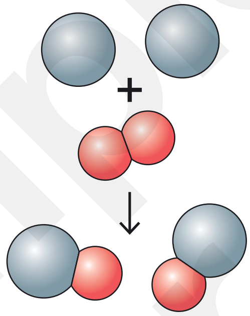
Reactions
Chemical energy *and* Types of reaction

Ideas you have met before

Changes in chemical reactions

Chemical reactions occur when the atoms of reactants are rearranged to form new products. Word equations and balanced symbol equations summarise the changes involved. Mass is conserved in all chemical changes.

Many chemical reactions, such as combustion, transfer energy as heat and light.



Burning

Burning materials (such as wood, wax and gas) produces new materials.

Burning is a chemical change. Burning is also known as combustion.

Physical and chemical changes

Melting ice is reversible. We can put water into a freezer and produce ice again. This is a physical change.

Some changes are not reversible. These are called chemical changes. Making toast is a chemical change; you can't change toast back into the bread it was made from.

In this chapter you will find out

Reaction energy and catalysts

- Some reactions transfer energy to their surroundings – these are known as exothermic reactions. Other reactions take in energy from their surroundings – these are known as endothermic reactions. Photosynthesis is the most common endothermic reaction.
- Catalysts are substances that can speed up or slow down a reaction. Enzymes are examples of biological catalysts.

Combustion and thermal decomposition

- We can control combustion by understanding what is needed for substances to burn.
- Combustion changes the atmosphere because of the new products that are formed.
- Air pollution from combustion can cause rain to become acidic and cause environmental problems.
- Thermal decomposition reactions happen when substances break down to simpler products when they are heated.

Reactions

- Chemical elements can join together in many ways to produce an amazing range of different substances.
- The Law of Conservation of Mass states that mass is never lost or gained in chemical reactions.

Understanding exothermic reactions

We are learning how to:

- Describe examples of exothermic reations.
- Explain the energy changes taking place during an exothermic reaction.

Many chemical changes result in a very obvious energy change. Fireworks, burning candles and burning fuels are common examples of exothermic reactions.

Examples of exothermic reactions

Energy changes occur in all chemical reactions. In some reactions there is a very clear energy change, with the transfer of energy by heat, light and sometimes sound to the surroundings. These are **exothermic reactions** – exothermic means 'to give out heat'. Exothermic reactions can be recognised because the temperature of the products is higher than the temperature of the reactants. The bigger the temperature rise, the more exothermic the reaction.

FIGURE 2.6.1a: Burning candles and fireworks are examples of exothermic reactions.

Some examples are:

- Adding strong bases or reactive metals to strong acids, causes the temperature to increase dramatically.
- The reaction between iron wool and oxygen – a type of hand-warmer – makes use of the heat produced.
- Adding calcium oxide (quicklime) to a bath of cold water, produces such an exothermic reaction that the cold water boils after about ten minutes!
- In the thermit reaction, aluminium powder reacts with iron oxide using a magnesium fuse – aluminium is more reactive than iron, displacing it to produce iron metal. The reaction is highly exothermic, and the heat produced melts the iron.

Did you know...?

Respiration is an exothermic process, releasing energy from glucose and oxygen in a form that our cells can use.

FIGURE 2.6.1b: The thermit reaction is useful in repairing or joining together railway tracks. The extreme heat melts the iron, which then runs into any cracks and fills them.

1. Which reaction is the more exothermic – adding calcium oxide to water or the thermit reaction? Give a reason for your answer.
2. Describe an exothermic reaction in which the main energy transfer is by sound.

Why are some reactions exothermic?

During all chemical changes, the reactant particles undergo collisions. During a collision, energy is absorbed from the surroundings to break **chemical bonds** within the reactant particles. Once all the bonds have broken down, the reactant atoms are now free to form bonds with other reactant atoms and make new products. During the formation of new bonds energy is transferred to the surroundings, usually in the form of heat.

If the energy transferred to the surroundings during the **bond-making** process is higher than the energy absorbed during the **bond-breaking** process, the reaction is exothermic.

3. Explain, using ideas about particles and atoms, why burning magnesium is an exothermic change.
4. What is happening if there is no overall energy change during a chemical reaction?

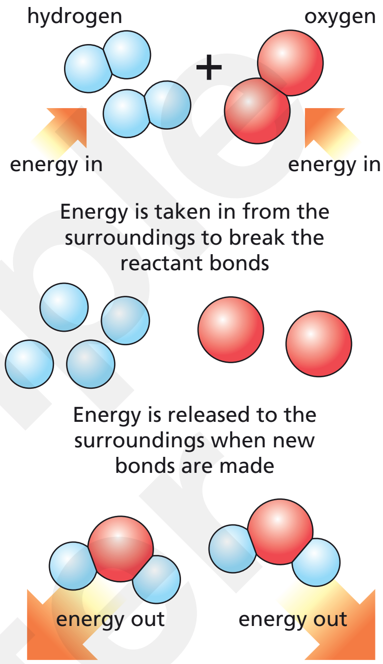


FIGURE 2.6.1c: Bond-making and bond-breaking processes occur when hydrogen is burned.

Energy diagrams for reactions

Figure 2.6.1d shows how the energy of the reactants and products changes during an exothermic reaction. As you can see, the products are always at a lower energy compared to the reactants. The difference in energy has been transferred to the surroundings. Remember the Law of Conservation of Energy – the total energy must always be the same.

$$\text{energy of reactants} - \text{energy of products} = \text{energy transferred}$$

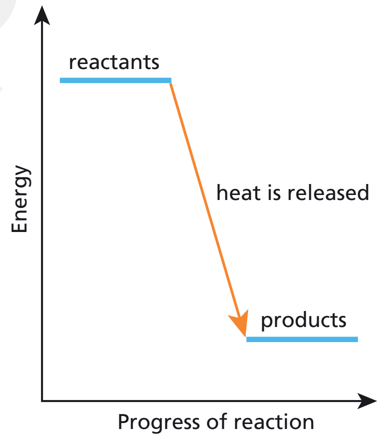


FIGURE 2.6.1d: Energy levels of reactants and products during an exothermic reaction.

5. Sketch two separate energy-level diagrams to compare the following two reactions:
   a) a neutralisation reaction, in which the temperature difference between the reactants and products is 10 °C up or down
   b) the thermit reaction.

Know this vocabulary

exothermic reaction
chemical bond
bond making
bond breaking

Comparing endothermic and exothermic changes

We are learning how to:

- Describe examples of endothermic reactions.
- Explain the energy changes taking place during an endothermic reaction.

Energy is given out in an exothermic change. What do you think will happen in an endothermic change?

FIGURE 2.6.2a: The most important endothermic reaction for life is photosynthesis. More energy is absorbed by plants from the Sun than is given out when glucose and oxygen are made.

Describing endothermic changes

In an **endothermic reaction** more energy is absorbed than is given out. Endothermic means 'to take in heat'. This results in a reaction in which the temperature is seen to fall as the reaction proceeds. These reactions are not very common, but have some useful applications.

When some salts like potassium chloride, ammonium chloride and ammonium nitrate are dissolved in water, the temperature decreases. Cold packs make use of this.

1. Why is there a drop in temperature during an endothermic change?
2. Would an endothermic change occur faster or slower in a very cold environment?

FIGURE 2.6.2b: When an ammonium salt is dissolved in water, the temperature drop is enough for ice to form on the outside of the flask.

Energy changes

Figure 2.6.2c shows energy diagrams for an exothermic change and an endothermic change. The energy of the products in the endothermic change is at a higher level than the energy of the reactants. The 'extra' energy comes from the surroundings, causing a cooling effect.

3. Draw a table summarising the differences between exothermic changes and endothermic changes. Include one example of each in your table.
4. The endothermic reaction between barium hydroxide crystals and ammonium chloride can produce a temperature drop to –20 °C in about 5 minutes. This is a much greater temperature drop than in the reaction between ammonium salts in water, used in cold packs and shown in Figure 2.6.2b. Sketch a graph to compare the energy changes in these two processes.

Did you know…?

It is estimated that about 4×10^{16} kJ of energy are absorbed by plants every year during photosynthesis. This is six times more than the amount used by the human race in a year.

Explaining endothermic changes

The reason why some reactions are endothermic relates to bond-making and bond-breaking. If the energy absorbed from the surroundings to break the reactant bonds is higher than the energy released on forming new product bonds, the process is endothermic. This results in a decrease in temperature. By calculating the difference between the energy needed to break bonds and that released on making bonds, you can determine if a reaction is exothermic or endothermic.

Some endothermic processes are physical changes. When salts dissolve in water, energy is needed from the surroundings to break the bonds between the solute particles. A smaller amount of energy is released when new attractions are formed between the solute and the solvent particles. Other endothermic physical processes include melting ice and evaporating water.

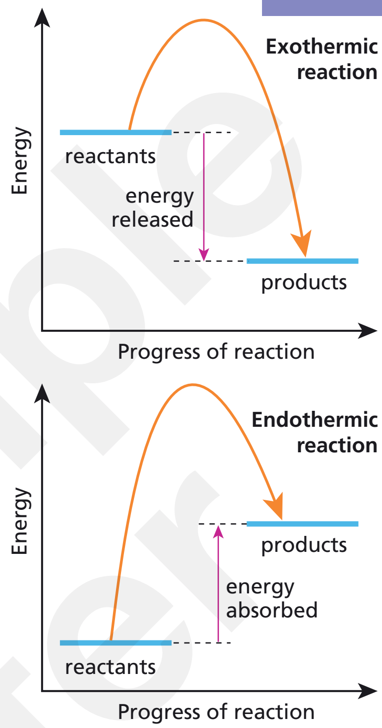


FIGURE 2.6.2c: Energy-level diagrams for exothermic and endothermic reactions.

5. Use the data in Table 2.6.2 to determine whether the reactions are exothermic or endothermic.

6. Why do you think some bonds are harder to break than others?

TABLE 2.6.2: Bond energies involved in different reactions.

Reaction	Energy to break reactant bonds (kJ/mol)	Energy released in making product bonds (kJ/mol)
a) between carbon and oxygen to make carbon dioxide	1213	1606
b) between hydrogen and chlorine to make hydrogen chloride	678	862
c) between nitrogen and hydrogen to make ammonia (NH_3)	2252	2328
d) decomposition of hydrogen bromide to make hydrogen and bromine	732	629

Know this vocabulary

endothermic reaction

Investigating endothermic reactions

We are learning how to:

- Choose a suitable range and interval of values in an investigation.
- Consider how to present data to make conclusions.

Instant cold packs are commonly used to treat sports injuries to reduce inflammation and pain. How do these work and what would make the best cold pack?

FIGURE 2.6.3a: Using an endothermic reaction to treat a sports injury.

The science behind a cold pack

An instant cold pack relies on an endothermic reaction. Each pack contains water and ammonium nitrate in sealed, separate chambers. Squeezing the bag causes the water and ammonium nitrate to mix. The ammonium nitrate dissolves, and the mixture cools rapidly. This is because the energy required to break the chemical bonds is more than the energy released on forming new chemical bonds in the product; this is an endothermic reaction.

1. Explain why cold packs are used in sport.
2. Describe the reaction that you could carry out to investigate how well cold packs work.

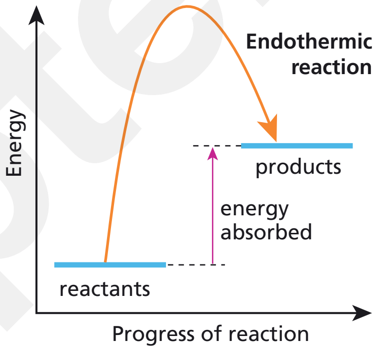


FIGURE 2.6.3b: Energy-level diagram of an endothermic reaction.

Selecting a range of values

We can mimic the reaction in a cold pack by adding ammonium nitrate directly to water. The temperature should decrease and we could measure the change in temperature.

The effectiveness of a cold pack could be investigated by measuring the effect of increasing the mass of ammonium nitrate on the temperature of the solution. Table 2.6.3a shows the **variables** in this investigation.

TABLE 2.6.3a: Can you suggest any other control variables in this investigation?

Independent variable	mass of ammonium nitrate
Dependent variable	change in temperature
Control variable	temperature of water at start, volume of water

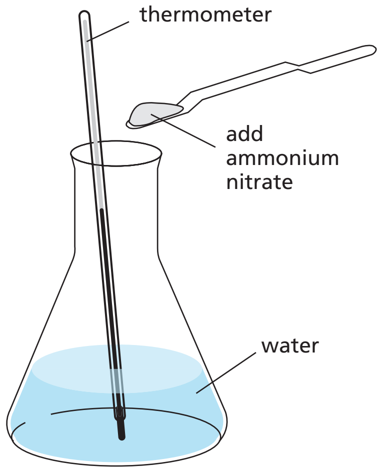


FIGURE 2.6.3c: Adding ammonium nitrate to water and using a thermometer to measure the change in temperature.

Before beginning an investigation, we must plan the **range** of values for our variables. We can decide on these by running a **trial** investigation. We would use this trial to plan the smallest and largest masses of ammonium nitrate that we will use; this is the range of the independent variable. We would need to be sure that those values cause a range of readings of the dependent variable. Once the range of the independent variable has been decided, we can plan the gaps between each independent variable value; this is the **interval**.

3. How might examining some real instant cold packs help you to plan the range of measurements?
4. If an investigation planned to use between 10 g and 60 g of ammonium nitrate, what is the range of values of the independent variable? Suggest a suitable interval for this investigation.

Presenting data

Before collecting data, you should draw a results table. You should label the table with the headings of the independent variable and dependent variable. The independent variable usually goes on the left-hand side. The table is populated with the values decided for the independent variable before the experiment begins.

The data can then be displayed on a graph to allow any patterns to be seen more easily. Continuous variables have values that can be any number. Continuous data is plotted on a line graph. The independent variable is plotted on the *x* axis and the dependent variable is plotted on the *y* axis. The graph should be given a title that represents the 'story' of the investigation, for example, based on 'graph to show the effect of independent variable on dependent variable'.

The graph can then be used to look for correlation between the increasing mass of ammonium nitrate on temperature. The original question may then be answered, 'what makes the best cool pack?'

5. What headings will be needed for your table? Include units.
6. What labels and title would you use for your graph?
7. Table 2.6.3b shows some data from an investigation. What conclusion can you make from this data? Suggest how the intervals could have been better planned.

Did you know…?

Instant hot packs work in a similar way to cold packs, but they use a chemical such as calcium chloride instead of ammonium nitrate. When the pack is squeezed, an exothermic reaction occurs and the packs heats up quickly. These can be used as handwarmers.

FIGURE 2.6.3d: An instant hot pack used as a handwarmer.

TABLE 2.6.3b

Mass of ammonium nitrate (g)	Decrease in temperature (°C)
1	5
2	9
3	14
5	25
8	38
10	44

Know this vocabulary

variable
range
trial
interval

Explaining the use of catalysts

We are learning how to:

- Describe what a catalyst is.
- Explain how catalysts work.

Without catalysts, we would not be able to make many of the products we rely on today. In fact, without biological catalysts (enzymes), life would not exist!

What are catalysts?

A **catalyst** is a substance that is added to a chemical reaction, causing it to happen faster or slower. Catalysts are not changed by the reaction – they alter the **rate of reaction**.

Catalysts are usually specific to particular reactions – a catalyst used in one reaction will not necessarily work in another. Different catalysts can be used for the same reaction. An important thing about a catalyst is that it can be fully recovered afterwards.

Hydrogen peroxide (H_2O_2) is a colourless liquid that decomposes very slowly over time, making water and oxygen. Different catalysts can speed up this process, including manganese dioxide and catalase (an enzyme found in liver, potatoes and apples).

1. How could you prove that something was a catalyst and not a reactant?
2. Why is it sometimes important to speed up a reaction?

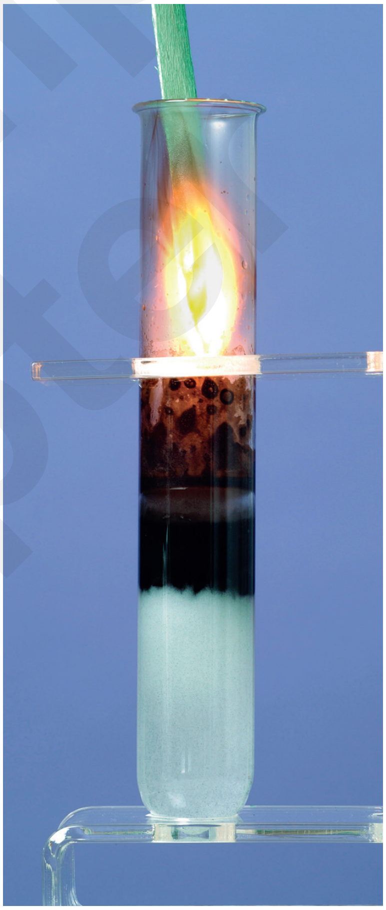


FIGURE 2.6.4a: Decomposition of hydrogen peroxide can be catalysed by manganese dioxide (black powder) to form water and oxygen. The oxygen allows a flame to burn on the wooden splint.

Using data to interpret the effect of catalysts

Enzymes are examples of biological catalysts. Many billions of reactions take place in our cells every second. Without enzymes, these reactions would not happen fast enough for life to exist.

Many industrial processes rely on catalysts to make the reactions fast enough to be profitable. In the manufacture of ammonia, the catalyst is made from iron or platinum. Many industrial catalysts are transition metals or transition metal oxides.

To investigate the effect of catalysts, you can observe how fast a reaction occurs. This can be done by recording either how quickly a product is made, or how quickly a reactant is used up.

Did you know…?

Catalysts can increase the rate of a reaction by up to 10^{17} times.

3. Which graph plotted in Figure 2.6.4b represents the reaction with a catalyst? Explain your answer.
4. How would you find out if catalase was a better catalyst than manganese dioxide?

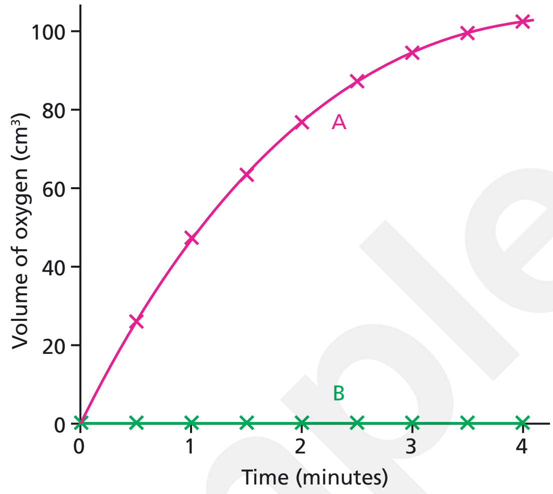


FIGURE 2.6.4b: How the decomposition of hydrogen peroxide proceeds with and without a catalyst.

How do catalysts work?

Most catalysts provide an alternative ‘pathway’ for the reaction. This lowers the amount of energy needed for the reaction to proceed, and helps reactions to occur faster.

Catalytic converters in car exhausts remove harmful gases. Platinum and rhodium in the converter remove oxides of nitrogen and convert them into nitrogen gas and oxygen gas:

nitrogen oxide → nitrogen gas + oxygen gas

The catalyst strips nitrogen atoms from the nitrogen oxide and holds onto them. These react with one another to make nitrogen gas and are then freed from the catalyst.

Carbon monoxide and hydrocarbons in the exhaust gases react with oxygen gas:

carbon monoxide + oxygen → carbon dioxide

hydrocarbon + oxygen → water + carbon dioxide

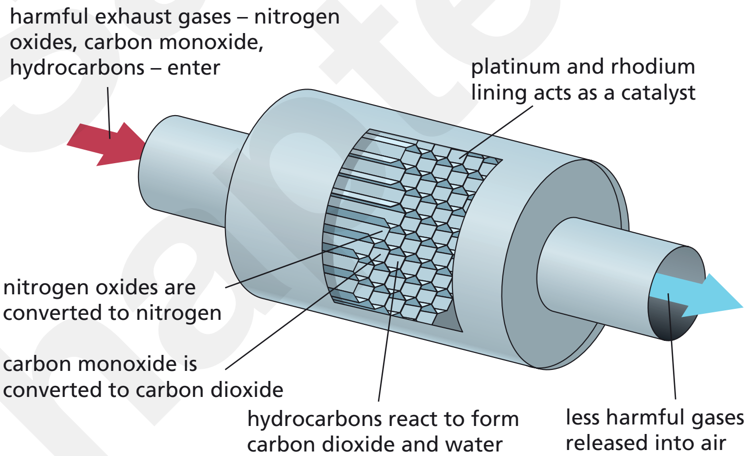


FIGURE 2.6.4c: A catalytic converter.

Enzymes involved in digestion catalyse reactions in which large molecules are broken down. They have a specific shape that locks onto food molecules and keeps hold of them. Water molecules then break down the food molecules. The enzyme is then free to work on other food molecules.

5. Draw an annotated diagram to show how an enzyme works.
6. In which form would you use a catalyst – as a lumpy solid, as small granules or in powdered form? Explain your answer.

Know this vocabulary

catalyst
rate of reaction
enzyme
catalytic converter

Exploring combustion

We are learning how to:

- Summarise combustion using an equation.
- Make observations during chemical reactions.
- Write word equations to represent chemical changes.

When you burn candles on a birthday cake or sit around a campfire, you do not often think about the science behind it. Burning is a chemical reaction, forming new products.

FIGURE 2.6.5a: Coal and wood are examples of fuels.

What is combustion?

When you burn wood or coal, new **products** are made. The reaction is irreversible – you cannot get the wood or coal back. This means that burning is a **chemical reaction**.

In order to start a fire, you need a **fuel** to burn. A fuel is any material that can be burned to release energy. Examples of fuels are wood and coal. Burning also needs oxygen. Without oxygen, a fire would go out.

The scientific name for burning is **combustion**.

1. Describe two reasons why burning is a chemical reaction.
2. Describe what is meant by:

   a) combustion **b)** fuel.
3. Explain why a fire burns more brightly if you fan the flames with air.

The combustion equation

Fuels like oil and gas contain the elements hydrogen and carbon – they are called hydrocarbons. We can summarise combustion using an equation:

hydrocarbon + oxygen → carbon dioxide + water

This reaction is called complete combustion. In this reaction, hydrocarbon and oxygen are the **reactants** and carbon dioxide and water are the products. This means that there is enough oxygen to react with all of the fuel. This is an example of an **oxidation** reaction because the fuel reacts with oxygen.

Did you know…?

You could not light a fire on the Moon. This is because there is no oxygen gas on the Moon.

Figure 2.6.5b shows the oxidation of carbon during the combustion reaction using particle models.

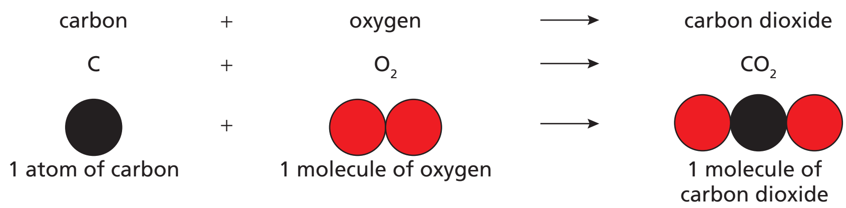


FIGURE 2.6.5b: Atoms are rearranged when a chemical reaction occurs.

Carbon dioxide is known as a ‘greenhouse gas’. Any excess gas that is not used by plants forms a blanket around the Earth. Most scientists believe that burning fossil fuels is contributing to the ‘greenhouse effect’.

4. Describe what is needed for complete combustion to take place.

5. Explain why combustion is also known as an oxidation reaction.

6. Describe a problem linked with production of carbon dioxide.

Incomplete combustion

If there is not enough oxygen available to react with all of the fuel, incomplete combustion takes place. Water is still produced, but carbon monoxide and carbon are produced instead of carbon dioxide. We can summarise incomplete combustion in this equation:

hydrocarbon + oxygen → carbon monoxide + carbon + water

Carbon monoxide is a poisonous gas. The carbon formed this way is soot. Soot is a fine black powder that can irritate the lungs and airways. Incomplete combustion also releases less energy than complete combustion.

7. Name the product that is the same in both complete and incomplete combustion.

8. Explain why both complete and incomplete combustion are chemical reactions.

9. Identify the products in incomplete combustion.

Know this vocabulary

product
chemical reaction
fuel
combustion
reactant
oxidation

Exploring the use of fuels

We are learning how to:

- Identify applications of combustion reactions.
- Identify fuels used in different applications.
- Compare the energy content of different fuels.

We use combustion reactions every day, from cooking the food that we eat to heating the homes that we live in. Combustion relies on fuels. What makes a good fuel?

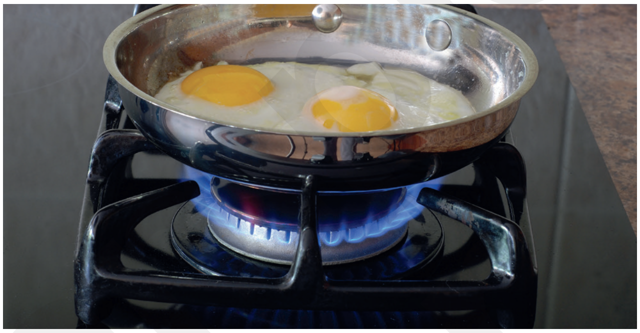


FIGURE 2.6.6a: We use combustion for cooking.

Applications of combustion

Combustion is an **exothermic** reaction. This means that the reaction releases **energy**. This energy is usually transferred as heat and sometimes also as light.

Combustion is important for transportation – for example, in steam engines and in the engines of cars and trucks. Fireworks are another good example of combustion in action.

1. Describe what an exothermic reaction is.
2. Draw a table to summarise the different uses of combustion.

So many fuels...

In situations such as burning logs on a fire, it is easy to identify the fuel as wood. However, in other situations, such as using an electric fire to heat a room, the fuel is not as obvious.

Electricity is not a fuel, but it is sometimes generated using a fuel. If the electricity was generated in a coal-fired power station, then the fuel used to heat the room was coal. Traditional steam engines also usually use coal as fuel.

Traditional cars use petrol or diesel as a fuel – these both come from crude oil. Biofuels, such as ethanol, can also be used in some cars. This is an **alcohol** made from grains like barley and maize. Space rockets can be fuelled by liquid hydrogen.

FIGURE 2.6.6b: Biofuels are made from grains.

3. State the fuel used in:
   a) a steam engine
   b) a log-burning fire.
4. Suggest what the fuel source is for electrical appliances such as TVs and washing machines.
5. Many biofuel cars can only run on a mixture of ethanol and petrol in a ratio of 1:9. Explain what this means.

The best fuel for the job

A class of students wanted to compare the energy in different alcohols. Each group burned a range of alcohols in turn and used the energy released to heat up water in a beaker above the burner (see Figure 2.6.6c). They measured the temperature change and the mass of alcohol burned. They then carried out a calculation to determine the energy contained in each alcohol.

Table 2.6.6 shows the results of four of the groups.

TABLE 2.6.6: The number of megajoules of energy per litre in each alcohol.

Alcohol	Energy contained within the alcohol (MJ/litre)			
	Group 1	Group 2	Group 3	Group 4
methanol	14	16	18	12
propan-1-ol	25	24	12	26
ethanol	22	22	23	21
butan-1-ol	32	34	32	34

Comparing results between groups allows a check on **precision**. Precise results are indicated by repeat measurements being close together. We can calculate a mean from repeat results; more results allow a better estimate to be made. If we spot a result that does not fit the pattern, we can choose to ignore it when calculating a mean. A result that does not fit the pattern is an **outlier**.

6. Identify which alcohol the results appear to be least precise for.
7. Which result should be ignored when calculating a mean for these results?
8. Calculate an average energy (MJ/l) contained in each alcohol. Write a conclusion for this investigation.

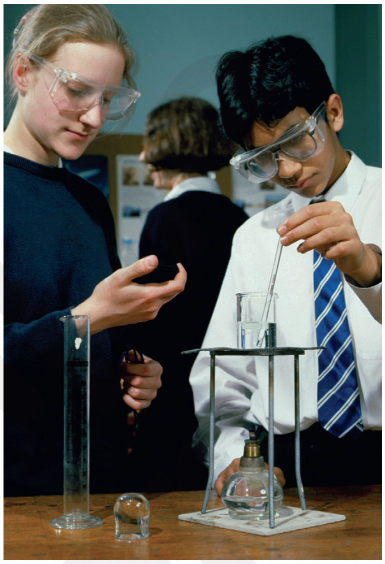


FIGURE 2.6.6c: How can we measure how much energy we get from this fuel?

Did you know…?

'Spontaneous human combustion' is a phenomenon in which humans are thought to burst into flames. Some scientists believe that a spark must act as the source of heat for the burning, with fat in the body then acting as the fuel for the reaction.

Know this vocabulary

exothermic
energy
precision
outlier

Understanding thermal decomposition

We are learning how to:

- Recognise and explain thermal decomposition reactions.
- Describe some uses of thermal decomposition.

Many metal ores are found in the form of carbonates. By using heat to break down the metal carbonate we can produce useful materials and this can be the first step in extracting metals. But how is this process different to combustion?

What is thermal decomposition?

Combustion and **thermal decomposition** are very different. Combustion is an oxidation reaction, which involves oxygen being added to another substance. Compounds called oxides are formed:

metal + oxygen ⟶ metal oxide

Thermal decomposition reactions happen when substances break down to simpler products when they are heated. No new substances are added. Many metal carbonates are decomposed on heating:

metal carbonate ⟶ metal oxide + carbon dioxide

1. What are the reactants and products of the thermal decomposition of a metal carbonate?
2. Why is thermal decomposition a good name for this type of reaction?

Decomposing carbonates

All **carbonate** compounds contain the same characteristic group of carbon and oxygen atoms.

calcium carbonate $CaCO_3$	magnesium carbonate $MgCO_3$	potassium carbonate K_2CO_3

These examples are all metal carbonates. Each unit of the compound contains a metallic element joined to the carbonate group. Most carbonates break down when heated but some carbonates can withstand high temperatures because they are thermally stable.

FIGURE 2.6.7a: Calcium carbonate in the form of shells or limestone is a common natural substance.

Did you know…?

As you go down a group in the periodic table, the metal carbonates tend to be more stable. They are harder to decompose. What does this tell you about the reactivity of metals as you go down a group?

When carbonates decompose they produce carbon dioxide. For example:

copper carbonate ⟶ copper oxide + carbon dioxide
(green solid) (black solid) (colourless gas)

$$CuCO_3\,(s) \longrightarrow CuO\,(s) + CO_2\,(g)$$

We can carry out this reaction in the laboratory (see Figure 2.6.7b). As the copper carbonate is heated in the test tube, the carbon dioxide gas passes through the delivery tube into the limewater making it go cloudy.

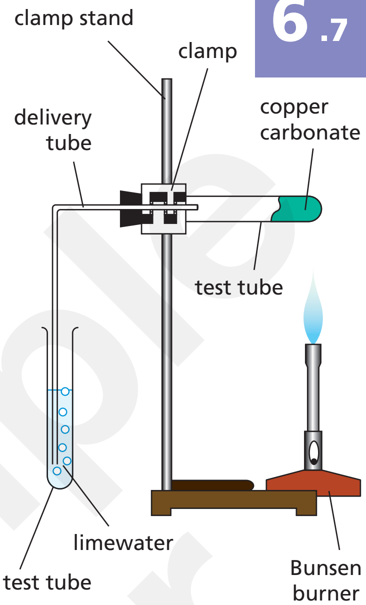


FIGURE 2.6.7b: This apparatus can be used to decompose copper carbonate.

3. Which elements does calcium carbonate contain?
4. What safety precautions should be taken during this experiment?
5. Describe the changes that you would expect to see during this experiment.
6. What do the (s) and (g) symbols mean in the equation?
7. Before it was heated, the test tube and copper carbonate had a mass of 50 g. Explain why, after the experiment, the mass was less than 50 g.

Applications of thermal decomposition

When heated, calcium carbonate forms lime, calcium oxide. Lime is used to make cement and glass. It is also added to soils to reduce acidity. The process of producing calcium oxide by heating calcium carbonate is also an important step in purifying iron. Calcium oxide can be added to water to produce calcium hydroxide; this is limewater. We use limewater to test for carbon dioxide.

Copper metal can be extracted from its green ore, malachite. Malachite contains copper carbonate. The carbonate is first thermally decomposed to form copper oxide. The copper oxide is then reacted with carbon (in the form of coke). As carbon is more reactive than copper, the copper is displaced to form copper metal. Figure 2.6.7c summarises the stages. The more reactive a metal in the carbonate, the harder it is to decompose the carbonate with heat. This is because more reactive metals form stronger bonds.

FIGURE 2.6.7c: Extracting copper from malachite.

8. Explain why calcium carbonate is thought to be one of the most useful carbonates.
9. Write a word equation for the reaction between calcium oxide and water.
10. Suggest which carbonate would be easier to decompose, magnesium carbonate or calcium carbonate. Explain your answer.

Know this vocabulary

thermal decomposition
carbonate

Explaining changes

We are learning how to:

- Observe and explain mass changes for chemical and physical processes.
- Use particle diagrams to explain chemical processes.

Some changes in chemistry, such as melting and freezing, are reversible. These are physical changes. Chemical reactions produce new products that are different from the reactants you started with. Chemical changes are generally not reversible. But what happens to the atoms when new products are made?

FIGURE 2.6.8a: Melting is a physical process.

Mass changes in physical processes

When chocolate is melted, the mass of the solid and liquid stays the same. When sugar is dissolved in water, the mass of the sugar and water is the same as the mass of the solution produced. When water is frozen the ice cubes have the same mass as the starting water. Nothing new has been added and nothing has been taken away.

We can model these changes using building bricks. During **physical changes**, the appearance of the **product** (for example, melted chocolate) may be different to the **reactant** (for example, solid chocolate) but there are no new products.

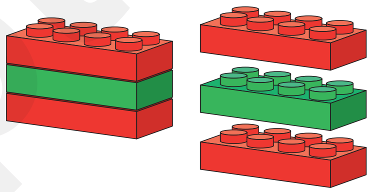


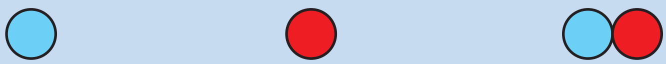
FIGURE 2.6.8b: The bricks are still the same before and after the physical change.

1. If 15 g of juice is frozen, what will be the mass of the frozen juice?
2. Explain why melting does not cause a change in mass. If possible, test the theory for yourself.

Law of Conservation of Mass

The Law of Conservation of Mass means that mass is never lost or gained in chemical reactions:

zinc	+	oxygen	→	zinc oxide
64 g	+	16 g	→	64 + 16 = 80 g



Reactants 80 g — Product 80 g

FIGURE 2.6.8c: The mass of the reactants is always the same as the mass of the products.

Did you know…?

The French chemist Antoine Lavoisier described the Law of Conservation of Mass in 1789. He was a revolutionary in chemistry, naming the elements carbon, hydrogen and oxygen and also discovered oxygen's role in combustion.

In the reaction in Figure 2.6.8c, the mass of the zinc increases as the two elements join to form zinc oxide. The total mass of the reactants is exactly the same as the mass of the new product. No additional mass is gained or lost – mass is **conserved**. In a chemical reaction, atoms rearrange but the total number of atoms stays the same.

3. How does the particle model in Figure 2.6.8c help to show the conservation of mass?

4. Calculate the mass of the products in these reactions:

a) magnesium + oxygen → magnesium oxide
(24 g) (16 g)

b) S (32 g) + O_2 (32 g) → SO_2

Applying the law of conservation of mass

During combustion of a metal, oxygen is added. This means that the mass of the metal will appear to *increase* unless we measure the mass of the oxygen as well as the metal.

During thermal decomposition, carbon dioxide is produced. The gas escapes during the reaction and mixes with the air. Even though no mass is lost or gained in the reaction, the mass can *seem* to decrease.

Heating carbonates produces carbon dioxide. The mass decreases as the gas escapes. If you trap the gas in a balloon, the mass does not fall.

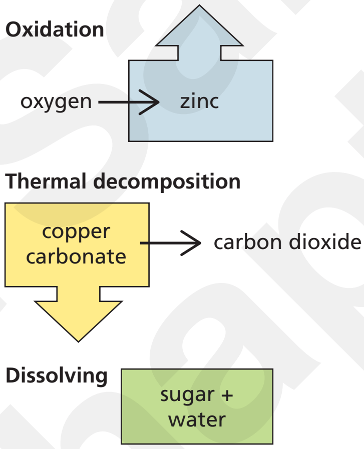


FIGURE 2.6.8d: Diagrams showing which substances are added or lost in different reactions.


FIGURE 2.6.8e: No mass is gained or lost when a gas is produced and captured.

calcium carbonate	→	calcium oxide	+	carbon dioxide
$CaCO_3$	→	CaO	+	CO_2
100 g		56 g		44 g

FIGURE 2.6.8f

5. a) Use the masses and the equations in Figure 2.6.8f to explain the conservation of mass for the thermal decomposition of calcium carbonate.

b) If the gas was allowed to escape, what would the start and end masses be for this reaction?

Know this vocabulary

physical change
product
reactant
conserved

Checking your progress

To make good progress in understanding science you need to focus on these ideas and skills.

☐ Describe what is meant by the term exothermic reaction, with examples.	☐ Explain the energy changes taking place during an exothermic reaction.	☐ Use energy-level diagrams to compare the energy in the reactants and products of exothermic reactions, explaining the energy changes in the particles.
☐ Describe what is meant by the term endothermic reaction, with examples.	☐ Explain the energy changes taking place during an endothermic reaction.	☐ Use energy-level diagrams to compare the energy in the reactants and products of endothermic reactions, explaining the energy changes in the particles.
☐ Describe the endothermic reaction that takes place in a cold pack.	☐ Plan an investigation including selecting a range of values and intervals.	☐ Design a suitable results table and draw a suitable graph to investigate a correlation.
☐ Describe what a catalyst is and give examples.	☐ Interpret data to explain how a catalyst affects a reaction.	☐ Explain how a catalyst works.
☐ Identify changes during a reaction, relate these to reactants and products.	☐ Make accurate observations, explain them using a simple model and a word equation and explain differences between chemical and physical changes in terms of atoms.	☐ Explain observations using word equations, relate chemical symbols to a simple particle model and use the correct terms and simple models to explain the differences between chemical and physical changes.

- Identify fuels used in different applications.
- Carry out an experiment to compare the energy in different fuels.
- Analyse data linked with the energy content of different fuels and make a conclusion.
- Identify combustion and decomposition reactions.
- Explain why combustion is a chemical reaction; explain the differences between oxidation and thermal decomposition.
- Use models and word equations to explain changes during combustion and thermal decomposition reactions.
- Summarise the reactants and products of complete combustion.
- Compare the reactants and products of complete and incomplete combustion.
- Explain the Law of Conservation of Mass and how it can be proven.

Questions

KNOW. Questions 1–8

See how well you have understood the ideas in this chapter.

1. Explain what is meant by the term 'catalyst'. [2]

2. An example of an endothermic reaction is: [1]

a) burning magnesium
b) mixing ammonium nitrate and water
c) the thermit reaction
d) adding a reactive metal to acid.

3. Describe two uses of exothermic reactions. [2]

4. Burning hydrogen is an exothermic change. Explain how an exothermic change occurs. Use ideas about bond-making and bond-breaking in your answer. [4]

5. What product is formed when magnesium is burned? [1]

a) magnesium hydroxide
b) magnesium oxide
c) magnesium carbonate
d) oxygen.

6. Hydrocarbon fuels contain the elements: [1]

a) carbon and hydrogen
b) carbon, helium and oxygen
c) hydrogen and chromium
d) carbon, hydrogen and nitrogen.

7. Carbonates of more reactive metals are harder to decompose with heat than carbonates of less reactive metals. Explain why. [2]

8. Explain the differences between combustion and thermal decomposition. [4]

APPLY. Questions 9–14

See how well you can apply the ideas in this chapter to new situations.

9. Which of the following statements about the energy diagrams in Figure 2.6.10a is true? [1]

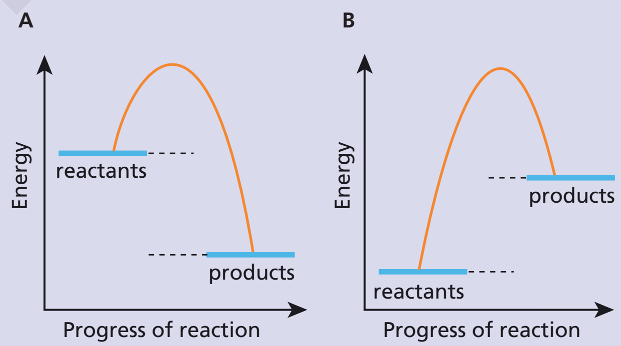


FIGURE 2.6.10a: Exothermic and endothermic energy diagrams.

a) **A** shows the diagram for dissolving ammonium nitrate in water.
b) A greater difference in energy would be observed in **A** when a weak acid reacts with a weak alkali compared to burning magnesium.
c) **B** shows that more energy is absorbed in bond-breaking than is released in bond-making.
d) If the energy of the reactants is the same as the products, an endothermic change has occurred.

10. A student investigates an exothermic reaction between calcium chloride and water. The table shows the mass values of calcium chloride that the student intends to use. Identify:

a) The range of values of the independent variable. [1]

b) The interval of values of the independent variable. [1]

c) Suggest what could be measured as the dependent variable, including a unit. [2]

TABLE 2.6.10

Mass of calcium chloride (g)	Dependent variable
25	
40	
55	
70	
85	
100	

11. The carbonates of metals X, Y and Z are decomposed. It is found that Z is easier to decompose than X, but harder to decompose than Y. What is the correct order of reactivity of the metals, with the most reactive first? [1]

a) Y, Z, X **b)** X, Y, Z **c)** X, Z, Y **d)** Z, X, Y

12. Magnesium reacts with oxygen to form magnesium oxide. The mass of the magnesium oxide at the end of the experiment is greater than the mass of magnesium at the start because: [1]

a) It burns with a bright light.

b) It gives off carbon dioxide.

c) Magnesium is not very dense.

d) The oxygen has added to the mass of the magnesium.

13. A student weighed a crucible containing steel wool. He then burned the steel wool and reweighed the crucible. The mass after burning would be: [1]

a) less than before **b)** more than before

c) the same as before **d)** zero.

14. A carbon monoxide detector picks up higher levels of carbon monoxide in the lounge of a house than in the dining room. What does this suggest about the type of combustion taking place in each of the room's fires? Explain your answer. [2]

EXTEND. Question 15

See how well you can understand and explain new ideas and evidence.

15. Hydrogen peroxide decomposes to make oxygen and water. The graph in Figure 2.6.10b shows the effect of a catalyst on the reaction. Sketch a graph to show the effect of a better catalyst. What is similar about the two graphs? [3]

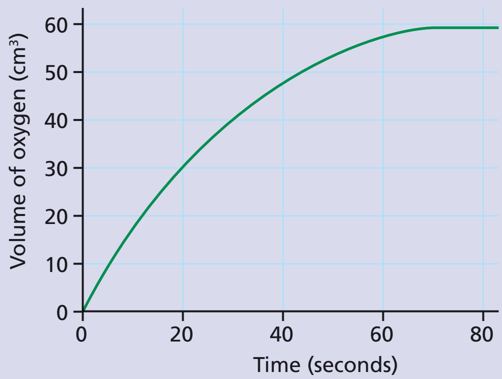


FIGURE 2.6.10b: Graph showing the rate of decomposition of hydrogen peroxide with a catalyst.