●●●●○ Level 4 · Science S4.7

Reactions, equations and amounts

Write formulae and equations, count particles by weighing, and see how metals, acids and energy decide what reacts.

Write the formula of a compound from its ions and balance an equation. Use the mole to turn masses into numbers of particles, then work out how much product a reaction makes. Then follow acids, metals and electricity through reactions, and see why some reactions give out heat and why some are faster than others.

YOU ARE READY FOR THIS BOOK IF

You can write a word equation for something burning.

One step up	S5.5 Bonding and structure
This book	**S4.7 Reactions, equations and amounts**
One step down	S3.6 Elements, mixtures, reactions and acids

Contents

S4.7.1 Chemical formulae

S4.7.2 Balancing equations

S4.7.3 The mole

S4.7.4 Reacting masses and yield

S4.7.5 Acids, bases and salts

S4.7.6 The reactivity series

S4.7.7 Electrolysis

S4.7.8 Energy changes and rates

Key words, A to Z

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S4.7.1 CHAPTER 1

Chemical formulae

Why is salt written NaCl, but magnesium chloride written $MgCl_2$?

YOUR GUESS

Pick one before you read on. It is fine to be wrong.

- ☐ **A** Magnesium atoms are bigger than sodium atoms, so they need more chlorine.
- ☐ **B** The charges of the ions must add up to zero.
- ☐ **C** The numbers are only a code, with no reason behind them.

IF THIS FEELS HARD, READ THIS FIRST

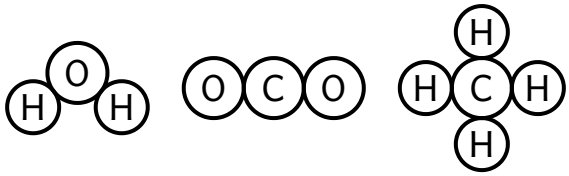
- Level 4, Atoms, bonding and the periodic table, S4.6.6. It shows how atoms become ions, and what the charge of an ion means.
- Level 4, Atoms, bonding and the periodic table, S4.6.7. It shows molecules such as water, whose formulae are counted atom by atom.
- Level 3, Elements, mixtures, reactions and acids, S3.6.1. It says that a compound has elements joined together, such as water.

BY THE END YOU CAN

- Write formulae for common compounds using ion charges
- Count the atoms of each element in a formula

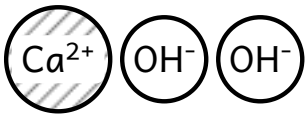
A **formula** is a short way to write what a substance is made of. It uses the symbols of the elements, and small numbers that say how many.

Water is H_2O. The small 2 sits after the H, so it counts hydrogen atoms. There is no number after the O, so that means 1. One water molecule has 2 hydrogen atoms and 1 oxygen atom.



Left to right: water H_2O, carbon dioxide CO_2 and methane CH_4. The circles show which atoms are joined, not their true sizes or angles.

A bracket groups atoms that belong together. The small number after the bracket multiplies everything inside it. In $Ca(OH)_2$ the group OH is there twice.



+2 −1 −1 = 0

$Ca(OH)_2$

Calcium hydroxide. One Ca^{2+} ion goes with two OH^- ions, and OH^- is a group, so it gets a bracket.

WORKED EXAMPLE

How many atoms of each element are in $Ca(OH)_2$?

1. Ca has no number after it, so there is 1 calcium atom.
2. The bracket holds one O and one H. The small 2 after the bracket multiplies both.
3. O: 1 × 2 = 2 oxygen atoms. H: 1 × 2 = 2 hydrogen atoms.

Answer: 1 Ca, 2 O and 2 H

Now think about salt. Sodium chloride is made of **ions**, which are atoms or groups of atoms with an electric charge. Na^+ has a charge of 1+. Cl^- has a charge of 1−.

In an ionic compound the charges of all the ions add up to zero. The formula gives the smallest whole-number ratio of the ions that does this. It does not describe a molecule.

Ion	Name	Charge
H^+	hydrogen	1+
Na^+	sodium	1+
NH_4^+	ammonium	1+
Mg^{2+}	magnesium	2+
Ca^{2+}	calcium	2+
Cu^{2+}	copper(II)	2+
Al^{3+}	aluminium	3+

Positive ions. Metals form positive ions. Hydrogen, H^+, and ammonium, NH_4^+, are positive ions too. Copper can form other ions too, so its name carries the charge: copper(II) means 2+.

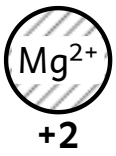
Ion	Name	Charge
Cl^-	chloride	1−
OH^-	hydroxide	1−
NO_3^-	nitrate	1−
O^{2-}	oxide	2−
CO_3^{2-}	carbonate	2−
SO_4^{2-}	sulfate	2−

Negative ions. OH^-, NO_3^-, CO_3^{2-} and SO_4^{2-} are each a group of atoms that carries one charge together.

A group of atoms with one charge is a **polyatomic ion**. NH_4^+, OH^- and SO_4^{2-} are polyatomic ions. They stay together when they join with other ions.

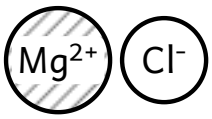
DRAW IT FIRST

Make magnesium chloride from its ions



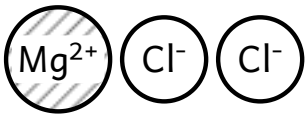
+2

1 Start with the magnesium ion, Mg^{2+}. Its charge is +2.



+2 −1 = +1

2 Add a chloride ion, Cl^-, with a charge of −1. The sum is +1, not zero. A charge is left over.



+2 −1 −1 = 0

$MgCl_2$

3 Add a second Cl^-. Now +2 −1 −1 = 0, so the formula is $MgCl_2$.

The rule has four parts. Find the smallest numbers of each ion that make the charges add to zero. Write the positive ion first. Write each number small and low, after its symbol. Leave out a 1.

WORKED EXAMPLE

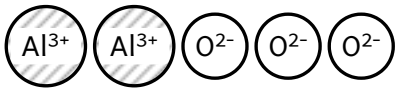
Write the formula of aluminium oxide. It is made of Al^{3+} ions and O^{2-} ions.

1. The ions are Al^{3+} and O^{2-}. The charges are 3+ and 2−.
2. Find the smallest number that both 3 and 2 go into. It is 6.
3. Aluminium: 6 ÷ 3 = 2 ions.
4. Oxygen: 6 ÷ 2 = 3 ions.
5. Write the numbers low, after each symbol: Al_2O_3.

Answer: 2 aluminium ions and 3 oxide ions, so Al_2O_3

SEE IT THREE WAYS

As a picture



+3 +3 −2 −2 −2 = 0

Al_2O_3

In words

Two Al^{3+} ions give a charge of +6. Three O^{2-} ions give −6. The charges cancel, so two aluminium ions go with three oxide ions.

In symbols

$2 \times (+3) + 3 \times (-2) = 0$, so the formula is Al_2O_3.

When a polyatomic ion is needed more than once, put it in a bracket. Calcium hydroxide is $Ca(OH)_2$. Without the bracket, $CaOH_2$ would mean one oxygen atom and two hydrogen atoms. With one OH^- only, as in NaOH, no bracket is needed.

Molecules are different. Water, carbon dioxide and methane are made of non-metal atoms that share electrons. Their formulae count the atoms in one molecule.

TRY IT

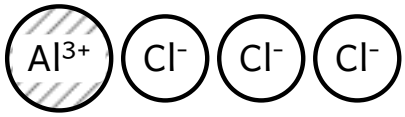
Ion cards: make the charges add to zero

You need: paper, torn into 15 small pieces, a pencil.

1. Write Na^+ on three pieces, Al^{3+} on three, and Mg^{2+} on three. Write Cl^- on three pieces and O^{2-} on three.
2. Put cards side by side, positive or negative, until the charges add up to zero.
3. Use as few cards as you can. Write down the formula each time.
4. Try every positive card with Cl^-, and then with O^{2-}.

What you will see: Na^+ takes one Cl^-. Two Na^+ take one O^{2-}. Mg^{2+} takes two Cl^- or one O^{2-}. Al^{3+} takes three Cl^-. Two Al^{3+} take three O^{2-}. The cards show why the numbers in a formula are what they are.

If you cannot try it, this is what happens.



+3 −1 −1 −1 = 0

$AlCl_3$

A WRONG IDEA MANY PEOPLE HAVE

~~In $MgCl_2$ the small 2 belongs to the magnesium, or is a charge.~~

Why it feels right: The 2 sits in the middle of the formula, and charges and small numbers look alike.

The test that breaks it: Draw $MgCl_2$ as discs. Count: there is one Mg^{2+} disc and two Cl^- discs. The 2 counted the Cl.

What is true: A small number counts the symbol just before it, or the bracket just before it. A charge is written raised, as in Mg^{2+}. A count is written low, as in Cl_2.

KEY WORDS

formula
symbols and small numbers that show what a substance is made of.

ion
an atom, or a group of atoms, with an electric charge.

polyatomic ion
a group of atoms that carries one charge together, such as OH^-.

BACK TO YOUR GUESS

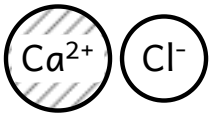
The answer is B: The charges of the ions must add up to zero.

The charges must add up to zero. A Mg^{2+} ion has a charge of 2+, and each Cl^- ion has 1−. So one magnesium ion needs two chloride ions.

CHECK YOURSELF

Try each one before you look. A wrong answer tells you where to go next.

1. One Ca^{2+} ion and one Cl^- ion are drawn, and their charges do not add up to zero. In calcium chloride, how many Cl^- ions go with each Ca^{2+} ion?



+2 −1 = +1

A 1 chloride ion

B 2 chloride ions

C 3 chloride ions

Answer at the back of the book.

2. Aluminium ions are Al^{3+} and chloride ions are Cl^-. What is the formula of aluminium chloride?

   A $AlCl$

   B Al_3Cl

   C $AlCl_3$

   Answer at the back of the book.

3. Sodium ions are Na^+ and sulfate ions are SO_4^{2-}. Which formula is right for sodium sulfate?

   A Na_2SO_4

   B $NaSO_4$

   C $Na(SO_4)_2$

   Answer at the back of the book.

4. One Ca^{2+} ion needs two OH^- ions. Which formula for calcium hydroxide shows this?

   A $CaOH_2$

   B Ca_2OH

   C $Ca(OH)_2$

   Answer at the back of the book.

5. How many oxygen atoms are in one unit of $Al_2(SO_4)_3$?

   A 3 oxygen atoms

   B 12 oxygen atoms

   C 4 oxygen atoms

   Answer at the back of the book.

6. What does the formula $MgCl_2$ tell you?

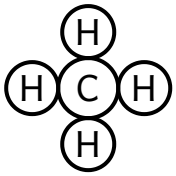
   A There are two chloride ions for each magnesium ion.

   B The chloride ion has a charge of 2−.

   C It is one molecule with two magnesium atoms.

   Answer at the back of the book.

7. A molecule is drawn as circles. Which formula matches it?



A C_4H

B CH_4

C CH

Answer at the back of the book.

8. How many atoms in all are in one unit of $Ca(OH)_2$?

Answer at the back of the book.

9. A positive ion has a charge of 3+ and a negative ion has a charge of 2−. How many of each ion are in one unit of the compound?

Answer at the back of the book.

KEEP IT

Copy this into your exercise book.

Write the positive ion first. Use the smallest numbers that make the charges add to zero. Write them low, after the symbol. Put a bracket round a group that is counted more than once.

Draw: $MgCl_2$ as one Mg^{2+} disc and two Cl^- discs, with the sum +2 −1 −1 = 0 under them.

S4.7.2 CHAPTER 2

Balancing equations

> **A candle burns away and leaves almost nothing. Where did the wax go?**

YOUR GUESS

Pick one before you read on. It is fine to be wrong.

- ☐ **A** It joins with oxygen from the air and becomes gases, such as carbon dioxide and water vapour.
- ☐ **B** It is destroyed when it burns.
- ☐ **C** It turns into heat and light, and nothing else.

IF THIS FEELS HARD, READ THIS FIRST

- Level 3, Elements, mixtures, reactions and acids, S3.6.5. It writes word equations, which this chapter turns into symbol equations.
- Level 3, Elements, mixtures, reactions and acids, S3.6.6. It gives the word equation for burning a fuel.
- Level 4, Atoms, bonding and the periodic table, S4.6.7. It shows molecules such as H_2, O_2 and H_2O, which the equations use.

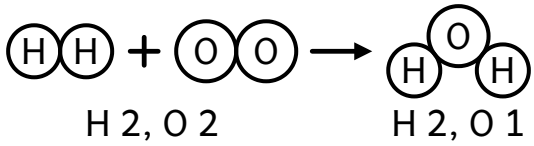
BY THE END YOU CAN

- Balance symbol equations and add state symbols
- Explain why mass is conserved in a reaction

When a candle burns, the wax seems to vanish. It does not. It changes into new substances. A reaction makes new substances from old ones.

We write a reaction as an equation. A word equation uses names: hydrogen + oxygen → water. The substances on the left are the **reactants**. The substances on the right are the **products**. The arrow means "makes".

A symbol equation uses formulae: $H_2 + O_2 \rightarrow H_2O$. Now count the atoms. The left has 2 oxygen atoms. The right has only 1. An oxygen atom has gone. That cannot happen.



H 2, O 2 H 2, O 1

A first try that is not balanced. The tallies are not the same, so one oxygen atom has no place to go.

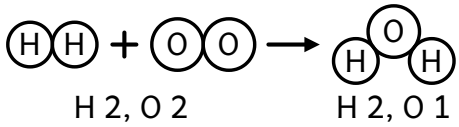
In a reaction, atoms are never made or destroyed. They only join in new ways. So an equation must have the same atoms on both sides. When it does, it is **balanced**.

We balance an equation by writing a number in front of a formula. This number is the **coefficient**. It multiplies the whole formula. $2H_2O$ means two water molecules, so 4 H atoms and 2 O atoms.

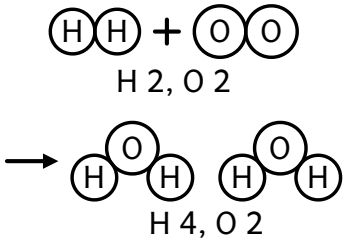
Never change the small number inside a formula to make an equation balance. H_2O_2 is not water. It is hydrogen peroxide, a different substance. A formula says what a substance is.

DRAW IT FIRST

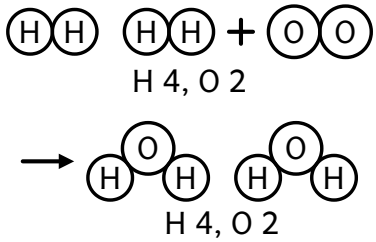
Balance hydrogen and oxygen making water



1 Count the atoms in $H_2 + O_2 \rightarrow H_2O$. Left: H 2, O 2. Right: H 2, O 1. The oxygen is not equal.



2 Write 2 in front of H_2O. Now the right has 2 O. But it has 4 H, and the left has only 2 H.



3 Write 2 in front of H_2. Now both sides have H 4 and O 2. The equation is balanced.

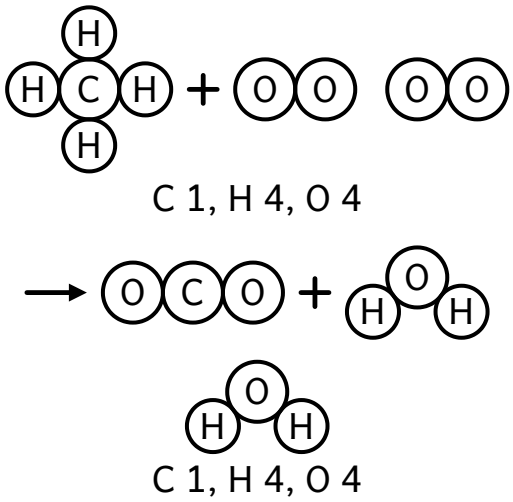
Here is how to balance any equation. Write the correct formula for every substance. Count each kind of atom on both sides. Change one number in front at a time, starting with an element that is in only one substance on each side. Leave an element on its own, such as O_2, for last. Then count everything again.

WORKED EXAMPLE

Balance methane burning: $CH_4 + O_2 \rightarrow CO_2 + H_2O$

1. Count the atoms. Left: C 1, H 4, O 2. Right: C 1, H 2, O 3.
2. Carbon is equal. Hydrogen is not: the left has 4 and the right has 2. Write 2 in front of H_2O.
3. Now the right has 2 O in CO_2 and 2 O in the two H_2O, so 4 oxygen atoms. The left has 2.
4. Write 2 in front of O_2. The left now has 2 × 2 = 4 oxygen atoms.
5. Check both sides: C 1, H 4, O 4. The equation is balanced.

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



Methane burning, balanced. Every circle on the left appears on the right, in new groups.

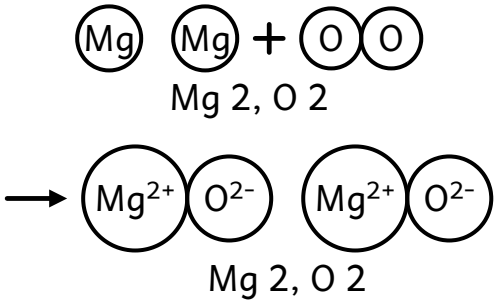
Equations also say what state each substance is in. A **state symbol** goes after the formula, in brackets.

Symbol	Means
(s)	solid
(l)	liquid
(g)	gas
(aq)	dissolved in water

The four state symbols. Aq is short for aqueous, which means in water.

Magnesium in acid is $Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$. Solid magnesium goes into hydrochloric acid, which is HCl dissolved in water. It makes magnesium chloride dissolved in water, and hydrogen gas.

Now think about mass. Atoms are only rearranged, and each atom keeps its mass. So the total mass of the reactants equals the total mass of the products. We say that mass is **conserved**.



$2Mg + O_2 \rightarrow 2MgO$. Each pair on the right is one Mg^{2+} ion beside one O^{2-} ion.

Substance	Mass
magnesium	48 g
oxygen	32 g
total before	80 g
magnesium oxide	80 g

Magnesium and oxygen make magnesium oxide. The product has exactly the mass of the two reactants added together.

WORKED EXAMPLE

In a closed flask 4 g of hydrogen reacts with 32 g of oxygen. What mass of water forms?

1. The flask is closed, so nothing escapes. Mass is conserved.
2. The mass of the reactants is 4 g + 32 g.
3. The mass of the reactants is 36 g.
4. The water has the same mass as the reactants: 36 g.

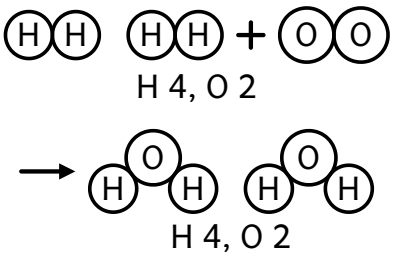
Answer: 36 g of water

Sometimes the mass seems to change. Burn magnesium in an open dish and the powder weighs more than the metal did. Oxygen from the air joined it. Heat chalk rock, which is calcium carbonate, in an open dish and the powder weighs less. Carbon dioxide gas escaped. In a closed container the mass stays the same.

Be safe. Burning magnesium makes a light that can hurt the eyes, and heating chalk rock needs a very hot furnace. Scientists do these in a laboratory, with eye protection. Do not try them at home.

SEE IT THREE WAYS

As a picture



In words

Two hydrogen molecules and one oxygen molecule make two water molecules. The same four hydrogen atoms and two oxygen atoms are on both sides.

In symbols

$2H_2 + O_2 \rightarrow 2H_2O$, with H 4 and O 2 on each side.

TRY IT

Catch a gas in a balloon

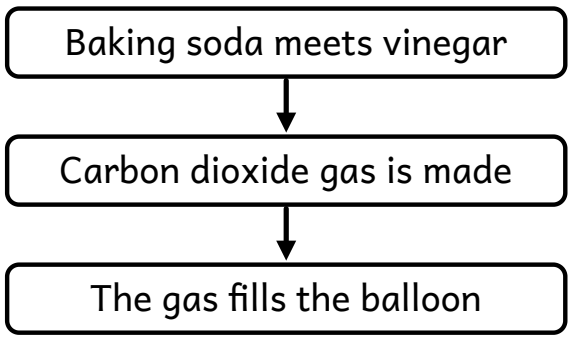
You need: a clean plastic bottle, a balloon, or a small plastic bag and string, vinegar, baking soda and a spoon, a paper funnel, made by rolling a sheet of paper.

Be safe: Use only vinegar and baking soda. Do not use a cap or cork, because pressure could push it out. Keep your face and eyes away from the balloon, and taste nothing.

1. Pour vinegar into the bottle until it is about a quarter full.
2. Use the paper funnel to put two spoons of baking soda into the balloon or bag.
3. Stretch the neck of the balloon over the top of the bottle. With a bag, tie its neck tight round the bottle with string. Let it hang down, so the soda does not fall in yet.
4. Lift the balloon or bag up so the baking soda falls into the vinegar. Watch the bottle and the balloon or bag.

What you will see: The mixture fizzes, and the balloon or bag swells. A new substance, carbon dioxide gas, is made from the two things you put in. The bottle and balloon are closed, so the gas cannot escape. It stays in the balloon or bag.

If you cannot try it, this is what happens.



A WRONG IDEA MANY PEOPLE HAVE

~~To balance an equation, change the small numbers in a formula. For example, change H_2O to H_2O_2.~~

Why it feels right: Changing a small number is the quickest way to equal the atom counts. The numbers also look like part of a puzzle.

The test that breaks it: Draw H_2O_2 as circles: it has 2 O atoms, not 1. It is hydrogen peroxide, which bleaches and is not water. The reaction in the picture makes water.

What is true: A small number inside a formula is part of what the substance is. Only the number in front, the coefficient, may be changed to balance.

KEY WORDS

reactants
the substances that react, written on the left of the arrow.

products
the substances that are made, written on the right of the arrow.

balanced
having the same atoms of every element on both sides of the equation.

coefficient
the number in front of a formula that says how many of it.

state symbol
a letter in brackets after a formula: (s), (l), (g) or (aq).

conserved
kept the same in a reaction, as the total mass is.

BACK TO YOUR GUESS

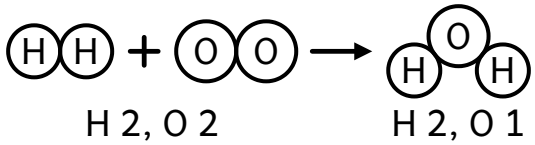
The answer is A: It joins with oxygen from the air and becomes gases, such as carbon dioxide and water vapour.

The atoms of the wax join with oxygen from the air. They make carbon dioxide and water vapour, which are gases and drift away. No atoms are destroyed.

CHECK YOURSELF

Try each one before you look. A wrong answer tells you where to go next.

1. The first try $H_2 + O_2 \rightarrow H_2O$ is drawn. It is not balanced. Which balanced equation makes water from hydrogen gas and oxygen gas?



   A $H_2 + O_2 \rightarrow H_2O_2$

   B $H_2 + O \rightarrow H_2O$

   C $2H_2 + O_2 \rightarrow 2H_2O$

   Answer at the back of the book.

2. Which equation for making ammonia is balanced?

   A $N_2 + 3H_2 \rightarrow 2NH_3$

   B $N_2 + 2H_2 \rightarrow 2NH_3$

   C $N_2 + 3H_2 \rightarrow NH_3$

   Answer at the back of the book.

3. In $Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$, what does (aq) mean?

   A a pure liquid

   B dissolved in water

   C a gas that escapes

   Answer at the back of the book.

4. Magnesium is burned in an open dish. The white powder weighs more than the metal did. Why?

   A Oxygen from the air joined the magnesium.

   B New matter was made by the heat.

   C The magnesium got heavier when it got hot.

   Answer at the back of the book.

5. Chalk rock, which is calcium carbonate, is heated strongly in an open dish, and the powder left weighs less. Why?

   A The heat took the mass away.

   B Some of the mass was destroyed.

   C Carbon dioxide gas escaped into the air.

   Answer at the back of the book.

6. **From an earlier chapter**

   How many hydrogen atoms are in $3Ca(OH)_2$?

   A 2 hydrogen atoms

   B 6 hydrogen atoms

   C 3 hydrogen atoms

   Answer at the back of the book.

7. Balance this equation: $Mg + O_2 \rightarrow MgO$. What are the smallest whole numbers in front of Mg, O_2 and MgO, in that order?

   Answer at the back of the book.

8. In a closed flask 8 g of A reacts with some B to make 20 g of C. How many grams of B reacted?

   Answer at the back of the book.

KEEP IT

Copy this into your exercise book.

Atoms are not made or destroyed, so both sides of an equation have the same atoms. Balance with numbers in front. Never change a formula. Mass is conserved.

Draw: The equation $2H_2 + O_2 \rightarrow 2H_2O$ with a tally of H 4, O 2 under each side.

S4.7.3 CHAPTER 3

The mole

> **How can a chemist count atoms when they are far too small to see?**

YOUR GUESS

Pick one before you read on. It is fine to be wrong.

- ☐ **A** By counting them one at a time under a very strong microscope.
- ☐ **B** It cannot be done. Chemists can only guess.
- ☐ **C** By weighing them, because the mass of a pile tells how many atoms it holds.

IF THIS FEELS HARD, READ THIS FIRST

- Level 4, Atoms, bonding and the periodic table, S4.6.3. It explains why some relative atomic masses, such as 35.5 for chlorine, are not whole numbers.
- Level 4, Atoms, bonding and the periodic table, S4.6.1. It gives the particles in an atom and how their masses compare.
- Level 3, Particles, S3.5.7. It names the solute, the solvent and the solution, which concentration describes.
- Level 3, Ratio and proportion, M3.4.4. It shows the method of finding one first, which moles use to scale up and down.

BY THE END YOU CAN

- Calculate relative formula mass
- Convert between mass and moles
- Calculate concentration in moles per cubic decimetre

One drop of water holds about a thousand million million million molecules. Nobody can count them one by one. Chemists use a trick: they weigh. This chapter shows

how weighing can count.

Every element has a **relative atomic mass**. It compares the mass of its atoms with one twelfth of a carbon 12 atom. Hydrogen is 1, carbon is 12 and oxygen is 16. It has no unit. It is an average over the isotopes, which is why chlorine is 35.5.

Element	Symbol	Mass
hydrogen	H	1
carbon	C	12
nitrogen	N	14
oxygen	O	16
sodium	Na	23
magnesium	Mg	24
sulfur	S	32
chlorine	Cl	35.5
calcium	Ca	40
iron	Fe	56

Relative atomic masses used in this book, part 1. The column Mass is the relative atomic mass, so it has no unit. Part 2 follows.

Element	Symbol	Mass
aluminium	Al	27
potassium	K	39
copper	Cu	63.5
zinc	Zn	65
bromine	Br	80
tin	Sn	119
lead	Pb	207

Relative atomic masses used in this book, part 2. These are the values the questions use when they do not give them.

The **relative formula mass**, written Mr, is the sum of the relative atomic masses of all the atoms in a formula. For a molecule it is also called the relative molecular

mass. Add the atoms one by one, and use a bracket the same way as in chapter 1.

WORKED EXAMPLE

What is the relative formula mass of $Ca(OH)_2$?

1. The atoms are Ca 1, O 2 and H 2. The bracket multiplies O and H by 2.
2. The relative atomic masses are Ca 40, O 16 and H 1.
3. Ca: 1 × 40 = 40. O: 2 × 16 = 32. H: 2 × 1 = 2.
4. Mr = 40 + 32 + 2 = 74.

Answer: 74

Now the key idea. A **mole** is an amount of substance. One mole of anything holds 6.02×10^{23} particles. This is 602 followed by 21 zeros. The particles may be atoms, molecules or the units of an ionic formula.

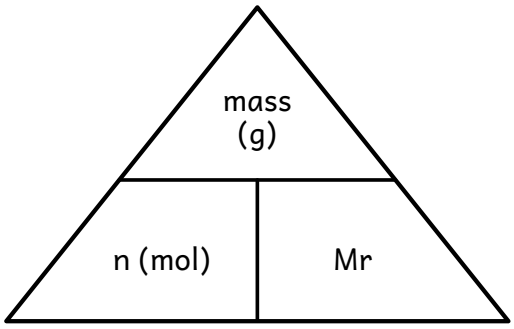
The mass of one mole, in grams, is the Mr of the substance. So 12 g of carbon is one mole of carbon atoms. 18 g of water is one mole of water molecules. 44 g of carbon dioxide is one mole of CO_2 molecules. Mr has no unit. The mass of one mole is Mr in grams.

Substance	Mr	1 mol
carbon	12	12 g
water	18	18 g
carbon dioxide	44	44 g
table salt	58.5	58.5 g

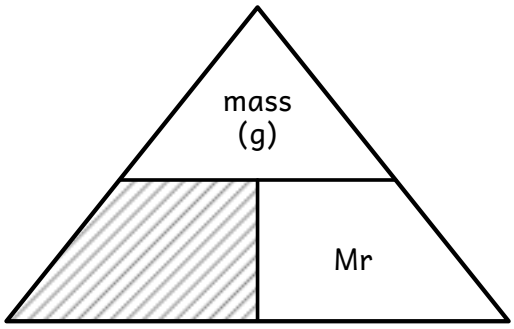
The column 1 mol is the mass of one mole. Table salt is sodium chloride, NaCl. Each row holds 6.02×10^{23} particles. The particles differ in mass, so the masses differ.

DRAW IT FIRST

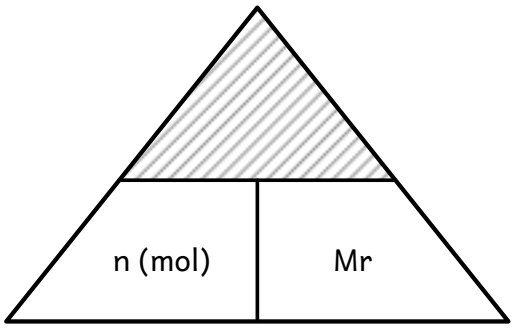
The triangle for mass, moles and Mr



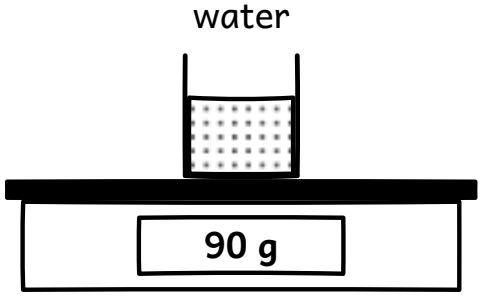
1 Write mass on top, and moles and Mr side by side below.



2 Cover moles. What is left is mass over Mr, so moles = mass ÷ Mr.



3 Cover mass. What is left is moles beside Mr, so mass = moles × Mr.



The scale for the worked example: water, with a mass of 90 g. The scale was set to zero with the empty cup on it, so it shows the water only.

WORKED EXAMPLE

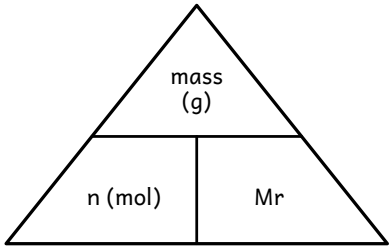
How many moles of water are on the scale?

1. Mr of H_2O = 2 × 1 + 16 = 18.
2. moles = mass ÷ Mr.
3. moles = 90 ÷ 18 = 5 mol.

Answer: 5 mol

SEE IT THREE WAYS

As a picture



In words

Cover the one you want. Mass over Mr gives moles. Moles beside Mr gives mass: multiply.

In symbols

moles = mass ÷ Mr, and mass = moles × Mr.

Reactions in water use solutions. The **concentration** of a solution is how many moles of the solute are in 1 dm^3 of the solution. A dm^3 is a cubic decimetre, which is one litre. It is 1 000 cm^3.

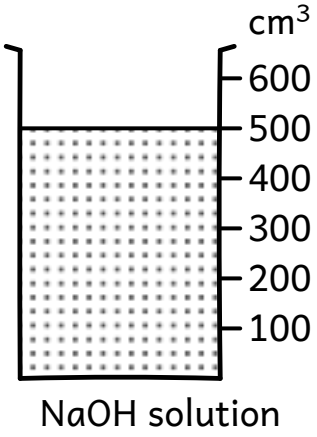
Concentration is measured in mol/dm^3. Say it as "moles per cubic decimetre". The same amount of solute in less water gives a more concentrated solution.

WORKED EXAMPLE

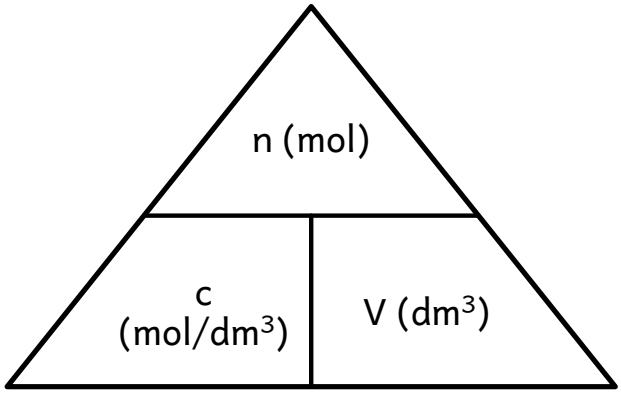
2 g of sodium hydroxide, NaOH, is dissolved in water to make 500 cm^3 of solution. What is the concentration in mol/dm^3?

1. Mr of NaOH = 23 + 16 + 1 = 40.
2. moles = 2 ÷ 40 = 0.05 mol.
3. volume = 500 cm^3 ÷ 1 000 = 0.5 dm^3.
4. concentration = moles ÷ volume = 0.05 ÷ 0.5 = 0.1 mol/dm^3.

Answer: 0.1 mol/dm^3



The solution for the worked example. It is at the 500 cm^3 mark.



The same triangle for concentration: c = n ÷ V, n = c × V and V = n ÷ c. Volume must be in dm^3.

TRY IT

Strong tea and weak tea

You need: cold, strong tea, three clear cups or glasses of the same size, water, a spoon and a sheet of white paper.

Be safe: An adult makes the tea and lets it cool completely. Drink none of it, and wash your hands afterwards.

1. Put the same amount of water in each of two cups, about half full. Add 1 spoon of tea to one and 2 spoons to the other. Stir.
2. Hold each cup against the white paper. Which looks darker?
3. Fill the third cup with twice as much water as the others. Add 4 spoons of tea and stir.
4. Compare this cup with the one that has 2 spoons.

What you will see: The cup with 2 spoons is darker than the cup with 1 spoon: more tea in the same amount of water. The third cup has 4 spoons in twice the water, which is 2 spoons for each cup of water. It looks like the second cup. Concentration is the amount of solute divided by the volume.

If you cannot try it, this is what happens.

Tea	Water	Colour
1 spoon	1 cup	lightest
2 spoons	1 cup	darker
4 spoons	2 cups	as row 2

A WRONG IDEA MANY PEOPLE HAVE

~~One mole of every substance has the same mass.~~

Why it feels right: Every mole has the same number of particles, so it seems it should weigh the same.

The test that breaks it: Look at the table of one mole. 1 mol of carbon is 12 g, but 1 mol of carbon dioxide is 44 g.

What is true: One mole always has the same number of particles, 6.02×10^{23}. The particles have different masses, so a mole of one substance is heavier than a mole of another.

KEY WORDS

relative atomic mass
the mass of an atom compared with one twelfth of a carbon 12 atom.

relative formula mass
Mr, the sum of the relative atomic masses in a formula.

mole
an amount of substance: 6.02×10^{23} particles.

concentration
the moles of solute in 1 dm^3 of solution.

BACK TO YOUR GUESS

The answer is C: By weighing them, because the mass of a pile tells how many atoms it holds.

Chemists weigh. Each kind of atom has its own mass, so a known mass of a substance holds a known number of particles. The mole is the name for that number.

CHECK YOURSELF

Try each one before you look. A wrong answer tells you where to go next.

1. What is the relative formula mass of CO_2? Use C 12 and O 16.

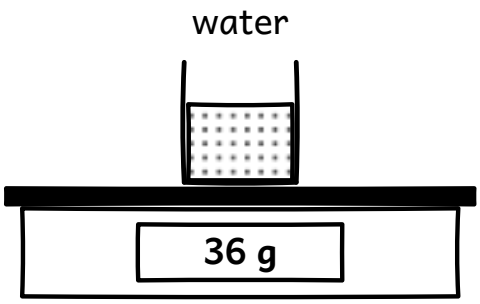
   A 28

   B 32

   C 44

   Answer at the back of the book.

2. The scale shows 36 g of water. It was set to zero with the empty cup on it. Mr of water is 18. How many moles of water is that?



   A 2 mol

   B 0.5 mol

   C 18 mol

   Answer at the back of the book.

3. What is the mass of 2 mol of calcium carbonate, $CaCO_3$?

   A 50 g

   B 200 g

   C 100 g

   Answer at the back of the book.

4. A 100 cm^3 sample of solution holds 0.2 mol of sodium chloride. What is its concentration?

   A 0.002 mol/dm^3

   B 20 mol/dm^3

   C 2 mol/dm^3

   Answer at the back of the book.

5. Which sample holds the most particles: 12 g of carbon, 18 g of water or 44 g of carbon dioxide?

   A 44 g of carbon dioxide, because it has the most mass.

   B All three hold the same number of particles.

   C 12 g of carbon, because atoms are smaller than molecules.

   Answer at the back of the book.

6. One mole holds 6.02×10^{23} particles. How many carbon atoms are in 0.5 mol of carbon?

   A 3.01×10^{23} atoms

   B 6.02×10^{23} atoms

   C 3.01×10^{22} atoms

   Answer at the back of the book.

7. Why is the relative atomic mass of chlorine 35.5, and not a whole number?

   A A chlorine atom has half a proton.

   B It was measured badly and rounded to 35.5.

   C It is the average of the masses of its isotopes, weighted by how common each is.

   Answer at the back of the book.

8. **From an earlier chapter**

   Calcium burns in oxygen to make calcium oxide, CaO. Which is the balanced equation for this?

   A $2Ca + O_2 \rightarrow 2CaO$

   B $Ca + O_2 \rightarrow CaO_2$

   C $Ca + O_2 \rightarrow CaO$

   Answer at the back of the book.

9. What is the relative formula mass of Na_2CO_3?

   Answer at the back of the book.

10. How many moles are in 22 g of carbon dioxide?

    Answer at the back of the book.

11. A solution of volume 250 cm^3 holds 0.5 mol of solute. What is its concentration in mol/dm^3?

    Answer at the back of the book.

KEEP IT

Copy this into your exercise book.

Mr is the sum of the relative atomic masses. One mole is Mr grams and 6.02×10^{23} particles. moles = mass ÷ Mr. concentration = moles ÷ volume in dm^3.

Draw: The triangle with mass on top and moles and Mr below. Add a second triangle for n, c and V.

S4.7.4 CHAPTER 4

Reacting masses and yield

If I burn 12 g of magnesium, how much magnesium oxide can I make?

YOUR GUESS

Pick one before you read on. It is fine to be wrong.

- ☐ **A** Exactly 12 g, because mass cannot change.
- ☐ **B** More than 12 g, and the equation shows how much more.
- ☐ **C** Less than 12 g, because some of it burns away.

IF THIS FEELS HARD, READ THIS FIRST

- Level 3, Fractions, decimals and percentages, M3.3.8. It shows how to write one amount as a percentage of another.
- Level 3, Ratio and proportion, M3.4.4. It shows how to scale an amount up and down in a fixed ratio.
- Level 3, Elements, mixtures, reactions and acids, S3.6.5. It gives reactions written as word equations that this chapter puts numbers on.

BY THE END YOU CAN

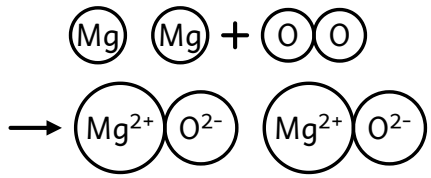
- Calculate the mass of product from a given mass of reactant
- Calculate percentage yield and explain why it is below 100

A balanced equation is a recipe. In $2Mg + O_2 \rightarrow 2MgO$, two magnesium atoms and one oxygen molecule make two units of magnesium oxide. A chemist wants to know how much of each to weigh.

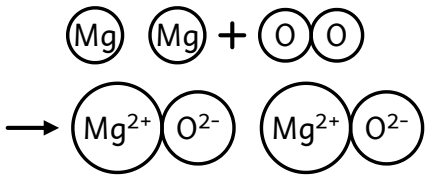
The numbers in front of the formulae count particles. So they also count moles. 2 mol of Mg and 1 mol of O_2 make 2 mol of MgO. They are not masses. A mole of each substance has its own mass.

DRAW IT FIRST

From the equation to the masses

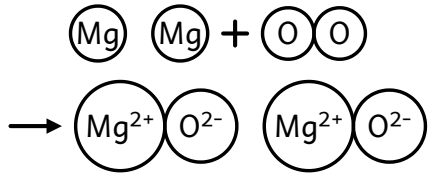


1 Write the balanced equation: $2Mg + O_2 \rightarrow 2MgO$.



2 mol : 1 mol : 2 mol

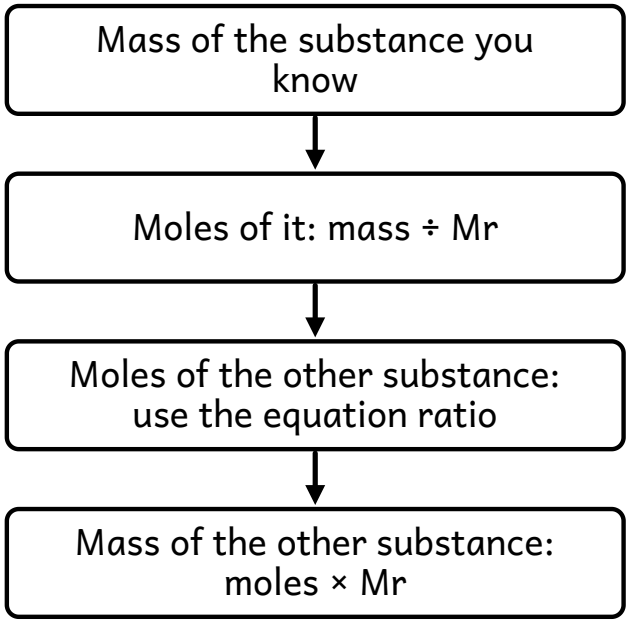
2 The numbers in front are moles: 2 mol of Mg and 1 mol of O_2 make 2 mol of MgO.



2 mol : 1 mol : 2 mol
48 g : 32 g : 80 g

3 Change moles into grams with Mr. 2 × 24 = 48 g, 1 × 32 = 32 g and 2 × 40 = 80 g.

To find the mass of a product, work in three steps. Change the mass you know into moles, with mass ÷ Mr. Use the equation to find the moles of the substance you want. Change those moles into mass, with moles × Mr.



The method for every reacting mass question.

WORKED EXAMPLE

What mass of magnesium oxide forms when 12 g of magnesium burns? Use $2Mg + O_2 \rightarrow 2MgO$.

1. The ratio of Mg to MgO in the equation is 2 to 2, which is 1 to 1.
2. Moles of Mg = 12 ÷ 24 = 0.5 mol.
3. Moles of MgO = 0.5 mol, from the 1 to 1 ratio.
4. Mr of MgO = 24 + 16 = 40.
5. Mass of MgO = 0.5 × 40 = 20 g.

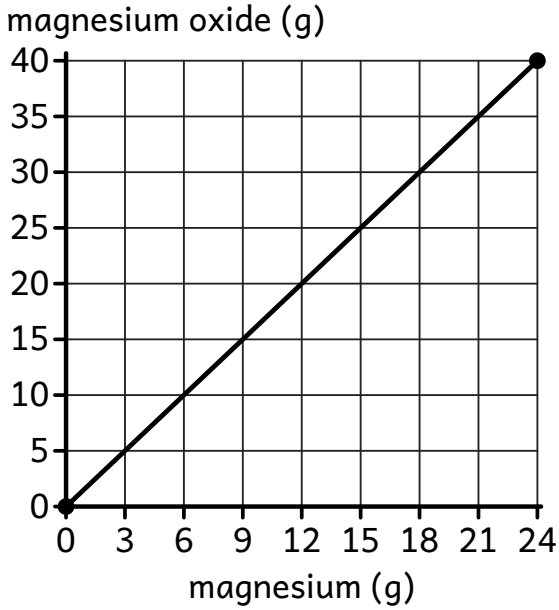
Answer: 20 g

WORKED EXAMPLE

What mass of hydrogen chloride, HCl, reacts with 12 g of magnesium? Use $Mg + 2HCl \rightarrow MgCl_2 + H_2$.

1. The ratio of Mg to HCl in the equation is 1 to 2.
2. Moles of Mg = 12 ÷ 24 = 0.5 mol.
3. Moles of HCl = 2 × 0.5 = 1 mol.
4. Mr of HCl = 1 + 35.5 = 36.5.
5. Mass of HCl = 1 × 36.5 = 36.5 g.

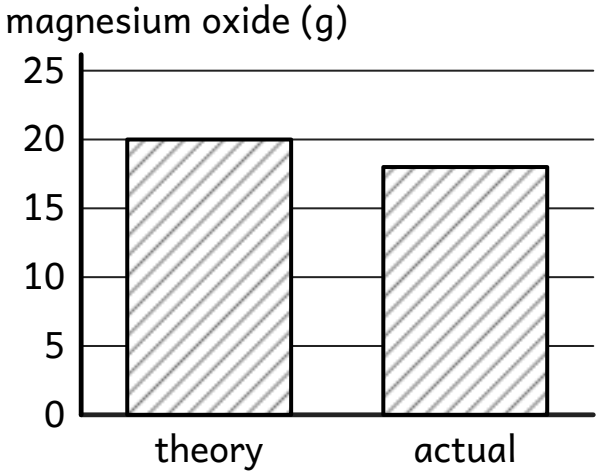
Answer: 36.5 g



More magnesium makes more oxide, in a fixed ratio. Double the magnesium and the oxide doubles. The line is straight and starts at 0.

The amount a perfect reaction would make is the **theoretical yield**. The amount we really collect is the ***actual yield***. The actual yield is nearly always smaller.

The **percentage yield** compares them. percentage yield = actual yield ÷ theoretical yield × 100.



The theory says 20 g. A student collects 18 g.

WORKED EXAMPLE

The theoretical yield of magnesium oxide is 20 g. A student collects 18 g. What is the percentage yield?

1. percentage yield = actual yield ÷ theoretical yield × 100.
2. Actual yield = 18 g. Theoretical yield = 20 g.
3. 18 ÷ 20 = 0.9.
4. 0.9 × 100 = 90%.

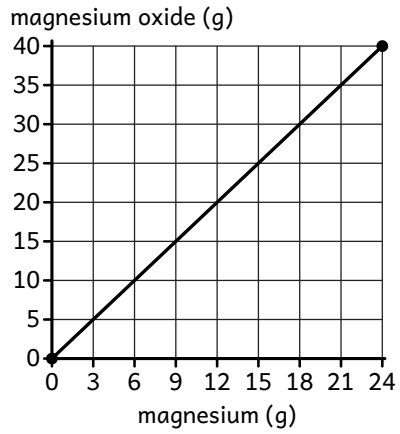
Answer: 90%

Why is the yield below 100%? Atoms are not lost. The product is somewhere, but not all of it reaches the scale. Some stays on the glass or the filter paper when it is moved. Another reaction may make a different product. The reaction may stop before all the reactants are used. Some product may stay dissolved.

A yield over 100% would be a mistake. The product may be wet or mixed with another substance, so it weighs too much.

SEE IT THREE WAYS

As a picture



In words

The oxide is always 40 for every 24 of magnesium, which is 5 for every 3. A straight line through zero shows that the two masses are in a fixed ratio.

In symbols

mass of MgO = mass of Mg × 40 ÷ 24

TRY IT

Where does the yield go?

You need: four cups, or two that you wash and dry, a spoon, water, cooking oil, paper and a pencil.

Be safe: Taste nothing. Wipe up any oil that spills, because it makes the floor slippery.

1. Count out 10 level spoons of water into one cup.
2. Pour all of it into the second, dry cup. Pour slowly, and wait until the last drop falls.
3. Use the same spoon to lift the water out of the second cup. Count the spoons, until you can lift no more.
4. Do the same with 10 spoons of cooking oil, using two clean, dry cups.

What you will see: You get back a little less than you put in, and the oil loses more than the water. The liquid clings to the cup, so it never all arrives. Real reactions lose product the same way, so the actual yield is below the theoretical yield. Your own counts may differ from the picture.

If you cannot try it, this is what happens.

Liquid	In	Out
water	10 spoons	9 spoons
oil	10 spoons	8 spoons

A WRONG IDEA MANY PEOPLE HAVE

~~In $2Mg + O_2 \rightarrow 2MgO$ the numbers say that 2 g of Mg reacts with 1 g of O_2.~~

Why it feels right: The numbers are in the equation, and they look like quantities to weigh out.

The test that breaks it: Work out the masses of 2 mol of Mg and 1 mol of O_2. They are 48 g and 32 g, which is not a ratio of 2 to 1.

What is true: The numbers in front are moles, or numbers of particles. To get masses, multiply the moles by Mr.

KEY WORDS

theoretical yield
the mass of product a perfect reaction would make.

actual yield
the mass of product really collected.

percentage yield
the actual yield divided by the theoretical yield, times 100.

BACK TO YOUR GUESS

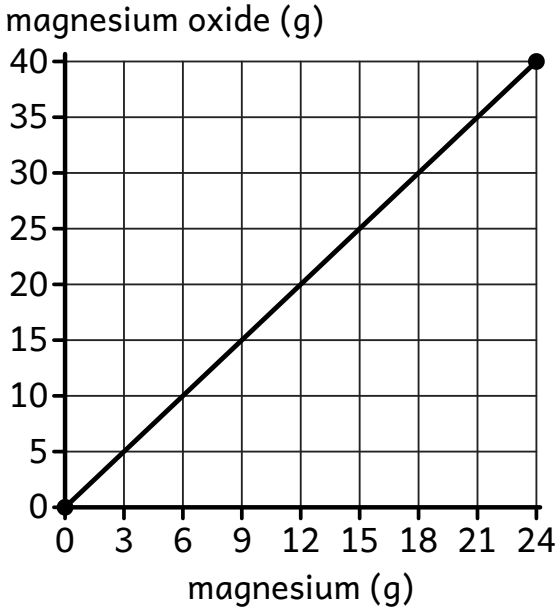
The answer is B: More than 12 g, and the equation shows how much more.

The product is 20 g. Oxygen from the air joins the magnesium, so the oxide weighs more than the metal. The equation, with Mr, tells us how much.

CHECK YOURSELF

Try each one before you look. A wrong answer tells you where to go next.

1. The graph shows magnesium oxide made from magnesium. Read it. How many grams of magnesium oxide form from 15 g of magnesium?



A 15 g

B 25 g

C 40 g

Answer at the back of the book.

2. In $N_2 + 3H_2 \rightarrow 2NH_3$, how many moles of NH_3 form from 3 mol of H_2?

A 3 mol

B 6 mol

C 2 mol

Answer at the back of the book.

3. Calcium carbonate breaks down: $CaCO_3 \rightarrow CaO + CO_2$. What mass of calcium oxide, CaO, forms from 10 g of calcium carbonate?

A 5.6 g

B 4.4 g

C 10 g

Answer at the back of the book.

4. A reaction should make 40 g of product. It makes 30 g. What is the percentage yield?

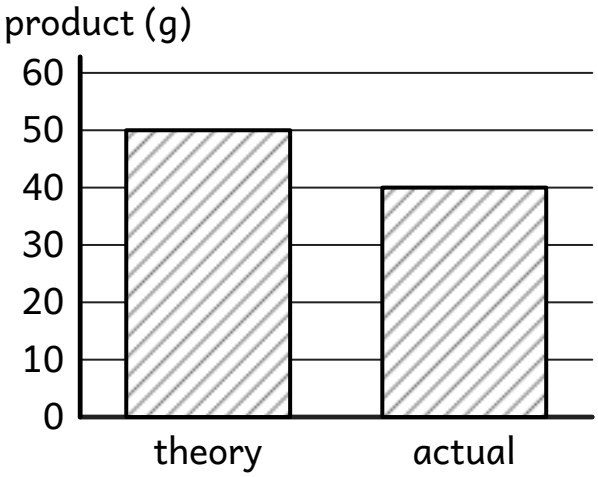
   A 133%

   B 75%

   C 25%

   Answer at the back of the book.

5. The bars show a theoretical yield and an actual yield. What is the percentage yield?



   A 80%

   B 125%

   C 10%

   Answer at the back of the book.

6. A student works out a yield of more than 100%. What is the most likely reason?

   A The new atoms were made in the reaction.

   B Some product was lost when it was moved.

   C The product was still wet or mixed with another substance.

   Answer at the back of the book.

7. **From an earlier chapter**

   How many moles are in 11 g of carbon dioxide, CO_2?

   A 4 mol

   B 0.25 mol

   C 0.5 mol

   Answer at the back of the book.

8. Magnesium burns: $2Mg + O_2 \rightarrow 2MgO$. What mass of magnesium oxide forms from 6 g of magnesium?

   Answer at the back of the book.

9. The theoretical yield is 40 g. The actual yield is 34 g. What is the percentage yield?

   Answer at the back of the book.

KEEP IT

Copy this into your exercise book.

Numbers in an equation are moles. Mass to moles with Mr, moles to moles with the ratio, moles to mass with Mr. Percentage yield = actual ÷ theoretical × 100.

Draw: The flow of four boxes: mass, moles, other moles, other mass, with the three operations on the arrows.

S4.7.5 CHAPTER 5

Acids, bases and salts

Why does vinegar fizz when I add baking soda?

YOUR GUESS

Pick one before you read on. It is fine to be wrong.

- ☐ **A** The acid in the vinegar reacts with the baking soda and makes a new gas.
- ☐ **B** Air trapped inside the baking soda is let out.
- ☐ **C** The vinegar boils when it touches baking soda.

IF THIS FEELS HARD, READ THIS FIRST

- Level 3, Elements, mixtures, reactions and acids, S3.6.7. It shows an indicator, and places acids and alkalis on the pH scale.
- Level 3, Elements, mixtures, reactions and acids, S3.6.8. It explains neutralisation as an acid and an alkali cancelling out.
- Level 4, Atoms, bonding and the periodic table, S4.6.6. It explains ions, which this chapter uses to say what an acid is.

BY THE END YOU CAN

- Write equations for acids reacting with metals, bases and carbonates
- Explain the pH scale in terms of hydrogen ions

Lemon juice, vinegar and the juice in your stomach are acids. Soap and baking soda solution are alkalis. This chapter shows what they have in common, and what they make when they react.

An ***acid*** is a substance that makes hydrogen ions, H^+, when it dissolves in water. Hydrochloric acid, HCl, splits into H^+ and Cl^- ions. Sulfuric acid is H_2SO_4 and nitric acid is HNO_3.

A **base** is a substance that reacts with an acid and cancels it. Metal oxides and metal hydroxides are bases. An **alkali** is a base that dissolves in water. It makes hydroxide ions, OH^-. Sodium hydroxide, NaOH, makes Na^+ and OH^- ions.

When an acid reacts, it makes a **salt**. A salt is a compound. It is made from the metal (or ammonium) part of the other substance and the negative ion of the acid. Hydrochloric acid makes chlorides. Sulfuric acid makes sulfates. Nitric acid makes nitrates.

Acid	Salt
hydrochloric	chloride
sulfuric	sulfate
nitric	nitrate

The name of the acid gives the end of the name of the salt. Zinc and hydrochloric acid make zinc chloride.

There are three kinds of reaction to know. An acid with a metal makes a salt and hydrogen. An acid with a base makes a salt and water. An acid with a carbonate makes a salt, water and carbon dioxide.

Acid with	Makes
metal	salt + H_2
base	salt + H_2O
carbonate	salt + H_2O + CO_2

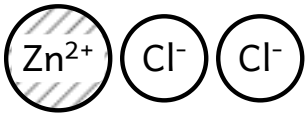
The three reactions. H_2 is hydrogen, H_2O is water and CO_2 is carbon dioxide.

WORKED EXAMPLE

Write a balanced equation for zinc reacting with hydrochloric acid.

1. Word equation: zinc + hydrochloric acid → zinc chloride + hydrogen.
2. Formulae: Zn + HCl → $ZnCl_2$ + H_2. Zinc chloride is $ZnCl_2$, because Zn^{2+} needs two Cl^-.
3. Count Cl: 1 on the left and 2 on the right. Write 2 in front of HCl.
4. Now H is 2 on each side. The equation is balanced.

Answer: Zn + 2HCl → $ZnCl_2$ + H_2



+2 −1 −1 = 0

$ZnCl_2$

The salt zinc chloride. One Zn^{2+} ion goes with two Cl^- ions.

WORKED EXAMPLE

Write a balanced equation for magnesium hydroxide reacting with hydrochloric acid.

1. Word equation: magnesium hydroxide + hydrochloric acid → magnesium chloride + water.
2. Formulae: $Mg(OH)_2$ + HCl → $MgCl_2$ + H_2O.
3. Count Cl: 1 on the left and 2 on the right. Write 2 in front of HCl.
4. Count H: 2 in $Mg(OH)_2$ and 2 in 2HCl, so 4 on the left. Write 2 in front of H_2O to make 4 on the right.
5. Check O: 2 on each side. The equation is balanced.

Answer: $Mg(OH)_2$ + 2HCl → $MgCl_2$ + 2H_2O

WORKED EXAMPLE

Write a balanced equation, with state symbols, for calcium carbonate reacting with hydrochloric acid.

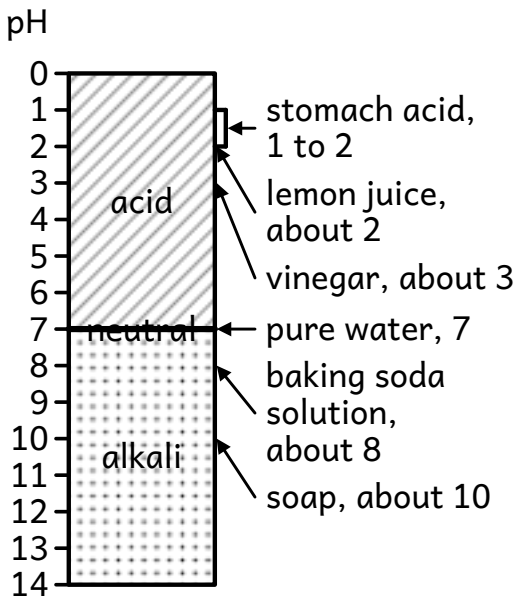
1. Word equation: calcium carbonate + hydrochloric acid → calcium chloride + water + carbon dioxide.
2. Formulae: $CaCO_3 + HCl \rightarrow CaCl_2 + H_2O + CO_2$.
3. Count Cl: 1 on the left and 2 on the right. Write 2 in front of HCl.
4. Now H is 2 on the left, from the 2HCl, and 2 on the right, in H_2O.
5. C is 1 on each side. O is 3 in $CaCO_3$ on the left and 1 + 2 = 3 on the right.
6. Add state symbols. The carbonate is a solid. The acid and the salt are dissolved. The water is a liquid, and the carbon dioxide is a gas.

Answer: $CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$

Be safe. Scientists test the gases in a laboratory. A lit splint pops in hydrogen. Carbon dioxide turns limewater cloudy. Strong acids such as hydrochloric acid burn the skin, so they are handled with goggles and gloves. Do not try them at home.

Now think about what makes a solution acid or alkaline. It is the number of H^+ ions. The **pH** scale measures it. A solution of pH 7 is neutral, at room temperature. Below 7 is acid, and above 7 is alkaline.

A lower pH means more H^+ ions in each dm^3. Each step of 1 on the scale means 10 times as many H^+ ions, or 10 times fewer. A solution of pH 3 has 10 times more H^+ than one of pH 4.



The pH scale with some things from a home. The values are about, because they change with the brand and the strength.

pH	Times more H^+
6	10 times
5	100 times
4	1 000 times
3	10 000 times

Compared with pure water, at pH 7. Each step down is 10 times more H^+. Vinegar, at about pH 3, has about ten thousand times as many H^+ ions as pure water.

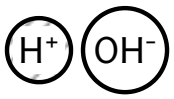
DRAW IT FIRST

An acid and an alkali meet



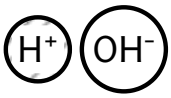
+1

1 An acid supplies H^+ ions. Each has a charge of +1.



+1 −1 = 0

2 An alkali supplies OH^- ions, each with a charge of −1. One of each makes a total charge of 0.



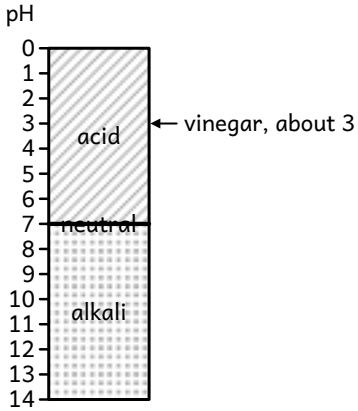
+1 −1 = 0

H_2O

3 They join to make a water molecule, H_2O. This is **neutralisation**: $H^+ + OH^- \rightarrow H_2O$.

SEE IT THREE WAYS

As a picture



In words

Lower pH, more H^+. Every step down the scale is ten times more H^+ ions in the same volume.

In symbols

pH 3 has 10 × more H^+ than pH 4, and 100 × more than pH 5.

TRY IT

Red cabbage tells acid from alkali

You need: a few leaves of red cabbage, hot water, poured by an adult, six clear cups, or four if you wash and dry two, vinegar, water, baking soda and a spoon.

Be safe: An adult pours the hot water and lets the cabbage liquid cool. Vinegar and baking soda are the strongest acid and alkali to use. Taste nothing, keep the liquids away from your eyes, and wash your hands after.

1. Tear the cabbage into small pieces in a cup. An adult pours hot water over them. Leave it for 15 minutes, then pour off the purple liquid into a second cup.
2. Stir a spoon of baking soda into half a cup of cold water, in a third cup, to make baking soda solution.
3. Put an equal amount of purple liquid into three clean cups.
4. Add 2 spoons of vinegar to the first cup. Add 2 spoons of plain water to the second. Add 2 spoons of baking soda solution to the third.
5. Look at the three colours.

What you will see: The vinegar turns the purple liquid pink or red. The water leaves it purple. The baking soda solution turns it blue, or blue green. The cabbage juice is an indicator. Its colour changes with the number of H^+ ions.

If you cannot try it, this is what happens.

Added	Colour
vinegar	pink or red
water	purple
baking soda	blue green

A WRONG IDEA MANY PEOPLE HAVE

~~The pH scale goes in equal steps, so pH 3 is only a little more acidic than pH 4.~~

Why it feels right: The numbers 3 and 4 are close together, like 3 cm and 4 cm on a ruler.

The test that breaks it: Take a strong acid, such as hydrochloric acid, at pH 3. Add water until it has 10 times the volume. Its pH rises by 1, to 4, because the H^+ ions are spread through ten times the space. A weak acid such as vinegar changes less.

What is true: Each step of 1 on the pH scale is a change of 10 times in the H^+ ions. A solution of pH 3 has 10 times more H^+ than one of pH 4.

KEY WORDS

acid
a substance that makes H^+ ions in water.

base
a substance that reacts with an acid and cancels it.

alkali
a base that dissolves in water and makes OH^- ions.

salt
a compound made when an acid reacts, such as zinc chloride.

pH
a scale that measures the H^+ ions in a solution.

neutralisation
the reaction of H^+ and OH^- to make water.

BACK TO YOUR GUESS

The answer is A: The acid in the vinegar reacts with the baking soda and makes a new gas.

Vinegar is an acid. It reacts with baking soda, sodium hydrogencarbonate, which reacts like a carbonate, and makes a new gas, carbon dioxide. The fizz is that gas leaving the liquid.

CHECK YOURSELF

Try each one before you look. A wrong answer tells you where to go next.

1. Zinc is added to hydrochloric acid and bubbles form. What gas is in the bubbles?

   A Hydrogen

   B Oxygen

   C Carbon dioxide

   Answer at the back of the book.

2. Which is the balanced equation for magnesium reacting with hydrochloric acid?

   A $Mg + HCl \rightarrow MgCl_2 + H_2$

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

   C $Mg + 2HCl \rightarrow MgCl + H_2$

   Answer at the back of the book.

3. An acid reacts with a carbonate. What does it make?

   A A salt and hydrogen

   B A salt and water only

   C A salt, water and carbon dioxide

   Answer at the back of the book.

4. How many times more H^+ ions does a solution of pH 3 have than a solution of pH 5?

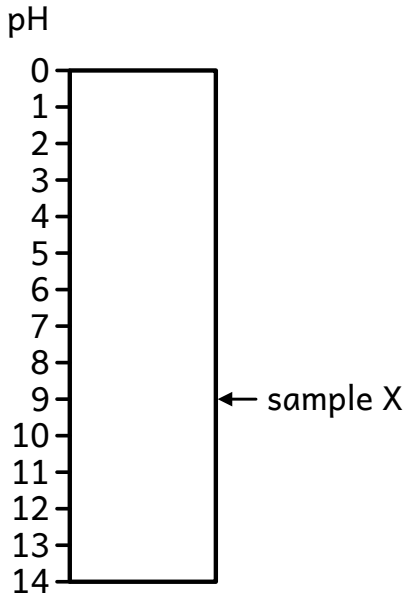
   A 100 times

   B 2 times

   C 1 000 times

   Answer at the back of the book.

5. A sample is at pH 9 on the scale. What is true of it?



A It is an acid, with many H^+ ions.

B It is neutral.

C It is alkaline, with fewer H^+ ions than pure water.

Answer at the back of the book.

6. What happens when an acid and an alkali neutralise each other?

A Both the acid and the alkali get stronger.

B H^+ and OH^- ions join to make water.

C Hydrogen gas is always given off.

Answer at the back of the book.

7. **From an earlier chapter**

How many moles of hydrochloric acid, HCl, neutralise 4 g of sodium hydroxide, NaOH? Use $NaOH + HCl \rightarrow NaCl + H_2O$. Mr of NaOH is 40.

A 10 mol

B 4 mol

C 0.1 mol

Answer at the back of the book.

8. Balance this equation: $Mg + H_2SO_4 \rightarrow MgSO_4 + H_2$. What are the smallest whole numbers in front of each formula, in order?

   Answer at the back of the book.

9. How many times more H^+ ions does a solution of pH 2 have than a solution of pH 3?

   Answer at the back of the book.

KEEP IT

Copy this into your exercise book.

Acid + metal makes salt and hydrogen. Acid + base makes salt and water. Acid + carbonate makes salt, water and carbon dioxide. Each pH step is ten times the H^+.

Draw: The pH scale from 0 to 14 with vinegar, water and soap marked, and $H^+ + OH^- \rightarrow H_2O$ underneath.

S4.7.6 CHAPTER 6

The reactivity series

Why is gold found shining in the ground, but iron is found as dull red rock?

YOUR GUESS

Pick one before you read on. It is fine to be wrong.

- ☐ **A** Gold is heavier, so it sinks out of the rock.
- ☐ **B** Iron is made by living things, and gold is not.
- ☐ **C** Gold hardly reacts with anything, but iron reacts with oxygen and is found joined to it.

IF THIS FEELS HARD, READ THIS FIRST

- Level 3, Elements, mixtures, reactions and acids, S3.6.5. It shows iron reacting with oxygen and water to make rust.
- Level 4, Atoms, bonding and the periodic table, S4.6.8. It describes metals and why they are useful.
- Level 3, Elements, mixtures, reactions and acids, S3.6.1. It says that a compound has elements joined together, such as an oxide.

BY THE END YOU CAN

- Order metals by how they react with water and acid
- Explain how carbon is used to extract iron from its ore

Some metals react at once with water or air. Others hardly change in a thousand years. The **reactivity** of a metal is how easily it takes part in reactions. We can find it by watching what a metal does with cold water and with dilute acid.

Metal	In cold water
potassium	very violent
sodium	violent
lithium	fizzes fast
calcium	fizzes steadily

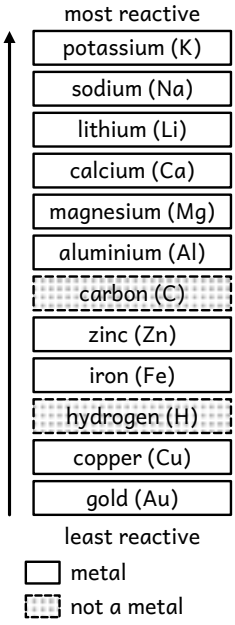
These four metals react with cold water. They make hydrogen and a metal hydroxide.

Be safe. Potassium, sodium and lithium react with the water on your skin and can burn badly. They are kept under oil and are never handled at home. Scientists use tiny pieces behind a screen.

Metal	In dilute acid
magnesium	fizzes fast
zinc	fizzes steadily
iron	fizzes slowly
copper	no change

These metals react little or not at all with cold water. In dilute acid they make a salt and hydrogen. The faster the fizz, the more reactive the metal.

Put the results together and the metals fall into a list. It is called the **reactivity series**. Carbon and hydrogen are not metals, but they have a place in the list, because they take part in the same reactions.



Part of the reactivity series. A metal above hydrogen reacts with dilute acid. A metal below hydrogen does not.

Aluminium seems to break the rule, because it reacts little with water and acid although it is high in the list. It is covered by a thin, tough skin of aluminium oxide, which forms within seconds in air. The skin keeps the acid and water away from the metal below.

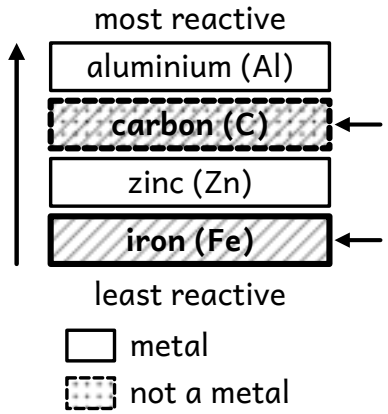
The series also tells us about **displacement**. A more reactive metal pushes a less reactive metal out of its compound. Iron put into copper sulfate solution takes the place of the copper: $Fe + CuSO_4 \rightarrow FeSO_4 + Cu$. Copper is left as a solid. Copper put into iron sulfate does nothing, because copper is below iron.

Most metals are found in rocks as compounds, mixed with other minerals. A rock with enough of a metal compound to be worth mining is an **ore**. Iron ore is mostly iron oxide, Fe_2O_3. To get the metal, we must take the oxygen away.

Taking oxygen away is **reduction**. Adding oxygen is **oxidation**. Carbon is more reactive than iron. So carbon can take the oxygen from iron oxide and leave the iron. Metals above carbon, such as aluminium, hold their oxygen too tightly for carbon to take it.

SEE IT THREE WAYS

As a picture



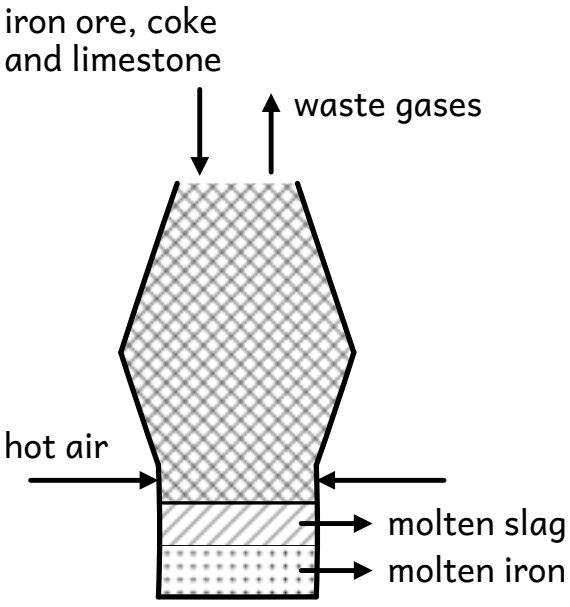
In words

Carbon is above iron in the series. So carbon wins the oxygen from iron oxide and the iron is left. Carbon is below aluminium, so it cannot do the same for aluminium oxide.

In symbols

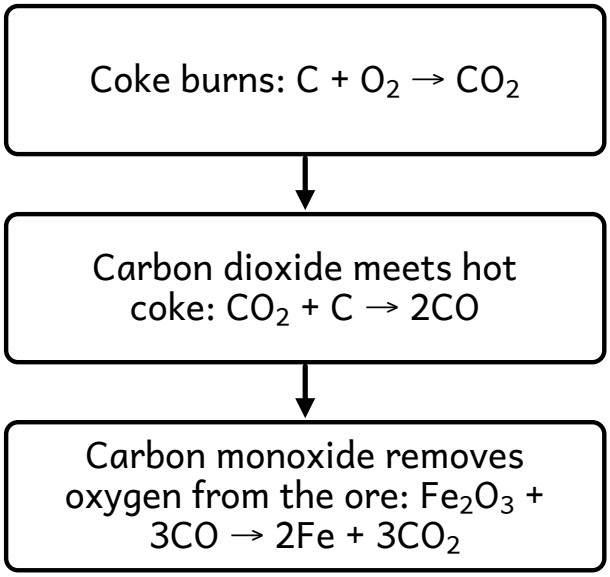
$$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$$

Iron is made in a **blast furnace**, a tower about 30 metres tall. Iron ore, coke and limestone go in at the top. Coke is nearly pure carbon. Hot air is blown in near the bottom.



The blast furnace. The slag floats on the iron, because it is less dense.

Three things happen in the furnace. The coke burns in the hot air and makes heat: $C + O_2 \rightarrow CO_2$. Then the carbon dioxide meets more hot coke and makes carbon monoxide: $CO_2 + C \rightarrow 2CO$. The carbon monoxide takes the oxygen from the ore: $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$.



The three reactions. In the last, the iron oxide is reduced and the carbon monoxide is oxidised.

WORKED EXAMPLE

Balance the main reaction in the furnace: Fe_2O_3 + CO → Fe + CO_2

1. Count Fe: 2 on the left. Write 2 in front of Fe.
2. Fe_2O_3 gives away its oxygen atoms. Each CO takes one and becomes CO_2. Fe_2O_3 has 3 oxygen atoms, so 3 CO are needed.
3. Write 3 in front of CO and 3 in front of CO_2.
4. Check: C is 3 and 3. O is 3 + 3 = 6 on the left and 3 × 2 = 6 on the right.

Answer: Fe_2O_3 + 3CO → 2Fe + $3CO_2$

Rock has impurities. The main one is sand, which is silicon dioxide. The limestone breaks down in the heat: $CaCO_3$ → CaO + CO_2. The calcium oxide then joins the sand and makes calcium silicate, called **slag**. Slag melts and floats on the iron. It is tapped off and used to make roads.

Metals above carbon cannot be extracted this way. They are extracted with electricity. That is the topic of the next chapter.

TRY IT

Which metal fizzes in vinegar?

You need: two plain iron nails, or a small pad of plain steel wool, a short piece of bare copper wire, if you have one; if not, do the iron cup only, two clear cups, vinegar and a spoon, a hand lens, if you have one.

Be safe: Nails and steel wool can cut skin, so use the spoon for steel wool. Keep vinegar away from your eyes. Taste nothing, and wash your hands afterwards.

1. Pour vinegar into the cups, about a hand deep.
2. Put the nails into one cup. If you use steel wool, push it in with the spoon and do not touch it with your fingers.
3. If you have copper wire, put it into the other cup.
4. Look closely at both after a few minutes, and again after some hours.

What you will see: Tiny bubbles of hydrogen gather on the iron. The copper wire, if you used it, stays bare. Iron is above hydrogen in the series, so it makes hydrogen with an acid. Copper is below hydrogen, so it does not. The bubbles are small and slow, because vinegar is a weak acid.

If you cannot try it, this is what happens.

Metal	In vinegar
iron	tiny bubbles
copper wire	no change

A WRONG IDEA MANY PEOPLE HAVE

~~Aluminium does not seem to react, so it must be low in the reactivity series.~~

Why it feels right: Aluminium pans and foil last for years and do not rust. A metal that does not change looks unreactive.

The test that breaks it: Aluminium is found in rock only as a compound, never as a metal. It is very hard to extract. A really unreactive metal, such as gold, is found as a pure metal.

What is true: Aluminium is high in the series. A thin tough oxide skin forms at once and protects the metal under it.

KEY WORDS

reactivity
how easily a metal takes part in reactions.

displacement
a more reactive metal pushing a less reactive one out of its compound.

ore
a rock with enough of a metal compound to be worth mining.

reduction
the loss of oxygen by a substance.

oxidation
the gain of oxygen by a substance.

blast furnace
a tall furnace that makes iron from iron ore, coke and limestone.

slag
the waste that floats on the molten iron, mostly calcium silicate.

BACK TO YOUR GUESS

The answer is C: Gold hardly reacts with anything, but iron reacts with oxygen and is found joined to it.

Gold is very unreactive, so it stays a pure metal. Iron reacts with oxygen, so in the ground it is found as a compound, iron oxide, and has to be extracted.

CHECK YOURSELF

Try each one before you look. A wrong answer tells you where to go next.

1. Which list shows the metals in order of reactivity, with the most reactive first?

   A sodium, magnesium, copper

   B magnesium, sodium, copper

   C copper, iron, zinc

   Answer at the back of the book.

2. Which of these mixtures will react?

   A copper in zinc sulfate solution

   B zinc in copper sulfate solution

   C copper in magnesium sulfate solution

   Answer at the back of the book.

3. Carbon can extract iron from its ore, but not aluminium from its ore. Why?

   A Carbon is more reactive than iron but less reactive than aluminium.

   B Aluminium is too hard to melt.

   C Aluminium oxide does not contain any oxygen for carbon to take.

   Answer at the back of the book.

4. In $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$, which substance is reduced?

   A CO

   B CO_2

   C Fe_2O_3

   Answer at the back of the book.

5. What does the limestone do in the blast furnace?

   A It supplies the carbon that takes oxygen from the ore.

   B It burns to heat the furnace.

   C It reacts with sand and makes slag.

   Answer at the back of the book.

6. Aluminium is above iron in the series, but aluminium foil does not react with air or water. Why?

   A Aluminium is below iron in the series.

   B A thin tough oxide skin covers it and protects it.

   C Aluminium does not react with oxygen at all.

   Answer at the back of the book.

7. **From an earlier chapter**

   Zinc reacts with sulfuric acid. What does it make?

   A Zinc sulfate and water

   B Zinc oxide and hydrogen

   C Zinc sulfate and hydrogen

   Answer at the back of the book.

8. How many moles of carbon monoxide react with 2 mol of iron oxide? Use $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$.

   Answer at the back of the book.

9. Carbon is heated with copper(II) oxide: $2CuO + C \rightarrow 2Cu + CO_2$. What mass of copper forms from 159 g of copper oxide? Use Mr of CuO = 79.5 and Cu = 63.5.

   Answer at the back of the book.

KEEP IT

Copy this into your exercise book.

A more reactive metal displaces a less reactive one. Carbon is above iron, so it removes the oxygen from iron oxide: reduction. Aluminium is above carbon.

Draw: The column of metals from potassium to gold with carbon and hydrogen in place, and $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$ underneath.

S4.7.7 CHAPTER 7

Electrolysis

Carbon cannot take the oxygen from aluminium oxide. So how is aluminium made?

YOUR GUESS

Pick one before you read on. It is fine to be wrong.

- ☐ **A** Aluminium is dug out of the ground as a pure metal.
- ☐ **B** Electricity splits aluminium oxide into aluminium and oxygen.
- ☐ **C** A much hotter furnace lets carbon do the job.

IF THIS FEELS HARD, READ THIS FIRST

- Level 4, Atoms, bonding and the periodic table, S4.6.6. It shows that the ions of a solid are fixed, and are free to move when it is molten.
- Level 2, Magnets and simple circuits, S2.8.6. It shows a complete circuit, a cell and a flow of current.
- Level 2, Magnets and simple circuits, S2.8.7. It sorts materials into those that conduct and those that do not.

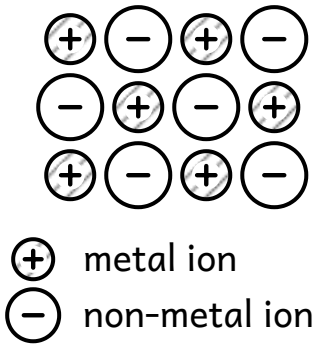
BY THE END YOU CAN

- Predict the products of electrolysis of a molten ionic compound
- Explain why aluminium is extracted by electrolysis, not with carbon

In the last chapter, carbon took the oxygen from iron oxide. Aluminium is above carbon in the series. Carbon cannot take its oxygen. The way out is a flow of electricity.

Electrolysis is the splitting of a compound by passing an electric current through it. The liquid that is split is the **electrolyte**. The current enters and leaves it by two **electrodes**, made of a material that conducts, such as graphite.

An ionic compound must be molten for this. In the solid, the ions are held in fixed places, so no charge can flow. When the compound is melted, the ions can move. Moving ions carry the current.



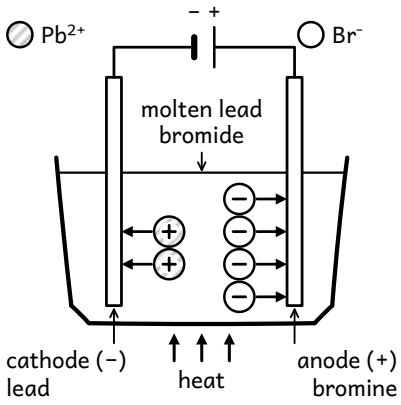
A solid ionic compound. Each ion is held in its place, so the solid does not conduct.

Think of the cell for lead bromide, $PbBr_2$. It melts at 371 °C. The melted compound has two kinds of ion, Pb^{2+} and Br^-. Two electrodes dip into it and are joined to a cell, or battery.

One electrode is joined to the negative end of the battery. It is the **cathode**. The other is joined to the positive end. It is the ***anode***. Opposite charges attract.

SEE IT THREE WAYS

As a picture



In words

The positive Pb^{2+} ions go to the negative cathode. There each gains two electrons and becomes a lead atom. The negative Br^- ions go to the positive anode. There each loses an electron, and pairs of bromine atoms join to make Br_2. Each disc in the picture shows the sign of the charge, and the key gives the size.

In symbols

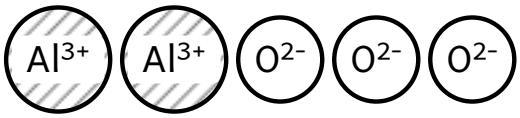
$$PbBr_2 \rightarrow Pb + Br_2$$

So the rule is short. Positive ions go to the cathode. A metal forms there. Negative ions go to the anode. A non-metal forms there. The charges of the ions tell you which way each one moves.

Compound	Cathode	Anode
$PbBr_2$	Pb	Br_2
NaCl	Na	Cl_2
$ZnCl_2$	Zn	Cl_2
Al_2O_3	Al	O_2
MgO	Mg	O_2

Products of electrolysis of five molten compounds. Br_2, Cl_2 and O_2 are bromine, chlorine and oxygen gas, made of two-atom molecules.

Be safe. Scientists do this experiment in a fume cupboard. Lead compounds are poisonous. Bromine is a brown vapour that burns the lungs and eyes. Lead bromide must be heated to 371 °C. It is never done at home, and nothing here uses mains electricity.



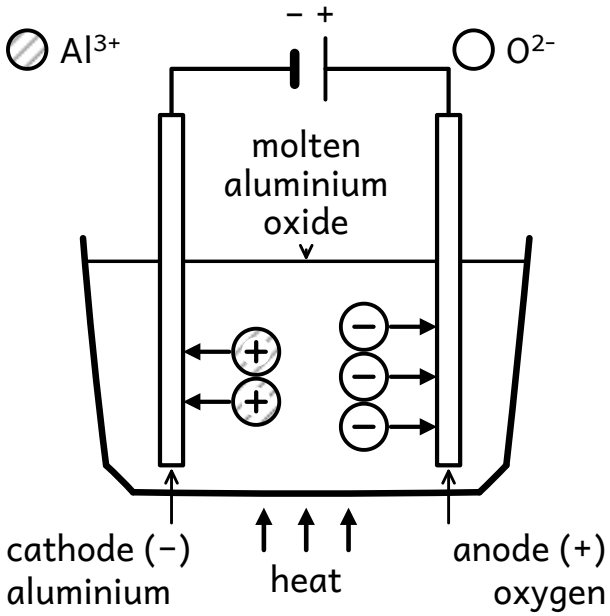
+3 +3 −2 −2 −2 = 0

Al_2O_3

Aluminium oxide has 2 Al^{3+} ions for each 3 O^{2-} ions.

Aluminium is the most common metal in the Earth's crust, but it is always combined. The ore is bauxite. It is purified to make aluminium oxide, Al_2O_3. Aluminium oxide melts above 2 000 °C, which is too hot to be practical.

The trick is to dissolve the oxide in molten **cryolite**, another aluminium compound. The oxide dissolves in the molten cryolite, so the mixture is liquid at about 950 °C. It is still very hot, but far lower. Cryolite does not split.



The same idea for aluminium. Two Al^{3+} ions to three O^{2-} ions balance the charges. In a real cell the oxide is dissolved in molten cryolite. Each disc shows the sign of the charge; the key gives the size.

At the cathode, Al^{3+} ions gain electrons and make molten aluminium, which sinks to the bottom and is tapped off. At the anode, O^{2-} ions lose electrons and make oxygen gas. The anodes are made of carbon. The hot oxygen burns the carbon and makes carbon dioxide, so the anodes wear away and must be replaced.

WORKED EXAMPLE

Balance the equation for the electrolysis of aluminium oxide: $Al_2O_3 \rightarrow Al + O_2$

1. Count the atoms. Left: Al 2, O 3. Right: Al 1, O 2.
2. O is 3 on the left and 2 on the right. The smallest number that both go into is 6. Write 2 in front of Al_2O_3 and 3 in front of O_2.
3. Now Al is 2 × 2 = 4 on the left. Write 4 in front of Al.
4. Check: Al is 4 and 4. O is 6 and 6. The equation is balanced.

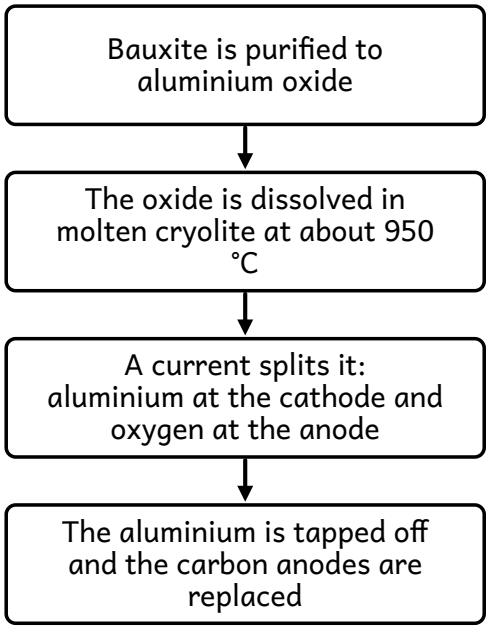
Answer: $2Al_2O_3 \rightarrow 4Al + 3O_2$

WORKED EXAMPLE

What mass of aluminium is made from 204 g of aluminium oxide? Use $2Al_2O_3 \rightarrow 4Al + 3O_2$.

1. Mr of Al_2O_3 = 2 × 27 + 3 × 16 = 102.
2. Moles of Al_2O_3 = 204 ÷ 102 = 2 mol.
3. The ratio of Al_2O_3 to Al is 2 to 4, which is 1 to 2. So 2 mol of Al_2O_3 make 4 mol of Al.
4. Mass of Al = 4 × 27 = 108 g.

Answer: 108 g



Making aluminium. The step with the current needs a great deal of electricity. A smelter is built where there is plenty of electricity, often from water power. Recycled aluminium needs far less energy.

TRY IT

Move the ions on paper

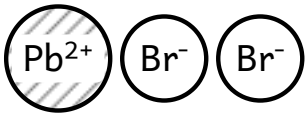
You need: a sheet of paper and a pencil, three small torn pieces of paper.

Be safe: Use only paper and a pencil. Do not try any of this with real electricity or real salts.

1. Draw a box in the middle of the sheet. Write a minus sign on the left side for the cathode. Write a plus sign on the right side for the anode.
2. Write Pb^{2+} on one torn piece and Br^- on the other two. Lay them in a row in the box. In the solid they cannot move.
3. Now melt the compound. Slide the pieces about freely.
4. Send the Pb^{2+} piece to the minus side. Send both Br^- pieces to the plus side.
5. At the minus side, write "lead" on the back of the Pb^{2+} piece. At the plus side, join the two Br^- pieces and write "bromine, Br_2".

What you will see: The ions of opposite charge go to opposite sides. One Pb^{2+} is paired with two Br^-, because +2 and −1 −1 add to zero. The metal forms at the negative side and the non-metal at the positive side.

If you cannot try it, this is what happens.



+2 −1 −1 = 0

$PbBr_2$

A WRONG IDEA MANY PEOPLE HAVE

~~In electrolysis the current in the liquid is a flow of electrons.~~

Why it feels right: In a copper wire the current is a flow of electrons, so it seems the same in a liquid.

The test that breaks it: Look at the cell. Ions move through the liquid, and lead and bromine are made where they arrive. Free electrons would not make new substances.

What is true: Electrons flow in the wires. In the liquid, the ions carry the charge. Electrons are gained and lost only at the electrodes.

KEY WORDS

electrolysis
splitting a compound by passing an electric current through it.

electrolyte
the molten or dissolved compound that is split.

electrodes
the two conductors that carry the current into and out of the liquid.

cathode
the negative electrode, where positive ions go.

anode
the positive electrode, where negative ions go.

cryolite
a molten compound that aluminium oxide dissolves in, so it is liquid at a lower temperature.

BACK TO YOUR GUESS

The answer is B: Electricity splits aluminium oxide into aluminium and oxygen.

Aluminium is above carbon in the reactivity series, so carbon cannot remove its oxygen at any temperature we use. A current of electricity does it instead. That is electrolysis.

CHECK YOURSELF

Try each one before you look. A wrong answer tells you where to go next.

1. Molten lead bromide is electrolysed. At which electrode does the lead form?

   A The anode, the positive electrode

   B The cathode, the negative electrode

   C Both electrodes

   Answer at the back of the book.

2. Why does solid lead bromide not conduct electricity, but molten lead bromide does?

   A Solid lead bromide has no ions in it.

   B Heat makes free electrons flow through the liquid.

   C The ions are free to move when it is molten.

   Answer at the back of the book.

3. Molten zinc chloride, $ZnCl_2$, is electrolysed. What forms at each electrode?

   A Zinc at the cathode and chlorine at the anode

   B Chlorine at the cathode and zinc at the anode

   C Zinc and chlorine both at the cathode

   Answer at the back of the book.

4. Why is aluminium made by electrolysis and not by heating its oxide with carbon?

   A The furnace is not hot enough.

   B Carbon is less reactive than aluminium, so it cannot take the oxygen.

   C Carbon would make the aluminium too hard.

   Answer at the back of the book.

5. What is the job of cryolite in the aluminium cell?

   A It takes the oxygen from the aluminium oxide.

   B It is the source of the aluminium.

   C It dissolves the aluminium oxide, so it is liquid at a much lower temperature.

   Answer at the back of the book.

6. Why must the carbon anodes in the aluminium cell be replaced from time to time?

   A The hot oxygen made at the anode burns the carbon away.

   B Aluminium sticks to them and cannot be removed.

   C The current rubs the carbon away like sandpaper.

   Answer at the back of the book.

7. **From an earlier chapter**

   Which of these metals can be made by heating its oxide with carbon?

   A Aluminium

   B Sodium

   C Iron

   Answer at the back of the book.

8. What mass of aluminium is made from 102 g of aluminium oxide? Use $2Al_2O_3 \rightarrow 4Al + 3O_2$. Mr of Al_2O_3 is 102 and the relative atomic mass of Al is 27.

   Answer at the back of the book.

9. Molten lead bromide has Pb^{2+} ions and Br^- ions. How many Br^- ions are there for each Pb^{2+} ion?

   Answer at the back of the book.

KEEP IT

Copy this into your exercise book.

A molten ionic compound conducts because its ions move. Positive ions go to the cathode and make a metal. Negative ions go to the anode. Aluminium needs electrolysis.

Draw: A cell with a cathode and anode, Pb^{2+} moving to the cathode and Br^- to the anode, and $PbBr_2 \rightarrow Pb + Br_2$.

S4.7.8 CHAPTER 8

Energy changes and rates

Why does a fire warm a room, but baking soda in vinegar makes the cup feel cold?

YOUR GUESS

Pick one before you read on. It is fine to be wrong.

- ☐ **A** Some reactions give energy to their surroundings, and some take it in from them.
- ☐ **B** Energy is made from nothing in a fire, and destroyed in the cup.
- ☐ **C** Only flames make heat, so the cup is cold for another reason.

IF THIS FEELS HARD, READ THIS FIRST

- Level 3, Elements, mixtures, reactions and acids, S3.6.4. It lists heat as a sign of a chemical change.
- Level 3, Particles, S3.5.4. It shows that particles move faster when they are warmer.
- Level 3, Particles, S3.5.7. It shows how warm water and stirring change how fast sugar dissolves.

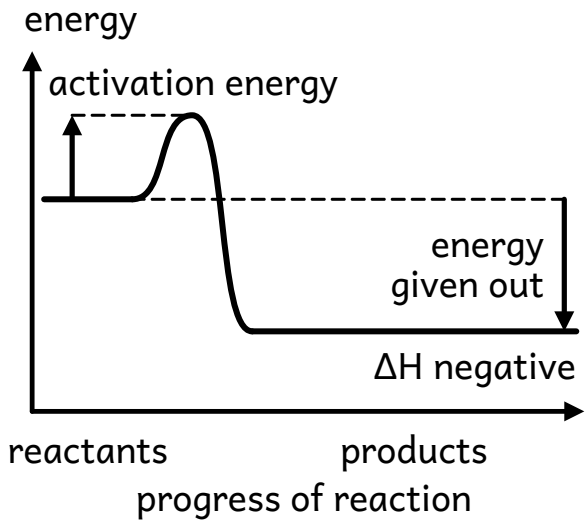
BY THE END YOU CAN

- Sort reactions into exothermic and endothermic
- Explain how temperature, concentration and surface area change reaction rate

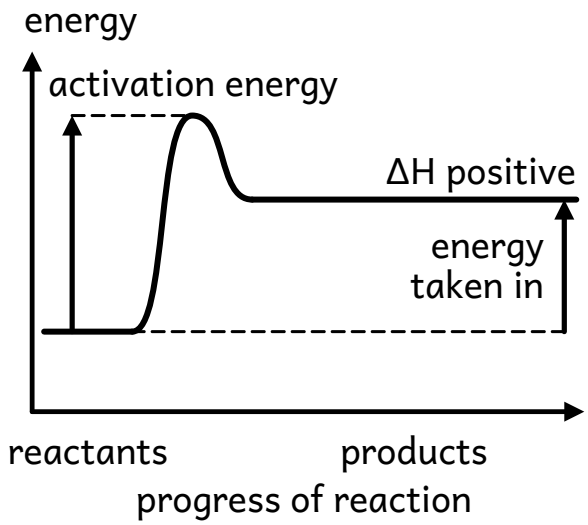
Every reaction moves energy. To react, bonds between the atoms of the reactants must break, and that takes energy in. Then new bonds form in the products, and that gives energy out.

If more energy is given out than was taken in, the reaction is **exothermic**. The extra goes to the surroundings, which get warmer. Burning, neutralisation and respiration in our cells are exothermic. Some hand warmers use iron rusting fast.

If more energy is taken in than is given out, the reaction is **endothermic**. The energy comes from the surroundings, which get cooler. Thermal decomposition and photosynthesis are endothermic. So is baking soda with vinegar, which is why the cup feels colder.



An exothermic reaction. The products are lower in energy than the reactants. The difference is given out.

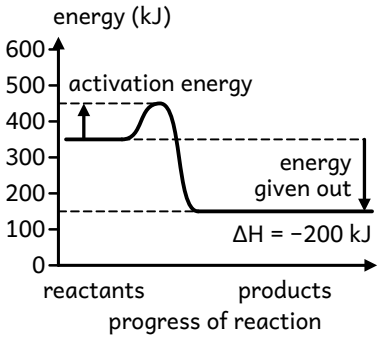


An endothermic reaction. The products are higher in energy than the reactants. The difference is taken in.

Both graphs have a hump. Particles must have a minimum energy to react. This is the ***activation energy***. It is the height from the reactants to the top of the hump.

SEE IT THREE WAYS

As a picture



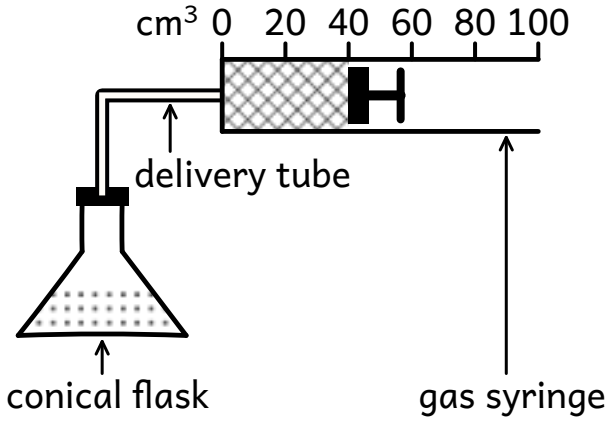
In words

The reactants are at 350 kJ and the products at 150 kJ, so 200 kJ is given out. The energy change is written ΔH. It is negative when energy is given out.

In symbols

ΔH = 150 − 350 = −200 kJ, so 200 kJ is given out.

Now think about speed. The **rate of reaction** is how fast reactants are used up or products are made. We can measure it by collecting a gas and timing it.



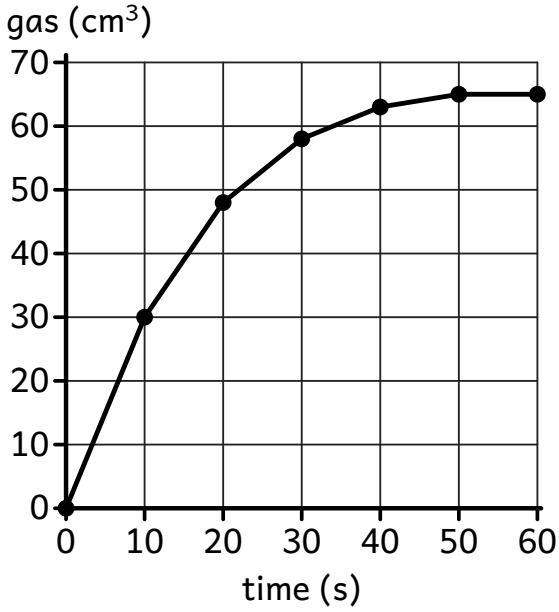
Collecting a gas in a gas syringe. Read the volume every 10 seconds.

WORKED EXAMPLE

A reaction makes 24 cm³ of gas in 8 seconds. What is the mean rate of reaction?

1. mean rate = amount of product ÷ time taken.
2. mean rate = 24 ÷ 8 = 3 cm³/s.

Answer: 3 cm³/s



The line is steepest at the start, so the reaction is fastest then. It flattens when a reactant is used up.

WORKED EXAMPLE

Use the graph. What is the mean rate of reaction between 10 s and 30 s?

1. At 10 s the graph reads 30 cm^3. At 30 s it reads 58 cm^3.
2. Gas made = 58 − 30 = 28 cm^3.
3. Time taken = 30 − 10 = 20 s.
4. mean rate = 28 ÷ 20 = 1.4 cm^3/s.

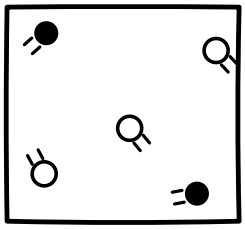
Answer: 1.4 cm^3/s

Reactions happen when particles **collide** with enough energy. A faster reaction has more successful collisions each second. Three things raise the number.

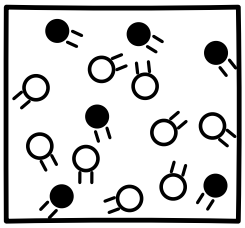
Temperature: warmer particles move faster. They collide more often, and more of the collisions have enough energy. The reaction goes faster. Concentration: more particles in the same volume collide more often. Surface area: a finer solid exposes more of its particles to the other reactant.

DRAW IT FIRST

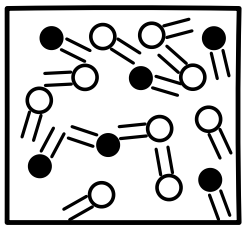
Three ways to make more collisions



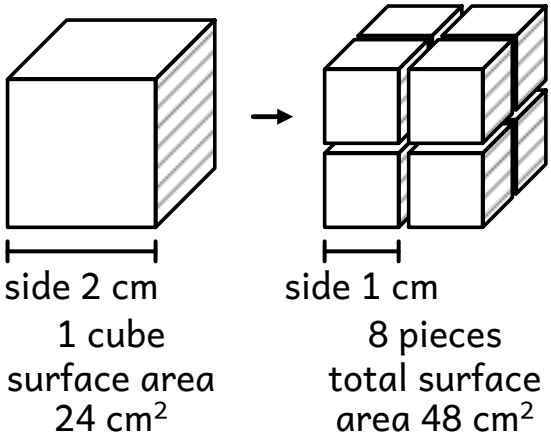
1 A few particles of two kinds, open circles and dark dots, move slowly in the box. Short trails show slow movement. They collide rarely.



2 Put in three times as many particles in the same volume. This is a higher concentration, and there are more collisions.



3 Keep them, and make them move faster. This is a higher temperature. A longer trail means a faster particle. There are even more collisions.



Cutting a cube into 8 pieces doubles the surface area. A reaction can happen only at a surface.

WORKED EXAMPLE

A cube has sides of 2 cm. It is cut into 8 small cubes. What is the total surface area of the 8 small cubes?

1. The whole cube has 6 faces of 2 × 2 = 4 cm^2. Its surface area is 6 × 4 = 24 cm^2.
2. Each small cube has a side of 1 cm. One face is 1 cm^2, so one small cube has 6 cm^2.
3. There are 8 small cubes. Their total surface area is 8 × 6 = 48 cm^2.
4. The area is twice as big, 48 cm^2 instead of 24 cm^2.

Answer: 48 cm^2

A **catalyst** speeds up a reaction and is not used up. It gives the particles an easier path, so more collisions are successful. The enzymes in your body are catalysts.

TRY IT

Warm and cold vinegar

You need: two cups, two bowls, vinegar and baking soda, cold tap water, and tap water that is warm but not hot, a spoon, and a clock or watch with a seconds hand.

Be safe: Use only tap water, never hot water from a kettle. Keep your face and eyes away from the cups, and taste nothing.

1. Put the same amount of vinegar in each cup, about a finger deep.
2. Stand one cup in a bowl of cold tap water, and the other in a bowl of warm tap water. Wait 5 minutes.
3. Add one level spoon of baking soda to each cup at the same moment. Do not stir.
4. Time how long each cup takes to stop fizzing.

What you will see: The warm cup usually fizzes faster and stops sooner. The same amount of gas is made in both, but the warmer particles collide harder and more often. You may also feel that the cups get cooler, because the reaction is endothermic.

If you cannot try it, this is what happens.

Vinegar	Fizzing stops
cold	later
warm	sooner

TRY IT

A whole piece and a powder

You need: two pieces of eggshell of the same size, or chalk that fizzes in vinegar, vinegar and two cups, paper and a spoon.

Be safe: Crush the eggshell or chalk on paper and do not breathe the dust. Keep your face and eyes away from the cups, and taste nothing.

1. Put a whole piece of eggshell, or chalk, into the first cup. Pour in vinegar.
2. Wrap the second piece in paper. Press it with the back of the spoon until it is a powder. Tip the powder into the second cup and pour in the same amount of vinegar.
3. Watch both cups for a minute. Look at the bubbles.

What you will see: The powder makes bubbles much faster than the whole piece. Eggshell, and some chalk, is calcium carbonate. Vinegar is an acid, so they make carbon dioxide. Some chalk is calcium sulfate and does not fizz: use eggshell then. The powder has far more surface in contact with the acid, so there are more collisions.

If you cannot try it, this is what happens.

Solid	Bubbles
whole piece	slowly
powder	quickly

A WRONG IDEA MANY PEOPLE HAVE

~~In an exothermic reaction energy is made, and in an endothermic reaction energy is destroyed.~~

Why it feels right: A fire seems to make heat from nothing, and a cold cup seems to lose it.

The test that breaks it: Think of a hand warmer. It gets warm, and when it is finished it cannot warm you again. The energy came from the store in the chemicals, and moved to your hand.

What is true: Energy is never made or destroyed. A reaction moves it between the chemicals and the surroundings.

KEY WORDS

exothermic
a reaction that gives out energy and warms its surroundings.

endothermic
a reaction that takes in energy and cools its surroundings.

activation energy
the least energy that particles need to react.

rate of reaction
how fast reactants are used up or products are made.

collide
to hit one another.

catalyst
a substance that speeds up a reaction and is not used up.

BACK TO YOUR GUESS

The answer is A: Some reactions give energy to their surroundings, and some take it in from them.

A reaction that gives out energy warms its surroundings. A reaction that takes energy in cools them. Energy is moved, never made or destroyed.

CHECK YOURSELF

Try each one before you look. A wrong answer tells you where to go next.

1. Which of these reactions is endothermic?

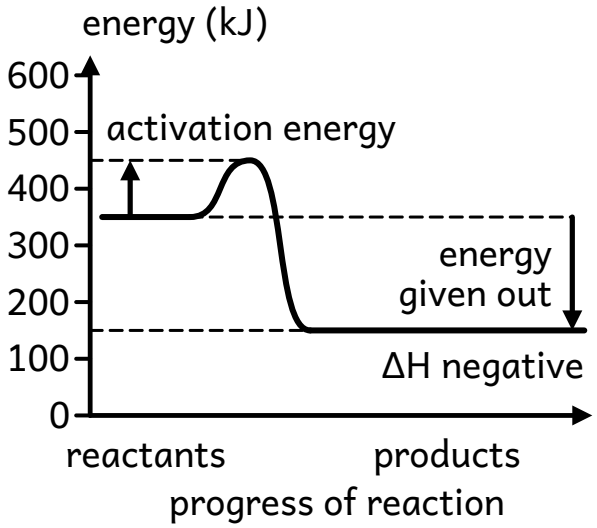
   A A candle burning

   B Acid and alkali neutralising each other

   C Baking soda and vinegar making the cup feel cold

   Answer at the back of the book.

2. The profile shows a reaction. How much energy does the reaction give out?



   A 200 kJ

   B 450 kJ

   C 100 kJ

   Answer at the back of the book.

3. Why does a reaction go faster when the temperature is raised?

   A The particles get bigger, so they hit more easily.

   B The particles move faster, so they collide more often and with more energy.

   C The reaction makes its own heat.

   Answer at the back of the book.

4. Powdered eggshell reacts faster with vinegar than a whole piece of eggshell of the same mass. Why?

   A The powder has more atoms than the whole piece.

   B The powder is warmer than the whole piece.

   C More of the eggshell is exposed to the acid, so there are more collisions.

   Answer at the back of the book.

5. Vinegar is mixed with an equal amount of water, and then poured onto eggshell. What happens to the rate of the reaction?

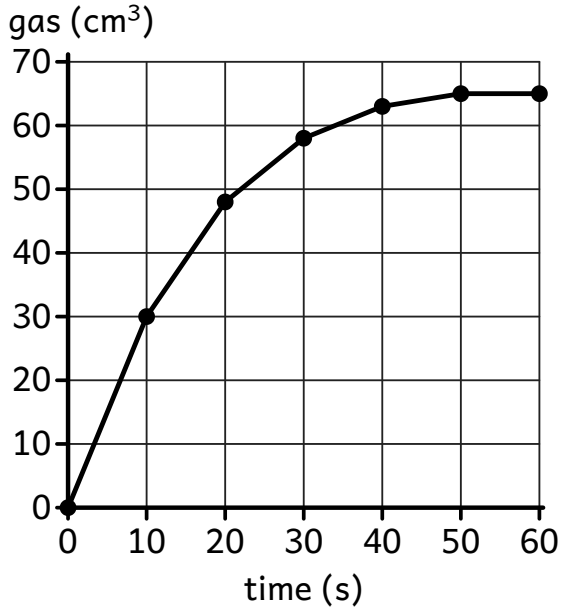
   A It is faster, because there is more liquid.

   B It is slower, because there are fewer acid particles in the same volume.

   C It does not change, because the same amount of acid is there.

   Answer at the back of the book.

6. The graph shows gas collected from a reaction. At what time did the reaction stop?



   A 50 s

   B 10 s

   C 60 s

   Answer at the back of the book.

7. What does a catalyst do?

   A It speeds up a reaction, and is not used up.

   B It makes the reaction give more product.

   C It is a reactant that is used up as the reaction goes on.

   Answer at the back of the book.

8. **From an earlier chapter**

   A reaction should make 50 g of product, but it makes 45 g. What is the percentage yield?

   A 111%

   B 90%

   C 10%

   Answer at the back of the book.

9. A reaction makes 30 cm^3 of gas in 6 seconds. What is the mean rate of reaction in cm^3/s?

   Answer at the back of the book.

10. A cube with sides of 4 cm is cut into 8 equal small cubes. What is the total surface area of the small cubes, in cm^2?

    Answer at the back of the book.

KEEP IT

Copy this into your exercise book.

Exothermic gives out energy and warms. Endothermic takes in energy and cools. Higher temperature, higher concentration and more surface area give more collisions, so a faster rate.

Draw: Two energy profiles, one for an exothermic and one for an endothermic reaction, with the energy change marked.

Key words, A to Z

Every key word in this book, what it means, and the chapter that teaches it.

acid
a substance that makes H^+ ions in water. S4.7.5

activation energy
the least energy that particles need to react. S4.7.8

actual yield
the mass of product really collected. S4.7.4

alkali
a base that dissolves in water and makes OH^- ions. S4.7.5

anode
the positive electrode, where negative ions go. S4.7.7

balanced
having the same atoms of every element on both sides of the equation. S4.7.2

base
a substance that reacts with an acid and cancels it. S4.7.5

blast furnace
a tall furnace that makes iron from iron ore, coke and limestone. S4.7.6

catalyst
a substance that speeds up a reaction and is not used up. S4.7.8

cathode
the negative electrode, where positive ions go. S4.7.7

coefficient
the number in front of a formula that says how many of it. S4.7.2

collide
to hit one another. S4.7.8

concentration
the moles of solute in 1 dm^3 of solution. S4.7.3

conserved
kept the same in a reaction, as the total mass is. S4.7.2

cryolite

a molten compound that aluminium oxide dissolves in, so it is liquid at a lower temperature. S4.7.7

displacement
a more reactive metal pushing a less reactive one out of its compound. S4.7.6

electrodes
the two conductors that carry the current into and out of the liquid. S4.7.7

electrolysis
splitting a compound by passing an electric current through it. S4.7.7

electrolyte
the molten or dissolved compound that is split. S4.7.7

endothermic
a reaction that takes in energy and cools its surroundings. S4.7.8

exothermic
a reaction that gives out energy and warms its surroundings. S4.7.8

formula
symbols and small numbers that show what a substance is made of. S4.7.1

ion
an atom, or a group of atoms, with an electric charge. S4.7.1

mole
an amount of substance: 6.02×10^{23} particles. S4.7.3

neutralisation
the reaction of H^+ and OH^- to make water. S4.7.5

ore
a rock with enough of a metal compound to be worth mining. S4.7.6

oxidation
the gain of oxygen by a substance. S4.7.6

percentage yield
the actual yield divided by the theoretical yield, times 100. S4.7.4

pH
a scale that measures the H^+ ions in a solution. S4.7.5

polyatomic ion
a group of atoms that carries one charge together, such as OH^-. S4.7.1

products
the substances that are made, written on the right of the arrow. S4.7.2

rate of reaction
how fast reactants are used up or products are made. S4.7.8

reactants
the substances that react, written on the left of the arrow. S4.7.2

reactivity
how easily a metal takes part in reactions. S4.7.6

reduction
the loss of oxygen by a substance. S4.7.6

relative atomic mass
the mass of an atom compared with one twelfth of a carbon 12 atom. S4.7.3

relative formula mass
Mr, the sum of the relative atomic masses in a formula. S4.7.3

salt
a compound made when an acid reacts, such as zinc chloride. S4.7.5

slag
the waste that floats on the molten iron, mostly calcium silicate. S4.7.6

state symbol
a letter in brackets after a formula: (s), (l), (g) or (aq). S4.7.2

theoretical yield
the mass of product a perfect reaction would make. S4.7.4

Answers

S4.7.1. Chemical formulae

1. **2 chloride ions**

   Ca^{2+} has a charge of +2. Each Cl^- has −1. Two Cl^- ions give −2, so +2 −1 −1 = 0. The formula is $CaCl_2$.

   - **If you chose A:** One Cl^- cancels only 1 of the 2 positive charges. The sum is +1, so a charge is left over. Go to S4.6.6.
   - **If you chose C:** Three Cl^- give −3, which is more than the +2 of the calcium ion. The sum would be −1.

2. **$AlCl_3$**

   One Al^{3+} has a charge of +3. It needs three Cl^- ions, each −1, so the charges add to zero.

   - **If you chose A:** That is one of each. The charges would be +3 and −1, so +2 is left over. Go to S4.6.6.
   - **If you chose B:** The numbers are the wrong way round. Three aluminium ions would give +9, and one chloride ion only −1.

3. **Na_2SO_4**

   Two Na^+ ions give +2. One SO_4^{2-} ion gives −2. The sum is zero, and the sulfate is needed once, so it needs no bracket.

   - **If you chose B:** One Na^+ and one SO_4^{2-} give +1 −2 = −1. The charges do not add to zero.
   - **If you chose C:** Two sulfate ions would give −4, and one sodium ion only +1. It is the sodium that is needed twice.

4. **$Ca(OH)_2$**

   The bracket groups O and H, and the 2 after it multiplies both. The formula has 1 Ca, 2 O and 2 H.

   - **If you chose A:** Here the small number counts only the H. That is 1 Ca, 1 O and 2 H. OH is a group, so it needs a bracket.
   - **If you chose B:** This has two calcium atoms and one OH. The count is on the wrong symbol.

5. **12 oxygen atoms**

   Each SO_4 has 4 oxygen atoms, and there are 3 of them: 4 × 3 = 12. The count also includes 2 Al and 3 S.

   - **If you chose A:** The 3 after the bracket is the number of sulfate groups. Each group has 4 oxygen atoms.
   - **If you chose C:** That is the oxygen in one sulfate group. The bracket holds 3 groups.

6. **There are two chloride ions for each magnesium ion.**

   The low 2 sits after Cl, so it counts chlorine. The formula gives the ratio of the ions in the lattice: 1 Mg^{2+} to 2 Cl^-.

   - **If you chose B:** A charge is written raised, as in Cl^-, and the chloride ion is 1−. The low 2 after Cl counts chloride ions. Go to S4.6.6.
   - **If you chose C:** There is only one Mg, and magnesium chloride is a lattice of ions, not a molecule. The formula gives the ratio of the ions. Go to S4.6.6.

7. **CH_4**

   One C circle and four H circles. The small number goes low, after the symbol it counts: CH_4.

   - **If you chose A:** That would be four carbon atoms and one hydrogen. Count the circles: one C and four H.
   - **If you chose C:** That is one carbon and one hydrogen. Count again: there are four H circles.

8. **5 atoms**

   Ca 1, O 2 and H 2. The bracket multiplies the O and the H by 2. 1 + 2 + 2 = 5.

9. **2 positive ions and 3 negative ions**

   The smallest number that 3 and 2 both go into is 6. 6 ÷ 3 = 2 positive ions and 6 ÷ 2 = 3 negative ions.

S4.7.2. Balancing equations

1. **$2H_2 + O_2 \rightarrow 2H_2O$**

   Two H_2O molecules hold 2 oxygen atoms and 4 hydrogen atoms. Two H_2 molecules give the 4 hydrogen atoms, and one O_2 gives the 2 oxygen atoms.

   - **If you chose A:** That balances the atoms by making a different substance, hydrogen peroxide. A small number inside a formula must never be changed.
   - **If you chose B:** Oxygen gas is made of O_2 molecules, so its formula is O_2. A formula cannot be changed to balance an equation.

2. **$N_2 + 3H_2 \rightarrow 2NH_3$**

   Two NH_3 molecules have 2 N and 6 H. The left has N_2, which is 2 N, and three H_2, which is 6 H.

   - **If you chose B:** The left has 4 H atoms, but two NH_3 molecules have 6. The hydrogen is not equal.
   - **If you chose C:** The hydrogen is not equal: 6 on the left but only 3 on the right. The nitrogen is not equal either: 2 on the left and 1 on the right.

3. **dissolved in water**

   Aq is short for aqueous, which means in water. HCl(aq) is hydrochloric acid, and $MgCl_2$(aq) is magnesium chloride dissolved in water.

   - **If you chose A:** A pure liquid is (l). Something with (aq) is a substance mixed into water. Go to S3.5.7.
   - **If you chose C:** A gas is (g). In this equation it is the hydrogen, H_2(g), that escapes.

4. **Oxygen from the air joined the magnesium.**

   Magnesium and oxygen make magnesium oxide. The oxide has the mass of the magnesium and the oxygen together. The oxygen came from the air, which an open dish does not hold back.

   - **If you chose B:** Matter is never made from nothing in a reaction. The extra mass came from the air. Go to S3.6.6.
   - **If you chose C:** Heat does not change the mass of a solid you could weigh. The extra mass came from oxygen that joined it.

5. **Carbon dioxide gas escaped into the air.**

   Chalk rock, $CaCO_3$, breaks into CaO and CO_2. The CO_2 is a gas and leaves the dish. In a closed container the total mass would stay the same.

   - **If you chose A:** The energy of the heat is far too small to change a mass you could weigh. The missing mass is in the gas.
   - **If you chose B:** Mass is never destroyed in a reaction. The missing mass is in the gas that left.

6. **6 hydrogen atoms**

   One $Ca(OH)_2$ has 2 H, because the bracket multiplies the H by 2. There are 3 of them, so 3 × 2 = 6.

   - **If you chose A:** That is one $Ca(OH)_2$. The 3 in front says there are three of them. Go to S4.7.1.
   - **If you chose C:** There is one H in each OH, but the bracket has a 2 after it. Each $Ca(OH)_2$ has 2 hydrogen atoms. Go to S4.7.1.

7. **2, 1 and 2**

   Two MgO have 2 Mg and 2 O. So write 2 in front of Mg. One O_2 has 2 O. The equation is $2Mg + O_2 \rightarrow 2MgO$.

8. **12 g**

   Mass is conserved, so the reactants weigh the same as the product. 20 g − 8 g = 12 g of B.

S4.7.3. The mole

1. **44**

   CO_2 has 1 carbon and 2 oxygen atoms. 12 + 2 × 16 = 12 + 32 = 44.

   - **If you chose A:** That is 12 + 16, for CO with one oxygen. CO_2 has two oxygen atoms.
   - **If you chose B:** That is 2 × 16, the two oxygen atoms. The carbon atom must be added too.

2. **2 mol**

   moles = mass ÷ Mr = 36 ÷ 18 = 2 mol.

   - **If you chose B:** That is 18 ÷ 36, the wrong way round. Moles are mass divided by Mr.
   - **If you chose C:** That is the Mr itself. Divide the mass by it: moles = mass ÷ Mr.

3. **200 g**

   Mr of $CaCO_3$ = 40 + 12 + 3 × 16 = 100. mass = moles × Mr = 2 × 100 = 200 g.

   - **If you chose A:** That is 100 ÷ 2. To go from moles to mass, multiply by Mr.
   - **If you chose C:** That is the mass of 1 mol. There are 2 mol, so multiply by 2.

4. **2 mol/dm³**

   100 cm^3 = 0.1 dm^3. concentration = moles ÷ volume = 0.2 ÷ 0.1 = 2 mol/dm^3.

   - **If you chose A:** That divides by 100 as if the volume were in dm^3. 100 cm^3 is 0.1 dm^3 first.
   - **If you chose B:** That multiplies by 100. To change cm^3 into dm^3 divide by 1 000, which gives 0.1 dm^3.

5. **All three hold the same number of particles.**

   Each sample is one mole, because its mass in grams equals its Mr: 12, 18 and 44. One mole always has the same number of particles.

   - **If you chose A:** More mass does not mean more particles. Each particle of carbon dioxide has more mass than a carbon atom.
   - **If you chose C:** The size of a particle does not decide it. Count the moles instead: 12 g of carbon is one mole.

6. **3.01×10^{23} atoms**

   Half a mole holds half the particles. 0.5 × 6.02 × 10^{23} = 3.01 × 10^{23} atoms.

   - **If you chose B:** That is the number in a whole mole. Here there is only half a mole, so half as many atoms.
   - **If you chose C:** Half of 6.02 is 3.01, but the power of ten stays at 23. A power of 22 would be ten times too small.

7. **It is the average of the masses of its isotopes, weighted by how common each is.**

   Chlorine atoms with 18 neutrons are about three times as common as those with 20. The average mass lies between 35 and 37, closer to 35, at 35.5.

   - **If you chose A:** Protons are never split. Every chlorine atom has 17 whole protons. Go to S4.6.1.
   - **If you chose B:** It is measured carefully. The value is 35.45, which school tables round to 35.5. It is not whole because chlorine is a mixture of two isotopes with different masses, and 35.5 is their average. Go to S4.6.3.

8. **2Ca + O_2 → 2CaO**

   Two CaO have 2 Ca and 2 O. So 2 Ca on the left, and one O_2 for 2 O.

   - **If you chose B:** This is balanced, but CaO_2 is not calcium oxide. The formula of the product must stay CaO. Only the number in front may change. Go to S4.7.2.
   - **If you chose C:** The left has 2 O atoms and the right has 1. The oxygen is not equal. Go to S4.7.2.

9. **106**

   Na_2CO_3 has 2 Na, 1 C and 3 O. 2 × 23 + 12 + 3 × 16 = 46 + 12 + 48 = 106.

10. **0.5 mol**

    Mr of CO_2 is 44. moles = mass ÷ Mr = 22 ÷ 44 = 0.5 mol.

11. **2 mol/dm^3**

    250 cm^3 ÷ 1 000 = 0.25 dm^3. concentration = 0.5 ÷ 0.25 = 2 mol/dm^3.

S4.7.4. Reacting masses and yield

1. **25 g**

   Go up from 15 g of magnesium to the line, then across to 25 on the side. The calculation agrees: 15 ÷ 24 × 40 = 25 g.

   - **If you chose A:** That is the mass of magnesium. The oxide weighs more, because oxygen joins the magnesium. Go to S4.7.2.
   - **If you chose C:** That is the top of the line, for 24 g of magnesium. Go up from 15 on the bottom scale to the line, and then across.

2. **2 mol**

   The ratio of H_2 to NH_3 is 3 to 2. So 3 mol of H_2 make 2 mol of NH_3.

   - **If you chose A:** The numbers in front are 3 for H_2 and 2 for NH_3. They are not equal. Go to S4.7.2.
   - **If you chose B:** That multiplies by 2, but the ratio is 3 H_2 to 2 NH_3. 3 mol of H_2 is one lot of the recipe.

3. **5.6 g**

   Mr of $CaCO_3$ is 100, so 10 g is 0.1 mol. The ratio is 1 to 1, so 0.1 mol of CaO forms. Mr of CaO is 56, so the mass is 0.1 × 56 = 5.6 g.

   - **If you chose B:** That is the mass of the carbon dioxide, 0.1 × 44. The question asks for the calcium oxide.
   - **If you chose C:** The product has less mass, because carbon dioxide gas leaves. Use moles: 10 g is 0.1 mol.

4. **75%**

   percentage yield = actual ÷ theoretical × 100 = 30 ÷ 40 × 100 = 75%.

   - **If you chose A:** That divides the wrong way round. The actual yield goes on top: 30 ÷ 40.
   - **If you chose C:** That is the percentage lost, 10 ÷ 40. The yield is the percentage collected.

5. **80%**

   percentage yield = actual ÷ theoretical × 100 = 40 ÷ 50 × 100 = 80%.

   - **If you chose B:** That divides the theoretical yield by the actual yield. The actual yield goes on top.
   - **If you chose C:** That is the difference in grams, 10 g, not a percentage of the theoretical yield.

6. **The product was still wet or mixed with another substance.**

   Water or an impurity adds mass, so the product weighs more than it should. The mistake is in the weighing, not in the chemistry.

   - **If you chose A:** Atoms are never made in a reaction. The product must have weighed more for another reason. Go to S4.7.2.
   - **If you chose B:** Losing product makes the yield smaller, not larger.

7. **0.25 mol**

   Mr of CO_2 is 44. moles = mass ÷ Mr = 11 ÷ 44 = 0.25 mol.

   - **If you chose A:** That is 44 ÷ 11, upside down. Moles are mass divided by Mr. Go to S4.7.3.
   - **If you chose C:** Mr of CO_2 is 12 + 2 × 16 = 44, so 11 g is a quarter of a mole, not a half. Go to S4.7.3.

8. **10 g**

   6 ÷ 24 = 0.25 mol of Mg. The ratio is 1 to 1, so 0.25 mol of MgO forms. Its mass is 0.25 × 40 = 10 g.

9. **85%**

   percentage yield = actual ÷ theoretical × 100 = 34 ÷ 40 × 100 = 85%.

S4.7.5. Acids, bases and salts

1. **Hydrogen**

   An acid with a metal makes a salt and hydrogen. Here zinc chloride and hydrogen gas form.

   - **If you chose B:** There is no oxygen to release. An acid with a metal makes a salt and hydrogen.
   - **If you chose C:** Carbon dioxide comes from a carbonate. Zinc is a metal, so it makes hydrogen. Go to S3.6.7.

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

   $MgCl_2$ has 2 Cl, so we need 2HCl. Then H is 2 on each side.

   - **If you chose A:** The Cl is not equal: 1 on the left and 2 on the right. A number in front of HCl is missing.
   - **If you chose C:** MgCl is not a formula that works: Mg^{2+} needs two Cl^-, so the salt is $MgCl_2$. Go to S4.7.1.

3. **A salt, water and carbon dioxide**

   The carbonate ion, CO_3^{2-}, is changed by the acid into water and carbon dioxide. The rest makes the salt.

   - **If you chose A:** That is what a metal makes. A carbonate makes carbon dioxide too.
   - **If you chose B:** That is what a base makes. A carbonate also gives off carbon dioxide gas, which is the fizz.

4. **100 times**

   pH 3 and pH 5 are 2 steps apart. Each step is 10 times, so 10 × 10 = 100.

   - **If you chose B:** That is the difference between the two pH numbers, 5 − 3. Each step is 10 times, so the answer is bigger.
   - **If you chose C:** That would be 3 steps. 3 and 5 are 2 steps apart.

5. **It is alkaline, with fewer H^+ ions than pure water.**

   A pH above 7 is alkaline. Higher pH means fewer H^+ ions and more OH^- ions.

   - **If you chose A:** Acids are below 7. Sample X is above 7, so it has few H^+ ions.
   - **If you chose B:** Only pH 7 is neutral, with as many H^+ ions as OH^- ions.

6. **H^+ and OH^- ions join to make water.**

   The equation is $H^+ + OH^- \rightarrow H_2O$. The other ions stay in the solution as the salt.

   - **If you chose A:** They cancel each other. The H^+ ions and the OH^- ions are used up. Go to S3.6.8.
   - **If you chose C:** Hydrogen comes from a metal and an acid. Acid and alkali make a salt and water.

7. **0.1 mol**

   Moles of NaOH = 4 ÷ 40 = 0.1 mol. The ratio of NaOH to HCl is 1 to 1, so 0.1 mol of HCl is needed.

   - **If you chose A:** That is 40 ÷ 4, upside down. Moles are mass divided by Mr. Go to S4.7.3.
   - **If you chose B:** The 4 is the mass in grams, not moles. Divide by Mr first. Go to S4.7.3.

8. **1, 1, 1 and 1**

   Mg is 1 on each side. SO_4 is 1 on each side. H_2 is 2 on each side. No change is needed.

9. **10 times**

   The two are 1 step apart. Each step is 10 times.

S4.7.6. The reactivity series

1. **sodium, magnesium, copper**

   Sodium reacts with cold water. Magnesium reacts with acid but hardly with cold water. Copper does not react with either.

   - **If you chose B:** Sodium is more reactive than magnesium. It reacts violently with cold water, and magnesium hardly reacts with cold water.
   - **If you chose C:** This is the order of least reactive first. Copper is the least reactive of the three.

2. **zinc in copper sulfate solution**

   Zinc is above copper in the series. It displaces copper: $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$.

   - **If you chose A:** Copper is below zinc, so it cannot push zinc out of its compound.
   - **If you chose C:** Copper is much lower than magnesium, so it cannot take its place.

3. **Carbon is more reactive than iron but less reactive than aluminium.**

   A more reactive element takes oxygen from a less reactive one. Carbon is above iron, so it takes the oxygen from iron oxide. It is below aluminium, so it cannot.

   - **If you chose B:** Melting is not the reason. Aluminium holds its oxygen too tightly for carbon to take it.
   - **If you chose C:** It does: Al_2O_3 has 3 oxygen atoms. Carbon cannot take them because it is below aluminium in the series.

4. **Fe_2O_3**

   Fe_2O_3 loses its oxygen and becomes iron. Losing oxygen is reduction.

   - **If you chose A:** CO gains oxygen and becomes CO_2. Gaining oxygen is oxidation.
   - **If you chose B:** CO_2 is a product, the result of the oxidation of CO. It is not the substance that loses oxygen.

5. **It reacts with sand and makes slag.**

   Limestone breaks down to calcium oxide, which joins the sand in the ore and makes slag. The slag floats on the iron and is tapped off.

   - **If you chose A:** The carbon comes from the coke. Limestone is a carbonate of calcium.
   - **If you chose B:** Coke burns to heat the furnace. Limestone does not burn.

6. **A thin tough oxide skin covers it and protects it.**

   The aluminium reacts with oxygen at once and makes a skin of aluminium oxide. The skin keeps air and water away from the metal below.

   - **If you chose A:** It is above iron. That is why aluminium is so hard to extract from its ore.
   - **If you chose C:** It reacts with oxygen at once. The oxide skin that forms is the reason it then stops.

7. **Zinc sulfate and hydrogen**

   An acid with a metal makes a salt and hydrogen. Sulfuric acid makes a sulfate, so the salt is zinc sulfate.

   - **If you chose A:** Water is made from an acid and a base. A metal makes hydrogen. Go to S4.7.5.
   - **If you chose B:** The salt of sulfuric acid is a sulfate. An oxide is not made. Go to S4.7.5.

8. **6 mol**

   The ratio of Fe_2O_3 to CO is 1 to 3. So 2 mol of Fe_2O_3 need 2 × 3 = 6 mol of CO.

9. **127 g**

   Moles of CuO = 159 ÷ 79.5 = 2 mol. The ratio of CuO to Cu is 1 to 1, so 2 mol of Cu form. Mass = 2 × 63.5 = 127 g.

S4.7.7. Electrolysis

1. **The cathode, the negative electrode**

   Pb^{2+} ions are positive and go to the negative electrode, the cathode. There they gain electrons and become lead.

   - **If you chose A:** Pb^{2+} is positive, so it is attracted to the negative electrode. The positive electrode attracts the Br^- ions.
   - **If you chose C:** Each kind of ion goes to one electrode only. Lead forms at one and bromine at the other.

2. **The ions are free to move when it is molten.**

   A current needs charged particles that can move. The ions are fixed in the solid and free in the liquid.

   - **If you chose A:** The solid is made of ions. They are fixed in a lattice and cannot move. Go to S4.6.6.
   - **If you chose B:** It is ions that move in the liquid, not electrons. The heat only frees the ions from the lattice.

3. **Zinc at the cathode and chlorine at the anode**

   Zn^{2+} goes to the cathode and becomes zinc. Cl^- goes to the anode and becomes chlorine, Cl_2.

   - **If you chose B:** Zn^{2+} is positive and goes to the negative cathode. Cl^- is negative and goes to the positive anode.
   - **If you chose C:** Ions of opposite charge go to opposite electrodes. Chlorine forms at the anode.

4. **Carbon is less reactive than aluminium, so it cannot take the oxygen.**

   A less reactive element cannot take oxygen from a more reactive one. Carbon is below aluminium in the series, so electricity is used instead.

   - **If you chose A:** Heat is not the problem. Carbon is below aluminium in the series, so in a furnace it cannot take the oxygen. Go to S4.7.6.
   - **If you chose C:** It is not about hardness. Carbon cannot take oxygen from aluminium oxide in a furnace. Go to S4.7.6.

5. **It dissolves the aluminium oxide, so it is liquid at a much lower temperature.**

   Aluminium oxide melts above 2 000 °C. Dissolved in molten cryolite, it can be electrolysed at about 950 °C, which saves energy.

   - **If you chose A:** Cryolite does not react. The current splits the oxide.
   - **If you chose B:** The aluminium comes from aluminium oxide. Cryolite only dissolves it.

6. **The hot oxygen made at the anode burns the carbon away.**

   O^{2-} ions become oxygen at the anode. Oxygen and hot carbon make carbon dioxide, so the carbon is used up.

   - **If you chose B:** The aluminium forms at the cathode. The anodes are where the oxygen is made.
   - **If you chose C:** A current does not wear a conductor away like that. The carbon burns in the hot oxygen.

7. **Iron**

   Iron is below carbon in the series, so carbon removes the oxygen from iron oxide in the blast furnace.

   - **If you chose A:** Aluminium is above carbon in the series. Carbon cannot take its oxygen. Go to S4.7.6.
   - **If you chose B:** Sodium is far above carbon in the series, so it is also made by electrolysis. Go to S4.7.6.

8. **54 g**

   102 ÷ 102 = 1 mol of Al_2O_3. The ratio of Al_2O_3 to Al is 1 to 2, so 2 mol of Al form. Mass = 2 × 27 = 54 g.

9. **2 bromide ions**

   The charges must add to zero. Pb^{2+} is +2 and each Br^- is −1, so 2 ÷ 1 = 2 bromide ions.

S4.7.8. Energy changes and rates

1. **Baking soda and vinegar making the cup feel cold**

   The reaction takes in energy from its surroundings, so the cup gets colder. A reaction that takes energy in is endothermic.

   - **If you chose A:** Burning gives out energy as heat and light. It is exothermic.
   - **If you chose B:** Neutralisation warms the mixture. It is exothermic. Go to S3.6.8.

2. **200 kJ**

   The reactants are at 350 kJ and the products at 150 kJ. 350 − 150 = 200 kJ is given out.

   - **If you chose B:** That is the top of the hump. The energy given out is the difference between reactants and products.
   - **If you chose C:** That is the activation energy, the height from the reactants to the top of the hump. The energy given out is between the two levels.

3. **The particles move faster, so they collide more often and with more energy.**

   Faster particles collide more often, and more of the collisions have at least the activation energy. So more collisions are successful.

   - **If you chose A:** The particles stay the same size. Heat makes them move faster. Go to S3.5.4.
   - **If you chose C:** Some reactions do, but a cold reaction goes faster when it is warmed from outside, and that is because of the particles.

4. **More of the eggshell is exposed to the acid, so there are more collisions.**

   Acid particles can hit only the surface of the eggshell. Powder has a much larger surface area than a whole piece, so there are more collisions each second.

   - **If you chose A:** The same mass has the same number of atoms. The difference is how much surface the acid can reach.
   - **If you chose B:** Both start at the same temperature. The difference is surface area.

5. **It is slower, because there are fewer acid particles in the same volume.**

   The concentration of the acid is halved, so acid particles meet the eggshell less often. Fewer collisions mean a slower rate.

   - **If you chose A:** There is more liquid, but the acid particles are spread through it. Fewer of them hit the chalk each second.
   - **If you chose C:** The amount of acid is the same, but the volume doubled. The concentration halved, so there are fewer collisions.

6. **50 s**

   The line stops rising at 50 s, and stays at 65 cm^3. No more gas is made, so the reaction has stopped.

   - **If you chose B:** At 10 s the line is steepest, so the reaction is fastest, not finished.
   - **If you chose C:** The graph ends at 60 s, but the line has been flat since 50 s. No more gas was made after 50 s.

7. **It speeds up a reaction, and is not used up.**

   A catalyst gives the particles an easier path, so more collisions are successful. It is not changed, so a little can be used over and over.

   - **If you chose B:** A catalyst changes the speed, not the amount of product that can be made.
   - **If you chose C:** A catalyst is not used up. It is there at the end, just as it was at the start.

8. **90%**

   percentage yield = actual ÷ theoretical × 100 = 45 ÷ 50 × 100 = 90%.

   - **If you chose A:** That divides the theoretical yield by the actual yield. The actual yield goes on top. Go to S4.7.4.
   - **If you chose C:** That is the percentage lost, 5 ÷ 50. The yield is the percentage that was collected. Go to S4.7.4.

9. **5 cm^3/s**

   mean rate = amount of product ÷ time = 30 ÷ 6 = 5 cm^3/s.

10. **192 cm²**

    Each small cube has a side of 2 cm, so one face is 4 cm². One cube has 6 × 4 = 24 cm², and 8 cubes have 8 × 24 = 192 cm².

About this book

For learners who can follow a written argument, use letters for numbers, and have met atoms, ions and bonding. In many schools this fits learners of about 14 to 16, and older learners can use it as a reference. Each chapter takes two or three short sessions, and the sums in chapters 3 and 4 need a pencil and a calculator. A learner can work alone: every exercise has its answer and the reason for it. The Try it activities use paper, vinegar, baking soda, water, cabbage and chalk. Nothing is tasted and nothing is heated except water poured by an adult. Experiments that need a strong chemical, a flame, a molten salt or mains electricity are described as things scientists do, and the book says why they are not done at home. Keep vinegar and baking soda solution away from the eyes, and keep small items away from young children.

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