5.6: Predicting Products from Chemical Reactions

Part of the lure of chemistry is that things don't always work out the way you expect. You plan a reaction, anticipate the products and, quite often, the results astound you! The exercise, then, is trying to figure out what was formed, why, and whether your observation leads to other useful generalizations. The first step in this process of discovery is anticipating or predicting the products which are likely to be formed in a given chemical reaction. The guidelines we describe here will accurately predict the products of most classes of simple chemical reactions. As your experience in chemistry grows, however, you will begin to appreciate the unexpected!

In simple **synthesis** reactions involving reaction of elements, such as aluminum metal reacting with chlorine gas, the product will be a simple compound containing both elements. In this case, it is easiest to consider the common charges that the elements adopt as ions and build your product accordingly. Aluminum is a Group III element and will typically form a +3 ion. Chlorine, being Group VII, will accept one electron and form a monoanion. Putting these predictions together, the product is likely to be $\mathbf{AlCl_3}$. In fact, if aluminum metal and chlorine gas are allowed to react, solid $AlCl_3$ is the predominant product.

$$2\,Al\ (s) + 3\,Cl_2\ (g) \rightarrow 2\,AlCl_3\ (s)$$

The **synthesis** reaction involving the non-metals hydrogen gas and bromine can be approached similarly. The product will contain both elements. Hydrogen, Group I, has one valence electron and will form one covalent bond. Bromine, Group VII, has seven valence electrons and will form one covalent bond. The likely product is therefore **HBr**, with one covalent bond between the hydrogen and the bromine.

$$H_2\ (g) + Br_2\ (g) < \rightarrow 2\,HBr\ (g)$$

For a **single-replacement** reaction, recall that (in general) metals will replace metals and non-metals will replace non-metals. For the reaction between lead(IV) chloride and fluorine gas, the fluorine will replace the chlorine, leading to a compound between lead and fluorine and the production of **elemental chlorine**. The lead can be viewed as a "spectator" in the reaction and the product is likely to be **lead(IV) fluoride**. The complete equation is shown below.

$$PbCl_4\ (s) + 2\,F_2\ (g) \rightarrow PbF_4\ (s) + 2\,Cl_2\ (g)$$

In single-replacement reactions in which metals (or carbon or hydrogen) are expected to replace metals, first you should check the activity series to see if any reaction is anticipated. Remember that metals can only replace metals that are *less active* than themselves (to the right in the Table). If the reaction is predicted to occur, use the same general guidelines that we used above. For example, solid iron reacting with aqueous sulfuric acid (H_2SO_4). In this reaction the question is whether iron will displace hydrogen and form hydrogen gas. Consulting the activity series, we see that hydrogen is to the *right* of iron, meaning that the reaction is expected to occur. Next, we reason that iron will replace hydrogen, leading to the formation of iron sulfate, where the sulfate is the "spectator" ion. The formation of hydrogen gas requires a change in oxidation number in the hydrogen of +1 to zero. Two hydrogen atoms must therefore be **reduced** (a *decrease* in oxidation number) and the two electrons required for the reduction must come from the iron. The charge on the iron is therefore most likely to be +2 (it starts off at zero and donates two electrons to the hydrogens). The final product is therefore most likely **iron(II) sulfate**. The complete equation is shown below.

$$Fe\ (s) + H_2SO_4\ (aq) \rightarrow FeSO_4\ (aq) + H_2\ (g)$$

Decomposition reactions are the most difficult to predict, but there are some general trends that are useful. For example, most **metal carbonates** will decompose on heating to yield the **metal oxide** and **carbon dioxide**.

$$NiCO_3\ (s) \rightarrow NiO\ (s) + CO_2\ (g)$$

Metal hydrogen carbonates also decompose on heating to give the **metal carbonate**, **carbon dioxide** and **water**.

$$2\,NaHCO_3\ (s) \rightarrow Na_2CO_3\ (s) + H_2O\ (g) + CO_2\ (g)$$

Finally, many **oxygen-containing compounds** will decompose on heating to yield **oxygen gas** and "other compounds". Identifying these compounds and building an understanding of why and how they are formed is one of the challenges of chemistry. Some examples:

$$H_2O_2\ (aq) \rightarrow O_2\ (g) + H_2O\ (l)$$

$$2\,HgO\ (s) \rightarrow O_2\ (g) + 2\,Hg\ (l)$$

$$2\,KClO_3\ (s) \rightarrow 3\,O_2\ (g) + 2\,KCl\ (s)$$

The potential products in **double-replacement** reactions are simple to predict; the anions and cations simply exchange. Remember, however, that one of the products must **precipitate**, otherwise no chemical reaction has occurred. For the reaction between lead(II) nitrate and potassium iodide, the products are predicted to be lead(II) iodide and potassium nitrate. No redox occurs, and the product, lead iodide, precipitates from the solution as a bright yellow solid. The question of how do you predict this type of solubility trend is addressed in the next section.

$$\mathbf{Pb(NO_3)_2}\ \mathit{(aq)} + \mathbf{2\ KI}\mathit{(aq)} < \rightarrow \mathbf{PbI_2}\ \mathit{(s)} + \mathbf{2\ KNO_3}\ \mathit{(aq)}$$
