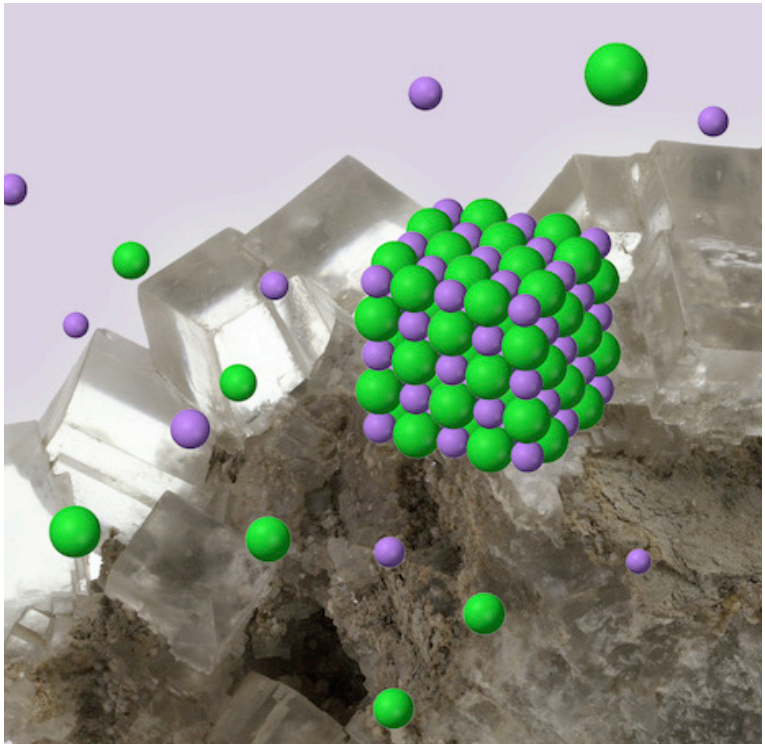


Chapter 6

How Atoms Bond

THE MAIN IDEA

Atoms bond by exchanging or sharing electrons.

6.3 Ionic Bonds

When an atom that tends to lose electrons is placed in contact with an atom that tends to gain them, the result is an electron transfer and the formation of two oppositely charged ions. This occurs when sodium and chlorine are combined. As shown in **Figure 6.7**, the sodium atom loses one of its electrons to the chlorine atom, resulting in the formation of a positive sodium ion and a negative chloride ion. The two oppositely charged ions are attracted to each other by the electric force, which holds them close together. This electric force of attraction between two oppositely charged ions is called an **ionic bond**.

A sodium ion and a chloride ion together make the chemical compound sodium chloride, commonly known as table salt. This and all other chemical compounds containing ions are referred to as **ionic compounds**. All ionic compounds are completely different from the elements from which they are made. As discussed in Section 3.4, sodium chloride is not sodium, nor is it chlorine. Rather, it is a collection of sodium and chloride ions that form a unique material having its own physical and chemical properties.

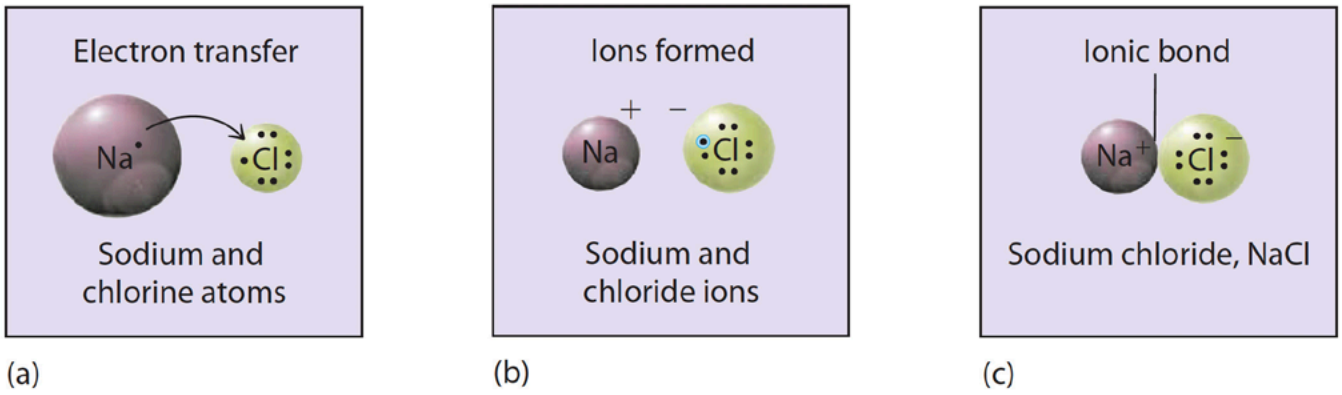
READING CHECK

What type of force gives rise to an ionic bond?

CONCEPT **CHECK**

Is the transfer of an electron from a sodium atom to a chlorine atom a physical change or a chemical change?

CHECK YOUR ANSWER Recall from Chapter 3 that only a chemical change involves the formation of new material. Thus, this or any other electron transfer, because it results in the formation of a new substance, is a chemical change.



Λ Figure 6.7

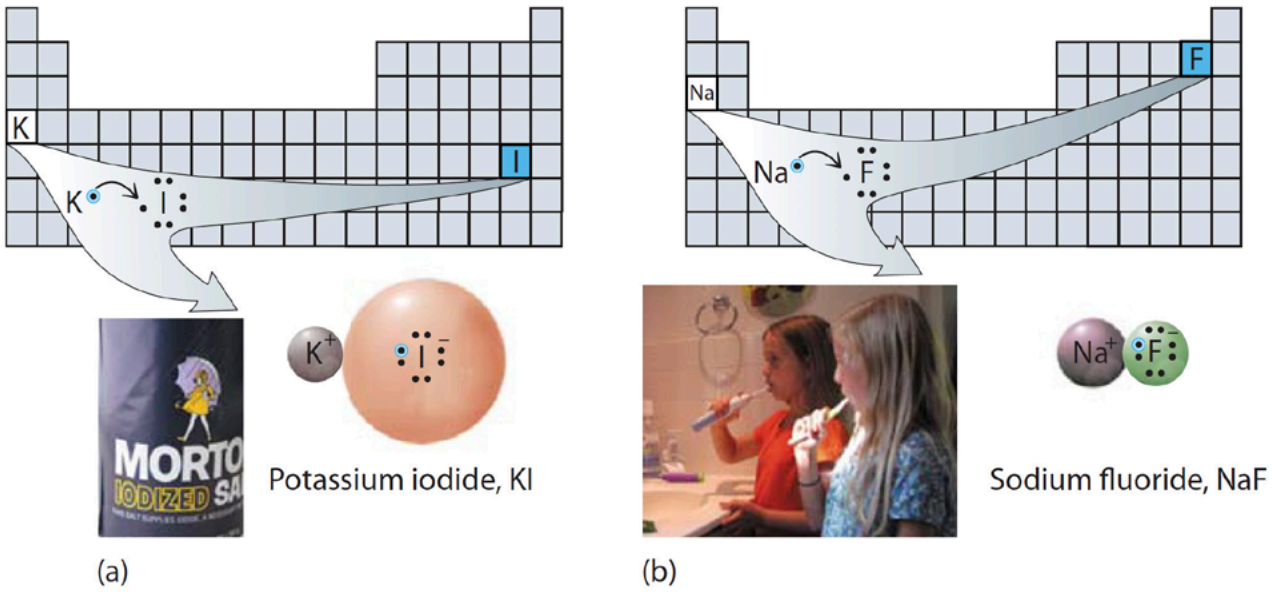
An electrically neutral sodium atom loses its valence electron to an electrically neutral chlorine atom. (b) This electron transfer results in two oppositely charged ions. (c) The ions are then held together by an ionic bond. The spheres drawn around these and subsequent illustrations of electron-dot structures indicate the relative sizes of the atoms and ions.

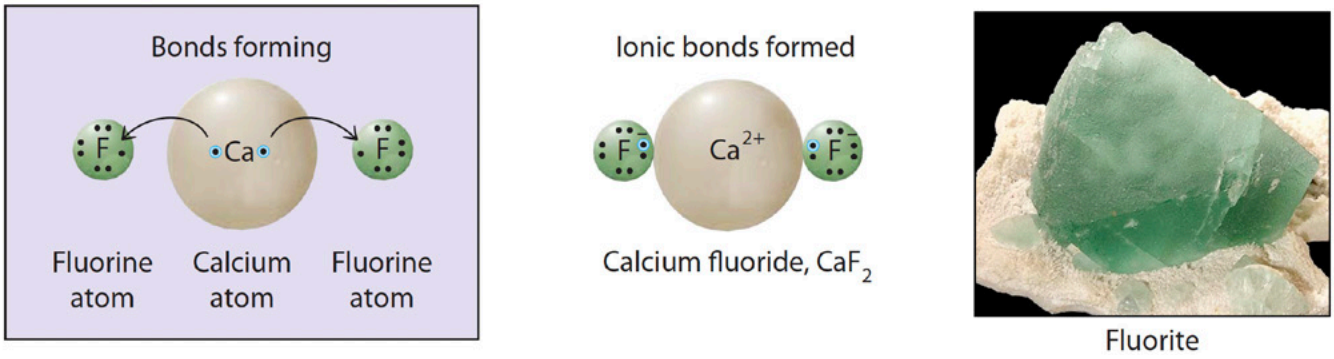
As **Figure 6.8** shows, ionic compounds typically consist of elements that are found on opposite sides of the periodic table. Also, because of how the metals and nonmetals are organized in the periodic table, positive ions are generally derived from metallic elements and negative ions are generally derived from nonmetallic elements.

For all ionic compounds, positive and negative charges must balance. In sodium chloride, for example, there is one sodium 1+ ion for every chloride 1– ion. Charges must also balance in compounds containing ions that carry various charges. The calcium ion, for example, carries a charge of 2+, but the fluoride ion carries a charge of only 1–. Because two fluoride ions are needed to balance each calcium ion, the formula for calcium fluoride is CaF_2, as **Figure 6.9** illustrates.

V Figure 6.8

The ionic compound potassium iodide, KI, is added in minute quantities to commercial salt because the iodide ion, I^-, that it contains is an essential dietary mineral. The ionic compound sodium fluoride, NaF, is often added to toothpastes because it is a good source of the tooth-strengthening fluoride ion, F^-.





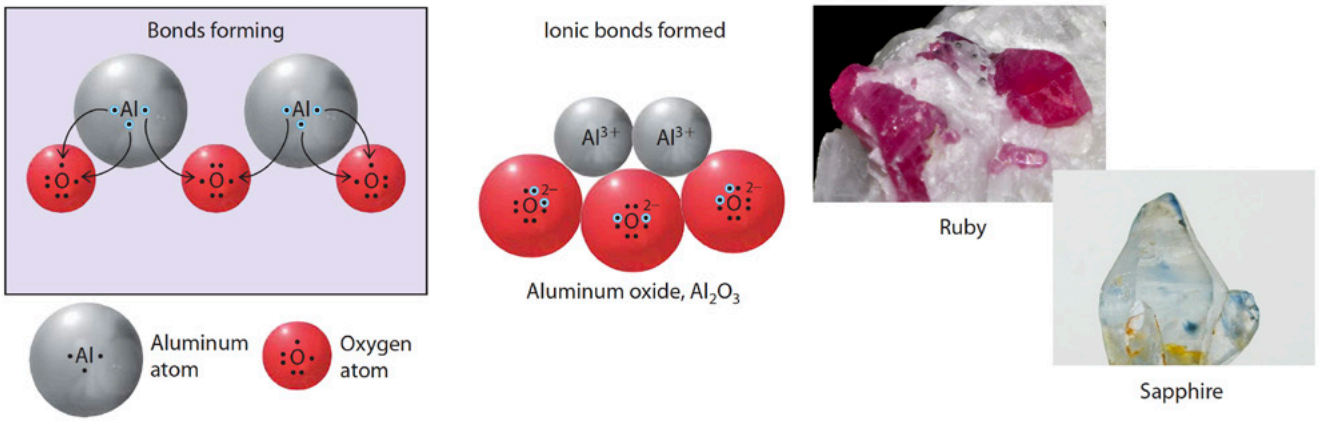
Λ Figure 6.9
A calcium atom loses two electrons to a pair of fluorine atoms. In the process, the calcium atom becomes a calcium ion, Ca^{2+}, and the fluorine atoms become fluoride ions, F^-. The oppositely charged ions join to form the ionic compound calcium fluoride, CaF_2, which occurs naturally as the mineral fluorite.

An aluminum ion carries a 3+ charge, and an oxide ion carries a 2– charge. Together, these ions make the ionic compound aluminum oxide, Al_2O_3, the main component of such gemstones as rubies and sapphires. **Figure 6.10** illustrates the formation of aluminum oxide. The three oxide ions in Al_2O_3 carry a total charge of 6–, which balances the total 6+ charge of the two aluminum ions. Rubies and sapphires differ in color because of the impurities they contain. Rubies are red because of minor amounts of chromium ions, and sapphires are blue because of minor amounts of iron and titanium ions.

CONCEPT **CHECK**
What is the chemical formula for the ionic compound magnesium oxide?

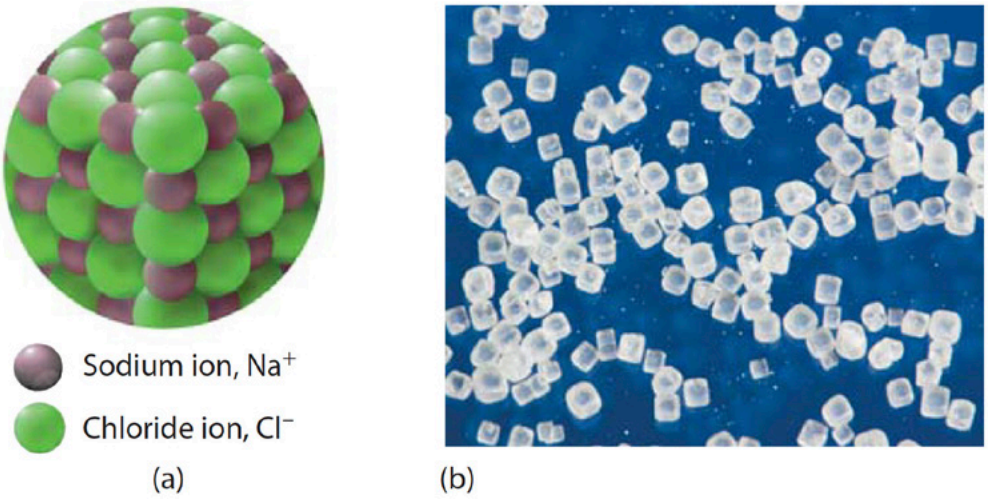
CHECK YOUR ANSWER Because magnesium is a group 2 element, you know a magnesium atom must lose two electrons to form a Mg^{2+} ion. Because oxygen is a group 16 element, an oxygen atom gains two electrons to form an O^{2-} ion. These charges balance in a one-to-one ratio, so the formula for magnesium oxide is MgO.

An ionic compound typically contains a multitude of ions grouped together in a highly ordered 3-dimensional array. In sodium chloride, for example, each sodium ion is surrounded by six chloride ions and each chloride ion is surrounded by six sodium ions (**Figure 6.11**). Overall, there is one sodium ion for each chloride ion, but there are no identifiable sodium–chloride pairs. Such an orderly array of ions is known as an *ionic crystal*. As mentioned at the onset of this chapter, on the atomic level, the crystalline structure of sodium chloride is cubic, which is why macroscopic crystals of table salt are also cubic. Smash a large cubic sodium chloride crystal with a hammer, and what do you get? Smaller cubic sodium chloride crystals! Similarly, the crystalline structures of other ionic compounds, such as calcium fluoride and aluminum oxide, are a consequence of how the ions pack together.



Λ Figure 6.10

Two aluminum atoms lose a total of six electrons to three oxygen atoms. In the process, the aluminum atoms become aluminum ions, Al^{3+}, and the oxygen atoms become oxide ions, O^{2-}. The oppositely charged ions join to form the ionic compound aluminum oxide, Al_2O_3. Certain gemstones are crystalline aluminum oxide with trace amounts of impurities, such as chromium, which makes ruby, and titanium, which makes sapphire.



Λ Figure 6.11

Sodium chloride, as well as other ionic compounds, forms ionic crystals in which every internal ion is surrounded by ions of the opposite charge. (For simplicity, only a small portion of the ion array is shown here. A typical NaCl crystal involves millions and millions of ions.) (b) A view of crystals of table salt through a microscope shows their cubic structure. The cubic shape is a consequence of the cubic arrangement of sodium and chloride ions.