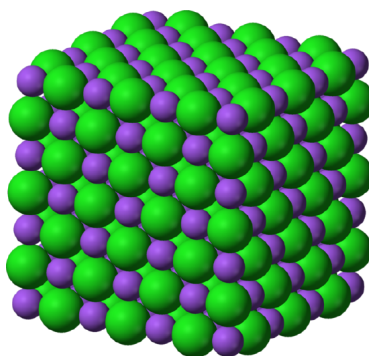
Most are soluble in water and form conducting solutions in which the ions can move around as independent entities. In general polyatomic ions are colorless, unless, like  $\text{CrO}_4^{2-}$  or  $\text{MnO}_4^-$ , they contain a transition-metal atom. The more negatively charged

polyatomic ions, like their monatomic counterparts, show a distinct tendency to react with water, producing hydroxide ions; for example,

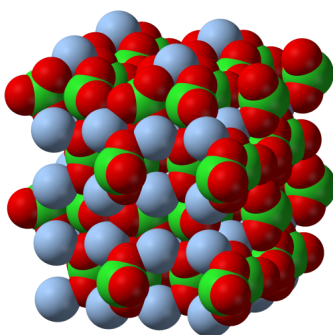


It is important to realize that compounds containing polyatomic ions must be *electrically neutral*. In a crystal of calcium sulfate, for instance, there must be equal numbers of  $\text{Ca}^{2+}$  and  $\text{SO}_4^{2-}$  ions in order for the charges to balance. The formula is thus  $\text{CaSO}_4$ . In the case of sodium sulfate, by contrast, the  $\text{Na}^+$  ion has only a single charge. In this case we need *two*  $\text{Na}^+$  ions for each  $\text{SO}_4^{2-}$  ion in order to achieve electroneutrality. The formula is thus  $\text{Na}_2\text{SO}_4$ .

Structurally, polyatomic ions are similar to the ionic solids we saw earlier. An example of a simple ionic compound,  $\text{NaCl}$ , is seen below, alongside a more complex ionic solid,  $\text{AgClO}_3$ . Notice how both are tightly packed and form a repeating pattern, which lends both compounds strength and brittleness. In the Silver Chlorate ( $\text{AgClO}_3$ ), however, polyatomic ions are present where the  $\text{Cl}^-$  ions are present in the Sodium Chloride ( $\text{NaCl}$ ).



A cubic sodium chloride lattice made up of stacked green and purple spheres. The spheres are stacked in an alternating pattern. The green sphere is slightly larger than the purple sphere.



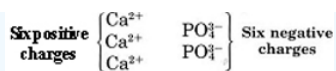
The three dimensional lattice of silver chlorate is complex because each silver sphere arranged in a regular cubic lattice is connected to a one green sphere which is connected to three red spheres.

*On the left is the lattice structure of the ionic solid  $\text{NaCl}$ , with  $\text{Na}$  represented by the green spheres and  $\text{Cl}$  represented by the purple spheres. On the right is the lattice structure of  $\text{AgClO}_3$ , with the silver spheres representing  $\text{Ag}$  and the red and green molecules representing the polyatomic ion  $\text{ClO}_3$*

#### ✓ Example 6.18.1 : Ionic Formula

What is the formula of the ionic compound calcium phosphate?

**Solution** It is necessary to have the correct ratio of calcium ions,  $\text{Ca}^{2+}$ , and phosphate ions,  $\text{PO}_4^{3-}$ , in order to achieve electroneutrality. The required ratio is the *inverse* of the ratio of the charges on ions. Since the charges are in the ratio of 2:3, the numbers must be in the ratio of 3:2. In other words the solid salt must contain three calcium ions for every two phosphate ions:



Composition of calcium phosphate is three moles of Ca ions which make up a total of six positive charges as well as two phosphate ions which has a total of six negative charges.

The formula for calcium phosphate is thus  $\text{Ca}_3(\text{PO}_4)_2$ .

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