CHEMISTRY

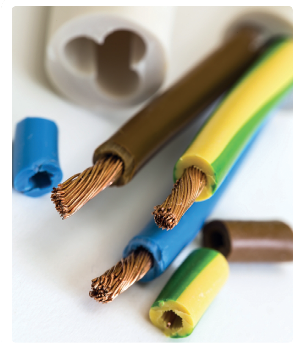
Obtaining Useful Materials

Ideas you have met before

Metals

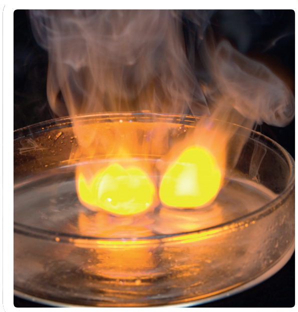
Metals are materials with many useful applications. All metals are good conductors of heat and electricity. Some, such as copper, are better conductors than others.

Many metals, like iron and steel, are strong and hard. Metals such as aluminium and sodium are light. The properties of metals determine their applications.



Reactions of metals

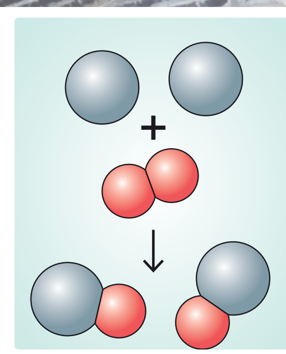
Sodium and magnesium are much more reactive than iron and copper. If sodium is put in some water, it catches fire. An extremely vigorous reaction occurs between sodium and an acid. When iron or copper are put in water or an acid, a very slow reaction occurs.



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.



Properties of materials

Different materials have different properties. We may be able to change the properties of materials to suit our purposes. Small amounts of metals can be added to each other to make alloys, like adding magnesium to aluminium to make duraluminium. Alloys are stronger than the original metals.

In this chapter you will find out

Metal ores

- Most metals are found in rocks known as ores.
- In an ore the metal is combined with other elements, both chemically and physically. Changes are needed to remove the metal from its ore so it can be useful.
- Metal ores are obtained from mines, but these can have wide-scale negative environmental impacts.

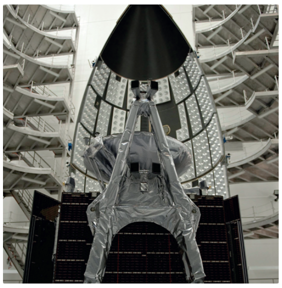
Reactivity

- The reactivity series is a list of metals arranged in order of their reactivity.
- More reactive elements will remove less reactive metals from their compounds. Carbon is more reactive than iron, copper, lead and zinc, and is used to obtain these metals from their ores.
- Metal carbonates can be decomposed by heat. The carbonates of more reactive metals are harder to decompose than those of less reactive metals.

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, without taking part in it. Enzymes are examples of biological catalysts.

Special materials



- Ceramics, polymers and composite materials have been in use for many thousands of years. Today, many new types of materials are being made, based on the chemistry of these earlier materials. These have exciting applications – as in racing cars, rockets and modern buildings.

Chemistry

Obtaining metals from ores

We are learning how to:

- Recognise how abundant common ores are in the Earth.
- Explain how ores are extracted from the Earth.

We rely on the use of metals to carry out different jobs. Metals are mined as ores from the Earth's crust. How are metals extracted from their ores?

What is an ore?

Only a few metals are found in their pure form on the Earth's surface. Gold, silver and platinum are examples of these 'native' metals.

The majority of other metals are found chemically combined with other elements in the form of an **ore**. An ore is a rock that contains a sufficient quantity of the metal to make it worth extracting the metal from it.

Ores are often mixtures of different **minerals**. Usually a combination of physical and chemical processes is needed to remove the metal from the other elements in the ore. Many ores contain a metal oxide or metal carbonate.

Did you know...?

The world's deepest iron ore mine in Sweden operates at 1.3 km below the surface.

Lead ore – galena PbS | Iron ore – haematite Fe_2O_3 | Copper ore – malachite $CuCO_3(OH)_2$

Lead metal – Pb | Iron metal – Fe | Copper metal – Cu

FIGURE 3.3.2a: The names and chemical formulas of some common metal ores and their metals

1. Why do many ores look very different from the metal they contain?
2. Why do you think gold is found uncombined?

First extraction of metals from ores

Copper exists in its native form, as well as in ores. We know that it was used in its native form as early as 6000 BCE. Around 4000 to 3000 BCE, it was discovered that copper could be extracted from ore. It may be that potters accidentally included copper ore in their furnaces. The temperature of around 1000 °C would have decomposed (split up) the ore.

Lead and tin were also extracted from their ores thousands of years ago. These ores require only about 200 °C to decompose them. It may be that the ores fell into camp fires.

Carbon, in the form of charcoal, played a major part in producing the metals from the ores, but people in those times would not have understood carbon's role.

3. Suggest why some metals were found much earlier than others.

4. Aluminum is the most abundant metal in the Earth's crust. It was not discovered until 1825. Suggest why it took so long to discover.

Extracting ores

Many metal ores make their way to the surface of the Earth's crust as a result of volcanic activity. The molten ores are pushed into seams of rock where they cool over many thousands of years. Some seams are very close to the surface. Others are deep within the crust and have to be mined. Many, beneath the ocean floor, are still to be uncovered.

Very reactive metals, like sodium, are extracted from their ores using electricity – this process is known as electrolysis. Less reactive metals, like iron, can be obtained by **smelting** (the ore is roasted with carbon). The ores of very unreactive metals, like copper, are heated to decompose the ore first, before smelting is carried out.

5. Why were most reactive metals not discovered until the late 1800s?

6. Why is it harder to remove metals from the compounds of reactive metals than from the compounds of unreactive metals?

7. Why are many metal ore seams beneath the ocean floor still to be uncovered?

3.2

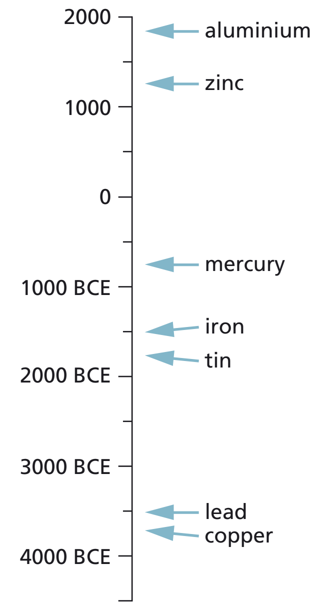


FIGURE 3.3.2b: A timeline showing the discovery of the extraction of metals from their ores

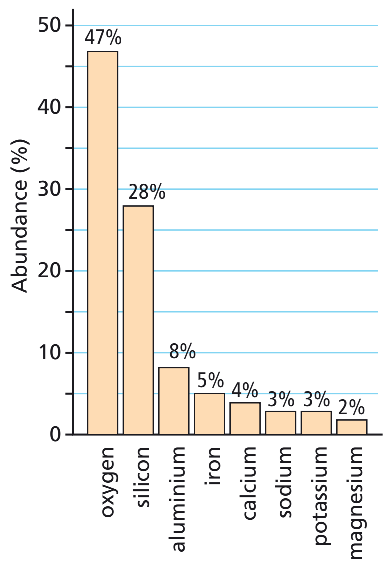


FIGURE 3.3.2c: The elements most commonly found in the Earth's crust

Key vocabulary

ore

mineral

smelting

Understanding reactivity

We are learning how to:

- Use evidence to identify the reactivity series of metals.
- Represent reactions using formulas and equations.

Many metal ores take the form of carbonates. By using heat to decompose (split up) metal carbonates, we can find out how reactive the metals are in comparison with each other. Do more reactive metal carbonates decompose more easily than less reactive metal carbonates?

Signs of how reactive metals are

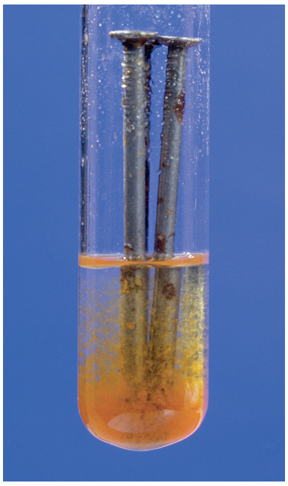
Some metals are clearly more reactive than others. If a piece of sodium is dropped into water, it fizzes and pops, releasing a gas that burns. If an iron nail is added to water, signs of a chemical change will be seen after a few days; but if copper is added to water, there is no change. The **reactivity** of the different metals can be compared by observing their reactions – the more vigorous the reaction, the more reactive the metal.

TABLE 3.3.3a: How different metals react with an acid. The general word equation for the reaction is: metal + hydrochloric acid → metal chloride + hydrogen

Name of metal	Observations with acid
sodium	explosive reaction occurs; any hydrogen produced catches fire spontaneously
copper	no visible change occurs
magnesium	vigorous production of hydrogen bubbles; the test tube becomes hot quickly

1. Use the observations in Table 3.3.3a to place the metals in order of reactivity with the most reactive metal first.
2. Zinc is less reactive than sodium but more reactive than iron. Predict how it will react with an acid.
3. Write word equations for the reactions of zinc, potassium and gold with hydrochloric acid.

Sodium and water (immediate reaction)



Iron nail and water after a week

Copper and water after a week

FIGURE 3.3.3a: The reaction between sodium and water, an iron nail and water, and copper in water. Which metal is the most reactive?

540235_P070_107.indd 74 24/04/2014 10:52

Why is reactivity important?

By understanding the reactivity of metals, we can make predictions about how to extract metals from compounds.

Some **metal carbonates**, like limestone (calcium carbonate), decompose on heating – a process known as **thermal decomposition**. Thermal decomposition of a metal carbonate can be the first stage in the extraction of a metal.

TABLE 3.3.3b: Energy is needed in varying amounts to decompose different metal carbonates.

Metal carbonate	Energy for thermal decomposition (kJ/mol)
magnesium carbonate	101
strontium carbonate	235
barium carbonate	269
calcium carbonate	178

4. Use Table 3.3.3b to put the metals magnesium, strontium, barium and calcium in order of reactivity.

5. Which metal(s) could you extract easily using thermal decomposition? Explain your answer.

Decomposing metal carbonates

The more reactive the metal in the carbonate, the harder it is for the carbonate to decompose. The reason is that metals with a high reactivity make stronger bonds with carbonate.

Strong bonds are harder to break because they require more energy to break. Higher temperatures will be needed to decompose their carbonates. The bonds formed by less reactive metals are easier to break because they require less energy.

The general word equation for decomposing a carbonate is:

metal carbonate → metal oxide + carbon dioxide

6. Suggest which metal carbonate will require the highest temperature for decomposition – iron carbonate, copper carbonate or potassium carbonate. Give a reason for your choice.

7. Write a balanced symbol equation for the thermal decomposition of sodium carbonate, which is Na_2CO_3. Sodium oxide is Na_2O.

3.3

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?

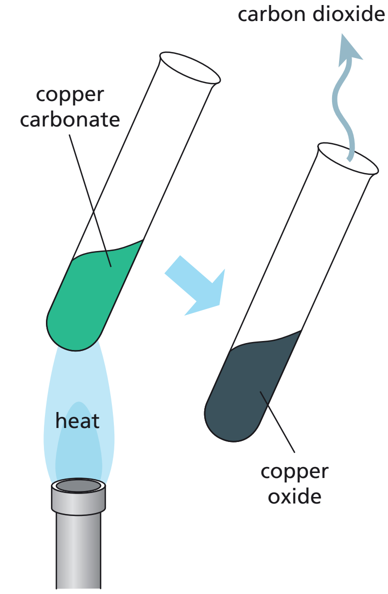


FIGURE 3.3.3b: Copper carbonate can be decomposed by heating.

Key vocabulary

reactivity

metal carbonate

thermal decomposition

540235_P070_107.indd 75 24/04/2014 10:52

Chemistry

Making use of displacement reactions

We are learning how to:

- Represent and explain displacement reactions using formulas and equations.
- Make inferences about reactivity from displacement reactions.

We can use the order of reactivity of elements to make predictions about reactions. Reactive metals can be thought of as 'chemical bullies'. Why might this be so?

Chemical bullies

When a reactive metal reacts with a compound of a less reactive metal, the more reactive metal 'pushes out' or 'displaces' the less reactive metal. The more reactive metal forms a chemical bond with whatever the less reactive metal was bonded to.

The situation is a bit like a basketball match. Imagine a weak player with the ball. A stronger player takes the ball from him, displacing the weaker player and leaving him on his own.

An example of such a **displacement reaction** is when iron is added to a blue copper sulfate solution. Iron is more reactive than copper. A chemical change occurs – iron displaces the copper, bonding with the sulfate to make iron sulfate, which is a pale green solution.

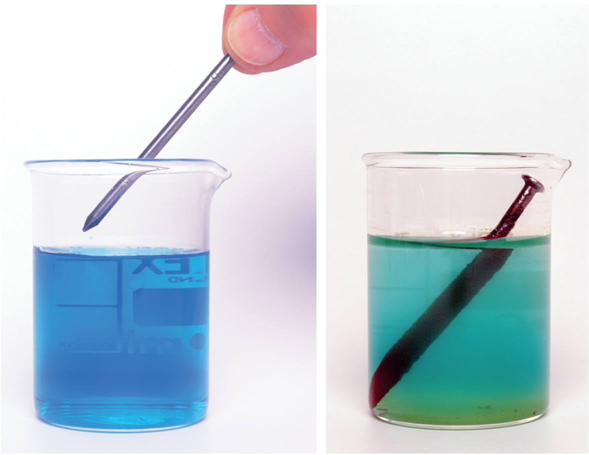


FIGURE 3.3.4a: Iron and copper sulfate solution – before and after the displacement reaction. Over time, the blue copper sulfate solution becomes paler, and the iron nail becomes covered with a brown coating of copper.

The word equation for the reaction is:

iron + copper sulfate → iron sulfate + copper

1. When magnesium is added to a solution of copper sulfate, the solution changes from blue to colourless much faster than with iron. Which is more reactive, magnesium or iron?
2. Write a word equation for the reaction between iron sulfate and magnesium.

Did you know...?

Old copper mines often become flooded, and a blue solution of copper sulfate results. By adding cheap scrap iron to this solution, copper metal is produced. This makes extra money for the mine owners.

Using displacement reactions

When reactive metals react with acids, a displacement reaction occurs and hydrogen is displaced. As long as a metal is above hydrogen in the **reactivity series**, they will react to displace hydrogen and form bubbles of the gas:

zinc + hydrochloric acid → zinc chloride + hydrogen

Non-metals also undergo displacement reactions. Chlorine is more reactive than iodine. When chlorine gas is passed through sodium iodide solution, the chlorine displaces the iodine as follows:

chlorine + sodium iodide → sodium chloride + iodine

This method is used to make iodine on an industrial scale.

3. Copper is more reactive than silver. Predict what would happen when copper foil is put in silver nitrate solution.

4. Write a balanced symbol equation for the reaction in question 3. Silver nitrate is $AgNO_3$; copper nitrate is $Cu(NO_3)_2$.

5. Bromine displaces iodine from sodium iodide, but there is no reaction when it is added to sodium chloride. What is the order of reactivity between chlorine, bromine and iodine?

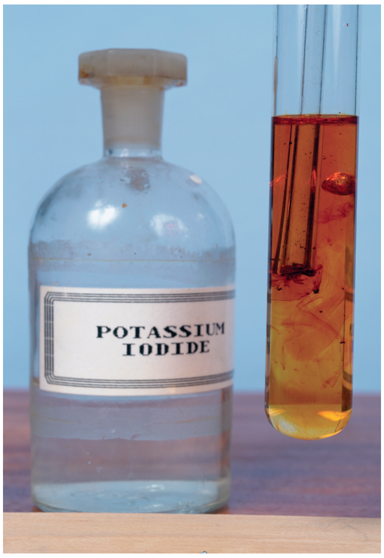


FIGURE 3.3.4b: Displacement of iodine by chlorine. The iodide particles in a potassium iodide solution are oxidised to form iodine – this gives the brown colour.

Making predictions

The reactivity series is shown in Figure 3.3.4c. The further elements are from each other in the series, the more vigorous the displacement reaction between the more reactive element and a compound of the less reactive element.

6. Write a balanced symbol equation for the reaction between the most reactive metal and the least reactive metal nitrate.

7. Why is no hydrogen produced when copper is added to hydrochloric acid?

8. Copper is a valuable metal. Suggest why it is not made commercially by reacting copper oxide with a more reactive metal, like sodium.

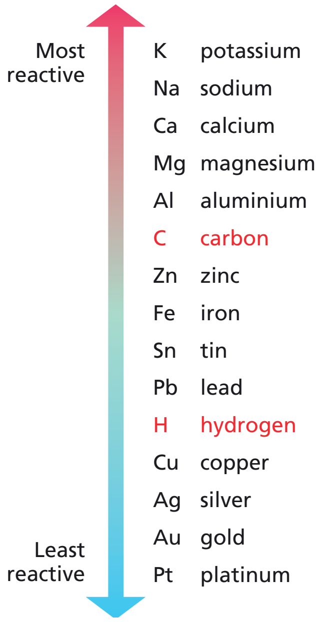


FIGURE 3.3.4c: The reactivity series

Key vocabulary

displacement reaction

reactivity series

Using carbon to extract iron

We are learning how to:

- Represent displacement reactions with carbon, metal oxides and iron using formulas and equations.
- Explain how mass is conserved in the extraction of metals.

Carbon has been used to obtain metals for thousands of years. What is so special about it and how does it work?

Using carbon to extract metals

Humans have burned wood, which is mostly carbon, for thousands of years. It is thought that the accidental addition of lead ore (galena) and tin ore (cassiterite) to wood fires resulted in the formation of lead and tin.

Coal is a richer source of carbon than wood. When it is burned slowly to temperatures over 1000 °C, in the absence of oxygen, **coke** is made. This was discovered in the 18th century. Coke is used in industry today to extract some metals from their ores.

Carbon is more reactive than metals such as iron, tin, lead and copper. When ores of these metals are roasted with carbon, a displacement reaction occurs. Carbon removes the oxygen or sulfur they are combined with, and displaces the metal.

When oxygen is removed from a metal, we call this **reduction**. It is the opposite of adding oxygen, which is known as **oxidation**. The carbon acts as a reducing agent.

1. What would happen if carbon was roasted with an ore of zinc sulfide?
2. Write a word equation for the displacement of lead from lead oxide with carbon.

Extraction of iron

Iron ore occurs in the form of iron oxide (Fe_2O_3) – it is called haematite.

To extract the iron, powdered coke is added to the crushed iron ore along with limestone, which removes impurities. All the ingredients are roasted in a large furnace about 30 metres in height, known as a **blast furnace**. Air is injected into the bottom of the furnace to improve the reducing properties of the carbon. A blast furnace operates at temperatures up to 1650 °C.

FIGURE 3.3.5a: Coke can provide much more heat than wood, and is a concentrated form of carbon.

Did you know...?

Iron, initially found native in meteorites, has been used since 4000 BCE. It is the sixth most abundant element in the Universe.

FIGURE 3.3.5b: An ancient iron spearhead

3. Why do you think the coke is powdered and the iron ore crushed?
4. What is the advantage of operating the blast furnace at this high temperature?

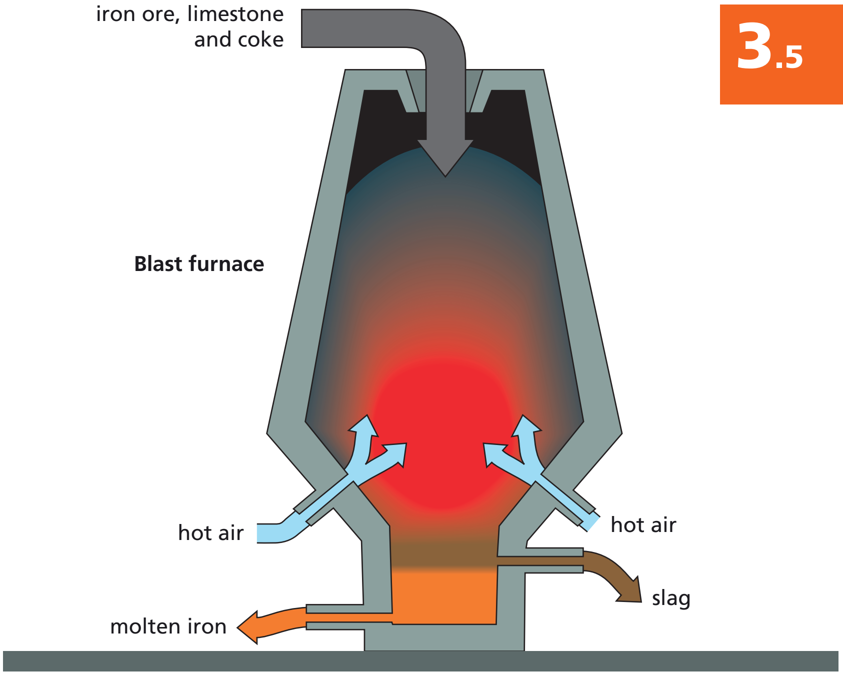


FIGURE 3.3.5c: In a blast furnace, the carbon reduces the iron oxide ore to make iron metal.

Predicting the mass of iron

The symbol equation for the overall reaction in a blast furnace is:

$2Fe_2O_3 + 3C \rightarrow 3CO_2 + 4Fe$

By knowing the quantity and purity of the iron ore and carbon added to the furnace, and knowing that mass is always conserved, you can predict the theoretical amount of iron made.

An example is given here.

If 100 tonnes of iron ore was added to the furnace and it had a purity where 20 per cent of the mass of the ore was iron, how much iron metal could theoretically be made?

The amount of iron entering the furnace = amount of ore × percentage purity = 100 × 0.2 = 20 tonnes.

Because mass is conserved, the amount going in should equal the amount coming out.

So the theoretical amount of iron metal made would be 20 tonnes.

5. Magnetite (Fe_3O_4) is another ore of iron used in the blast furnace. Write a balanced equation to show the products made.
6. How much iron metal could be made from 250 tonnes of magnetite with a purity where 30 per cent of its mass is iron?

FIGURE 3.3.5d: Molten iron in a blast furnace

Key vocabulary

coke

reduction

oxidation

blast furnace

Extracting copper, lead and zinc

We are learning how to:

- Explain how copper, lead and zinc are extracted from their ores.
- Calculate the yield of the extraction process.

Copper, lead and zinc are all below carbon in the reactivity series. This enables carbon to play an active role in the extraction of these metals.

Extracting copper

Malachite is copper carbonate, a form of copper ore. You can see its striking green colour in Figure 3.3.6a. In order to extract the copper, the carbonate first has to be heated to over 200 °C. This causes thermal decomposition and carbon dioxide is released. Copper oxide is made. The reaction is:

$$CuCO_3 \rightarrow CuO + CO_2$$

The copper oxide is then heated with carbon in the form of coke. Because carbon is more reactive than copper, the copper from copper oxide is displaced:

$$2CuO + C \rightarrow 2Cu + CO_2$$

The copper will still have other impurities. A process known as electrolysis further purifies the copper.

FIGURE 3.3.6a: Extracting copper from copper carbonate

1. Which product occurs in both the thermal decomposition of copper carbonate and the reduction of copper oxide?
2. Which reactant is reduced?

Extracting lead and zinc

One of the ores of lead is galena, which is lead sulfide. To extract the metal, the ore is first crushed into small particles. These are added to a mixture of oil and water. Air is blown upwards to push the lead ore particles to the top, separating them from other impurities – this is called 'froth flotation'.

Oil is needed because lead sulfide is very dense and this helps it to rise to the top. The lead sulfide is then heated in air at high temperatures, converting it to lead oxide. The word equation for the reaction is:

lead sulfide + oxygen → lead oxide + sulfur dioxide

Roasting lead oxide with carbon reduces it to lead. The word equation for the reaction is:

lead oxide + carbon → lead + carbon dioxide

Zinc ore (sphalerite) is zinc sulfide. Before it can be displaced with carbon, the zinc sulfide needs to be changed into zinc oxide. This is achieved by blowing hot air through a concentrated mixture of zinc sulfide and water, by froth flotation. The concentrated zinc sulfide is then roasted in air to make zinc oxide. This is reduced by roasting it with carbon.

3. Draw a flow chart to show the process for making lead from lead sulfide.

4. Write two word equations for the main reactions in making zinc from zinc sulfide.

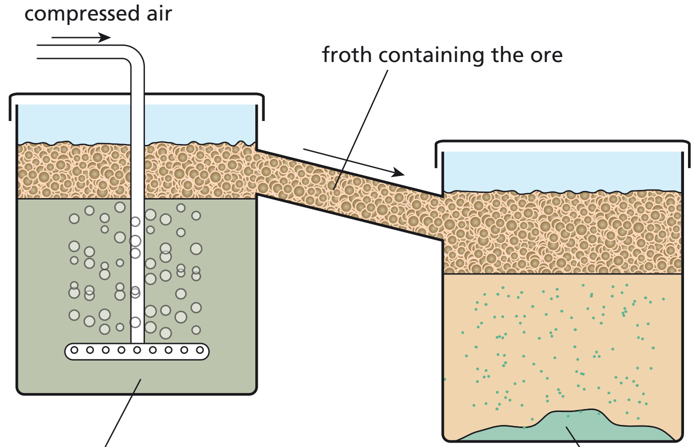


FIGURE 3.3.6b: Froth flotation to concentrate lead sulfide ore

Making predictions from equations

The symbol equations for the production of lead and zinc from their oxides are:

$2PbO + C \rightarrow 2Pb + CO_2$ $\quad$ $2ZnO + C \rightarrow 2Zn + CO_2$

In reality, processes for extracting metals from their ores are inefficient because not all the metal is removed from ores. The **yield** of the process is less than 100 per cent, where the yield is defined by:

$$\text{yield} = \frac{\text{actual amount produced}}{\text{theoretical amount}} \times 100\%$$

5. 500 tonnes of zinc is produced from an ore containing 800 tonnes. Work out the yield of the process.

6. 446 tonnes of lead oxide is roasted with coke, and 200 tonnes of lead are made. What is the yield of the process? Assume that the lead oxide is 50 per cent by mass lead, and use ideas from Topic 3.5 to help you.

Did you know...?

75 per cent of the lead produced is used to make batteries; copper is mainly used in electrical wiring and zinc is also a component of batteries.

Key vocabulary

yield

Chemistry

Looking at the impact of metal extraction

We are learning how to:

- Describe the environmental impacts of metal extraction.
- Describe how recycling of metals reduces damage to the environment.

There are about 2500 large-scale mines over the world extracting different metal ores. Our reliance on metals may be costing our planet more than we think.

Surface impacts of metal mining

The largest copper-producing mine in the world is 4 km wide and 1.2 km deep.

Mining involves removing many hundreds of tonnes of rock, often crushing them and putting them somewhere suitable. Much of the waste rock, if it is free of heavy metals, can be crushed and used for road filler or building materials.

FIGURE 3.3.7a: One of the main impacts of mining is that it scars the landscape. This is an open-pit copper mine in Utah, USA.

Once a mine ceases to operate, companies have to plant the area with trees and other plants to restore the landscape – this is known as **reclamation**. The hole caused by mining can often be made into a lake, adding recreational value.

Deep mining can lead to **subsidence**. The ground becomes unstable, causing it to cave in.

1. What can mine owners do to reduce scarring of the landscape?
2. Why might people object to a mine being sited near their home?

Environmental impact of mining

Sometimes, waste rock and materials from processing an ore contain small amounts of heavy metals or other toxic materials. These can dissolve out of the rock over time. This is called 'leaching'. Toxic materials enter the soil, rivers and lakes, and harm aquatic and terrestrial life.

FIGURE 3.3.7b: Nearby houses and buildings can be badly affected by subsidence.

Waste liquids from the mining process are called **leachates**. They have to be stored in specially lined pools to avoid contaminating the ground or water systems.

Some mining processes use carbon to displace the metal from its ore. This produces carbon dioxide, which is a greenhouse gas. In addition, the metal ore is often roasted with carbon, again producing carbon dioxide because fossil fuels are burned to provide the heat.

Metals, such as lead, that come from sulfide ores must be heated in oxygen so that the metal oxide can be made. Sulfur dioxide is produced as a result, which causes acid rain.

Finally, mines are very noisy places. Blasting, heavy machinery and trucks transporting to and from the mine all contribute to a noisy environment.

3. Suggest two other processes involved in mining in which carbon dioxide is produced.
4. Which of the problems caused by mining is the most difficult to solve? Explain your answer.

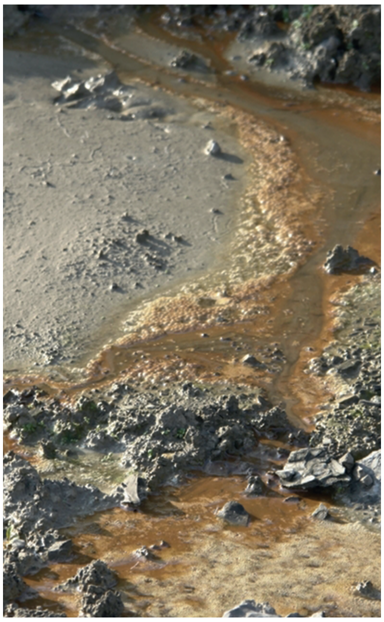


FIGURE 3.3.7c: Leachates from mining can contaminate water systems.

The importance of recycling metals

Recycling avoids the need to mine and process new material, saving metal reserves and energy. One tonne of new aluminium cans requires five tonnes of aluminium ore and produces five tonnes of waste that is hazardous to the environment.

Recycling metals is by far the most effective way of reducing environmental impact. Aluminium cans are a classic example – it takes as much energy to make one can from newly mined metal as it does to make 20 cans by recycling.

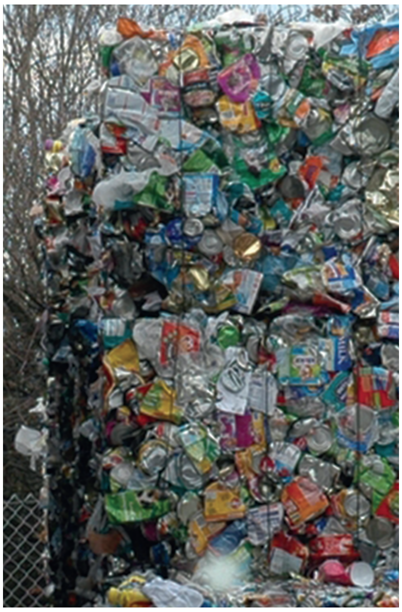


FIGURE 3.3.7d: Aluminium cans are recycled to produce aluminium.

5. Discuss the advantages and disadvantages of recycling.
6. How can we improve the processes involved in recycling metals?

Did you know...?

In 1902, rich deposits of lead were found in Kabwe, Zambia and were mined without preventative measures. Today the levels of lead in the water and soil are high enough to kill people.

Key vocabulary

reclamation

subsidence

leachate

recycling

540235_P070_107.indd 83 24/04/2014 10:53

Applying key ideas

You have now met a number of important ideas in this chapter. This activity gives an opportunity for you to apply them, just as scientists do. Read the text first, then have a go at the tasks. The first few are fairly easy – then they get a bit more challenging.

Metal protection

Understanding the reactivity series has enabled scientists and engineers to develop ways of protecting metals.

Aluminium is near the top of the reactivity series. When exposed to air, it reacts with oxygen quickly. This forms a layer of aluminium oxide over the aluminium's surface and protects the metal beneath from further corrosion. Aluminium oxide is hard, and quite resistant to chemical attack. Figure 3.3.8a shows aluminium and iron after exposure to air for many years. The aluminium has hardly corroded because of its protective oxide layer.

Metals less reactive than aluminium, such as zinc and titanium, may be protected with an aluminium coating. This process is called anodising. Anodised titanium is used in dental implants.

Zinc, which is more reactive than iron or steel, can be used to protect these metals – this process is called galvanising. The iron is cleaned and then dipped in a bath of molten zinc. The zinc coating reacts with oxygen in the air, before oxygen has the chance to react with the iron – this is because zinc is more reactive than iron. The iron is now protected by the zinc, until all the zinc has reacted. This procedure protects iron and steel in underground pipes, large ships and oil tankers. It is an example of sacrificial protection – because zinc is more reactive, it will react with oxygen in the air before the iron does. In this way the iron stays intact.

Sometimes less reactive metals are used to protect more reactive metals. Tin is coated over steel (a much stronger metal) in the manufacture of tin cans. Tin is less reactive than iron so is less likely to react with air than iron. By covering the steel can with tin, the can will last longer. The tin forms a protective coating for the more reactive metal, preventing it from oxidising. Tin is useful because it is non-toxic. It can be safely used for coating food cans.

Copper coins can be plated with silver by dipping them in silver nitrate solution. The more reactive copper displaces the silver, forming copper nitrate, and a thin layer of silver is deposited on the coin.

FIGURE 3.3.8a: Aluminium (top) and iron (bottom) after lengthy exposure to air

FIGURE 3.3.8b: Zinc-coated steel (top) and steel that has not been coated (bottom): both have been exposed to air for some time.

Task 1

Use information from the text to explain what is meant by the following terms:

a) anodising

b) galvanising

c) sacrificial protection.

Task 2

Write word equations to show the following:

a) Formation of oxide layer when aluminium is exposed to air.

b) Plating of silver onto copper using silver nitrate solution.

Task 3

Magnesium is more reactive than aluminium. However, aluminium is used to anodise magnesium. Explain how this works.

Task 4

Write balanced symbol equations to explain the chemistry behind each of the following:

a) Zinc can be used to protect iron.

b) Copper can be plated onto aluminium using copper nitrate solution.

c) Tin is used to protect steel (iron) in tin cans.

> Use the following information:
> aluminium nitrate = $Al(NO_3)_3$
> tin oxide = SnO_2
> zinc oxide = ZnO

Task 5

Explain how the reactivity series is used to extract each these metals from their ores: iron, zinc and copper.

Why is aluminium not extracted from its ore in this way?

Understanding exothermic reactions

We are learning how to:

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

Many chemical changes result in a very obvious energy change. Fireworks, using glow sticks 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 3.3.9a: Fireworks and glow sticks make use of exothermic reactions.

Some examples are:

- Adding strong bases or reactive metals to strong acids, causing the temperature to increase dramatically.
- The reaction between iron wool and oxygen – a type of hand-warmer makes use of the heat produced by this.
- Adding calcium oxide (quicklime) to a bath of cold water, producing such an exothermic reaction that the cold water boils after about ten minutes!
- The thermit reaction, in which aluminium powder reacts with iron oxide using a magnesium fuse – aluminium is

Did you know...?

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

FIGURE 3.3.9b: The thermit reaction is useful in repairing railway tracks. The extreme heat melts the iron, which runs into any crack.

more reactive than iron, displacing it to produce iron metal. The reaction is highly exothermic, and the heat produced melts the iron.

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 where 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 bonds between 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?

Energy diagrams for reactions

Figure 3.3.9d shows how the energy of the reactants and products change 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.

energy of reactants – energy of products = energy transferred

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

   b) the thermit reaction.

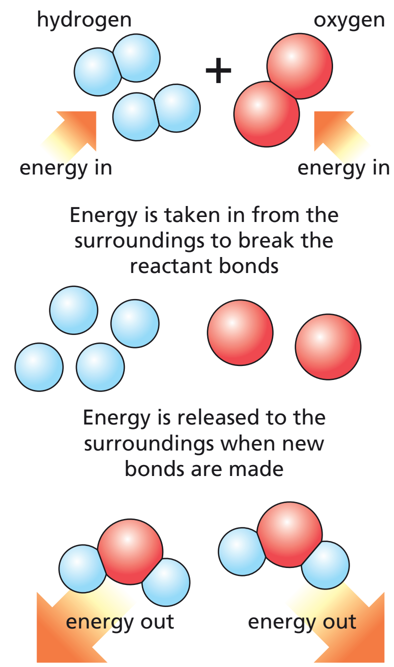


FIGURE 3.3.9c: Bond-making and bond-breaking processes occur when hydrogen is burned.

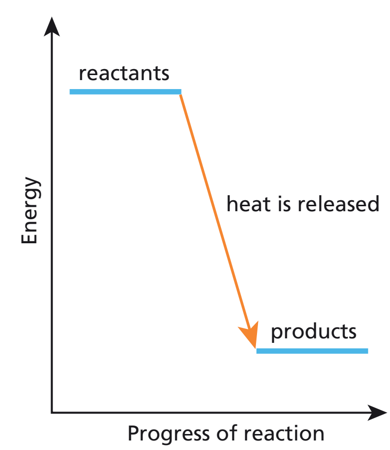


FIGURE 3.3.9d: Energy levels of reactants and products during an exothermic reaction

Key vocabulary

exothermic

bond-making

bond-breaking

Comparing endothermic and exothermic changes

We are learning how to:

- Describe examples of endothermic reactions.
- Compare the energy changes during exothermic and endothermic reactions.

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

FIGURE 3.3.10a: 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. Water and ammonium nitrate are sealed in separate chambers in a sealed bag – squeezing the bag causes the water and ammonium nitrate to mix, cooling the mixture rapidly.

FIGURE 3.3.10b: When an ammonium salt is dissolved in water, the temperature drop is enough for ice to form on the outside of the flask.

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?

Energy changes

Figure 3.3.10c 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.

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.

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 3.3.10b. Sketch a graph to compare the energy changes in these two processes.

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.

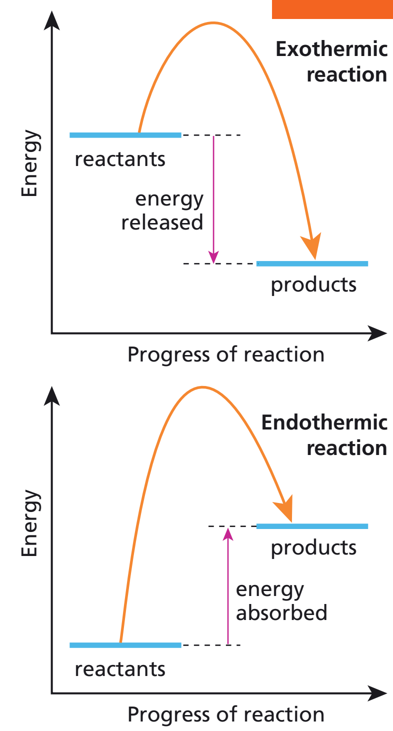


FIGURE 3.3.10c: Energy-level diagrams for exothermic and endothermic reactions

TABLE 3.3.10: 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	496	1486
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

5. Use the data in Table 3.3.10 to determine whether the reactions are exothermic or endothermic.
6. Why do you think some bonds are harder to break than others?

Key vocabulary

endothermic

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 does not actually take part in the reaction, and 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?

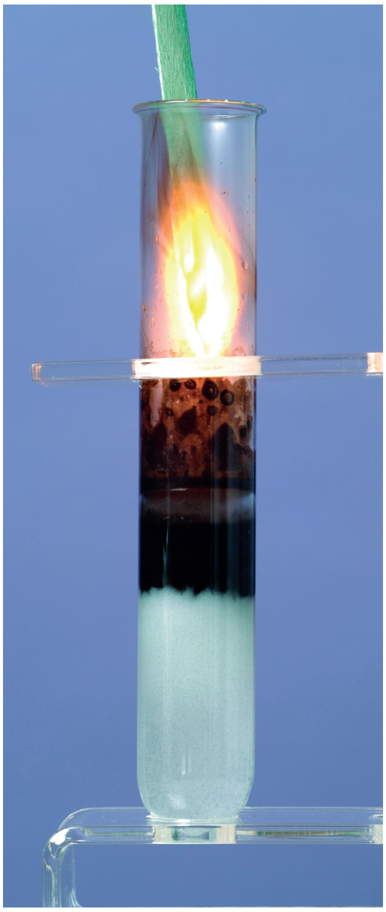


FIGURE 3.3.11a: Decomposition of hydrogen peroxide can be catalysed by manganese dioxide (black powder).

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 metals or metal oxides.

To investigate the effect of catalysts, you can observe how fast a reaction occurs. This can be done by either recording 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 3.3.11b represents the reaction with a catalyst? Explain your answer.
4. How would you find out if catalase was a better catalyst than manganese dioxide?

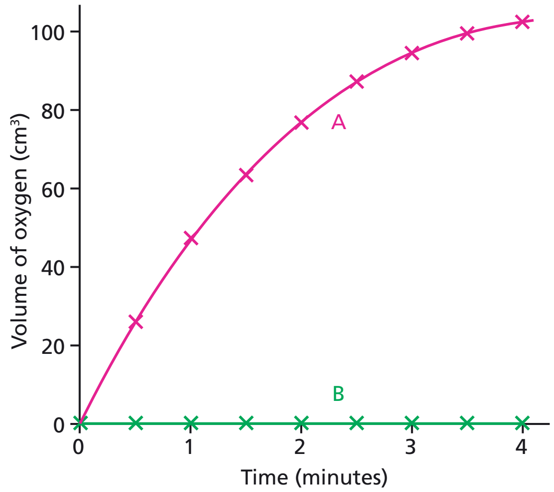


FIGURE 3.3.11b: How the decomposition of hydrogen peroxide proceeds with and without a catalyst

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 is not part of the reaction. It 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

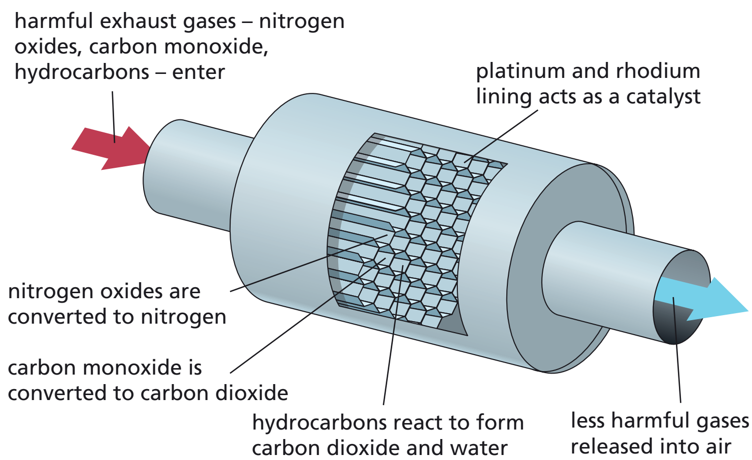


FIGURE 3.3.11c: A catalytic converter

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.

Key vocabulary

catalyst

rate of reaction

enzyme

catalytic converter

Exploring ceramics and their properties

We are learning how to:

- Describe what is meant by the term ceramic.
- Describe the properties of ceramics.

We think of a 'ceramic' as clay or pottery. This group of materials has greatly changed over the centuries, with the development of a wide set of very useful properties.

What is a ceramic?

Archaeologists have uncovered human-made **ceramics** dating back to 24 000 BCE. Animal and human figurines were made from animal fat, bones, bone ash and fine clay and fired in a kiln. Ceramic pottery vessels have been used since 9000 BCE to store grain and other foods. In 4000 BCE, glass was first discovered and in 1600 BCE the first porcelain ('china') was made in China.

A ceramic is an inorganic (not carbon-based), non-metallic solid. It is prepared by the action of heat followed by cooling. Ceramics are used for making tiles, glass, bricks, plates and vases and ornamental objects.

1. List three items made from ceramics in your home.
2. Ceramic materials have been uncovered since earliest human history. What does this tell you about the nature of ceramics?

General properties of ceramics

Ceramics are very useful because of their properties. Most are:

- hard and resistant to wear
- relatively light
- brittle – they can break easily if a force is applied
- thermal insulators – they keep heat in
- electrical insulators – they do not allow electric current to pass through
- non-magnetic
- chemically stable – they do not break down in air
- non-toxic – they can be used for food and drink
- non-ductile – they cannot be drawn out into wire.

FIGURE 3.3.12a: A Bronze Age ceramic pot

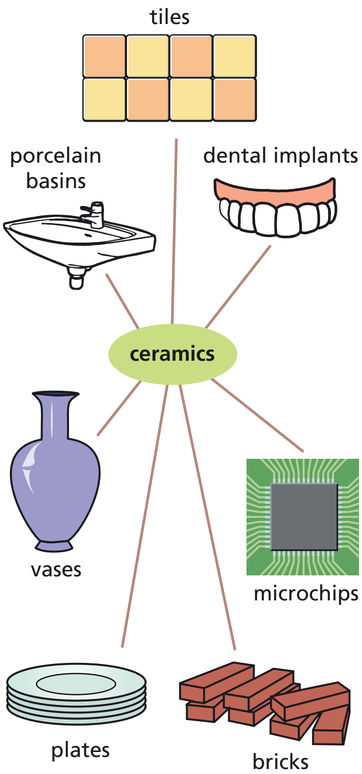


FIGURE 3.3.12b: Some of the uses of ceramics

540235_P070_107.indd 92 24/04/2014 10:53

3. Draw a table to compare the properties of ceramics with metals.
4. Suggest why ceramics may be used for some purposes instead of metals.

The chemistry of ceramics

Clay, sand and other natural materials were important ingredients in early ceramics. Nowadays, advanced ceramics are based on oxides like aluminium oxide – nitrides, silicides and carbides, for example boron carbide (B_4C), are also used. Hardly any natural materials are used now. The ingredients are carefully manufactured to produce exact properties.

There are two main types of ceramic, although with modern materials the classification is less simple:

- **crystalline** – usually made from one or more varieties of a metal oxide
- **amorphous** (which means without shape) – glass based ceramics come into this category.

The atoms are bonded in a regular 3D pattern. Powdered raw materials are used, and additives and water added to form specific shapes. The mixture is then heated to a high temperature, which expels water and causes the particles to take up a permanent regular structure.

When molten glass mixtures are thrust in very cold conditions quickly, they cannot form a regular structure and as a result they can be 'blown' or moulded into very specific shapes. Once they are cooled they form permanent irregular structures.

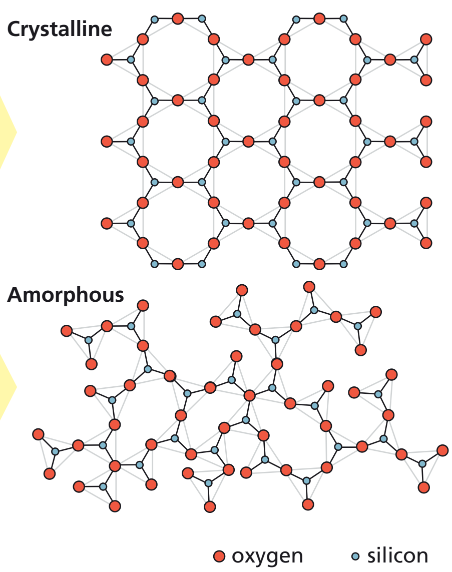


FIGURE 3.3.12c: Some ceramic materials, like silicon dioxide (SiO_2), can exist in either amorphous or crystalline form.

5. Summarise the key differences between crystalline ceramics and amorphous ceramics.
6. Why are ingredients that are taken directly from nature no longer used in making ceramics?

Did you know...?

The world's most expensive 18th century Chinese vase sold for £53 million in 2010.

FIGURE 3.3.12d: The world's most expensive Chinese vase

Key vocabulary

ceramic

crystalline

amorphous

Matching properties of ceramics to their uses

We are learning how to:

- Explain how the properties of ceramics determine their uses.

Ceramics are probably the most widespread materials in use today. The ability to manufacture them to have particular properties has provided an edge over more traditional materials like metals.

Different uses of ceramics

Ceramics can be classed according to their main uses:

- Refractory uses These are industrial uses such as linings for furnaces, gas-fire linings, steel-making and glass-making crucibles.
- Structural uses These include roofing tiles, floor tiles, pipes and bricks. Ordinary clay is used for these purposes with ingredients like sand, lime and iron oxide added to change the characteristics.
- Whiteware These include tableware, cookware, wall tiles, toilets, basins and baths. They are largely made from **earthenware**, **stoneware**, **porcelain** or fine china-clay ceramics. Earthenware and stoneware tend to be used for tableware and cookware. Porcelain is harder and more durable and is used for making baths and toilets. China clay-based ceramics are the hardest and most durable of all these types.

1. What properties of ceramics are shown in the photos?

2. Which of the above uses are specific only to ceramics?

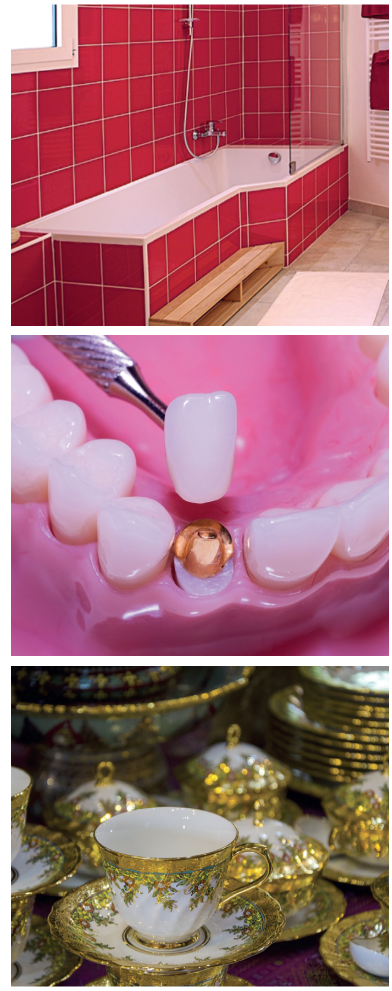


FIGURE 3.3.13a: Ceramics are used in bathrooms. Porcelain is used in dentistry, as well as for tableware.

Matching properties to uses

Refractory ceramics retain their strength at high temperatures, and resist corrosion and chemical attack. Oxides of aluminium, silicon, calcium and magnesium are some of the ingredients used to make refractory ceramics. They are used in furnaces, like the blast furnace, where metals are extracted from their ores.

Advanced applications of ceramics include specialist uses such as tiles for space shuttles, high temperature parts for aeroplane engines, turbo-jet engine blades, gas burner

FIGURE 3.3.13b: Refractory ceramics like these bricks are used to line kilns.

nozzles and missile nose cones. They are also of great importance in the electronics industry.

TABLE 3.3.13: Properties of some common ceramics – with metals for comparison

Type of material	Name of material	Melting point (°C)	Measure of hardness*	Density (g/cm³)	Measure of expansion on heating*
ceramic	aluminium oxide	2050	9	3.8	8.2
ceramic	silicon carbide	2800	9	3.2	4.3
ceramic	zirconium oxide	2660	8	5.6	6.6
ceramic	porcelain	1840	7	2.3	8
metal	mild steel	1370	5	7.9	15
metal	aluminium	660	3	2.7	24

*The higher the number, the bigger the hardness, or the greater the amount of expansion.

3. Describe, in general, how the properties of ceramics differ from metals.

4. a) Which properties would be most important when lining a furnace?

b) Which ceramic would be most suitable for this purpose? Explain your answer.

Problems with the use of ceramics

Manufacturing ceramics relies on both chemical and physical processes. The formation of bonds between ceramic particles depends on the perfect composition of the raw materials, and the conditions under which they are heated. These are not always attainable, and defects may be found after manufacture.

Another problem is that ceramics are very brittle compared to metals, shattering on impact.

Producing ceramics is a high-energy and expensive process. Clay has to be dug from the ground and many raw materials need to be manufactured to high specifications.

5. Are ceramics compounds or mixtures? Explain your answer.

6. Consider whether the statement ‘ceramic could completely replace metals’ is true or false. Justify your answer.

Did you know...?

Tantalum hafnium carbide is a refractory ceramic that can withstand extremely high temperatures. It has a melting point of over 4200 °C.

Key vocabulary

earthenware

stoneware

porcelain

refractory ceramics

Exploring natural polymers

We are learning how to:

- Explain what a polymer is.
- Describe examples of natural polymers.

Polymers are chemicals that have been around since the start of life. Natural polymers make up the constituents of living organisms. But what makes them so special?

FIGURE 3.3.14a: This beetle has a hard covering of a polymer called chitin.

What is a polymer?

Polymers can be found in nature. They are chemicals made of long chains of repeating chemical units – the repeating molecule is called a **monomer**.

One of the most familiar natural polymers is starch. Plants store glucose in the form of starch – glucose is its monomer.

Figure 3.3.14b shows a glucose molecule and the structure of starch. There are about 10 000 glucose monomers in a starch molecule. Plants store glucose as starch, which is insoluble in cold water – this means that starch can be stored within plants. Glucose, however, is soluble in cold water. When a plant needs glucose, enzymes break bonds in the starch. This releases glucose molecules for the plant to use.

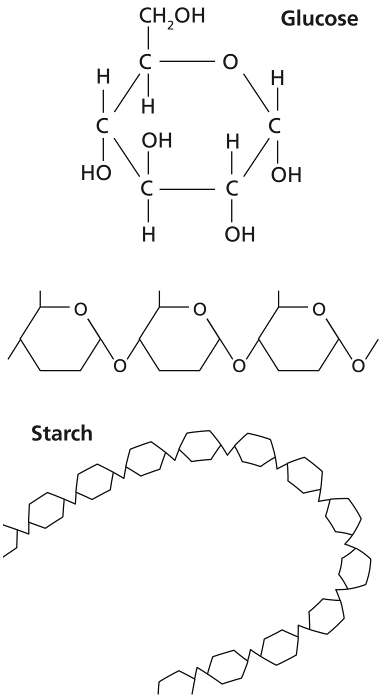


FIGURE 3.3.14b: Starch is made up of many glucose monomers.

1. Polymers can be broken down to the molecules they are made from. Is this a physical or a chemical change?
2. Why is it useful to store small molecules (such as glucose) in the form of polymers (such as starch)?

Examples of natural polymers

Proteins are some of the most important natural polymers. The monomers of proteins are called amino acids – there are over 20 different types. This means that different combinations of amino acids can give rise to an enormous variety of different proteins, each with different properties. Enzymes, muscle fibres, collagen (found in skin, ligaments and bones), haemoglobin (in red blood cells) and antibodies are all proteins.

DNA, shown in Figure 3.1.9b in Topic 3.1, is another polymer. It was one of the first polymers to appear on Earth, enabling life to reproduce.

Cellulose is the polymer that makes up the cell wall of plants, providing them with strength. Cotton is the purest form of cellulose.

Insects and crustaceans have a hard covering to their bodies made from the polymer **chitin**. It is waterproof, but flexible so that the animal can move inside it and grow.

Silk and rubber are natural polymers made by living organisms. Silk is made by silk worms – rubber is a polymer found in the sap of rubber trees.

3. Which of the following are likely to be polymers?

a) water

b) keratin, the component of nails and hair

c) sugar

4. Plants store sugar in the form of starch; animals store it in the form of glycogen. What prediction(s) can you make about glycogen?

Some properties of natural polymers

Polymers have very large molecules. Their structure often has a particular shape that provides them with particular properties. The arrangement of molecules within a polymer defines this shape.

Cellulose and starch are both made from glucose, but in different arrangements. Cellulose is very hard to break down, extremely tough and strong enough to make fibres for clothes. Starch is easy to break down.

Many polymers are strong because of the number of chemical bonds within their structure. Some are elastic, like muscle fibre and rubber. In elastic polymers the long chains are tangled up in their natural state and they straighten to long lengths when a force is applied.

5. Do you think that polymers are chemically the same as the monomers that make them? Explain your answer.

6. Draw a model to represent a polymer with elastic properties.

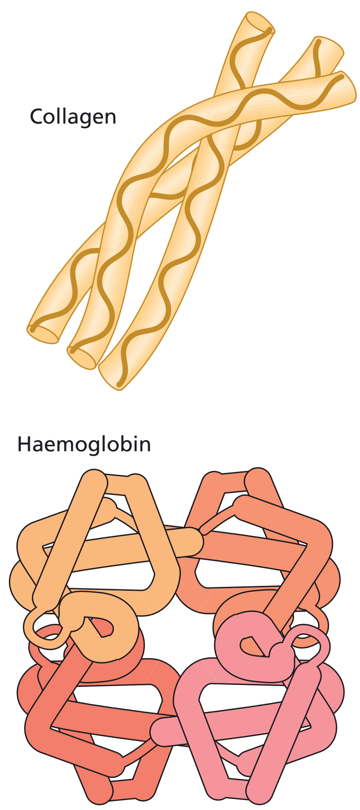


FIGURE 3.3.14c: Different proteins have different shapes.

Did you know...?

Cellulose is the most abundant compound made from plants.

Key vocabulary

polymer

monomer

protein

cellulose

chitin

Using human-made polymers

We are learning how to:

- Describe how human-made polymers are made in simple terms.
- Describe uses for human-made polymers.

The usefulness of polymers in nature has inspired people to imitate their chemistry. We have designed a range of synthetic polymers, which we now depend on.

Making synthetic polymers

Humans have been using natural polymers for thousands of years, largely in the form of cellulose from cotton and hemp, and also rubber from rubber plants. But there was no chemical understanding of how polymers worked until the 1900s, when **synthetic** polymers began to be developed. Herman Staudinger won a Nobel Prize in 1953 for his research in explaining how polymers work.

In the development of synthetic polymers, carefully selected monomers were heated under great pressure. Catalysts were added until, almost by chance, polymers were made. **Polythene** is a synthetic polymer, which has many uses. It is a type of plastic.

FIGURE 3.3.15a: Polythene has many uses including the construction of polytunnels for growing plants.

1. What are the similarities between synthetic polymers and natural polymers?
2. Why did it take so long for chemists to find out what polymers are made from?

Uses of synthetic polymers

The name of a polymer is derived from its monomer. In polystyrene, the monomer is styrene; in polyvinyl chloride (**PVC**) the monomer is vinyl chloride. Most synthetic polymers are derived from monomers that come from crude oil. They are mostly made of hydrogen and carbon.

Table 3.3.15 shows different types of polymers and their uses.

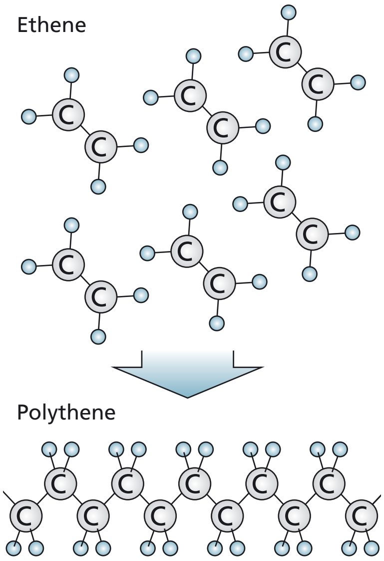


FIGURE 3.3.15b: Polythene can be made from its monomer, ethene.

3. What do all monomer units have in common?
4. Describe some examples of uses of polymers in place of metals.

TABLE 3.3.15: Uses of some polymers

Name of polymer	Uses of polymer
polythene	plastic bags, plastic containers, cling film, plastic milk bottles
polystyrene	packaging, model kits, containers
acrylics	aircraft canopies, covers for car lights
nylon	ropes, fabrics, gear wheels
polypropylene	ropes, containers
polychloroethene	water pipes

Did you know...?

Kevlar is a synthetic polymer used to make bulletproof vests. Its strength comes from many strong intermolecular bonds between the polymer chains.

Properties of synthetic polymers

The types of monomer, the way they are bonded and the length of a polymer chain all determine the properties of synthetic polymers. By understanding the chemistry, scientists have found ways to improve on their properties.

FIGURE 3.3.15c: Contact lenses are made from polyacrylamide, which is cross-linked and holds water molecules inside its structure.

The length of a polymer chain alters the melting and boiling points of the polymer. The longer the chain, the higher the melting and boiling points, and generally the more viscous the polymer is in the liquid state.

The overall structure of a polymer affects its properties. **Cross-links** within the polymer can be made by inserting small amounts of other elements. The natural polymer rubber is strengthened by adding small amounts of sulfur. These sulfur cross-links enable tyres to be made from rubber. Cross-links also allow polymers to hold other molecules within them, forming gels.

The amount of branching in a polymer chain affects its properties. Low-density polythene is used for plastic shopping bags – it is light, flexible and has chains with many branches. High-density polythene is made of single straight chains – it is rigid, strong and dense, and so is used to make plastic buckets. Both are made from the same monomer, ethene.

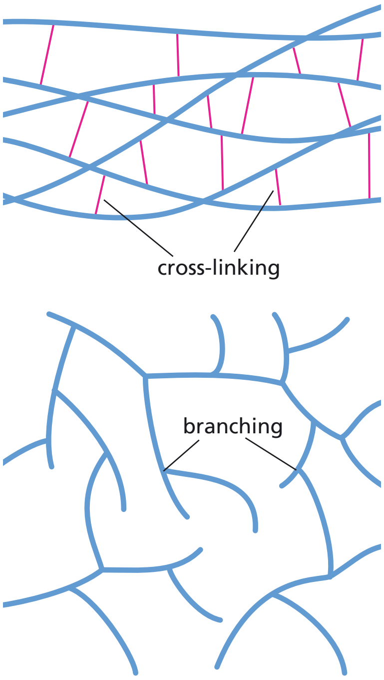


FIGURE 3.3.15d: Cross-linking and branching determine the properties of a polymer.

5. Draw a model of a polymer molecule with a high melting point which is very light.
6. Explain how cross-linked polymers might be used in the delivery of medicines into our bodies.

Key vocabulary

synthetic
polythene
PVC
cross-link

540235_P070_107.indd 99 24/04/2014 10:53

Explaining composites

We are learning how to:

- Explain what is meant by the term 'composite'.
- Describe some uses of natural composites.

There is a saying that 'two is better than one'. In the case of making composite materials this is certainly the case.

What are composites?

Composites are formed when two or more materials, often with different properties, are combined. The composite is usually stronger, more durable or has other desirable properties compared to the materials it is made from. The materials involved are not often chemically combined together, and are ususally recognisable within the composite.

Around 1500 BCE, Ancient Egyptians were making bricks from mud – this is an early example of a composite. Straw was added to the mud mixture, resulting in stronger and more durable bricks. The straw was not chemically combined with the mud and acted to enhance its properties.

FIGURE 3.3.16a: These bricks are made from mud and straw, in an ancient traditional method.

In the 12th century the Mongols improved the design of their archery bows by adding cattle tendons, horn, bamboo or birch, silk and pine resin. These were far stronger, superior bows compared with their bows constructed of single materials.

1. Define the term 'composite'. Give one everyday example of a composite.
2. Draw a diagram to show how straw might add strength to bricks made from mud.

Explaining concrete

Concrete is a composite made from natural materials, some of which have been processed. First, limestone and clay are heated to over 700 °C in a kiln to make cement. This is then added to sand, water and gravel to make concrete. The proportions of the ingredients determine the overall properties of the concrete.

FIGURE 3.3.16b: The Three Gorges Dam in China is made from concrete.

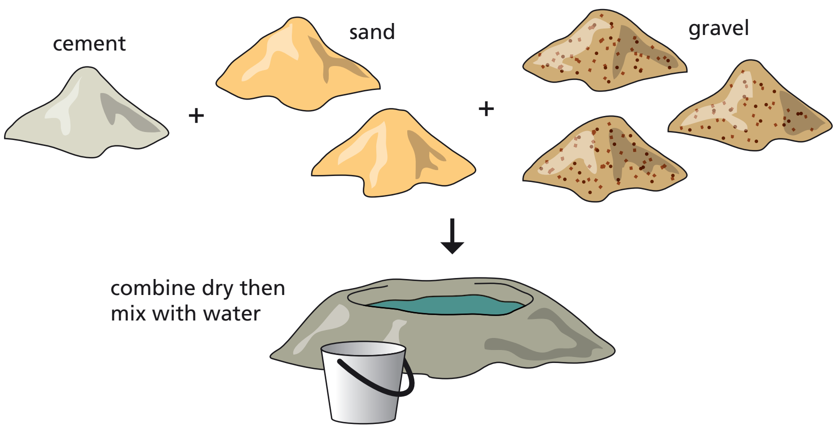


FIGURE 3.3.16c: How concrete is made

3. a) Civil engineers routinely test the strength, density and ability of concrete to soak up water. Why might the results of such tests not be reliable for all the concrete samples they test?

b) What could be done to improve the reliability of the tests?

Composites in nature

Composites are normally made from two parts. One acts as a **matrix** or 'binder'. The other is the **reinforcement**, which is usually fibres, crystals or fragments.

Wood is a natural composite – it is composed of cellulose and lignin. Without the lignin, the cellulose is much weaker (as in cotton which contains cellulose but no lignin). Together, they bond to make a much stronger material. The lignin acts like a glue, binding the fibres of cellulose together.

Bone is another composite found in nature. It is composed of a soft, flexible protein called collagen and a hard, brittle mineral made from calcium phosphate. The mineral reinforces the collagen making it stronger, so the bone is strong but also slightly flexible and not brittle.

4. Explain which is the binder and which is the reinforcement found in wood and bone.

5. Wood from the Brazilian Cherry is four times harder than wood from the Douglas Fir. Draw a model of the wood from each tree, showing how the structure of the composite materials might account for these differences.

6. Osteoporosis is a condition in which bones break easily and become less dense. Which part of the composite material is lacking in a person with osteoporosis?

Did you know...?

Concrete is the most widely used material in the world today, with two billion tonnes produced a year.

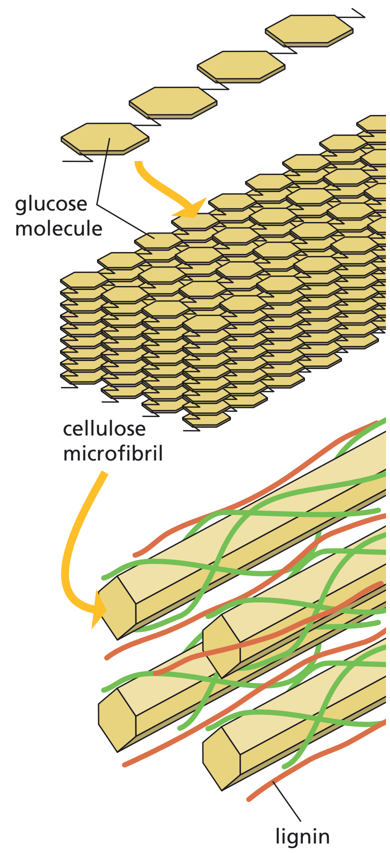


FIGURE 3.3.16d: Cellulose forms long fibres, composed of long chains of glucose molecules. Lignin, found in wood, binds the fibres together.

Key vocabulary

composite

concrete

matrix

reinforcement

Using human-made composites

We are learning how to:

- Explain how human-made composites were developed.
- Describe the properties and uses of human-made composites.

Human-made composites are relatively new, with plastics paving the way. Nowadays, we use a host of new materials with improved features. Will the world of composites finally replace metals?

Development of human-made composites

In 1935, scientists developed **fibreglass** by adding short glass fibres to a plastic matrix (polyester). An incredibly strong material was created, which was also lightweight. Fibreglass dominates the world of composites today, accounting for 90 per cent of the market.

The space race in the 1950s led to new metal-matrix composites in which fibres of ceramic, plastic or metal were fixed in a metal matrix. These were able to withstand very high temperatures, without causing too much thermal expansion.

In the 1960s, fibres of carbon (from the graphite) were investigated, leading to carbon fibres being added to a plastic matrix. The product, called **carbon fibre**, is the strongest material on the planet.

Today there are many types of composites. These have combinations of plastic, ceramic and metal matrices and different types of materials to reinforce these, depending on the properties required. Glass and carbon fibres are still mostly used to reinforce the matrix.

1. What makes glass and carbon fibres a popular choice as reinforcers?
2. Suggest why plastic matrices were preferred to metal or composite ones for the development of carbon fibre composites.

Some uses of human-made composites

Fibreglass is lightweight, strong, impact-resistant, corrosion-resistant, waterproof and can be moulded into many shapes. It is also relatively cheap to make and the raw materials are abundant. This set of unique properties has made it ideal for

FIGURE 3.3.17a: Denver International Airport is made from fibreglass.

540235_P070_107.indd 102 24/04/2014 10:53

manufacturing boats, ships, swimming-pool linings, house insulation and roofing materials.

Carbon fibre is one of the most lightweight and strongest materials. It has many applications including making car, aircraft and spacecraft bodies, the construction of buildings, manufacture of bikes and audio equipment, and sports equipment such as tennis racquets.

Cermets are composites in which a ceramic matrix, often titanium carbide, has metal particles added. They are particularly useful where high temperatures are needed, such as in some electrical applications. They are also used for making machine tools, dental fillings and hip replacements. Some cermets are being considered for use in spacecraft shielding to resist high-speed space debris and small meteors.

3. Fibreglass is waterproof. Suggest why carbon fibre might be preferred in the construction of buildings.
4. Can you think of other uses of fibreglass and carbon fibre?

FIGURE 3.3.17b: Cermets are used in power tools.

Comparing human-made composites

Table 3.3.17 shows some data about different types of composite – some metals are included for comparison.

TABLE 3.3.17

Type of material	Material	Density (g/cm^3)	Strength (MPa)*	Strength/ weight ratio
composite	fibreglass	1.9	3400	1307
composite	carbon fibre	1.6	4300	2457
metal	aluminium	2.8	600	214
metal	stainless steel	7.86	2000	254
composite	concrete	2.3	12	4.35

*The pressure needed to squash the material until it breaks.

5. What conclusions can you draw from the data in Table 3.3.17?
6. Explain what might cause the differences in data between carbon fibre and fibreglass. Use diagrams and models to help your explanation.

Did you know...?

Formula One racing cars are made almost entirely of carbon fibre. Each costs over one million dollars to build.

FIGURE 3.3.17c: A racing car made from carbon fibre

Key vocabulary

fibreglass
carbon fibre
cermet

Checking your progress

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

Write word equations to represent the decomposition of metal carbonates.	Use observations from thermal decomposition reactions to make inferences about metal reactivity.	Write balanced symbol equations for the decomposition of metal carbonates.
Give uses of displacement reactions and write word equations to represent them.	Use models to explain displacement and relate it to the reactivity series.	Write balanced symbol equations for displacement reactions.
Describe different ways to extract metal ores from the Earth and describe the associated environmental issues.	Explain how metals are recycled and how this affects the environment.	Evaluate the positive and negative aspects of metal mining and extraction.
Describe the use of carbon in extracting iron from its ore.	Describe the process of extracting iron from its ore in a blast furnace.	Use balanced symbol equations to make predictions about the mass of iron produced when extracted from ore, showing that mass is conserved, and explain the advantages of using carbon.
Write word equations for the reactions between carbon and metal ores.	Describe the extraction processes for lead, copper and zinc.	Work out the yield of an extraction process.

Describe what is meant by the terms exothermic and endothermic reactions, with examples.	Explain the energy changes taking place during an exothermic and endothermic reaction.	Use energy-level diagrams to compare the energy in the reactants and products of exothermic and endothermic reactions, explaining the energy changes in the particles.
Describe what a catalyst is and give examples.	Interpret data to explain how a catalyst affects a reaction.	Explain how a catalyst works.
Describe what is meant by the term 'ceramic', describing their properties and uses, with some examples.	Explain how different types of ceramic vary in their properties.	Explain how the chemistry and bonding within a ceramic affects its properties.
Describe what is meant by the term 'polymer', using examples of natural and human-made polymers.	Describe the properties of polymers, explaining how these relate to their uses.	Explain how the properties of polymers are affected by their bonding, using simple models.
Describe what is meant by the term 'composite' using examples of natural and human-made composites.	Describe the properties of composites, explaining how the properties relate to their uses.	Use models to explain how composites are constructed and use these to explain their properties.

540235_P070_107.indd 105 24/04/2014 10:53

Questions

Questions 1–7

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

1. Which of the following is a natural polymer? [1]

a) cement **b)** protein **c)** plastic **d)** brick

2. Which is the most reactive element in this list? [1]

a) sodium **b)** silver **c)** carbon **d)** copper

3. Which of the following is an example of an endothermic change? [1]

a) burning magnesium **b)** dissolving calcium chloride
c) photosynthesis **d)** firework

4. Which of the following are *not* extracted by using carbon? [1]

a) zinc **b)** iron **c)** copper **d)** aluminium

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

6. Describe the difference between a polymer and a composite. [2]

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

Questions 8–14

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

8. Rubidium is more reactive than sodium. Which of the following correctly shows the word equation between rubidium and sodium chloride? [1]

a) rubidium chloride + sodium → sodium chloride + rubidium
b) rubidium + sodium chloride → rubidium chloride + sodium
c) sodium + rubidium → sodium chloride + rubidium
d) sodium chloride + rubidium → sodium chloride + rubidium

9. 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

10. Which of the following is likely to be a very viscous polymer with the highest melting and boiling point? [1]

a)  **b)** 
c)  **d)** 

11. Which of the following statements about the energy diagrams in Figure 3.3.19a is true? [1]

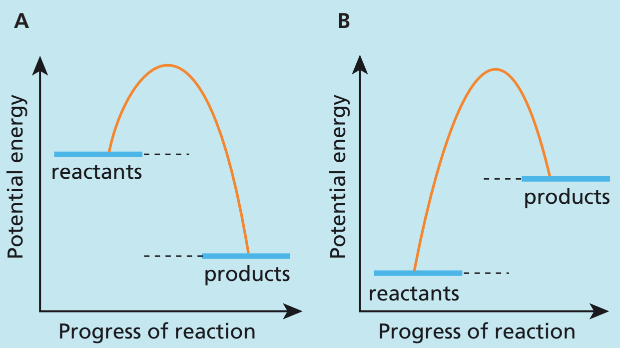


FIGURE 3.3.19a: Exothermic and endothermic energy diagrams

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.

12. Zinc ore is 40 per cent pure. Carbon is used to extract the zinc from its oxide. The process has a yield of 50 per cent. If 100 tonnes of zinc ore were processed, how much zinc would be obtained? [2]

13. Which will have the biggest impact on the metal underneath – scratching a 'tin' can or scratching a galvanised steel plate? Explain your answer. [2]

14. A mine owner wants to start a copper mine in an area of outstanding natural beauty. Explain the issues involved that will impact on the environment. [4]

Questions 15–16

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 3.3.19b 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? [2]

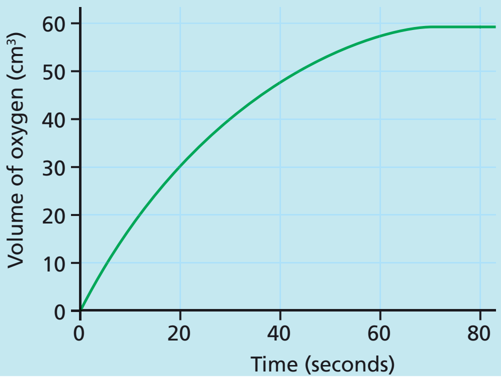


FIGURE 3.3.19b: Graph showing the rate of decomposition of hydrogen peroxide with a catalyst

16. Titanium metal produces fewer bubbles when placed in acid, compared to aluminium. It oxidises more quickly than copper in air. Explain, using ideas about reactivity, how:

a) aluminium **b)** copper can be used to protect titanium in a new application. [4]