Representing chemical change

14

Introduction

ESADY

As we have already mentioned, a number of changes can occur when elements are combined with one another. These changes may either be *physical* or *chemical*. In this chapter we will look at chemical changes. One way of representing chemical changes is through **balanced chemical equations**. A chemical equation describes a chemical reaction by using symbols for the elements involved. For example, if we look at the reaction between iron (Fe) and sulphur (S) to form iron sulphide (FeS), we could represent these changes in a sentence, in a word equation or using chemical symbols:

> **Sentence:** Iron reacts with sulphur to form iron sulphide. **Word equation:** Iron + sulphur $\rightarrow$ iron sulphide. **Chemical symbols:** Fe + S $\rightarrow$ FeS

Another example would be:

> **Sentence:** Ammonia reacts with oxygen to form nitrogen monoxide and water. **Word equation:** Ammonia + oxygen $\rightarrow$ nitrogen monoxide + water. **Chemical symbols:** $4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$

See introductory video: (▶ Video: VPbkm at www.everythingscience.co.za)

Compounds on the left of the arrow are called the **reactants** and these are needed for the reaction to take place. The compounds on the right are called the **products** and these are what is formed from the reaction.

In order to be able to write a balanced chemical equation, there are a number of important things that need to be done:

1. Know the chemical symbols for the elements involved in the reaction
2. Be able to write the chemical formulae for different reactants and products
3. Balance chemical equations by understanding the laws that govern chemical change
4. Know the state symbols for the equation

We will look at each of these steps separately in the next sections.

Chemical symbols ESADZ

It is very important to know the chemical symbols for common elements in the periodic table, so that you are able to write chemical equations and to recognise different compounds.

Activity:	*Revising common chemical symbols*

- Write down the chemical symbols and names of all the elements that you know.
- Compare your list with another learner and add any symbols and names that you don't have.
- Know the symbols for at least the first thirty six elements in the periodic table. You should also learn the symbols for other common elements that are not in the first thirty six.
- Set a short test on naming elements and compounds for someone else in the class and then exchange tests with them so that you each have the chance to answer a test.

Writing chemical formulae ESAEA

A **chemical formula** is a concise way of giving information about the atoms that make up a particular chemical compound. A chemical formula shows each element by its symbol and also shows how many atoms of each element are found in that compound. The number of atoms (if greater than one) is shown as a subscript.

The following exercise serves as revision. If you do not recall how to write chemical formulae refer back to chapter 2.

Exercise 14 - 1

1. Write down the chemical formula for each of the following compounds:

a. iron (III) chloride
b. zinc nitrate
c. aluminium sulphate
d. calcium hydroxide
e. magnesium carbonate
f. the product when carbon reacts with oxygen
g. the product when hydrogen reacts with nitrogen
h. potassium oxide
i. copper (II) bromide
j. potassium dichromate

2. Write down the name for each of the following compounds:

a. SO_2
b. $KMnO_4$
c. $(NH_4)_2SO_4$
d. BaF_2
e. $Cr(HSO_4)_3$
f. CH_4

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(1.) 02u2 (2.) 02u3

Balancing chemical equations

ESAEB

The law of conservation of mass

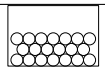
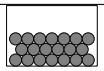
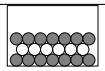
ESAEC

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

DEFINITION: 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 equation (in a closed system) 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. An example is shown below:

<table>
<tr><td colspan="2">   </td><td>  </td></tr>
<tr><td colspan="2">$Fe + S \rightarrow FeS$</td><td></td></tr>
<tr><td>Mass of one atom of Fe is $55,8$</td><td>Mass of one atom of S is $32,1$</td><td>Mass of one atom of FeS is $87,9$</td></tr>
<tr><td colspan="2">Mass of reactants is $87,9$</td><td>Mass of products is $87,9$</td></tr>
</table>

To calculate the **mass of the molecules** we use the relative atomic masses for iron and sulphur, as seen in table 14.2. You will notice that the mass of the reactants equals the mass of the product. A chemical equation that is **balanced** will always reflect the **law of conservation of mass** and the **law of conservation of atoms**.

Tip

Iron is a metal. When we represent it in a balanced chemical equation, we write only Fe. Sulphur occurs as S_8 but we write only the empirical formula: S. We do this for all network structures. Writing formulae like this represents *one unit* of the compound or network structure.

Activity: *Balancing chemical equations*

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

We will try to balance the following equation:

$$Al + O_2 \rightarrow Al_2O_3$$

Take one 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 the first colour and three balls of the second colour to form Al_2O_3. Place this compound on your right. On a piece of paper draw coloured circles to represent the balls. Draw a line down the centre 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 of each colour 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 four balls of the first colour for Al and three pairs of balls of the second colour (i.e. six 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:

$4Al + 3O_2 \rightarrow 2Al_2O_3$ **2.** Use jelly tots and toothpicks to build the following chemical equation. Make sure that your atoms are balanced. Use the same colour jelly tots for the same atoms.

$C + H_2O \rightarrow CO_2 + CO + H_2$

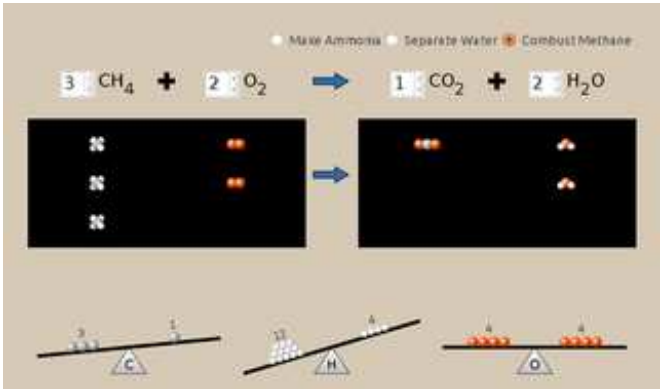
Add compounds until the atoms are balanced. Write the equation down and use a coefficient to indicate how many compounds you used. For example if you had to use three water molecules then write $3H_2O$ **3** Use ball and stick drawings to balance the atoms in the following reaction:

$NH_3 + O_2 \rightarrow NO + H_2O$

Use your drawings to write a balanced chemical equation for the reaction.

4 Lead (Pb), lead (IV) oxide (PbO_2) and sulphuric acid (H_2SO_4) are used in car batteries. The following reaction takes place: $Pb + PbO_2 + H_2SO_4 \rightarrow PbSO_4 + H_2O$

Cut out circles from four different colours of paper to represent each of the atoms. Build a few of the compounds (Pb PbO_2 H_2SO_4). These are the reactants. Do not build the products. Rearrange the atoms so that the products are formed. Add more reactants if needed to balance the atoms (e.g. you will need two H_2SO_4 molecules). Use what you have learnt to write a balanced equation for the reaction.



Steps to balance a chemical equation through inspection

ESAED

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 symbols.

Example 1: *Balancing chemical equations 1*

QUESTION

Balance the following equation:

$$Mg + HCl \rightarrow MgCl_2 + H_2$$

SOLUTION

Step 1 : ***Identify the reactants and products***

This has been done in the question.

Step 2 : ***Write the equation for the reaction***

This has been done in the question.

Step 3 : ***Count the number of atoms of each element in the reactants and products***

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

Step 4 : ***Balance the equation***

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

$$Mg + 2HCl \rightarrow MgCl_2 + H_2$$

Step 5 : ***Check that the atoms are balanced***

If we count the atoms on each side of the equation, we find the following:

Reactants: $Mg = 1;\ H = 2;\ Cl = 2$

Products: $Mg = 1;\ H = 2;\ Cl = 2$

The equation is balanced. The final equation is:

$$Mg + 2HCl \rightarrow MgCl_2 + H_2$$

Example 2: *Balancing chemical equations 2*

QUESTION

Balance the following equation:

$$CH_4 + O_2 \rightarrow CO_2 + H_2O$$

SOLUTION

Step 1 : ***Count the number of atoms of each element in the reactants and products***

Reactants: $C = 1;\ H = 4;\ O = 2$

Products: $C = 1;\ H = 2;\ O = 3$

Step 2 : ***Balance the equation***

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

$$CH_4 + O_2 \rightarrow CO_2 + 2H_2O$$

Step 3 : ***Check that the atoms balance***

Reactants: $C = 1;\ H = 4;\ O = 2$

Products: C $= 1$; H $= 4$; 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:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

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.

Example 3: *Balancing chemical equations 3*

QUESTION

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.

SOLUTION

Step 1 : ***Identify the reactants and products in the reaction.***

Reactants: sugar ($C_6H_{12}O_6$) and oxygen (O_2)

Products: carbon dioxide (CO_2) and water (H_2O)

Step 2 : ***Write the equation***

$C_6H_{12}O_6 + O_2 \rightarrow CO_2 + H_2O$

Step 3 : ***Count the number of atoms of each element in the reactants and in the products***

Reactants: C $= 6$; H $= 12$; O $= 8$

Products: C $= 1$; H $= 2$; O $= 3$

Step 4 : ***Balance the equation***

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:

$C_6H_{12}O_6 + O_2 \rightarrow 6CO_2 + H_2O$

Reactants: C $= 6$; H $= 12$; O $= 8$

Products: C $= 6$; H $= 2$; O $= 13$

Step 5 : ***Change the coefficients again to try to balance the equation.***

Let us try to get the number of hydrogens the same this time.

$C_6H_{12}O_6 + O_2 \rightarrow 6CO_2 + 6H_2O$

Reactants: C $= 6$; H $= 12$; O $= 8$

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

Step 6 : ***Now we just need to balance the oxygen atoms.***

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

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

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

See simulation: (▶ Simulation: VPeea at www.everythingscience.co.za)

Exercise 14 - 2

Balance the following equations:

1. $Mg + O_2 \rightarrow MgO$
2. $Ca + H_2O \rightarrow Ca(OH)_2 + H_2$
3. $CuCO_3 + H_2SO_4 \rightarrow CuSO_4 + H_2O + CO_2$
4. $CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + NaCl$
5. $C_{12}H_{22}O_{11} + O_2 \rightarrow H_2O + CO_2$
6. Barium chloride reacts with sulphuric acid to produce barium sulphate and hydrochloric acid.
7. Ethane (C_2H_6) reacts with oxygen to form carbon dioxide and steam.
8. Ammonium carbonate is often used as a smelling salt. Balance the following reaction for the decomposition of ammonium carbonate: $(NH_4)_2CO_3(s) \rightarrow NH_3(aq) + CO_2(g) + H_2O(\ell)$
9. 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: $H_2(g) + O_2(g) \rightarrow H_2O(\ell)$
10. The synthesis of ammonia (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: $N_2(g) + H_2(g) \rightarrow NH_3(g)$

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(1.) 005g (2.) 005h (3.) 005i (4.) 005j (5.) 005k (6.) 005m

(7.) 005n (8.) 005p (9.) 005q (10.) 005r

State symbols and other information ESAEE

The state (phase) of compounds can be expressed in the chemical equation. This is done by placing the correct label on the right hand side of the formula. The following four labels can be used:

1. (g) for gaseous compounds
2. (ℓ) for liquids
3. (s) for solid compounds
4. (aq) for an aqueous (water) solution

To show that heat is needed for a reaction, a Greek delta (Δ) is placed above the arrow. For example: $NH_4Cl \xrightarrow{\Delta} NH_3 + HCl$

Example 4: *Balancing chemical equations 4*

QUESTION

Solid zinc metal reacts with aqueous hydrochloric acid to form an aqueous solution of zinc chloride ($ZnCl_2$) and hydrogen gas. Write a balanced equation for this reaction.

SOLUTION

Step 1 : ***Identify the reactants and products***

The reactants are zinc (Zn) and hydrochloric acid (HCl). The products are zinc chloride ($ZnCl_2$) and hydrogen (H_2).

Step 2 : ***Write the equation***

$Zn + HCl \rightarrow ZnCl_2 + H_2$

Step 3 : ***Balance the equation***

You will notice that the zinc atoms balance but the chlorine and hydrogen atoms do not. Since there are two chlorine atoms on the right and only one on the left, we will give HCl a coefficient of 2 so that there will be two chlorine atoms on each side of the equation.

$Zn + 2HCl \rightarrow ZnCl_2 + H_2$

Step 4 : ***Check that all the atoms balance***

When you look at the equation again, you will see that all the atoms are now balanced.

Step 5 : ***Ensure all details (e.g. state symbols) are added***

In the initial description, you were told that zinc was a metal, hydrochloric acid and zinc chloride were in aqueous solutions and hydrogen was a gas.

$Zn\ (s) + HCl\ (aq) \rightarrow ZnCl_2(aq) + H_2(g)$

See video: VPemn at www.everythingscience.co.za

Exercise 14 - 3

Write balanced equations for each of the following reactions, include state symbols:

1. Lead (II) nitrate solution reacts with a potassium iodide solution to form a precipitate (solid) of lead iodide while potassium nitrate remains in solution.
2. When heated, aluminium metal reacts with solid copper oxide to produce copper metal and aluminium oxide (Al_2O_3).
3. When calcium chloride solution is mixed with silver nitrate solution, a white precipitate (solid) of silver chloride appears. Calcium nitrate ($Ca(NO_3)_2$) is also produced in the solution.
4. Solid ammonium carbonate decomposes to form three gaseous products.

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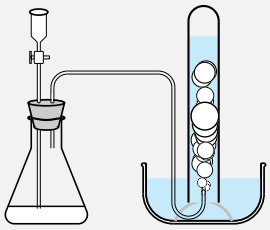
(1.) 00b7 (2.) 00b8 (3.) 00b9 (4.) 00ba

General experiment: *The relationship between product and reactant*

Aim: To investigate the relationship between the amount of product and the amount of reactant.

Apparatus:

- flask
- measuring cylinder
- water bowl
- delivery tube
- funnel with stopcock
- stopper
- sodium hydrogen carbonate ($NaHCO_3$) powder
- dilute sulphuric acid (H_2SO_4)



Method:

1. Weigh 20 g of $NaHCO_3$ and place it into a flask.
2. Set up the above apparatus.
3. Measure out 5 ml of H_2SO_4 and carefully pour this into the funnel (make sure that the stopcock is closed).
4. Slowly add the H_2SO_4 to the $NaHCO_3$ by opening the stopcock.
5. Observe what happens.
6. Record the volume of gas collected in the measuring cylinder.
7. Repeat the above steps but this time use 10 ml of H_2SO_4.
8. Write a balanced equation for this reaction. (Hint: carbon dioxide gas is formed, as well as water and sodium sulphate.)

Results and discussion: You should observe that more gas is formed when using more H_2SO_4.

Chapter 14 | Summary

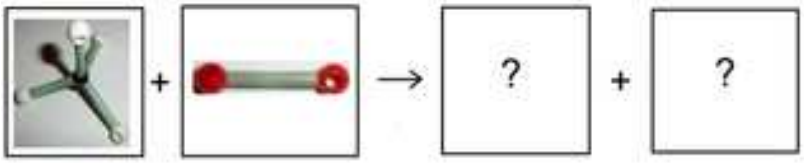
See the summary presentation (▶ Presentation: VPeca at www.everythingscience.co.za)

- A **chemical equation** uses symbols to describe a chemical reaction.
- In a chemical equation, **reactants** are written on the left hand side of the equation and the **products** on the right. The arrow is used to show the direction of the reaction.

- When representing chemical change, it is important to be able to write the **chemical formula** of a compound.
- The law of conservation of mass states that 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.
- In any chemical reaction, the **law of conservation of mass** applies. This means that the total atomic mass of the reactants must be the same as the total atomic mass of the products. This also means that the total number of atoms of the reactants must be the same as the total number of atoms of the product.
- If the number of atoms of each element in the reactants is the same as the number of atoms of each element in the product, then the equation is **balanced**.
- If the number of atoms of each element in the reactants is not the same as the number of atoms of each element in the product, then the equation is **not balanced**.
- In order to balance an equation, **coefficients** can be placed in front of the reactants and products until the number of atoms of each element is the same on both sides of the equation.
- The state of the compounds in a chemical reaction can be expressed in the chemical equation by using one of four symbols. The symbols are g (gas), ℓ (liquid), s (solid) and aq (aqueous solutions). These symbols are written in brackets after the compound.

Chapter 14 End of chapter exercises

1. Propane is a fuel that is commonly used as a heat source for engines and homes. Balance the following equation for the combustion of propane: $C_3H_8(\ell) + O_2(g) \rightarrow CO_2(g) + H_2O(\ell)$
2. Methane (CH_4) burns in oxygen according to the following reaction.



a. Complete the diagrams by drawing ball-and-stick models of the products.

b. Write a balanced chemical equation for the reaction and include state symbols.

3. Chemical weapons were banned by the Geneva Protocol in 1925. According to this protocol, all chemicals that release suffocating and poisonous gases are not to be used as weapons. White phosphorus, a very reactive allotrope of phosphorus, was recently used during a military attack. Phosphorus burns vigorously in oxygen. Many people got severe burns and some died as a result. The equation for this spontaneous reaction is: $P_4\,(s) + O_2\,(g) \rightarrow P_2O_5\,(s)$

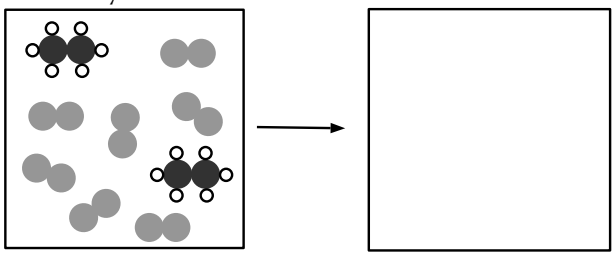
a. Balance the chemical equation.

b. Prove that the law of conservation of mass is obeyed during this chemical reaction.

c. Name the product formed during this reaction.

d. Classify the reaction as a synthesis or decomposition reaction. Give a reason for your answer.

4. The following diagrams represent the combustion of ethane (C_2H_6). Complete the diagrams and write a balanced equation for the reaction. Indicate the state symbols.



5. Balance the following chemical equation:
$N_2O_5 \rightarrow NO_2 + O_2$
Draw submicroscopic diagrams to represent this reaction.

6. Sulphur can be produced by the Claus process. This two-step process involves reacting hydrogen sulphide with oxygen and then reacting the sulphur dioxide that is produced with more hydrogen sulphide. The equations for these two reactions are:

$$H_2S + O_2 \rightarrow SO_2 + H_2O$$
$$H_2S + SO_2 \rightarrow S + H_2O$$

Balance these two equations.

7. Aspartame, an artificial sweetener, has the formula $C_{14}H_{18}N_2O_2$. Write the balanced equation for its combustion (reaction with O_2) to form CO_2 gas, liquid H_2O, and N_2 gas.

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(1.) 005s (2.) 005t (3.) 005u (4.) 005v (5.) 005w (6.) 005x

(7.) 005y