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 OH^- as the polyatomic anion, calcium carbonate ($CaCO_3$), and ammonium nitrate (NH_4NO_3), which contains two polyatomic ions: NH^+ and 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	PO_4^{3-}
	Arsenate	AsO_4^{3-}
-2	Carbonate	CO_3^{2-}
	Peroxide	O_2^{2-}
	Sulfate	SO_4^{2-}
	Sulfite	SO_3^{2-}
	Chromate	CrO_4^{2-}
	Dichromate	$Cr_2O_7^{2-}$
	Hydrogen phosphate	HPO_4^{2-}
-1	Hydrogen carbonate (bicarbonate)	HCO_3^-
	Superoxide	O_2^-
	Hydrogen sulfate	HSO_4^-
	Dihydrogen phosphate	$H_2PO_4^-$
	Hydroxide	OH^-
	Nitrate	NO_3^-
	Nitrite	NO_2^-
	Acetate	$C_2H_3O_2^-$ or CH_3COO^-
	Cyanide	CN^-
	Permanganate	MnO_4^-
	Perchlorate	ClO_4^-
	Chlorate	ClO_3^-
	Chlorite	ClO_2^-
	Hypochlorite	ClO^-
+1	Ammonium	NH_4^+
	Hydronium	H_3O^+

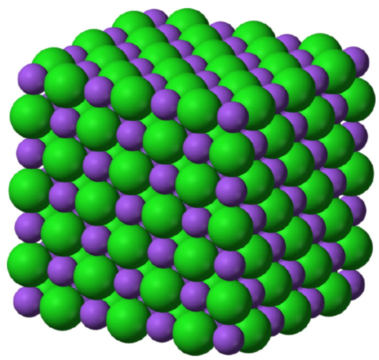
The properties of compounds containing polyatomic ions are very similar to those of binary ionic compounds. The ions are arranged in a regular lattice and held together by coulombic forces of attraction. The resulting crystalline solids usually have high melting points (1500 °F for $CaCO_3$) and all 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 CrO_4^{2-} or 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,

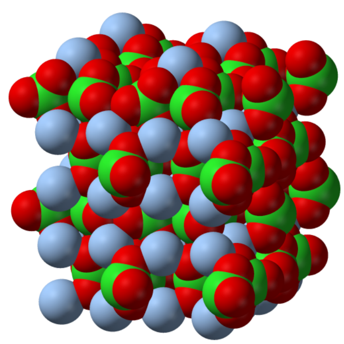
$$PO_4^{3-} + H_2O \rightarrow HPO_4^{2-} + OH^-$$

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 Ca^{2+} and SO_4^{2-} ions in order for the charges to balance. The formula is thus $CaSO_4$. In the case of sodium sulfate, by contrast, the Na^+ ion has only a single charge. In this case we need *two* Na^+ ions for each SO_4^{2-}ion in order to achieve electroneutrality. The formula is thus Na_2SO_4.

Structurally, polyatomic ions are similar to the ionic solids we saw earlier. An example of a simple ionic compound, NaCl, is seen below, alongside a more complex ionic solid, $AgClO_3^-$. Notice how both are tightly packed and form a repeating pattern, which lends both compounds strength and brittleness. In the Silver Chlorate ($AgClO_3^-$), however, polyatomic ions are present where the Cl^- ions are present in the Sodium Chloride (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.



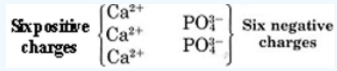
The three dimensional lattice of silver chlorate is complex because each silver sphere arranged in a regular cubic lattice is connected to a one green sphere which is connected to three red spheres.

On the left is the lattice structure of the ionic solid NaCl, with Na represented by the green spheres and Cl represented by the purple spheres. On the right is the lattice structure of $AgClO_3$, with the silver spheres representing Ag and the red and green molecules representing the polyatomic ion 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, Ca^{2+}, and phosphate ions, 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 $Ca_3(PO_4)_2$.
