# CHEMICAL REACTIONS

http://www.ric.edu/faculty/ptiskus/reactions/

http://misterguch.brinkster.net/6typesofchemicalrxn.html

http://www.chymist.com/Equations.pdf

**What is a chemical reaction?**

A chemical reaction is the change of a substance into a new one that has a different chemical identity.

**How can I tell if a chemical reaction is occurring?**

A chemical reaction is usually accompanied by easily observed physical effects, such as -

- the emission of heat and light
- the formation of a precipitate
- the evolution of gas
- or a color change

**THE MEANING OF A CHEMICAL EQUATION**

A chemical equation is a chemist's shorthand expression for describing a chemical change. As an example, -consider what takes place when iron rusts. The equation for this change is:

$$Fe + O_2 \rightarrow Fe_2O_3$$

In this expression, the symbols and formulas of the reacting substances, called the reactants, are written on the left side of the arrow and the products of the reaction are written on the right side. The arrow is read as "gives", "yields", or "forms" and the plus (+) sign is read as "and". When the plus (+) sign appears between the formulas for two reactants, it can be read as "reacts with". (The + sign does not imply mathematical addition.) The equation, above, can be read as iron reacts with oxygen to yield (or form) iron(III) oxide.

**BALANCING A CHEMICAL EQUATION**

As it is written, the equation indicates in a qualitative way what substances are consumed in the reaction and what new substances are formed. In order to have quantitative information about the reaction, the equation must be balanced so that it conforms to the Law of Conservation of Matter. That is, there must be the same number of atoms of each element on the right hand side of the equation as there are on the left hand side.

If the number of atoms of each element in the equation above are counted, it is observed that there are 1 atom of Fe and 2 atoms of O on the left side and 2 atoms Fe and 3 atoms of O on the right.

| | | |
|---|---|---|
| $Fe + O_2$ | $\rightarrow$ | $Fe_2O_3$ |
| Left side | : | Right side |
| 1 atom Fe | | 2 atoms Fe |
| 2 atoms O | | 3 atoms O |

The balancing of the equation is accomplished by introducing the proper number or coefficient before each formula.
To balance the number of O atoms, write a 3 in from of the $O_2$ and a 2 in front of the $Fe_2O_3$

$$Fe + 3\ O_2 \rightarrow 2\ Fe_2O_3$$

The equation, above, now has 6 atoms of O on each side, but the Fe atoms are not balanced. Since there is 1 atom of Fe on the left and 4 atoms of Fe on the right, the Fe atoms can be balanced by writing a 4 in front of the Fe

$$4\ Fe + 3\ O_2 \rightarrow 2Fe_2O_3$$

This equation is now balanced. It contains 4 atoms of Fe and 6 atoms of O on each side of the equation. The equation is interpreted to mean that 4 atoms of Fe will reaction with 3 molecules of $O_2$ to form 2 molecules of $Fe_2O_3$
It is important to note that the balancing of an equation is accomplished by placing numbers in front of the proper atoms or molecules and not as subscripts. In an equation, all chemical species appear as correct formula units. The addition (or change) of a subscript changes the meaning of the formula unit and of the equation. Coefficients in front of a formula unit multiply that entire formula unit.

# Types of chemical reactions

There are many different types of chemical reactions. Chemists have classified the many different reactions into general categories.

**<u>1] Synthesis/Combination Reaction</u>**

In a synthesis/combination reaction, two or more substances combine to form a new compound. This type of
reaction is represented by the following equation.

A + B -------------> AB
reactants product

A and B represent the reacting elements or compounds while AB represents a compound as the product. The following examples are representative of synthesis reactions.

One example of a synthesis reaction is the combination of iron and sulfur to form iron (II) sulfide:

$$8\ Fe + S_8 \text{--->} 8\ FeS$$

**2] Decomposition Reaction**

In a decomposition reaction, single compound undergoes a reaction that produces two or more simpler substances. A decomposition reaction can be represented by the following equation.

AB ----------> A + B

One example of a decomposition reaction is the electrolysis of water to make oxygen and hydrogen gas:

$$2\ H_2O \text{ ---> } 2\ H_2 + O_2$$

**3] Single-displacement Reaction**

In a single-displacement reaction one element replaces a similar element in the compound. Single-displacement reactions can be represented by the following equations.

AB + C -------------> AC + B

One example of a single displacement reaction is when magnesium replaces hydrogen in water to make magnesium hydroxide and hydrogen gas:

$$Mg + 2\ H_2O \text{ ---> } Mg(OH)_2 + H_2$$

**4] Double-displacement Reaction**

In a double-displacement reaction, the ions of two compounds exchange places in an aqueous solution to form two new compounds. A double-displacement reaction can be represented by the following equation.

AB + CD ------------> AC + BD

One example of a double displacement reaction is the reaction of lead (II) nitrate with potassium iodide to form lead (II) iodide and potassium nitrate:

$$Pb(NO_3)_2 + 2\ KI \text{ ---> } PbI_2 + 2\ KNO_3$$

**5] Combustion Reaction**

In a combustion reaction, a substance combines with oxygen, releasing a large amount of energy in the form of light and heat. For organic compounds, such as hydrocarbons, the products of the combustion reaction are carbon dioxide and water.

$$CH_4 + 2O_2 \text{ ---------------------> } CO_2 + 2H_2O$$

List what type the following reactions are:

1) $NaOH + KNO_3$ --> $NaNO_3 + KOH$
2) $CH_4 + 2O_2$ --> $CO_2 + 2H_2O$
3) 2 Fe + 6 NaBr --> 2 $FeBr_3$ + 6 Na
4) $CaSO_4 + Mg(OH)_2$ --> $Ca(OH)_2 + MgSO_4$
5) Pb + $O_2$ --> $PbO_2$
6) $Na_2CO_3$ --> $Na_2O + CO_2$

Classify the following chemical reactions and balance them.

1. $KNO_3$ ----> $KNO_2 + O_2$

2. 2 $C_2H_2$ + 5 $O_2$ -----> 4 $CO_2$ + 2 $H_2O$

3. $C_4H_8$ + 6 $O_2$ ----> 4 $CO_2$ + 4 $H_2O$

4. Hg + $O_2$ ----> HgO

5. $AgNO_3$ + NaCl ----> AgCl + $NaNO_3$

6. Zn + $H_2SO_4$ -----> $ZnSO_4$ + $H_2$

7. $H_2CO_3$ -----> $CO_2$ + $H_2O$

8. $CaCO_3$ + HCl ------> $CaCl_2$ + $H_2CO_3$

9. $AgNO_3$ + Zn -----> Zn $(NO_3)_2$ + Ag

10. $C_3H_8$ + $O_2$ -----> $CO_2$ + $H_2O$

# Unit 3.1 Chemical reactions

## context

Chemical reactions are occurring constantly inside us, around us, in the soil, in the sea, in the air and throughout the universe—absolutely everywhere! A chemical reaction is taking place whenever fireworks explode, iron rusts or you digest food. However, not all chemical reactions are obvious. Scientists must look for certain signs to tell them when a reaction is taking place.

**Fig 3.1.1** Explosions are chemical reactions that happen incredibly quickly, releasing large quantities of heat and light energy.

## Physical change

PP Quick Quiz

There are many cases where a substance changes the way it looks, feels or behaves, even when no chemical change has taken place. If no new substance is formed during the change, then the process is classified as a **physical change**. When you break a plate, you have changed the way the plate looks but you have not created any new substance. This then is a physical change. It is important to be able to identify physical changes to distinguish them from chemical changes.

Physical changes are happening whenever:

- materials or objects are broken or crushed into smaller pieces
- changes of state happen. A physical change is happening, for example, when a solid melts to form a liquid, or when a liquid boils to form a gas
- a mixture is created by mixing different materials together without them reacting
- something is dissolved in a liquid. For example, the characteristics of sugar change when it is dissolved in water. The characteristics of the water change too. No new substance has been formed, however, and you can still taste the sugar and can easily get it back by evaporating off the water. Dissolving one material in another creates a mixture known as a solution
- mixtures are separated, such as when sand is filtered from water or fresh water is distilled from seawater.

**Fig 3.1.2** Melting is a physical change. When ice cubes melt, the solid water forms liquid water. Although both solid and liquid water behave differently, no new substance has formed.

## Chemical change

The key difference between a physical change and a **chemical change** is that new substances are formed in a chemical change. When a chemical change occurs, scientists say that a **chemical reaction** has taken place.

Chemical changes happen regularly in everyday life. For example, it's difficult to eat a lump of raw dough. Cook it, however, and the dough changes into a new substance called bread. By heating the dough in the oven, you have caused a chemical reaction to occur. Anywhere you see a new substance being produced, you can be sure that there has been a chemical change—whether it is cooking meat, letting an apple turn brown in the sun or leaving iron to rust in the rain.

Chemical reactions are happening whenever:

- food is cooked
- fruit and vegetables ripen
- something that was living rots and decays
- something is burnt
- something explodes
- a metal corrodes.

PP Animation

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**Science Clip**

**Chemical reactions are all around you!**

When you strike a match, you are setting off several chemical reactions that you can detect with your senses. As the match is burning you can see energy being emitted as light, feel the heat energy being emitted and smell new gases being produced. Once the match has burnt, you are left with a black piece of charcoal, which is very different from what you started with. All of these are signs that a chemical reaction is taking place.

Cooking involves chemical reactions to make the substances more palatable and softer and making them easier to digest.

Rusting happens because of a slow chemical reaction in which iron reacts with water and the oxygen in the air to form a completely new substance called rust. Rust contains iron but is very different from it. Iron is hard and grey while rust is orange and flaky.

**Fig 3.1.3** Chemical changes happen regularly in everyday life.

# Chemical equations

Chemists write **chemical equations** to show and explain what is happening in a chemical reaction. Chemical equations are useful because they provide a quick and easy way to represent complex reactions.

## Word equations

The simplest form of chemical equation is a **word equation**. Word equations represent chemical reactions by using the full names of all the chemicals involved. Word equations take this general form:

substance A + substance B → substance C + substance D

In this word equation, substance A reacts with substance B to produce substances C and D. Substances A and B are known as the **reactants** and substances C and D are known as the **products**. This can be expressed even more generally using another word equation:

reactants → products

Consider, for example, the reaction between magnesium and copper oxide. This reaction produces copper and magnesium oxide and so can be written as the word equation:

magnesium + copper oxide → copper + magnesium oxide

reactants → products

## Using formulae

A chemical equation tells you even more information if it includes the element symbols and chemical formulae of all the substances involved. In the above reaction, for example, the reactants are magnesium (symbol Mg) and copper oxide (formula CuO). The products are copper (Cu) and magnesium oxide (MgO).

The reaction can therefore be written as:

$$Mg + CuO \rightarrow Cu + MgO$$

## Solid, liquid, gas or aqueous?

A chemical equation is even more useful to chemists if they know whether the reactants and products are solids, liquids, gases or **aqueous**, meaning that the chemical has been dissolved in water to make an aqueous solution.

To make this clear in the chemical equation, chemists use the labels (s) for solid, (l) for liquid, (g) for gas and (aq) for aqueous, usually presented as subscripts written just below the chemical they are referring to. In the above equation, for example, all the substances are solid. The chemical equation then is best written as:

$$Mg_{(s)} + CuO_{(s)} \rightarrow Cu_{(s)} + MgO_{(s)}$$

**Fig 3.1.4** The reaction of magnesium and copper oxide is spectacular.

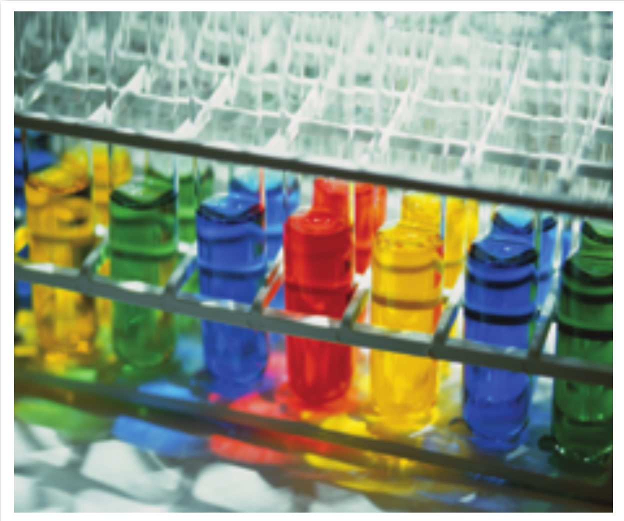

**Fig 3.1.5** A colour change is a sign that a chemical reaction is taking place. Indicators are weak acids or bases that change colour because of the strength of another acid or base.

As another example, consider what happens when a solution of sulfuric acid reacts with solid sodium carbonate. Liquid water, carbon dioxide gas and a solution of sodium sulfate are produced. This can be written simply using the word equation:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| sulfuric acid (aq) | + | sodium carbonate (s) | → | water (l) | + | carbon dioxide (g) | + | sodium sulfate (aq) |

The whole equation can be written to give even more information by using chemical formulae instead of the full name of each chemical. Using chemical formulae, the equation becomes:

$$H_2SO_{4\,(aq)} + Na_2CO_{3(s)} \rightarrow H_2O_{(l)} + CO_{2(g)} + Na_2SO_{4(aq)}$$

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PP Animation

## Signs of chemical change

There are several signs that indicate whether a chemical reaction has occurred. A chemical reaction has definitely occurred if one or more of the following is observed.

### Permanent colour change

A permanent change in colour is an indication that a chemical reaction has taken place. For example, if you bleach your hair with peroxide, toast bread to make it brown (or black!) or fry an egg to make it white.

### A gas is given off

If a reaction is taking place in a liquid, it is very easy to see a gas being produced because bubbling will be observed. With other reactions it can be more difficult to see the gas because most gases, like oxygen, hydrogen, nitrogen and carbon dioxide, are colourless and odourless.

**Fig 3.1.6** Bubbles in a liquid or solution are an indication that a chemical reaction is happening. Here hydrogen gas is bubbling out of a reaction between magnesium metal and hydrochloric acid.

**Science Clip**

**Carbon monoxide poisoning**

Carbon monoxide (chemical formula CO) is a deadly gas emitted by cars. It is produced when carbon-based fuels like petrol burn in a limited supply of oxygen. Haemoglobin is the molecule in red blood cells that transports oxygen around your body. Carbon monoxide, which is odourless and colourless, is extremely toxic because it binds to haemoglobin 200 times more strongly than oxygen does. This leaves no space for the oxygen, so your cells quickly become starved of oxygen and die … and so do you!

### A precipitate forms

A **solution** is made up of a **solute** (the substance that dissolves) and a **solvent** (the liquid that the solute dissolves in). A salt solution, for example, is made when solid sodium chloride (table salt NaCl) is dissolved in water ($H_2O$). Solutions are always clear, although they can be coloured.

Sometimes a **precipitate** forms when two solutions are mixed. A precipitate is an insoluble substance. It does not dissolve in water and first appears as cloudiness in the solution. If the solid precipitate particles are

**Fig 3.1.7** Lead iodide precipitate is a distinctive yellow colour.

**Fig 3.1.8** This baby mouse has been genetically modified to glow. A gene from a naturally bioluminescent jellyfish was inserted into the egg from which the mouse developed. The release of energy is an indication that a chemical reaction is happening.

heavy enough then they will sink to the bottom of the solution. The appearance of a precipitate is an indication that a chemical reaction has occurred.

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### Energy is produced or absorbed

Many chemical reactions produce or absorb energy in the form of heat, light or sound.

Reactions that absorb energy are called **endothermic**. The general equation for an endothermic reaction can be written as:

reactants + energy → products

If an endothermic reaction occurs in a test tube, you will feel the test tube getting colder because the reaction is absorbing the heat energy from its surroundings. Chemical cold packs, for example, work by absorbing heat from injuries and therefore work using an endothermic process.

Photosynthesis is one endothermic chemical reaction that is vital to life on Earth. Plants contain a green dye called chlorophyll that absorbs energy from the Sun. Without this energy, the reaction of photosynthesis doesn't happen. The overall chemical equation for the photosynthesis reaction can be written as a word equation:

carbon dioxide + water + energy → glucose + oxygen

or an unbalanced chemical equation:

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

Reactions that produce energy such as heat or light are known as exothermic. The general word equation for an **exothermic** reaction is:

reactants → products + energy

Heat is generated when fossil fuels such as petrol, oil and coal are burnt. These are examples of exothermic reactions. The heat produced can be converted into other forms of energy and then used to do things like make cars move, produce electricity in power stations and heat your home.

The burning of magnesium ribbon is an exothermic reaction that releases both heat and light energy. The word equation for this reaction is:

magnesium + oxygen → magnesium oxide + energy

It can also be written as an unbalanced chemical equation:

$$Mg + O_2 \rightarrow MgO + \text{energy}$$

PP Drag-and-drop

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## Why do chemical reactions occur?

Most chemical reactions need some energy before they can occur. For example, a sparkler lit for a birthday party needs a flame to get it going. It then keeps burning until all of the chemicals have reacted.

For some reactions, the energy needed to get them started is very small and so they occur on their own, simply by taking the heat energy from the environment. Rusting of iron is an example of a chemical reaction that occurs (slowly) without the need for any extra energy. Chemical reactions that can proceed by themselves, like rusting, are known as **spontaneous** reactions. The sparkler reaction is also classified as spontaneous because the reaction keeps going once it has been started. It needs no more energy to keep it going.

Other reactions need a continual energy input to keep them going. The electrolysis of water splits water into hydrogen and oxygen gases. This reaction needs a continuous electric current for it to continue. Stop the current and the reaction stops too. These reactions are known as **non-spontaneous** reactions.

# Unit 3.2 Combination, combustion and decomposition

**context** Although each substance is unique, similar substances behave in a similar way in chemical reactions. This allows chemists to classify reactions into several general categories. Combination, combustion and decomposition reactions are three general classes of chemical reactions that occur when chemicals combine or break apart to form new substances.

**Fig 3.2.1** A bushfire is a combustion reaction in which timber, leaves and grass burn in oxygen. The most obvious product is the black carbon and charcoal that the fire leaves in its path. The reaction is highly exothermic, releasing heat and light energy.

## Combination reactions

In **combination reactions**, different substances combine to form just one new substance. These reactions have the general equation:

$$x + y \rightarrow xy$$

For example, carbon and oxygen combine to form carbon dioxide. This is shown as a word equation:

carbon + oxygen → carbon dioxide

A chemical equation:

$$C + O_2 \rightarrow CO_2$$

$O_2$ is used instead of just O because the oxygen in the air around us exists as pairs of atoms known as diatomic molecules. **Diatomic** means that two oxygen atoms bond together to form a stable molecule.

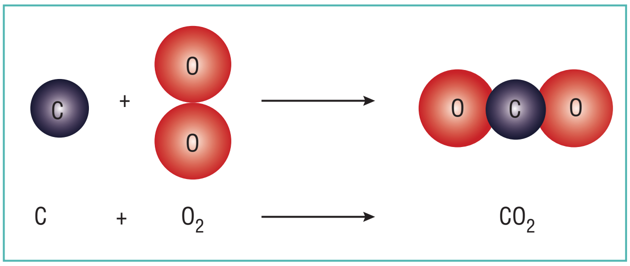


**Fig 3.2.2** One atom of carbon combines with one molecule of oxygen to form one molecule of carbon dioxide.

PP Video Clip

## Combustion reactions

Ever since the first cave dwellers learnt to use fire, people have been using combustion reactions to keep warm, to cook food, to give light, to scare off wild animals and to forge metals into tools and weapons.

A **combustion reaction** is simply burning a substance in oxygen. This means that oxygen gas ($O_2$) is always a reactant. The products will vary, depending on the substance that is burnt.

Compare two gases, methane ($CH_4$) and ethane ($C_2H_6$). Both burn in oxygen in a very similar way, giving out lots of heat in an exothermic combustion reaction.

Word equations:

methane (g) + oxygen (g) → carbon dioxide (g) + water (g)

ethane (g) + oxygen (g) → carbon dioxide (g) + water (g)

Unbalanced chemical equations:

$$CH_{4(g)} + O_{2(g)} \rightarrow CO_{2(g)} + H_2O_{(g)}$$

$$C_2H_{6(g)} + O_{2(g)} \rightarrow CO_{2(g)} + H_2O_{(g)}$$

Balanced chemical equations:

$$CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(g)}$$

$$2C_2H_{6(g)} + 7O_{2(g)} \rightarrow 4CO_{2(g)} + 6H_2O_{(g)}$$

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Science Clip

### How a bullet works

A combustion reaction occurs when a bullet is fired. The combustion of the chemical propellant in the bullet case produces a gas which expands and forces the bullet out of the barrel at great speed.

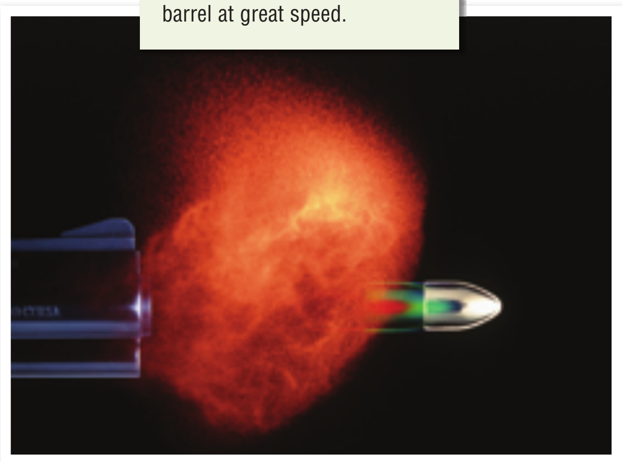

**Fig 3.2.3** The combustion of a chemical propellant forces a bullet from a barrel.

**Fig 3.2.4** Magnesium burns in oxygen and releases intense light that is dangerous to look at. This reaction is both a combustion reaction (involving oxygen) and a combination reaction (combining Mg and $O_2$).

Reactions can sometimes fall into more than one general category. Combustion reactions, for example, can also be combination reactions. Magnesium oxide is produced when you burn magnesium metal in oxygen. Its equation can be written as follows.

A word equation:

magnesium + oxygen → magnesium oxide

An unbalanced chemical equation:

$$Mg_{(s)} + O_{2(g)} \rightarrow MgO_{(s)}$$

A balanced chemical equation:

$$2Mg_{(s)} + O_{2(g)} \rightarrow 2MgO_{(s)}$$

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## Decomposition reactions

The term **decomposition** is often used to describe the rotting of animal or plant matter caused by bacteria and exposure to air. Chemists, however, use the word decomposition to describe a specific set of chemical reactions.

**Decomposition reactions** are the opposite of combination reactions. One substance breaks down to form two or more new substances. The general equation for decomposition reactions can be written:

$$xy \rightarrow x + y$$

For example, household bleach or hydrogen peroxide ($H_2O_2$) spontaneously decomposes to form oxygen gas and water. The equation for this reaction is written as follows.

A word equation:

hydrogen peroxide (l) → oxygen (g) + water (l)

An unbalanced chemical equation:

$$H_2O_{2(aq)} \rightarrow O_{2(g)} + H_2O_{(l)}$$

A balanced chemical equation:

$$2H_2O_{2(aq)} \rightarrow O_{2(g)} + 2H_2O_{(l)}$$

Science Clip

### Phlogiston

Before scientists learnt about the chemistry of combustion, many thought that substances only burned because they contained an imaginary element called phlogiston. They believed that when a substance was burned, its phlogiston was released into the atmosphere. Only the ashes would be left behind. When magnesium ribbon is burnt, its ash is heavier than the metal ribbon it started as. This indicates that the magnesium metal must be gaining something from the air rather than losing phlogiston. These observations suggest that the phlogiston theory was incorrect!

**Fig 3.2.5** Carbonic acid ($H_2CO_3$) decomposes spontaneously over time to form carbon dioxide and water. This reaction is what puts the fizz in soft drinks: $H_2CO_{3(aq)} \rightarrow H_20_{(l)} + CO_{2(g)}$.

## Thermal decomposition

Decomposition reactions are usually endothermic and as such can be enhanced by adding heat to them.

**Thermolysis reactions** are a special type of decomposition reaction. In these reactions, heat causes a reactant to break up into two or more products. The **decomposition temperature** of a substance is the temperature at which the substance decomposes into two or more components.

Calcium carbonate, for example, decomposes at temperatures above 825°C into calcium oxide and carbon dioxide. The reaction for this is written as:

calcium carbonate (s) + heat → calcium oxide (s) + carbon dioxide (g)

$$CaCO_{3(s)} + heat \rightarrow CaO_{(s)} + CO_{2(s)}$$

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### Science Clip

**Airbags**

It's hard to believe that a decomposition reaction saves lives every day! Inside the airbag in a car is a chemical, sodium azide, which decomposes explosively when triggered into sodium and nitrogen. Amazingly, 100 grams of sodium azide forms about 56 litres of nitrogen in 0.03 seconds which then inflates the airbag. The chemical equation for the reaction is as follows.

Word equation:

sodium azide (s) → sodium (s) + nitrogen (g)

Unbalanced chemical equation:

$$NaN_{3(s)} \rightarrow Na_{(s)} + N_{2(g)}$$

Balanced chemical equation:

$$2NaN_{3(s)} + 2Na_{(s)} + 3N_{2(g)}$$

PP Video Clip


**Fig 3.2.6** The deployment of an airbag during a crash is caused by a decomposition reaction.

### Science Clip

**In hot water**

Even water decomposes into its components hydrogen and oxygen when heated to well over 2000°C.