Representing chemical change: Balancing chemical equations*

Free High School Science Texts Project

1 Balancing chemical equations

1.1 The law of conservation of mass

In order to balance a chemical equation, it is important to understand the law of conservation of mass.

Definition 1: The law of conservation of mass
The mass of a closed system of substances will remain constant, regardless of the processes acting inside the system. Matter can change form, but cannot be created or destroyed. For any chemical process in a closed system, the mass of the reactants must equal the mass of the products.

In a chemical equation then, the **mass** of the reactants must be equal to the mass of the products. In order to make sure that this is the case, the number of **atoms** of each element in the reactants must be equal to the number of atoms of those same elements in the products. Some examples are shown below:

Example 1:

$$Fe + S \rightarrow \text{FeS} \tag{1}$$

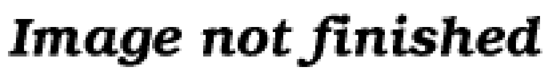

Figure 1

Reactants

Atomic mass of reactants $= 55,8\,u + 32,1\,u = 87,9\,u$

Number of atoms of each element in the reactants: $(1 \times Fe)$ and $(1 \times S)$

Products

Atomic mass of products $= 55,8\,u + 32,1\,u = 87,9\,u$

Number of atoms of each element in the products: $(1 \times Fe)$ and $(1 \times S)$

Since the number of atoms of each element is the same in the reactants and in the products, we say that the equation is **balanced**.

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Example 2:

$$H_2 + O_2 \rightarrow H_2O \tag{2}$$

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Figure 2

Reactants
Atomic mass of reactants $= (1+1) + (16+16) = 34\,u$
Number of atoms of each element in the reactants: $(2 \times H)$ and $(2 \times O)$
Product
Atomic mass of product $= (1+1+16) = 18\,u$
Number of atoms of each element in the product: $(2 \times H)$ and $(1 \times O)$
Since the total atomic mass of the reactants and the products is not the same and since there are more oxygen atoms in the reactants than there are in the product, the equation is **not balanced**.
Example 3:

$$NaOH + HCl \rightarrow NaCl + H_2O \tag{3}$$

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Figure 3

Reactants
Atomic mass of reactants $= (23+6+1) + (1+35,4) = 76,4\,u$
Number of atoms of each element in the reactants: $(1 \times Na) + (1 \times O) + (2 \times H) + (1 \times Cl)$
Products
Atomic mass of products $= (23+35,4) + (1+1+16) = 76,4\,u$
Number of atoms of each element in the products: $(1 \times Na) + (1 \times O) + (2 \times H) + (1 \times Cl)$
Since the number of atoms of each element is the same in the reactants and in the products, we say that the equation is **balanced**.

We now need to find a way to balance those equations that are not balanced so that the number of atoms of each element in the reactants is the same as that for the products. This can be done by changing the **coefficients** of the molecules until the atoms on each side of the arrow are balanced. You will see later that these coefficients tell us something about the **mole ratio** in which substances react. They also tell us about the volume relationship between gases in the reactants and products.

TIP: Coefficients

Remember that if you put a number in front of a molecule, that number applies to the *whole* molecule. For example, if you write $2H_2O$, this means that there are 2 molecules of water. In other words, there are 4 hydrogen atoms and 2 oxygen atoms. If we write 3HCl, this means that there are 3 molecules of HCl. In other words there are 3 hydrogen atoms and 3 chlorine atoms in total. In the first example, 2 is the coefficient and in the second example, 3 is the coefficient.

1.2 Activity: Balancing chemical equations

You will need: coloured balls (or marbles), prestik, a sheet of paper and coloured pens.

We will try to balance the following equation:

$$Al + O_2 \rightarrow Al_2O_3 \quad (4)$$

Take 1 ball of one colour. This represents a molecule of Al. Take two balls of another colour and stick them together. This represents a molecule of O_2. Place these molecules on your left. Now take two balls of one colour and three balls of another colour to form a molecule of Al_2O_3. Place these molecules on your right. On a piece of paper draw coloured circles to represent the balls. Draw a line down the center of the paper to represent the molecules on the left and on the right.

Count the number of balls on the left and the number on the right. Do you have the same number of each colour on both sides? If not the equation is not balanced. How many balls will you have to add to each side to make the number of balls the same? How would you add these balls?

You should find that you need 4 balls of one colour for Al and 3 pairs of balls of another colour (i.e. 6 balls in total) for O_2 on the left side. On the right side you should find that you need 2 clusters of balls for Al_2O_3. We say that the balanced equation is:

$$4Al + 3O_2 \rightarrow 2Al_2O_3 \quad (5)$$

Repeat this process for the following reactions:

- $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
- $2H_2 + O_2 \rightarrow 2H_2O$
- $Zn + 2HCl \rightarrow ZnCl_2 + H_2$

1.3 Steps to balance a chemical equation

When balancing a chemical equation, there are a number of steps that need to be followed.

- STEP 1: Identify the reactants and the products in the reaction and write their chemical formulae.
- STEP 2: Write the equation by putting the reactants on the left of the arrow and the products on the right.
- STEP 3: Count the number of atoms of each element in the reactants and the number of atoms of each element in the products.
- STEP 4: If the equation is not balanced, change the coefficients of the molecules until the number of atoms of each element on either side of the equation balance.
- STEP 5: Check that the atoms are in fact balanced.
- STEP 6 (we will look at this a little later): Add any extra details to the equation e.g. phase.

Exercise 1: Balancing chemical equations 1 ***(Solution on p. 5.)***

Balance the following equation:

$$Mg + HCl \rightarrow MgCl_2 + H_2 \quad (6)$$

Exercise 2: Balancing chemical equations 2 ***(Solution on p. 5.)***

Balance the following equation:

$$CH_4 + O_2 \rightarrow CO_2 + H_2O \quad (7)$$

Exercise 3: Balancing chemical equations 3 *(Solution on p. 5.)*
(Solution on p. 5.)

Nitrogen gas reacts with hydrogen gas to form ammonia. Write a balanced chemical equation for this reaction.

Exercise 4: Balancing chemical equations 4 *(Solution on p. 6.)*

In our bodies, sugar $(C_6H_{12}O_6)$ reacts with the oxygen we breathe in to produce carbon dioxide, water and energy. Write the balanced equation for this reaction.

This simulation allows you to practice balancing simple equations.

Figure 4

run demo[1]

1.3.1 Balancing simple chemical equations

Balance the following equations:

1. Hydrogen fuel cells are extremely important in the development of alternative energy sources. Many of these cells work by reacting hydrogen and oxygen gases together to form water, a reaction which also produces electricity. Balance the following equation: $H_2(g) + O_2(g) \rightarrow H_2O(l)$Click here for the solution[2]
2. The synthesis of ammonia ($\mathrm{NH_3}$), made famous by the German chemist Fritz Haber in the early 20th century, is one of the most important reactions in the chemical industry. Balance the following equation used to produce ammonia: $N_2(g) + H_2(g) \rightarrow NH_3(g)$Click here for the solution[3]
3. $Mg + P_4 \rightarrow Mg_3P_2$ Click here for the solution[4]
4. $Ca + H_2O \rightarrow Ca(OH)_2 + H_2$ Click here for the solution[5]
5. $CuCO_3 + H_2SO_4 \rightarrow CuSO_4 + H_2O + CO_2$ Click here for the solution[6]
6. $CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + NaCl$ Click here for the solution[7]
7. $C_{12}H_{22}O_{11} + O_2 \rightarrow H_2O + CO_2$ Click here for the solution[8]
8. Barium chloride reacts with sulphuric acid to produce barium sulphate and hydrochloric acid. Click here for the solution[9]
9. Ethane (C_2H_6) reacts with oxygen to form carbon dioxide and steam. Click here for the solution[10]
10. Ammonium carbonate is often used as a smelling salt. Balance the following reaction for the decomposition of ammonium carbonate: $(\mathrm{NH_4})_2\mathrm{CO_3}(s) \rightarrow \mathrm{NH_3}(\mathrm{aq}) + \mathrm{CO_2}(g) + H_2O(l)$ Click here for the solution[11]

[1] http://phet.colorado.edu/sims/balancing-chemical-equations/balancing-chemical-equations_en.jnlp
[2] http://www.fhsst.org/lOg
[3] http://www.fhsst.org/lO4
[4] http://www.fhsst.org/lO2
[5] http://www.fhsst.org/lOT
[6] http://www.fhsst.org/lOb
[7] http://www.fhsst.org/lOj
[8] http://www.fhsst.org/lOD
[9] http://www.fhsst.org/lOW
[10] http://www.fhsst.org/lOZ
[11] http://www.fhsst.org/lOB

Solutions to Exercises in this Module

Solution to Exercise (p. 3)

Step 1. Reactants: $Mg = 1$ atom; $H = 1$ atom and $Cl = 1$ atom
Products: $Mg = 1$ atom; $H = 2$ atoms and $Cl = 2$ atoms

Step 2. The equation is not balanced since there are 2 chlorine atoms in the product and only 1 in the reactants. If we add a coefficient of 2 to the HCl to increase the number of H and Cl atoms in the reactants, the equation will look like this:

$$Mg + 2HCl \rightarrow MgCl_2 + H_2 \quad (8)$$

Step 3. If we count the atoms on each side of the equation, we find the following:
Reactants: $Mg = 1$ atom; $H = 2$ atom and $Cl = 2$ atom
Products: $Mg = 1$ atom; $H = 2$ atom and $Cl = 2$ atom
The equation is balanced. The final equation is:

$$Mg + 2HCl \rightarrow MgCl_2 + H_2 \quad (9)$$

Solution to Exercise (p. 3)

Step 1. Reactants: $C = 1$; $H = 4$ and $O = 2$
Products: $C = 1$; $H = 2$ and $O = 3$

Step 2. If we add a coefficient of 2 to H_2O, then the number of hydrogen atoms in the reactants will be 4, which is the same as for the reactants. The equation will be:

$$CH_4 + O_2 \rightarrow CO_2 + 2H_2O \quad (10)$$

Step 3. Reactants: $C = 1$; $H = 4$ and $O = 2$
Products: $C = 1$; $H = 4$ and $O = 4$
You will see that, although the number of *hydrogen* atoms now balances, there are more oxygen atoms in the products. You now need to repeat the previous step. If we put a coefficient of 2 in front of O_2, then we will increase the number of oxygen atoms in the reactants by 2. The new equation is:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \quad (11)$$

When we check the number of atoms again, we find that the number of atoms of each element in the reactants is the same as the number in the products. The equation is now balanced.

Solution to Exercise (p. 3)

Step 1. The reactants are nitrogen (N_2) and hydrogen (H_2) and the product is ammonia (NH_3).

Step 2. The equation is as follows:

$$N_2 + H_2 \rightarrow NH_3 \quad (12)$$

Step 3. Reactants: $N = 2$ and $H = 2$
Products: $N = 1$ and $H = 3$

Step 4. In order to balance the number of nitrogen atoms, we could rewrite the equation as:

$$N_2 + H_2 \rightarrow 2NH_3 \quad (13)$$

Step 5. In the above equation, the nitrogen atoms now balance, but the hydrogen atoms don't (there are 2 hydrogen atoms in the reactants and 6 in the product). If we put a coefficient of 3 in front of the hydrogen (H_2), then the hydrogen atoms and the nitrogen atoms balance. The final equation is:

$$N_2 + 3H_2 \rightarrow 2NH_3 \quad (14)$$

Solution to Exercise (p. 4)

Step 1. Reactants: sugar ($C_6H_{12}O_6$) and oxygen (O_2)
Products: carbon dioxide (CO_2) and water (H_2O)

Step 2.

$$C_6H_{12}O_6 + O_2 \rightarrow CO_2 + H_2O \quad (15)$$

Step 3. Reactants: $C = 6$; $H = 12$ and $O = 8$
Products: $C = 1$; $H = 2$ and $O = 3$

Step 4. It is easier to start with carbon as it only appears once on each side. If we add a 6 in front of CO_2, the equation looks like this:

$$C_6H_{12}O_6 + O_2 \rightarrow 6CO_2 + H_2O \quad (16)$$

Reactants: $C = 6$; $H = 12$ and $O = 8$
Products: $C = 6$; $H = 2$ and $O = 13$

Step 5. Let's try to get the number of hydrogens the same this time.

$$C_6H_{12}O_6 + O_2 \rightarrow 6CO_2 + 6H_2O \quad (17)$$

Reactants: $C = 6$; $H = 12$ and $O = 8$
Products: $C = 6$; $H = 12$ and $O = 18$

Step 6.

$$C_6H_{12}O_6 + 12O_2 \rightarrow 6CO_2 + 6H_2O \quad (18)$$

Reactants: $C = 6$; $H = 12$ and $O = 18$
Products: $C = 6$; $H = 12$ and $O = 18$