5.2: Balancing Chemical Equations

As noted earlier, a *balanced* chemical equation shows the same number of each kind of atom on both sides of the equation. The process of balancing chemical equations is an important exercise in chemistry and is addressed here.

Consider a simple example of balancing a chemical equation, the reaction of methane, CH_4, with elemental chlorine, Cl_2, to produce dichloromethane, CH_2Cl_2, an important laboratory solvent, and byproduct hydrogen chloride, HCl. The unbalanced chemical equation is

$$\mathrm{CH_4 + Cl_2 \rightarrow CH_2Cl_2 + HCl} \tag{5.2.1}$$

Inspection of this equation as it is written shows that it is not balanced because it has 4 H on the left, but just 3 on the right and 2 Cl on the left, but 3 Cl on the right. In order to balance such an equation, consider one element at a time. Carbon is already balanced, so it is best to avoid changing any of the numbers in front of the C-containing compounds. The equation can be balanced for H by putting a 2 in front of HCl:

$$\mathrm{CH_4 + Cl_2 \rightarrow CH_2Cl_2 + 2\,HCl} \tag{5.2.2}$$

Now everything is balanced except for Cl, of which there are 4 on the right, but just 2 on the left.Placing a 2 in front of Cl, gives the required 4 Cls on the left:

$$\mathrm{CH_4 + 2\,Cl_2 \rightarrow CH_2Cl_2 + 2\,HCl} \tag{5.2.3}$$

This equation is now balanced with 1 C, 4 Hs, and 4 Cls on both the left and the right.

A crucial thing to remember in balancing a chemical equation is that *the chemical formulas must not be altered. Only the relative numbers of reactant and product species may be changed.*

Next consider the reaction of methane, CH_4, with iron oxide, Fe_2O_3, to give iron metal, Fe, carbon dioxide, CO_2, and water, H_2O. The unbalanced equation is

$$\mathrm{CH_4 + Fe_2O_3 \rightarrow Fe + CO_2 + H_2O} \tag{5.2.4}$$

In this case it is helpful to note that CH_4 is the only source of both C and H and that 4 times as many H atoms as C atoms must appear in the products. That means that for each CO_2 there must be 2 H_2Os. Both C and H are balanced in the following:

$$\mathrm{CH_4 + Fe_2O_3 \rightarrow Fe + CO_2 + 2\,H_2O} \tag{5.2.5}$$

But now O is not balanced. Furthermore, the 3 Os in Fe_2O_3 means that the number of O atoms must be divisible by 3, so try multiplying the three species balanced so far — CH_4, CO_2, and $2H_2O$ — by 3:

$$\mathrm{3\,CH_4 + Fe_2O_3 \rightarrow Fe + 3\,CO_2 + 6\,H_2O} \tag{5.2.6}$$

That gives a total of 12 O atoms on the right, 6 each in 3 CO_2 and 6 H_2O. Taking 4 times Fe_2O_3 gives 12 Os on the left:

$$\mathrm{3\,CH_4 + 4\,Fe_2O_3 \rightarrow Fe + 3\,CO_2 + 6\,H_2O} \tag{5.2.7}$$

The only species remaining to be balanced is Fe, which can be balanced by putting 8 in front of Fe on the right. The balanced equation is

$$\mathrm{3\,CH_4 + 4\,Fe_2O_3 \rightarrow 8\,Fe + 3\,CO_2 + 6\,H_2O} \tag{5.2.8}$$

Checking the answer shows on both left and right 3 C, 8 Fe, 12 H, and 12 O demonstrating that the equation is in fact balanced.

Exercise: Balance the following:

1. $\mathrm{Fe_2O_3 + CO \rightarrow Fe + CO_2}$
2. $\mathrm{FeSO_4 + O_2 + H_2O \rightarrow Fe(OH)_3 + H_2SO_4}$
3. $\mathrm{C_2H_2 + O_2 \rightarrow CO_2 + H_2O}$
4. $\mathrm{Mg_3N_2 + M_2O \rightarrow Mg(OH)_2 + NH_3}$
5. $\mathrm{NaAlH_4 + H_2O \rightarrow H_2 + NaOH + Al(OH)_3}$

6. $Zn(C_2H_5)_2 + O_2 \rightarrow ZnO + CO_2 + H_2O$

Answers: (1) $Fe_2O_3 + 3\,CO \rightarrow 2\,Fe + 3\,CO_2$, (2) $4\,FeSO_4 + O_2 + 10\,H_2O \rightarrow 4\,Fe(OH)_3 + 4\,H_2SO_4$, (3) $2\,C_2H_2 + 5\,O_2 \rightarrow 4\,CO_2 + 2\,H_2O$, (4) $Mg_3N_2 + 6\,H_2O \rightarrow 3\,Mg(OH)_2 + 2\,NH_3$ (5) $NaAlH_4 + 4\,H_2O \rightarrow 4\,H_2 + NaOH + Al(OH)_3$, (6) $Zn(C_2H_5)_2 + 7\,O_2 \rightarrow ZnO + 4\,CO_2 + 5\,H_2O$