# 12.1 Mass and energy in chemical reactions

## Objective

- Give definitions for the terms *mass is conserved*, *energy is conserved*, *symbol equation*, and *balancing numbers*

The fuel for the bus is methane. Where does the methane come from?

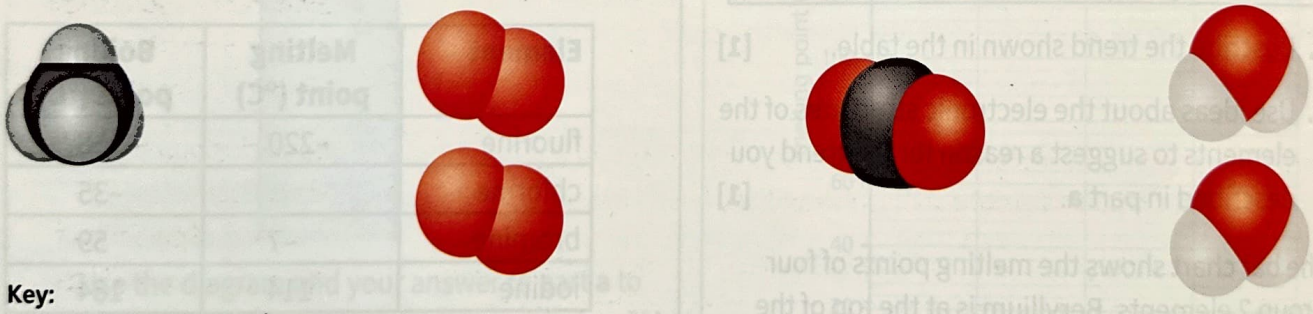

Bacteria make the methane from human waste. The waste comes from toilets, via a sewage works.

## Conserving mass

In the bus engine, there is a chemical reaction. The fuel, methane, reacts with oxygen from the air. The combustion reaction has two products – carbon dioxide and water.

As in all chemical reactions, the atoms rearrange and join together differently. The diagram below models the reaction. Each sphere represents one atom.

Methane… reacts with… oxygen… to make… carbon dioxide… and… water.



**Key:**

- carbon atom
- oxygen atom
- hydrogen atom

As you can see, there are the same number of atoms of each element before and after the reaction:

- 1 carbon atom
- 4 hydrogen atoms
- 4 oxygen atoms.

Since the number of atoms does not change, the mass of reactants is equal to the mass of products. The total mass does not change. As in all chemical reactions, **mass is conserved**.

## Conserving energy

The combustion of methane is an exothermic chemical reaction. At the start, energy is stored in the methane and oxygen molecules. As methane

burns, thermal energy is transferred to the surroundings (in this case, to the bus engine and – in the end – to the air). The total amount of energy does not change. **Energy is conserved.**

Energy is conserved in all chemical reactions, whether they are exothermic or endothermic.

## Symbol equations

You can show the reaction of methane with oxygen as a word equation:

methane + oxygen ⟶ carbon dioxide + water

The word equation shows the reactants on the left, and the products on the right. The arrow means 'reacts to make'.

**Symbol equations** also show chemical reactions. For example:

| methane | + | oxygen | ⟶ | carbon dioxide | + | water |
|---|---|---|---|---|---|---|
| $CH_4$ | + | $2O_2$ | ⟶ | $CO_2$ | + | $2H_2O$ |

The symbol equation shows the chemical formula for each substance:

- $CH_4$ for methane
- $O_2$ for oxygen
- $CO_2$ for carbon dioxide
- $H_2O$ for water.

As in the word equation, the reactants are on the left, and the products are on the right. The arrow means 'reacts to make'.

The numbers shown above in red are balancing numbers. **Balancing numbers** show the relative numbers of particles of the reactants and products. The symbol equation above shows that:

- One methane molecule reacts with two oxygen molecules to make one carbon dioxide molecule and two water molecules.

Or that:

- One billion methane molecules react with two billion oxygen molecules to make one billion carbon dioxide molecules and two billion water molecules.

And so on. A balancing number is written to the left of its chemical formula. It is written on the line, and is the same size as the letters in the formula.

### Key points

- Mass is conserved in chemical reactions – the total mass of products equals the total mass of reactants.
- Energy is conserved in chemical reactions – the total amount of energy does not change.
- Symbol equations show chemical reactions with chemical formulae.
- Balancing numbers show the relative numbers of particles of reactants and products.

### Questions

1. Write definitions for *mass is conserved* and *energy is conserved* in a chemical reaction.
2. TWS Give the meaning of the arrow in word and symbol equations.
3. Look at the symbol equation for the combustion of methane.
   a. Name the two elements whose atoms are in a methane molecule.
   b. Write the names and formulae of the products of the reaction.
   c. TWS Give the number of oxygen molecules that react with one million methane molecules.

Extension

12.2

## Objective

- Write balanced symbol equations for chemical reactions

▲ *A precipitate of silver iodide*

# Writing symbol equations

Darpan mixes two colourless solutions, silver nitrate and potassium iodide. There is a chemical reaction. The reaction makes two products – silver iodide (a yellow precipitate) and potassium nitrate (a colourless solution). Here is the word equation for the reaction:

silver nitrate + potassium iodide ⟶ potassium nitrate + silver iodide

How do you write a symbol equation for the reaction?

## Symbol equations

As you know, symbol equations show the reactants and products in a chemical reaction. They also show:

- the chemical formulae of the reactants and products
- the relative numbers of particles of reactants and products
- the states of the reactants and products.

The symbol equation for the precipitation reaction in the photo is:

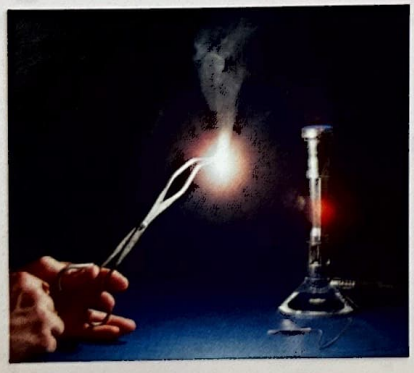
| potassium iodide | + | silver nitrate | ⟶ | silver iodide | + | potassium nitrate |
|---|---|---|---|---|---|---|
| $KI(aq)$ | + | $AgNO_3(aq)$ | ⟶ | $AgI(s)$ | + | $KNO_3(aq)$ |

There are no balancing numbers because there are the same numbers of atoms of each element in the reactants and products.

### State symbols

The letters in brackets are state symbols. State symbols show the state of the substances in a reaction. They are given below. Write one state symbol to the right of each formula. Do not use capital letters.

- (s) for solid
- (l) for liquid
- (g) for gas
- (aq) for a substance dissolved in water.



▲ *Burning magnesium*

## Writing symbol equations

### Magnesium and oxygen

Magnesium burns brightly in oxygen. The product is magnesium oxide. Follow the steps below to write a balanced symbol equation for the reaction.

1. Write a word equation, with the chemical formula under each substance. Do not guess the chemical formulae – look them up, or ask your teacher.

| magnesium | + | oxygen | ⟶ | magnesium oxide |
|---|---|---|---|---|
| $Mg$ | + | $O_2$ | ⟶ | $MgO$ |

2. Balance the amounts of oxygen. There are two oxygen atoms on the left, and one on the right. Write a big number 2 to the left of MgO. Do not change or add any little numbers.

$$Mg + O_2 \longrightarrow 2MgO$$

The big 2 applies to every atom in the formula that follows it. Here it means that there are two magnesium atoms and two oxygen atoms. The equation now shows two oxygen atoms on each side of the arrow.

3. Balance the amounts of magnesium. Write a big 2 on the left of the Mg. The equation now shows two magnesium atoms on each side of the arrow. The equation is balanced.

$$2Mg + O_2 \longrightarrow 2MgO$$

4. Add state symbols: $2Mg(s) + O_2(g) \longrightarrow 2MgO(s)$

### Zinc and hydrochloric acid

Zinc reacts with dilute hydrochloric acid to make zinc chloride solution and hydrogen gas. Follow these steps to write a balanced symbol equation for the reaction:

1. Write the word equation, with the chemical formula under each substance.

zinc + hydrochloric acid ⟶ zinc chloride + hydrogen

$Zn + HCl \longrightarrow ZnCl_2 + H_2$

2. Balance the amounts of hydrogen. There is one hydrogen atom on the left of the arrow, and there are two hydrogen atoms on the right. Write a big number 2 to the left of HCl.

$$Zn + 2HCl \longrightarrow ZnCl_2 + H_2$$

3. The equation is now balanced. It shows:
   - one Zn on each side of the arrow
   - two H on each side of the arrow
   - two Cl on each side of the arrow.

4. Add state symbols: $Zn(s) + 2HCl(aq) \longrightarrow ZnCl_2(aq) + H_2(g)$

▲ *The reaction of zinc with hydrochloric acid.*

## Key points

To write a balanced symbol equation:

- Write a word equation for the reaction, with the chemical formula below each name.
- Balance the equation by writing balancing numbers where needed.
- Add state symbols.

## Questions

Write balanced symbol equations for these chemical reactions:

1. The reaction of solid lithium (Li) with oxygen gas ($O_2$) to make solid lithium oxide ($Li_2O$).
2. The reaction of solid magnesium (Mg) with dilute hydrochloric acid (HCl) to make magnesium chloride solution ($MgCl_2$) and hydrogen gas ($H_2$).
3. The reaction of nitrogen gas ($N_2$) with oxygen gas ($O_2$) to make nitrogen monoxide gas (NO).

# 12.3 Metal displacement reactions

A worker is using a chemical reaction to make liquid iron. The liquid iron cools and freezes, joining the rails together. The reaction is called the thermite reaction.

aluminium + iron oxide ⟶ aluminium oxide + iron

## Objectives

- Define the term *metal displacement reaction*
- Predict whether given pairs of substances take part in displacement reactions

## Classifying chemical reactions

There are several types of chemical reaction, including combustion, corrosion, and precipitation. The reaction of aluminium with iron is an example of another type of chemical reaction – displacement.

**Part of the reactivity series**

calcium
magnesium
aluminium
zinc
iron
copper
silver
gold

## Displacement reactions

### The reactivity series

As you know, the reactivity series lists metals in order of how vigorously they react with other substances. Calcium reacts vigorously with oxygen, water, and acids. It is near the top of the reactivity series. Gold, at the bottom of the reactivity series, is inert. It does not take part in chemical reactions.

### Displacement reactions involving metal oxides

In a **metal displacement reaction**, a more reactive metal displaces – or pushes out – a less reactive metal from its compound.

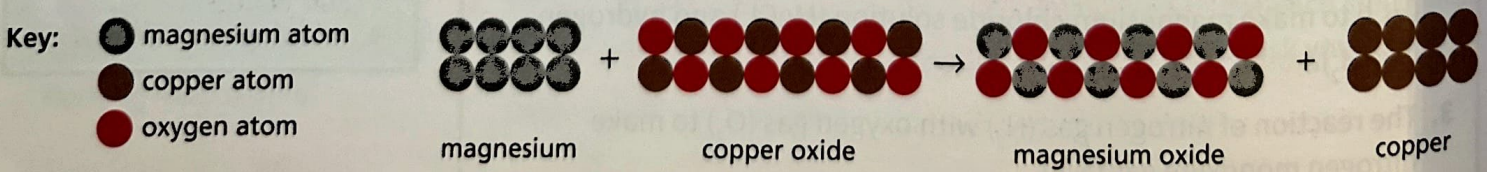
The reactivity series shows that aluminium is more reactive than iron. In the thermite reaction, aluminium pushes iron out of iron oxide. The products are aluminium oxide and iron.

In another displacement reaction, magnesium reacts with copper oxide:

magnesium + copper oxide ⟶ magnesium oxide + copper

The particle diagram below models what happens. For each substance, a small part of the giant structure is shown. Each circle represents one atom. The charges on the ions, and the electrons, are not shown.

▼ *Particle diagram for the reaction of magnesium with copper oxide.*



## Thinking and working scientifically

### Carrying out an investigation

Alex heats some pairs of substances. He looks for signs of reaction and observes any products made, and writes his results in a table.

| Metal element | Metal oxide | Observations |
|---|---|---|
| iron | copper oxide | glows red, pink-brown metal formed |
| copper | iron oxide | no reaction |
| zinc | copper oxide | glows red, pink-brown metal formed |
| copper | zinc oxide | no reaction |
| zinc | iron oxide | glows red, silver-coloured metal formed |

Alex writes word equations for the reactions:

iron + copper oxide ⟶ iron oxide + copper

zinc + copper oxide ⟶ zinc oxide + copper

zinc + iron oxide ⟶ zinc oxide + iron

Alex writes a conclusion:

My results confirm that displacement reactions happen when the metal on its own is higher in the reactivity series than the metal in the compound. If the metal on its own is less reactive than the metal in the compound, there is no reaction.

### Displacement reactions in solution

A more reactive metal also displaces a less reactive metal from its compounds in solution.

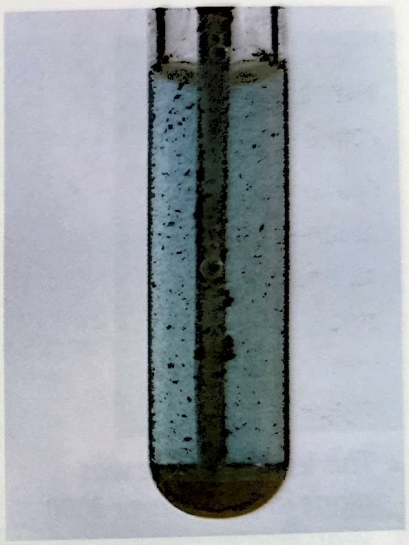
Mandeep adds magnesium to blue copper sulfate solution. After a few minutes, she sees copper metal in the test tube. The blue solution becomes paler.

There has been a displacement reaction. Magnesium is more reactive than copper, so magnesium displaces copper from copper sulfate solution:

magnesium + copper sulfate ⟶ magnesium sulfate + copper

$Mg(s) + CuSO_4(aq) \longrightarrow MgSO_4(aq) + Cu(s)$

Later, Mandeep adds copper to magnesium chloride solution. Nothing happens. There is no reaction, because copper is less reactive than magnesium. Copper cannot displace magnesium from magnesium compounds.



▲ *Iron displaces copper from copper sulfate solution.*

## Questions

1. Give the meaning of the term *metal displacement reaction*.
2. Decide which of these pairs of substances react. Write word equations for the reactions that occur:
   a. Magnesium and iron oxide
   b. Zinc and magnesium oxide
   c. Zinc and copper sulfate solution
   d. Copper and silver nitrate solution.

## Key points

- In a metal displacement reaction, a more reactive metal displaces – pushes out – a less reactive metal from its compound.

Science in context

12.4

# Extracting metals

The 55 km Hong Kong-Zhuhai-Macau Bridge is the longest sea-crossing bridge in the world. It is made from steel. Engineers used thousands of tonnes of iron to make the steel. Where did the iron come from?

## Objectives

- Define the term *ore*
- Describe the link between the position of a metal in the reactivity series, and how the metal is extracted from its ore
- Describe an application of science

▲ *This lead statuette was made in Greece over 3000 years ago.*

**Part of the reactivity series**

sodium
calcium
magnesium
aluminium
**carbon**
zinc
lead
iron
copper
silver
gold

## Extracting metals with carbon

In the Earth's crust, most metals are joined to other elements, in compounds. These compounds are mixed with other substances in rocks. A rock that a metal can be extracted from is an **ore**.

### Extracting carbon

There are two steps in getting iron from its ore:

1. Separate iron oxide from the compounds it is mixed with.
2. Use a chemical reaction to get iron from iron oxide.

In the chemical reaction, iron is heated with charcoal. Charcoal is a type of carbon.

iron oxide + carbon ⟶ iron + carbon dioxide

### Extracting lead

People have used lead for up to 8000 years. As you know, lead is now used for roofing and to protect from X-rays. Lead exists as lead sulfide in the Earth's crust. It is extracted like this:

1. Heat lead sulfide in air:
   lead sulfide + oxygen ⟶ lead oxide + sulfur dioxide
2. Heat the lead oxide with carbon:
   lead oxide + carbon ⟶ lead + carbon dioxide

### Extracting other metals with carbon

Carbon is not a metal. But we can place it in the reactivity series, as shown left. The metals below carbon can be extracted from their oxides by heating with carbon. Carbon is chosen because it is cheap and easy to obtain.

## Using electricity to extract metals

The cans below are made from aluminium. Aluminium is above carbon in the reactivity series. In the Earth's crust, it exists as aluminium oxide. Carbon cannot remove oxygen from aluminium oxide. Electricity is used instead. There are two main steps:

1. Dissolve pure aluminium oxide in a special solvent.
2. Pass a 100 000 amp electric current through the solution. The electricity splits up the aluminium oxide. This makes liquid aluminium and oxygen.

◂ *Aluminium drink cans*

Other reactive metals are also extracted from their compounds by electricity. For example, sodium is extracted by passing an electric current through seawater.

## Extracting gold

Gold is at the bottom of the reactivity series. It is unreactive. It is found as an element in the Earth's crust. The metal is easily separated from the substances it is mixed with.

Some gold is found in stream beds, mixed with sand and gravel. You can separate gold by placing the mixture in a pan, and adding water. Gold has a higher density than sand and gravel. It sinks to the bottom of the pan.

◂ *Panning for gold*

### Questions

1. Write the definition for *ore*.
2. Name two metals that are extracted from their compounds by heating with carbon, and two that are extracted using electricity.
3. Give examples to show why extracting metals from their compounds is useful.
4. Predict whether magnesium is extracted from its ore by heating with carbon or with electricity. Give a reason for your prediction.

### Key points

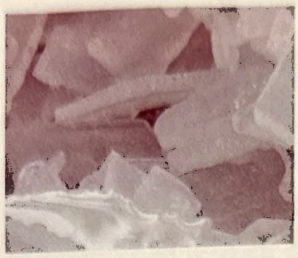
- An ore is a rock that a metal can be extracted from.
- Metals above carbon in the reactivity series are extracted from their compounds by electricity.
- Zinc, and the metals below it, are extracted from their compounds by heating with carbon.

# 12.6 Making salts from acids and metals

## Objectives

- Define the term *salt*
- Describe how to make a salt from a metal and acid
- Choose suitable equipment
- Do a risk assessment

The pictures show crystals. What do they have in common?



▲ *Magnesium chloride crystals*

▲ *Nickel nitrate crystals*

▲ *Copper sulfate crystals*

The crystals are all salts. A **salt** is a compound made when a metal ion replaces the hydrogen ion in an acid.

## Thinking and working scientifically

### Making a salt

Seeta is making a salt from magnesium and hydrochloric acid. The equation for the reaction is:

| magnesium | + | hydrochloric acid | → | magnesium chloride | + | hydrogen |
|---|---|---|---|---|---|---|
| Mg | + | 2HCl | → | $MgCl_2$ | + | $H_2$ |

### Doing a risk assessment

Seeta carries out a risk assessment. She identifies hazards and risks linked to the reactants, the products, and the equipment. She decides how to reduce the chance and consequences of injury from each risk.

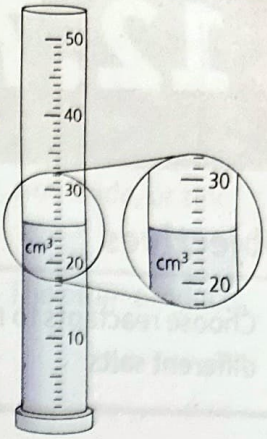
| Hazard | Risk | Reduce chance of injury and damage by... |
|---|---|---|
| magnesium | flammable | keep magnesium away from flames |
| dilute hydrochloric acid | corrosive – damages eyes and skin | do not touch<br>wear eye protection |
| magnesium chloride solution | | |
| hydrogen gas | mixture with air explosive | use small quantities of reactants to make only a small quantity of hydrogen |
| hot equipment and solutions | burns | wait to cool before touching |
| breaking apparatus | cuts | wear eye protection |

▲ *Flammable hazard symbol*

▲ *Corrosive hazard symbol*

### The chemical reaction

Seeta measures out 25 $cm^3$ of hydrochloric acid. She uses a measuring cylinder. She does not use a beaker because a measuring cylinder measures smaller differences in volume.



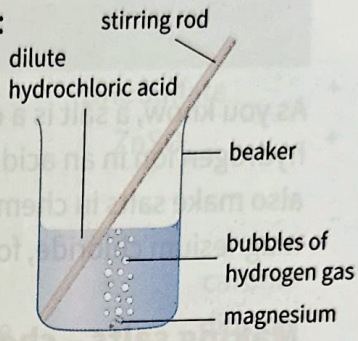

Seeta pours the acid into a beaker. She does not use a conical flask because it is easier to stir the mixture in the beaker.

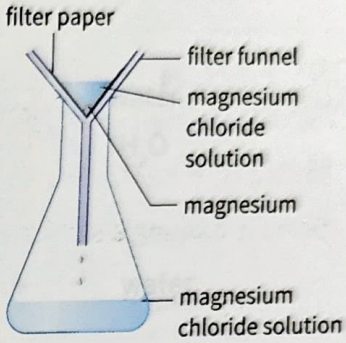
Next, Seeta adds magnesium to the acid. Bubbles of hydrogen gas form. Soon, the bubbles stop. All the magnesium has reacted. Seeta adds more pieces of magnesium, one by one. She stops when some magnesium remains in the beaker. This shows that all the acid has reacted.

### Separating magnesium chloride from the mixture

The beaker contains a mixture. The mixture includes:

- magnesium chloride solution
- solid magnesium.



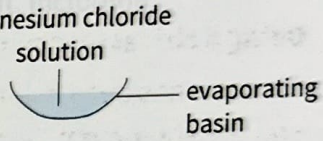




### Filtration

Seeta filters the mixture. She chooses a conical flask, not a beaker, because the conical flask holds the filter funnel upright.

### Evaporation

Seeta pours the magnesium chloride solution into an evaporating dish. She chooses an evaporating basin because of its shape – there is a big surface for water to evaporate from.




▲ *Evaporation removes water from the solution.*

Seeta heats the solution over a water bath. Water evaporates. After a while, white crystals start to form around the edge. Seeta stops heating.

### Crystallisation

Seeta waits for the evaporating basin to cool.
She moves it to a warm, dry place. The water continues to evaporate, but more slowly.
This allows time for crystals to form. Seeta has made her salt, magnesium chloride.

## Questions

1. Define the term *salt*.
2. Jay makes a salt from an acid and a metal. Name the process to separate the salt solution from unreacted metal.
3. Write a word equation for the reaction of zinc with hydrochloric acid. Name the salt made.
4. Suggest the metal and acid you could use to make iron sulfate crystals.

## Key points

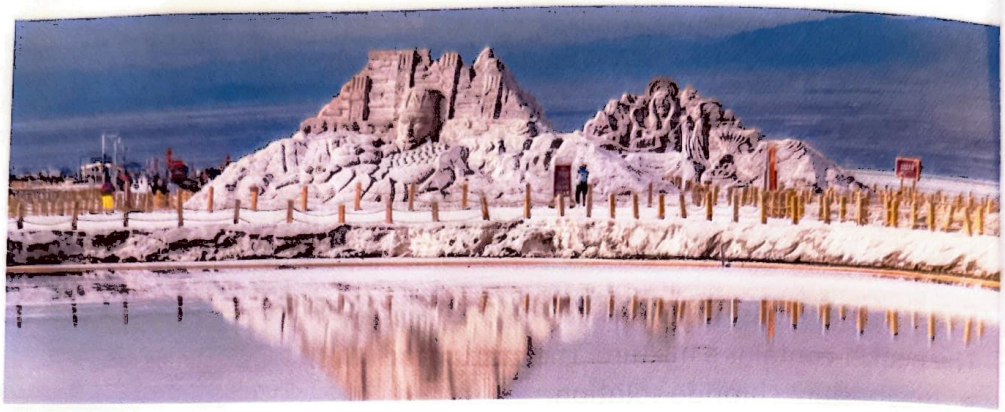
- Make a salt in a chemical reaction. Purify by filtration, evaporation, and crystallisation.
- Do a risk assessment by identifying hazards and risks, and describing how to reduce chance of injury or damage.

# 12.7 More about salts

## Objectives

- Choose reactants to make different salts

The picture shows a sculpture. It is made from salts that were dissolved in the waters of Lake Qinghai, in China.



As you know, a salt is a compound made when a metal ion replaces the hydrogen ion in an acid. The salts in the lake exist naturally. You can also make salts in chemical reactions – unit 12.6 describes how to make magnesium chloride, for example.

### Making salts – choosing reactants

One of the reactants to make a salt is an acid. Different acids make different salts:

- hydrochloric acid, HCl, makes chlorides
- sulfuric acid, $H_2SO_4$, makes sulfates
- nitric acid, $HNO_3$, makes nitrates.

The other reactant must include atoms of the metal element in the salt that is being made. The picture below shows some different salts.


▲ *Some salts: sodium manganate, zinc sulfate, copper sulfate, potassium dichromate, nickel chloride, cobalt sulfate.*

## Thinking and working scientifically

### Making zinc sulfate

Lim wants to make zinc sulfate. He needs two reactants. One of the reactants is sulfuric acid. The other reactant must include zinc. There is a choice of zinc-containing reactants: zinc metal, zinc oxide, or zinc carbonate.

Each of the zinc-containing substances reacts with sulfuric acid to make zinc sulfate. The other products are different:

Reaction 1

zinc + sulfuric acid → zinc sulfate + hydrogen

Zn + $H_2SO_4$ → $ZnSO_4$ + $H_2$

Reaction 2

zinc oxide + sulfuric acid → zinc sulfate + water

ZnO + $H_2SO_4$ → $ZnSO_4$ + $H_2O$

Reaction 3

zinc carbonate + sulfuric acid → zinc sulfate + carbon dioxide + water

$ZnCO_3$ + $H_2SO_4$ → $ZnSO_4$ + $CO_2$ + $H_2O$

There are several factors to consider when choosing the metal-containing reactant, including:

- What are the other products of the reaction?
- Is it easy to separate the salt from the other products?
- Is the metal-containing reactant easily available, and what is its cost?

For example, reaction 1 has two disadvantages compared to reactions 2 and 3:

- Zinc is more expensive than zinc oxide and zinc carbonate.
- Hydrogen (made in reaction 1) is flammable, but the products of the other reactions are not.

Lim decides to make his zinc sulfate from zinc carbonate.

## Questions

1. Name the acid to make each of these salts in the laboratory:
   a. Nickel chloride
   b. Cobalt sulfate
   c. Sodium nitrate
2. Suggest two reactants that react together to make copper sulfate.
3. A chemist makes nickel chloride from hydrochloric acid and nickel carbonate. Write a word equation for the reaction.

## Key points

- A salt is made in a chemical reaction between an acid and a metal-containing substance, for example an oxide or carbonate.