

Every worked example has a parallel **Now try this** formative exercise.

Now try this 6.2

6 What is the percentage of aluminium in aluminium oxide?

Fully-worked answers to all **Now try this** tasks are at the back of the book.



The percentages of the important elements in this fertiliser are shown on the tag.

Test yourself questions for mastery of just-learnt material.

Example 6.2

Percentage composition (2)

What is the percentage of magnesium in magnesium chloride?

$$\begin{aligned} \text{percentage of Mg} &= \frac{M(\text{Mg})}{M(\text{MgCl}_2)} \times \frac{100}{1} \\ &= \frac{24}{95} \times \frac{100}{1} \\ &= 25.26\% \end{aligned}$$

Worked examples show students how to do common problems

Application

Fertilisers

Nine elements are particularly important for plant growth—C, O, H, N, P, K, Ca, S, and Mg. C, O, and H are obtained from air and water, and the rest are dissolved minerals in the soil. In a closed system (e.g. a natural forest), nutrients are recycled when plants and animals die and are decomposed. Farming is an open system—we export vital nutrients as meat, wool and other produce. Fertilisers are necessary to redress (top-dress?) the balance.

Soils differ, and each crop has different nutrient demands. Farmers need to know the nutrient mix in each fertiliser so that they can choose the right product for their particular needs.

The percentage of important elements is quoted on the packet. Examples are:

sulfate of ammonia:	nitrogen (N) 20.5%
	sulfur (S) 24.0%
sulfate of potash:	potassium 40%
ammonium nitrate:	ammoniacal nitrogen 17.2%
	nitric nitrogen 17.3%
	total nitrogen (N) 34.5%

(Nitric nitrogen can be used immediately by the plant, but ammoniacal nitrogen must be acted on by soil bacteria before it becomes available to the plants.)

Applications answer the question "who cares"?

Test yourself 6A

Percentage composition

- Write the formula for calculating the percentage mark in a test.
- If you get 15 multiple-choice questions correct out of a total of 60 in a test, what percentage did you get:
 - right?
 - wrong?
- What is the percentage of water in butter if 3.7 g of butter contains 0.80 g of water?
- What is the percentage of orange juice in a drink if 200 mL of drink contains 58 mL of orange juice?
- What is the percentage of chlorine in magnesium chloride? $A_r(\text{Mg}) = 24$; $A_r(\text{Cl}) = 35.5$.
- Calculate the percentage of nitrogen in urea, $\text{CH}_4\text{N}_2\text{O}$.

Chemistry at work features stories of NZers using chemistry.

Chemistry at Work

Ross Davidson—Mines Chemist

Ross Davison does analysis for the Waihi Gold Mining Company. He is involved in every aspect of mining—from ore analysis through to waste water analysis.

Geological staff take samples from the surface of the pit floor and send them to the laboratory. Ross crushes the rock to a fine powder, mixes it in hot acids to dissolve all the metals (including gold), then analyses the solution with an atomic absorption spectrometer (AA). Ross reports the composition of every rock sample. While the concentration of some metals is given as a percentage (grams in 100 g), the concentration of gold is reported in parts per million (mg per 1000 g or grams per tonne). An open-cast gold mine today may be profitable if the ore contains at least 1 part per million of gold.

At the mine, the gold is extracted from crushed and milled rock using sodium cyanide solution. After extraction, the water fraction of the tailings (a suspension of powdered rock, lime and dilute cyanide in water) are treated to ensure compliance with standards set down by the Regional Council before the water is discharged into a stream. Ross monitors the cyanide content of the water at each stage of treatment to make sure that toxic cyanide does not enter the environment. With Ross's help, the cyanide content of the discharge water is kept below 0.2 ppm—well below that found in table salt (13 ppm), coffee (6 ppm), or cigarette smoke (1600 ppm).

Ross enjoyed the sciences and mathematics at school, and studied for a New Zealand Certificate in Science (Chemistry) through Wellington Polytechnic. Ross's first job was in soil science, but after two years he was invited to become an analytical chemist at the Thames Dairy factory—because his cricket skills were needed by the local cricket club! Later he worked as a chemist in a London brewery before returning to New Zealand to take up his present job in 1992.

Ross feels he is doing valuable work—not only for the company, but also in protecting the local environment. When the mine closes he isn't sure what he will do, but he is confident that his analytical skills will be needed somewhere.



Excess water from the gold extraction process is treated and then held in this pool. It is checked to make sure it meets the required standard of purity before being discharged.

Empirical formulae

The empirical formula of a compound is the simplest ratio of its elements.

Glucose molecules contain 6 carbon atoms, 12 hydrogen atoms, and 6 oxygen atoms— $C_6H_{12}O_6$. The **empirical formula** for glucose is CH_2O . Similarly, the molecular formula for hydrogen peroxide is H_2O_2 and its empirical formula is HO . The empirical and molecular formulae for water are both H_2O .

The empirical formula of a compound is calculated by knowing the ratios of the elements it contains, or its percentage composition. You will be expected to calculate empirical formula from experimental data.

Definitions of important terms are displayed for easy reference.

Full-colour photographs are essential for the most colourful of sciences.

Example 8.3

Percentage composition of a solution

Vinegar should contain more than 4% acetic acid (CH_3COOH , molar mass 60 g mol^{-1}). 25.0 mL of vinegar is diluted to 100.0 mL (a factor of 4), and 10.0 mL samples of this solution are titrated against 0.100 mol L^{-1} NaOH solution. An average of 18.1 mL NaOH were required to neutralise the vinegar. Calculate the concentration of the diluted solution, and hence the percentage concentration of acetic acid in the original vinegar.



$$V(\text{NaOH}) = 18.1 \text{ mL} \quad c(\text{NaOH}) = 0.100 \text{ mol L}^{-1} \quad n(\text{NaOH}) = ?$$

$$= 18.1 \times 10^{-3} \text{ L}$$

$$n(\text{NaOH}) = cV$$

$$= 0.100 \text{ mol L}^{-1} \times 18.1 \times 10^{-3} \text{ L}$$

$$= 1.81 \times 10^{-3} \text{ mol}$$

From the equation:

$$n(\text{CH}_3\text{COOH}) = n(\text{NaOH})$$

$$= 1.81 \times 10^{-3} \text{ mol}$$

$$n(\text{CH}_3\text{COOH}) = 1.81 \times 10^{-3} \text{ mol} \quad V(\text{CH}_3\text{COOH}) = 10.0 \text{ mL} \quad c(\text{CH}_3\text{COOH}) = ?$$

$$= 10.0 \times 10^{-3} \text{ L}$$

$$c(\text{CH}_3\text{COOH}) = \frac{n}{V}$$

$$= \frac{1.81 \times 10^{-3} \text{ mol}}{10.0 \times 10^{-3} \text{ L}}$$

$$= 0.181 \text{ mol L}^{-1}$$

$$c(\text{diluted}) = 0.181 \text{ mol L}^{-1} \quad V(\text{flask}) = 100.0 \text{ mL} \quad V(\text{pipette}) = 25.0 \text{ mL}$$

$$c(\text{vinegar}) = ?$$

$$c(\text{vinegar}) = c(\text{dilute}) \times \frac{V(\text{flask})}{V(\text{pipette})}$$

$$= 0.181 \text{ mol L}^{-1} \times \frac{100.0 \text{ mL}}{25.0 \text{ mL}}$$

$$= 0.724 \text{ mol L}^{-1}$$

Concentration as a percentage:

$$c(\text{vinegar}) = 0.724 \text{ mol L}^{-1} \times 60.0 \text{ g mol}^{-1}$$

$$= 43.44 \text{ g L}^{-1}$$

$$= 4.344 \text{ g}/100 \text{ mL}$$

$$= 4.34\%$$



The phenolphthalein endpoint is the first faint pink colour that lasts for 15 seconds (top). If your solution is bright pink (bottom), you have added too much base.

Now try this 8.3

10.0 mL of household ammonia solution was diluted to 100.0 mL with water, and 10.0 mL samples of this solution were titrated against 0.108 mol L^{-1} HCl solution, using methyl orange indicator. An average of 31.4 mL of HCl was required.



Calculate the concentration of the diluted ammonia solution, and hence the percentage of ammonia in the household solution.

Each chapter ends with about 2 pages of exam-style questions.

Additional questions

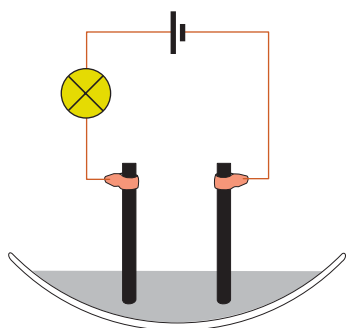
1 Copy and complete this chart about the states of matter:

Property	Solid	Liquid	Gas
Compressibility	very low		
Fixed volume?			takes volume of container
Diffusion of particles			
Strength of forces between particles			
Space between particles			

2 Describe experiments which demonstrate that:

- particles move more rapidly at higher temperatures
- liquids diffuse readily
- there are gaps between the particles in a liquid.

3



When the watch glass contains solid sodium chloride, the bulb does not light. When the sodium chloride is dissolved in water or molten, the bulb does light. Why?

4 You are given two white solids, and told that one is sugar and the other is common salt. Describe two simple tests that you could carry out in the laboratory to distinguish them. (You are not permitted to taste the solids!)

5 Copy and complete the following table:

Substance	State at 20 °C	Conducts electricity?	Charge carriers	Crystal type
Magnesium	solid	yes	electrons	metallic
Carbon dioxide				
Lead bromide				
Graphite				

6 Use the information provided in the table to answer the following questions.

Element	Melting point (°C)	Conducts electricity when solid?
A	-189	no
B	-7.2	no
C	28.4	yes
D	2300	no
E	1083	yes

- Which two elements are metals?
 - Which element has a macromolecular structure?
 - Which element could be a noble gas?
 - Which element is likely to be liquid at room temperature (20 °C)?
- 7 Decide the structure of these substances:
- Solid A melts at 839 °C and conducts electricity in the solid and molten phases.
 - Solid B melts at 44 °C and does not conduct electricity when solid or molten.

If you really want to know... boxes provide extension material for able students.

If you really want to know...

The reality is not quite as simple as the model on page 197 suggests, because a double bond is not really a pair of single bonds—just as a double bed is different from two single beds. So, in an addition reaction the double bond is broken and three single bonds are made to replace it. The energy released in bond formation is greater than that required to break the double bond, so addition reactions are energetically favourable.



13

Bromine water is immediately decolourised when added to pentene.

Demonstrations introduce important reactions.

Halogenation: adding a halogen

Halogens—especially chlorine and bromine—can be added across the double bond to form haloalkanes. The reaction:

- is fast—the test tube reaction appears to be instantaneous
- does not require the presence of light (which substitution of alkanes does)
- forms only one product (not two, as in the case of the reaction between alkanes and halogens)
- does not form a large number of different organic products, since addition only occurs where there is a double bond
- can be used to indicate the presence of a double bond, or the degree of unsaturation of compounds such as vegetable oils.

Demonstration

Cyclohexene and bromine water



Organic layer

Cyclohexene is added to bromine water.



Organic layer

As soon as the liquids are mixed, the bromine is decolourised, showing that it has reacted.

Application

Iodine value

Fat or oil	Iodine value
Coconut oil	8–10
Butter	26–45
Lard	46–66
Olive oil	79–90
Peanut oil	83–98
Sunflower oil	129–132
Linseed oil	170–204

Most naturally occurring vegetable oils are **polyunsaturated** (contain many double bonds). Peanut, olive and sunflower oils all contain mixtures of compounds which vary according to the particular plants which produced them, the climate and the soil conditions. While two samples of olive oil will be very similar, they are unlikely to be identical. As the oil deteriorates with age, some of the double bonds break as oxygen is added across them.

The iodine value of an oil is defined as the number of grams of iodine that react with 100 g of the oil. It gives an indication of the number of double bonds in the oil. Chemists doing quality-control tests on imported oils do a simple titration, calculate the iodine value of the sample, and then compare it with the acceptable range for that particular oil.

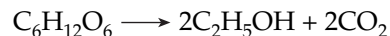


The ethanol in these solutions was made by the fermentation of a variety of carbohydrates.

Great moments tell stories of Kiwis breaking new ground in chemistry.

14

The final reaction is:

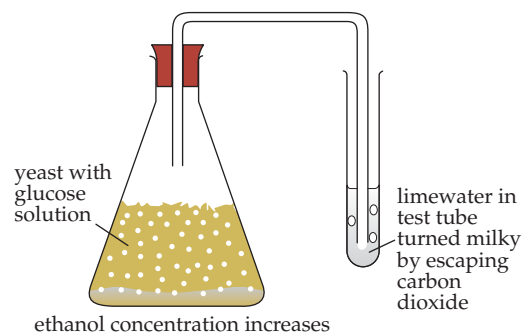


In New Zealand we produce ethanol in award-winning wines or beers, but we also export industrial ethanol made by the fermentation of lactose (milk sugar, see below).

Demonstration

Fermentation of glucose

The fermentation of glucose is relatively simple to demonstrate in the school laboratory, as shown above. After several days, the ethanol produced can be distilled off. To confirm that ethanol has been produced, ignite the distillate.



Great Moments in New Zealand Chemistry

Establishment of the Anchor Ethanol factory at Reporoa

Milk is a complex mixture of fats, protein, lactose ('milk sugar') and minerals. In the 1970s the Anchor dairy factory at Reporoa (about 50 km south of Rotorua) manufactured protein products from skimmed milk. After extracting the protein, the whey (containing about 4% lactose and minerals) was used to irrigate farmland. In 1978, the company's chemists wondered whether they could do anything with the lactose.

They didn't have a market for lactose itself, or for a polymer that could be made from lactose. There was a market in New Zealand for ethanol though, and there were people in Ireland and Denmark who had found a way to convert the lactose in whey into ethanol.

The NZ Dairy Group had contacts with the Irish factory already, and whey technologist Mike Howell made 'home brew' and knew something about fermentation.

In consultation with scientists from Carbery (Ireland), Mike supervised the construction and establishment of the ethanol plant which began production



The copper condenser at Reporoa.

in 1980. By paying a royalty to the Carbery plant, Anchor was able to set up their Reporoa factory quickly, without having to repeat Carbery's initial research and development.

Today, Fonterra, the successor

company, has three separate ethanol plants, producing about 15 million litres of ethanol per year, over half of which is exported. New Zealand customers say that it is cheaper than any other option, and they praise the quality. A

few keen chemists in a factory in Reporoa in 1978 were instrumental in turning an unwanted waste product into a million dollar export industry.

The company now produces seven different types of ethanol for uses ranging from the production of gin and vodka to the manufacture of cooking sauces, inks and hairsprays. New markets have been secured recently in Japan, Singapore, Sri Lanka, Tahiti and Dubai.

Mike Howell



Mike liked Chemistry at school, but was no great scholar. While he began a university degree, he soon dropped out and went to work as a technician at the Dairy Company. There he discovered, somewhat to

his dismay, that he was expected to carry on learning! After several years he completed his New Zealand Certificate of Science in Chemistry, and then decided to finish his BSc as well. By 1979 Mike had spent 8 years in the laboratories of the Dairy Company, so, although he was still a young man, he was well trained in the chemistry of whey when he went to Ireland and then took charge of the New Zealand factory.

Mike is fascinated by chemistry and the way it can explain what happens in the world. Although he has spent many years in the same industry, he still says he 'learns something new every day'. He is proud of the ethanol plants he helped establish at Reporoa and Tirau, and is continuing to find new ways to sell other components of whey.

The biographies show students that you don't have to be a top scholar to succeed.

Production of methanol

Methanol was originally called wood alcohol, because it was obtained by the destructive distillation of wood. Hardwoods such as beech or birch were heated in the absence of air. The vapour produced contained a mixture of organic compounds, from which methanol could be extracted by fractional distillation.

Today methanol is produced from methane gas and steam. It is one of the top 25 chemicals (ranked according to chemical sales in billions of dollars) used in the industrial world.



During World War II, imports of chemicals to New Zealand were severely restricted. A small factory on Kawau Island produced charcoal, methanol and acetone from manuka. This photograph shows logs about to enter the kiln.

Practical Investigations summarise key student practicals.

Practical Investigation $\text{NO}_2/\text{N}_2\text{O}_4$ equilibrium

The brown gas produced when copper reacts with nitric acid is nitrogen dioxide, NO_2 . It exists in equilibrium with a colourless gas, the dimer dinitrogen tetroxide, N_2O_4 .

- Write the equilibrium reaction for the $\text{NO}_2/\text{N}_2\text{O}_4$ system.



- Prepare the mixture of gases by placing 1 or 2 copper granules in a boiling tube and adding 5–10 mL of concentrated nitric acid. Half-fill a large syringe with the brown gas and seal it.

Response to pressure changes

- Double the pressure of the gas by pushing in the plunger until the volume has halved. What happens to the colour of the gas?

The colour fades.

- Halve the original pressure by pulling out the plunger to the maximum volume. What happens to the colour of the gas?

The colour gets deeper.

- Complete the following table.

	Colour change	Change in $[\text{NO}_2]$	Change in $[\text{N}_2\text{O}_4]$	Reaction favoured
Pressure increased	Lighter	Decreased	Increased	Forwards
Pressure decreased	Darker	Increased	Decreased	Reverse

- Explain the response to an increase in pressure in terms of the number of particles of gas on each side of the equilibrium reaction.

An increase in pressure favours the forward reaction because there are fewer particles of gas on the right-hand side.

Response to temperature change

- Fill three small test tubes with the brown mixture and stopper them. Place one in a beaker of ice-water, the second in boiling water and leave the third as a control. Complete the following table:

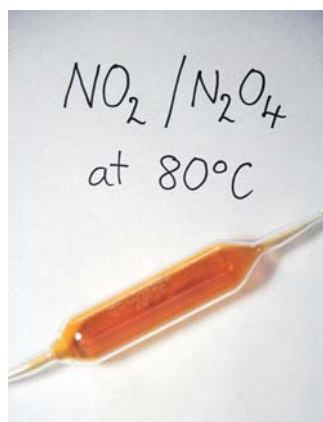
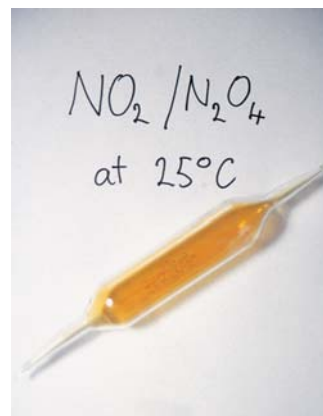
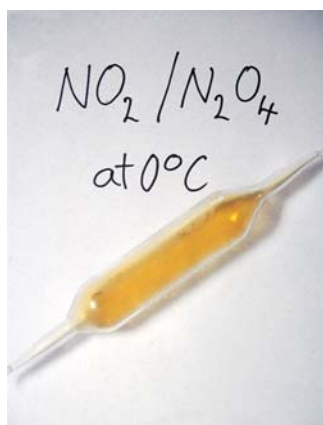
	Colour change	Change in $[\text{NO}_2]$	Change in $[\text{N}_2\text{O}_4]$	Reaction favoured
Temperature increased	Darker	Increased	Decreased	Reverse
Temperature decreased	Lighter	Decreased	Increased	Forwards

- Is the conversion from NO_2 to N_2O_4 endothermic or exothermic?

Exothermic

- Why?

Increasing the temperature favoured the reverse reaction, therefore the forwards reaction produces heat—it is exothermic.



A, M, E grades on all questions help students to learn what is required for full marks from each question.

- 5 a $\text{Ba}^{2+}(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) \rightarrow \text{BaSO}_4(\text{s})$
 b $\text{CO}_3^{2-}(\text{aq}) + \text{Zn}^{2+}(\text{aq}) \rightarrow \text{ZnCO}_3(\text{s})$
 c $\text{Fe}^{3+}(\text{aq}) + 3\text{OH}^{-}(\text{aq}) \rightarrow \text{Fe}(\text{OH})_3(\text{s})$
 d $\text{Ag}^{+}(\text{aq}) + \text{Cl}^{-}(\text{aq}) \rightarrow \text{AgCl}(\text{s})$
M = 3 of 4
- 6 a A pale blue precipitate. **A**
 b $\text{Cu}^{2+}(\text{aq}) + 2\text{OH}^{-}(\text{aq}) \rightarrow \text{Cu}(\text{OH})_2(\text{s})$ **M**
 c The pale blue precipitate dissolves to form a clear, royal blue solution. **A**
 d $\text{Cu}(\text{OH})_2(\text{s}) + 4\text{NH}_3(\text{aq}) \rightarrow [\text{Cu}(\text{NH}_3)_4]^{2+}(\text{aq}) + 2\text{OH}^{-}(\text{aq})$ **E**
- 7 a A milky-coffee brown precipitate forms. **A**
 b The precipitate dissolves, forming a clear, colourless solution. **A**
 c $\text{Ag}(\text{aq}) + 2\text{NH}_3(\text{aq}) \rightarrow [\text{Ag}(\text{NH}_3)_2]^{+}(\text{aq})$
 or $\text{AgCl}(\text{s}) + 2\text{NH}_3(\text{aq}) \rightarrow [\text{Ag}(\text{NH}_3)_2]^{+}(\text{aq}) + \text{Cl}^{-}(\text{aq})$ **E**
- 8 a Add sodium hydroxide solution and warm, test any gas coming off with red litmus paper. No reaction with sodium sulfate, but ammonium sulfate will produce a pungent gas which turns the litmus paper blue.
 $\text{NH}_4^{+}(\text{aq}) + \text{OH}^{-}(\text{aq}) \rightarrow \text{NH}_3(\text{g}) + \text{H}_2\text{O}(\text{l})$
 b Add sodium hydroxide solution. The iron(II) solution forms a green precipitate while the iron(III) solution forms an orange/brown precipitate.
 $\text{Fe}^{2+}(\text{aq}) + 2\text{OH}^{-}(\text{aq}) \rightarrow \text{Fe}(\text{OH})_2(\text{s})$
 $\text{Fe}^{3+}(\text{aq}) + 3\text{OH}^{-}(\text{aq}) \rightarrow \text{Fe}(\text{OH})_3(\text{s})$
 c Add sodium hydroxide solution. The sodium chloride does not react, but the magnesium chloride forms a white precipitate.
 $\text{Mg}^{2+}(\text{aq}) + 2\text{OH}^{-}(\text{aq}) \rightarrow \text{Mg}(\text{OH})_2(\text{s})$
 d Add water. Zinc carbonate is insoluble while sodium carbonate dissolves.
 OR
 Do a flame test: the sodium carbonate will turn a flame yellow, while the zinc carbonate will not change the flame colour. **A** = 3 of 4 methods, **M** = 3 of 4 ionic equations
- 9 a iodide **A**
 b $\text{Ag}^{+}(\text{aq}) + \text{I}^{-}(\text{aq}) \rightarrow \text{AgI}(\text{s})$ **M**
 c Add lead nitrate solution to the original solution: a bright yellow precipitate will be formed. **A**
- 10 a sodium sulfate
 b aluminium oxide and sodium chloride
A = one, **M** = both
 c sodium nitrate **A**
 d $\text{Ba}^{2+}(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) \rightarrow \text{BaSO}_4(\text{s})$ **M**
- 11 (Many solutions are possible.) The blue solution is copper sulfate, and the orange solution is iron(III) chloride. Add a drop of the orange solution to each of the four colourless solutions. The one that forms a precipitate is silver nitrate.
 Add a drop of the blue solution to fresh samples of each of the other colourless solutions. Two will form blue precipitates, and the third is hydrochloric acid.
 Add a drop of the hydrochloric acid to the blue precipitates from step 2. One will fizz: it originally contained sodium carbonate. The final solution (which does not fizz with acid) originally contained sodium hydroxide. **A** = steps to ID 2 compounds, **M** = a method that will work, **E** = complete method with all obs
- 12 Test 1: add ammonia solution. If copper is present you will see a pale blue precipitate which redissolves with excess ammonia to form a royal blue solution.
 Test 2: hold a little of the fungicide in a blue Bunsen flame. If copper is present the flame will turn green. **A** = one test
- 13 a Calcium carbonate is insoluble in water but a flame test can be done by taking a wooden splint that has soaked in distilled water for a few minutes, dipping it into the powder, and holding the powder-coated splint in a blue Bunsen flame. A brick-red colour will confirm that calcium ions are present. **A**
 b Add a pinch of the powder to a few mL of hydrochloric acid. If carbonate ions are present the powder will fizz, producing carbon dioxide gas (which could be tested for using limewater). **A**
- 14 a barium and copper **A**
 b barium: most copper compounds are coloured (green or blue). **A**
 c Dissolve a little of the white powder in distilled water and add 1 mL of nitric acid followed by a few drops of barium nitrate solution. If barium ions are present a white precipitate will form. **A**
 $\text{Ba}^{2+}(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) \rightarrow \text{BaSO}_4(\text{s})$ **M**

Chapter 5 The mole

Now try this 5.1

$$\begin{aligned} M_r(\text{H}_2) &= [2 \times A_r(\text{H})] \\ &= 2 \times 1 \\ &= 2 \end{aligned} \quad \mathbf{A}$$

$$\begin{aligned} M_r(\text{CO}_2) &= [A_r(\text{C}) + 2 \times A_r(\text{O})] \\ &= 12 + (2 \times 16) \\ &= 44 \end{aligned} \quad \mathbf{A}$$

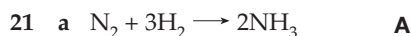
Test yourself 5A Relative masses

- 1 One gram of H_2 contains more molecules than one gram of Cl_2 . **A**
- 2 The number of particles of gas in each balloon is the same. **A**
- 3 A_r = relative atomic mass, M_r = relative molar mass. **A**
- 4 The relative atomic mass of an element is a ratio, it is relative to the carbon-12 atom whose mass is defined as 12.000. Mass number gives the number of protons and neutrons present in the nucleus of a particular isotope of an element. **A** = partial, **M** = complete
- 5 They are comparisons or ratios of masses, not actual masses. **A**
- 6 They are weighted averages of the masses of many isotopes (like an average of 2.4 children in NZ families). **A**
- 7 a $M_r(\text{N}_2) = [2 \times A_r(\text{N})]$
 $= 2 \times 14$
 $= 28$
 b $M_r(\text{HCl}) = [A_r(\text{H}) + A_r(\text{Cl})]$
 $= 1 + 35.5$
 $= 36.5$

All calculations are fully-worked, modelling correct setting out for every problem.

$$\begin{aligned} \text{c} \quad \frac{n(\text{KClO}_2)}{n(\text{O}_2)} &= \frac{2}{3} \\ n(\text{KClO}_2) &= \frac{2 \times n(\text{O}_2)}{3} \\ &= \frac{2 \times 1.25 \text{ mol}}{3} \\ &= 0.833 \text{ mol} \quad \mathbf{A} \end{aligned}$$

$$\begin{aligned} \text{d} \quad m(\text{KClO}_2) &= nM \\ &= 0.833 \text{ mol} \times 122.5 \text{ g mol}^{-1} \\ &= 102 \text{ g} \quad \mathbf{A} \end{aligned}$$



$$\begin{aligned} \text{b} \quad \frac{n(\text{H}_2)}{n(\text{NH}_3)} &= \frac{3}{2} \\ n(\text{H}_2) &= \frac{3 \times n(\text{NH}_3)}{2} \quad \mathbf{A} \end{aligned}$$

1.5 mol of H_2 are required for each mol of NH_3 .

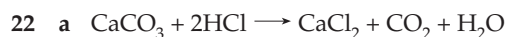
$$\begin{aligned} \text{c} \quad \frac{n(\text{N}_2)}{n(\text{NH}_3)} &= \frac{1}{2} \\ n(\text{N}_2) &= \frac{n(\text{NH}_3)}{2} \\ &= 0.5 \text{ mol} \quad \mathbf{A} \\ n(\text{N}_2) &= nM \\ &= 0.5 \text{ mol} \times 14 \text{ g mol}^{-1} \\ &= 7.0 \text{ g} \quad \mathbf{M} \end{aligned}$$

$$\begin{aligned} \text{d} \quad m(\text{H}_2) &= 1000 \text{ kg} = 1.000 \times 10^6 \text{ g} \\ n(\text{H}_2) &= \frac{m}{M} \\ &= \frac{1.000 \times 10^6}{2.0 \text{ g mol}^{-1}} \\ &= 5.00 \times 10^5 \text{ mol} \quad \mathbf{A} \\ \frac{n(\text{NH}_3)}{n(\text{H}_2)} &= \frac{2}{3} \\ n(\text{NH}_3) &= \frac{2 \times n(\text{H}_2)}{3} \\ &= \frac{2 \times 5.00 \times 10^5 \text{ mol}}{3} \\ &= 3.33 \times 10^5 \text{ mol} \\ m(\text{NH}_3) &= nM \\ &= 3.33 \times 10^5 \text{ mol} \times 17 \text{ g mol}^{-1} \\ &= 5.67 \times 10^6 \text{ g or } 5.67 \text{ tonne} \end{aligned}$$

M = with error, **E** = correct with units + 3 sig figs

$$\begin{aligned} \text{e} \quad 2\text{NH}_3 + \text{H}_2\text{SO}_4 &\rightarrow (\text{NH}_4)_2\text{SO}_4 \quad \mathbf{A} \\ \text{f} \quad m((\text{NH}_4)_2\text{SO}_4) &= 198 \text{ tonnes} \\ &= 198 \times 10^6 \text{ g} \\ M((\text{NH}_4)_2\text{SO}_4) &= 132 \text{ g mol}^{-1} \\ n((\text{NH}_4)_2\text{SO}_4) &= \frac{m}{M} \\ &= \frac{198 \times 10^6 \text{ g}}{132 \text{ g mol}^{-1}} \\ &= 1.50 \times 10^6 \text{ mol} \quad \mathbf{A} \\ \frac{n(\text{NH}_3)}{n((\text{NH}_4)_2\text{SO}_4)} &= \frac{2}{1} \\ n(\text{NH}_3) &= 2 \times n((\text{NH}_4)_2\text{SO}_4) \\ &= 2 \times 1.50 \times 10^6 \text{ mol} \\ &= 3.00 \times 10^6 \text{ mol} \\ m(\text{NH}_3) &= nM \\ &= 3.00 \times 10^6 \text{ mol} \times 17 \text{ g mol}^{-1} \\ &= 5.10 \times 10^7 \text{ g or } 51.0 \text{ tonnes} \end{aligned}$$

M = with error, **E** = fully correct



$$\begin{aligned} \text{b} \quad m(\text{CaCO}_3) &= m(\text{limestone}) \times 75\% \\ &= 4.0 \text{ g} \times 75\% \\ &= 3.0 \text{ g} \quad \mathbf{A} \end{aligned}$$

$$\begin{aligned} \text{c} \quad n(\text{CaCO}_3) &= \frac{m}{M} \\ &= \frac{3.0 \text{ g}}{100 \text{ g mol}^{-1}} \\ &= 0.030 \text{ mol} \quad \mathbf{A} \end{aligned}$$

$$\begin{aligned} \text{d} \quad n(\text{CO}_2) &= n(\text{CaCO}_3) \\ &= 0.030 \text{ mol} \quad \mathbf{A} \end{aligned}$$

$$\begin{aligned} \text{e} \quad m(\text{CO}_2) &= nM \\ &= 0.030 \text{ mol} \times 44 \text{ g mol}^{-1} \\ &= 1.32 \text{ g} \quad \mathbf{A} \end{aligned}$$



Per day, $\hat{V}(\text{H}_2\text{O}) = 2.4 \text{ L}$

$$m(\text{H}_2\text{O}) = 2.4 \text{ kg or } 2400 \text{ g}$$

For 10 days we need to absorb $10 \times 2400 \text{ g}$ of water which is 24 000 g.

$$\begin{aligned} n(\text{H}_2\text{O}) &= \frac{m}{M} \\ &= \frac{24\,000 \text{ g}}{18 \text{ g mol}^{-1}} \\ &= 1333 \text{ mol} \quad \mathbf{A} \end{aligned}$$

$$n(\text{Li}_2\text{O}) = n(\text{H}_2\text{O})$$

$$= 1333 \text{ mol}$$

$$m(\text{Li}_2\text{O}) = nM$$

$$= 1333 \text{ mol} \times 30 \text{ g mol}^{-1}$$

$$= 40 \times 10^3 \text{ g or } 40 \text{ kg} \quad \mathbf{M}$$