KNOWLEDGE

ST MARY'S SCIENCE DEPARTMENT:
CHEMISTRY

A LEVEL CHEMISTRY

BRIDGING COURSE

WEEK 3

AMOUNT OF SUBSTANCE [MOLAR CALCS.]

NAME	
CHEMISTRY CLASS	

VERSION 1.2

THIS MUST BE BROUGHT TO CHEMISTRY LESSONS AT THE START OF YEAR 12.

WEEK 1
Contents
2.1 Atoms and Isotopes
2.2 Ions

This bridging course will provide you with a mixture of information about A-level Chemistry's fundamental topics, and what to expect from the course, as well as key work to complete.

Students who are expecting to study Chemistry at A-level, and are likely to meet the entry requirements, must complete the bridging course fully and thoroughly, to the best of their ability. You should complete all work on paper and keep it in a file, in an ordered way. You will submit it to your teacher in September.

All of the work will be reviewed, and selected work will be formally assessed, and you will be given feedback on it. This work will be signalled to you. If you do not have access to the internet, please contact the school and appropriate resources will be sent to you.

If you are thinking about studying Chemistry at A-level you should attempt this work to see whether or not you think studying a subject like this is right for you. If you later decide to study Chemistry, you must ensure you complete this work in full. This work should be completed after you have read and completed the Study Skills work that all of Year 12 should complete.

Course outline

Assessment overview of A – level Chemistry

Content is in six modules:

Module 1 – Development of practical skills in chemistry
Module 2 – Foundations in chemistry
Module 3 – Periodic table and energy
Module 4 – Core organic chemistry
Module 5 – Physical chemistry and transition elements
Module 6 – Organic chemistry and analysis

Component	Marks	Duration	Weighting	
Periodic table, elements and physical chemistry (01)	**100**	2 hour 15 mins	37%	Assesses content from modules 1, 2, 3 and 5
Synthesis and analytical techniques (02)	**100**	2 hour 15 mins	37%	Assesses content from modules 1, 2, 4 and 6
Unified chemistry (03)	**70**	1 hour 30 minute	26%	Assesses content from all modules (1 to 6)
Practical endorsement in chemistry (04)	**-**	-	-	Non-exam assessment

All components include synoptic assessment.

Students must complete all components (01, 02, 03, and 04) to be awarded the OCR A Level in Chemistry A.

The course in Year 12 will follow Scheme of Work as set out below (this leads onto Y13 work):

Assessment overview Y12 Chemistry

Content is in four modules:

Module 1 – Development of practical skills in chemistry
Module 2 – Foundations in chemistry
Module 3 – Periodic table and energy
Module 4 – Core organic chemistry

Component	Marks	Duration	Weighting	
Breadth in chemistry (01)	70	1 hour 30 mins	50%	Assesses content from all four modules
Depth in chemistry (02)	70	1 hour 30 mins	50%	Assesses content from all four modules

Both components include synoptic assessment.

Students will complete the TWO exam papers in Chemistry at the end of Year 12 as a **MOCK EXAM** to gauge the students' progress in their first year of study.

Content overview

The four modules are each divided into key topics:

Module 1: Development of practical skills in chemistry

Practical skills assessed in a written examination

Module 2: Foundations in chemistry

Atoms, compounds, molecules and equations
Amount of substance
Acid–base and redox reactions
Electrons, bonding and structure

Module 3: Periodic table and energy

The periodic table and periodicity
Group 2 and the halogens
Qualitative analysis
Enthalpy changes
Reaction rates and equilibrium (qualitative)

Module 4: Core organic chemistry

Basic concepts
Hydrocarbons
Alcohols and haloalkanes
Organic synthesis
Analytical techniques (IR and MS)

Practical activities are embedded throughout the course to encourage practical activities in the laboratory, enhancing students' understanding of chemical theory and practical skills.

Aim

In this bridging course, we will outline the basic principles of key topics covered in Year 12 Chemistry.

In each topic, we will start by reviewing the understanding which you gained in GCSE Chemistry and apply it to more advanced applications found in A-Level Chemistry.

This is not a comprehensive overview of the A-Level Chemistry specification, rather a taster on what is covered throughout the course.

Important

Please remember to look after your own wellbeing as you work through this bridging course.

Please take regular breaks as you go through this work.

This work should take approximately 5 hours, so should not be completed in one sitting. Do not worry if you cannot complete all of the exercise's set. Use them, with the appropriate mark scheme provided, to judge how well you understand a topic

WEEK 3: AMOUNT OF SUBSTANCE [MOLAR CALCULATIONS]

Instructions

The content that will be covered in this part of the course is mainly an extension of GCSE Chemistry Quantitative Chemistry work related to Topic 3 from the GCSE course.

There will be 1x PowerPoint booklet (see below) which will take you through Amount of substances [molar calculations]. **COMPLETE THE POWERPOINT WORK BOOK BEFORE THE STUDY GUIDE WHICH FOLLOWS THE INSTRUCTIONS.** There will be questions as you go that I suggest you complete (remember complete as required to aid in your understanding of the topic and file them to aid in your when we resume our studies in school) which are in the text, here the mark schemes will be supplied within the PowerPoints.

At the end of the Amount of Substance booklet (or PowerPoint) it directs you to answer some further **practice examination questions**

Attempt these questions after you have also completed this study guide and the PowerPoint.

THESE WILL BE REQUIRED TO BE HANDED IN UPON YOUR RETURN TO SCHOOL FOR FORMAL MARKING.

Power Points [should be attached or available for download]

- Combined Ppt's 3.1 + 3.2 + 3.3 + 3.4 Ch 3 Amount of Substance [remember there are suggested exercises to aid your understanding in these PowerPoints]

This information is also found in the attached PowerPoints in the form of directed questions.

The formally assessed questions are highlighted clearly in the appropriate PowerPoint.

RE-CAP IONIC AND COVALENT BONDING FROM WEEK 2

Complete the following questions to help re-cap the chemical content from last week's Bridging Course:

1 Information about two isotopes of an element is given in the table.

Isotope	Mass number	% Abundance
A	144	24
B	145	9

Which statement is correct?

A The relative atomic mass of the element is 47.61.

B Isotope B has more protons than isotope A.

C Isotope B has fewer neutrons than isotope A.

D The relative isotopic mass of isotope B is 145.

Your answer ☐

[1]

23 Europium, atomic number 63, has two isotopes, ^{151}Eu and ^{153}Eu.

(a) Complete the table to show the number of protons, neutrons and electrons in the $^{153}Eu^{3+}$ ion of europium.

	protons	neutrons	electrons
$^{153}Eu^{3+}$			

[1]

Q2.

(b) In an experiment, a scientist prepared a 0.500 g sample of a salt made by neutralisation.

Analysis of the sample gave the following data.

Element	Mass present / g
hydrogen	0.025
oxygen	0.300
nitrogen	0.175

(i) Calculate the empirical formula of the salt.

empirical formula = ... **[2]**

ANSWERS

Q1 D

Question			Answer	Marks	Guidance
23	(a)		63 p 90 n 60 e ✓	1	

Q25

	(b)	(i)	*Amount of each element mark* H: $\frac{0.025}{1.0}$ O: $\frac{0.300}{16.0}$ N: $\frac{0.175}{14.0}$ = 0.025 0.01875 0.0125 ✓ *Simplest whole number ratio empirical formula* $\frac{0.025}{0.0125} = 2$ $\frac{0.01875}{0.0125} = 1.5$ $\frac{0.0125}{0.0125} = 1$ AND $H_4O_3N_2$ ✓	2	ALLOW 2 marks for correct answer without working

Introduction

When you carry out chemical reactions you use known quantities of the reacting substances by measuring out their mass or volume. Chemists need a way of using these measurements to calculate the number or ratio of atoms, molecules, or ions that react together.

In this chapter you will see how the concept of the mole allows chemists to do this. You will develop your skills in using mass, volume, and concentration to find the number of moles of particles involved in chemical reactions.

The sodium chloride crystal in the photo probably contains around 10^{22} ions in total. What can you say about the number of Na^+ ions and Cl^- ions in the crystal?

Prior Knowledge

From Chapter 2 of the student book, you should have a good understanding of:

The meaning of relative atomic mass

How to find relative atomic mass values from the periodic table

The meaning of chemical formulae

How to use ionic charges to write the formulae of ionic compounds

How to write balanced chemical equations.

In addition, it will be helpful if you are comfortable with the following skills from your

Key Stage 4 studies:

Calculating relative formula masses

Using balanced chemical equations to calculate the masses of reactants and products in a chemical reaction.

3.1 Amount of Substance and the Mole – Introduction

When chemists talk about the amount of a substance, they mean the number of particles of that substance, measured in terms of moles. A mole is simply an amount of substance that contains a fixed number of particles. There is a precise definition that tells you exactly what this fixed number of particles is.

There are also other definitions and related terms, such as 'molar mass'. Knowing the mass and molar mass of a substance, you can easily calculate the amount of it.

Each of the watch glasses shown in the picture contains one mole of an element. Will the mass of each element be the same or different? Explain your answer.

3.1 Amount of Substance and The Mole – The Mole

Explain the terms:

- **amount of substance**
- **mole**
- **Avogadro constant**
- **molar mass.**

You need to know and understand what these terms mean. Some of these definitions – for example the one for the Avogadro constant – need to be very carefully worded, and some have particular units that you need to learn and mention whenever you use the term. Look at the student book pages 20 and 21 to find the definitions and units. You can revise the mole with BBC Bitesize revision – the mole.

Why does the Avogadro constant (6.02×10^{23} mol^{-1}) have units mol^{-1}?

3.1 Amount of Substance and the Mole

– Calculating Amounts of Substance from Mass

Calculate amounts of substance from mass data.

If you are given the mass of a substance you need to be able to calculate the equivalent number of moles. '3.1 Maths skills: Moles' shows you how to calculate the number of moles of a compound in a given mass and gives you some practice.

Using the Avogadro constant, you can calculate the actual number of particles present. The worksheet '3.1 Calculation sheet: The Avogadro constant' helps you practise.

In any calculation of the amount of substance from mass data, you will need to think about an appropriate number of significant figures to use in your answer. The worksheet '3 Calculation sheet: Standard form and significant figures' explains how to do this.

The molar mass of germanium is 72.6 g mol^{-1}. Use the equation shown below to calculate the amount of germanium, in moles, present in 0.156 g of the element. Give your answer in standard form and to 3 significant figures.

$$\text{amount, } n \text{ (mol)} = \frac{\text{mass, } m \text{ (g)}}{\text{molar mass, } M \text{ (g mol}^{-1}\text{)}}$$

3.1 Amount of Substance and the Mole – More Calculations Involving Mass

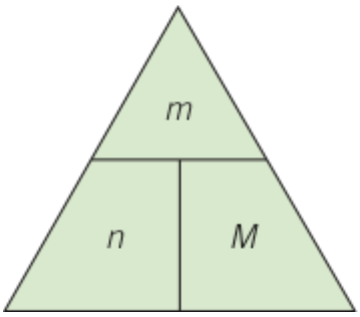
Use ideas about amounts of substance to solve problems involving masses.

On the previous screen, you recalled how to calculate the amount of a substance from mass data, using the equation

$$\text{amount, } n \text{ (mol)} = \frac{\text{mass, } m \text{ (g)}}{\text{molar mass, } M \text{ (g mol}^{-1}\text{)}}$$

You are also expected to be able to rearrange this equation to work out the mass of a certain amount of substance (given its molar mass) or even the molar mass of a substance (given the amount and the mass).

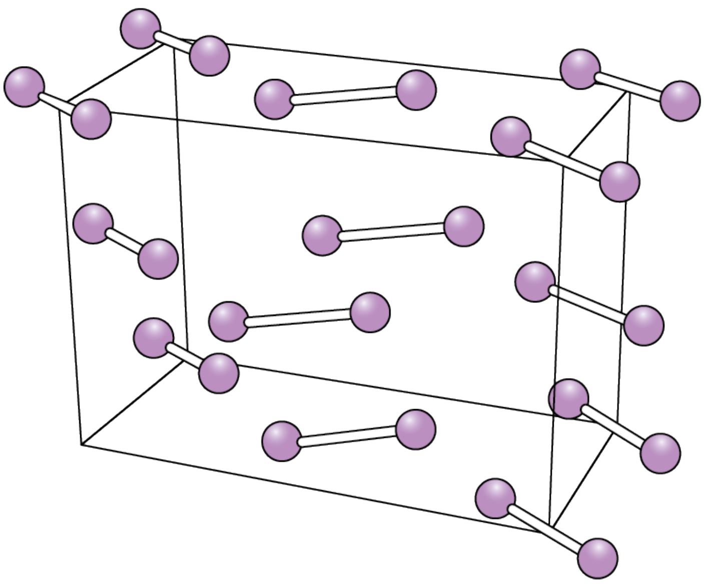
Some students like to use a triangle method for rearranging equations. Use the triangle opposite (or any other method you prefer) to write down an equation to enable you to calculate the molar mass M of a substance.

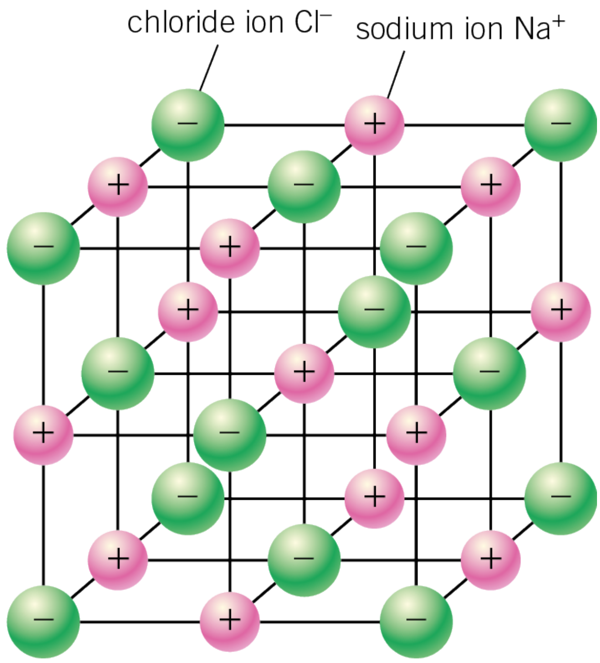


3.2 Determination of Formulae – Introduction

In this topic, you will see how to extrapolate ideas about the amount of reacting substances to the amounts of molecules and ionic compounds formed in a reaction. The ideas of molecular formula, empirical formula, and relative formula mass are introduced to enable you to calculate the amount of product formed. You will see how experimental techniques allow you to calculate empirical and molecular formulae.

The structures of iodine and sodium chloride are shown here. Which of these is made up of molecules?





3.2 Determination of Formulae – Relative Masses of Molecules and Formula Units

Understand the quantities relative formula mass, relative molecular mass, and molar mass.

Describe the difference between molecular formulae and empirical formulae.

To carry out calculations to find the amount of a compound or an element consisting of molecules, you need to use the molar mass of the compound or molecule. If it is not given, you can calculate it if you know the relative molecular mass or the relative formula mass of a substance.

Calculate the relative molecular mass of iron(III) sulfate, whose empirical formula is $Fe_2(SO_4)_3$. Write down the value of the molar mass of this substance with the correct units.

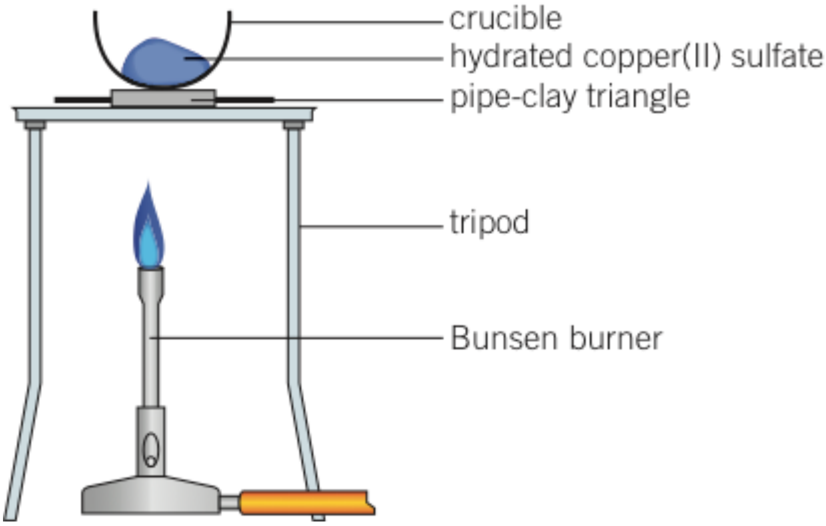
3.2 Determination of Formulae – Calculating Empirical and Molecular Formulae

Calculate empirical and molecular formulae from data on mass or percentage composition, including the formulae of hydrated salts.

Now that you are more confident with moles and formulae, you need to be able to apply these ideas to solve more complex questions.

There are worked examples to show you how to do these on page 23 of the student book. '3.2 Maths skills: Empirical and molecular formulae' and '3.2 Support: Calculating empirical and molecular formulae' gives you practice. You can also do '3.2 Practical: Finding the formula of a product' and '3.2 Follow up: Finding the formula of a product' which involve analysing results from a precipitation reaction.

What happens to the mass of hydrated copper (II) sulfate when it is heated? Explain your answer.



3.3 Moles and volumes – Introduction

Many reactions you carry out in a laboratory involve solutions that react together and, in some cases, produce a gas.

To calculate the amounts of solutions or gases, you need to measure volumes and, in the case of solutions, know the concentration of the solution.

The volume of gases changes when conditions of temperature and pressure are altered, so the Ideal Gas Law is used to link volume to the amount of a gas.

Which of these pieces of glassware might enable you to measure out a volume of solution with the greatest precision?

3.3 Moles and Volumes – Calculations Involving Moles, Concentration, and Volumes

Carry out calculations using amount of substance in moles, involving solution volumes and concentrations.

You will need to be confident with applying the equation that links amount, volume, and concentration, and rearranging it when necessary. '3.3 Maths skills: moles and concentration' gives you practice.

Volumes can be expressed in cm^3 or dm^3, and so you need to be able to convert between the two. '3.3 Calculation sheet: Units and concentration' will help you.

Rearrange the equation below to show how you could calculate a concentration from an amount in moles and a volume in cm^3.

$$\text{amount, } n \text{ (mol)} = \text{concentration, } c \text{ (mol cm}^{-3}\text{)} \times \frac{\text{volume, } V \text{ (cm}^3\text{)}}{1000}$$

3.3 Moles and Volumes – Experiments involving Solutions

Understand the experimental techniques and procedures used to obtain data used in calculations involving amount of substance.

There is a lot of practical work you can do that relates to the calculations in this topic. Such practical work could include '3.3 Practical: Making a standard solution of sodium hydrogen carbonate', '3.3 Practical: Determining the concentration of limewater', and '3.3 Practical: Determining the conc. of HCl using a standard solution of sodium hydrogen carbonate'.

3.3 Moles and Volumes – Amounts of Gas and the Gas Equation

Carry out calculations involving gas volumes and the ideal gas equation.

If you are given the molar gas volume, then you can easily calculate the amount in moles from the following equation:

$$\text{amount, } n \text{ (mol)} = \frac{\text{volume, } v \text{ (dm}^3\text{)}}{\text{molar gas volume, } v_m \text{ (dm}^3 \text{ mol}^{-1}\text{)}}$$

However, you also need to be able to carry out calculations using the ideal gas equation:

$$\text{pressure, } p \text{ (Pa)} \times \text{volume, } V \text{ (m}^3\text{)} = \text{amount, } n \text{ (mol)} \times \text{ideal gas constant, } R \text{ (J mol}^{-1} \text{ K}^{-1}\text{)} \times \text{temperature, } T \text{ (K)}$$

'3.3 Maths skills: Mass of a gas' and '3.3 Maths skills: The ideal gas equation' will help with calculating the mass of gas. '3.4 Stretch and challenge: Gas calculations' gives you more practice in a range of such calculations.

The volume of the helium balloon shown is 0.24 m^3 (240 dm^3). Calculate the density of helium, in kg m^{-3}, at RTP. The molar volume of gas = 24 dm^3.

3.4 Reacting Quantities – Introduction

In this topic the ideas about calculating amounts of substances in moles are applied to balanced chemical equations. This will allow you to calculate reacting masses, volumes, and concentrations. You can then apply this to experimental data to find the percentage yield of a reaction and see how the concept of atom economy helps chemists evaluate the sustainability of a process.

3.4 Reacting Quantities – Using Balanced Equations

Use stoichiometric relationships in calculations.

The stoichiometry of a reaction is the ratio, in moles, of the reacting substances. You can deduce this from the balanced equation.

You can revise ideas about balancing equations using '3.4 Calculation sheet: Balancing equations', while the worksheet '3.4 Calculation sheet: Ratios and amount of substance' gives you practice in using the information from balanced equations to calculate reacting masses. '3.4 Stretch and challenge: Investigating carbon dioxide absorption' provides some more challenging calculations, extending to problems involving gases and solutions.

Magnesium reacts with hydrochloric acid (HCl) to form hydrogen gas and magnesium chloride. Write a balanced chemical equation for this reaction and use it to calculate the volume of hydrogen formed when 1.00 g of magnesium reacts.

3.4 Reacting Quantities – Percentage Yield and Atom Economy

Calculate percentage yield and atom economy of reactions, given suitable data.

Explain the benefits of high atom economy.

You need to be clear about the difference between these two terms. To calculate percentage yield you will need to use stoichiometric ratios in order to calculate reacting masses. '3.4 Calculation sheet: Percentage yield' shows you how to do this. Atom economy can be calculated directly from a balanced equation, without needing any experimental data. '3.4 Calculation sheet: Atom economy' explains how.

'3.4 Application sheet: How does our understanding of chemicals benefit sustainability' puts all these different calculations together and helps you to discuss the benefits of atom economy.

$$\text{percentage yield (\%)} = \frac{\text{actual yield (g)}}{\text{theoretical yield (g)}} \times 100$$

$$\text{atom economy} = \frac{\text{total molar mass of desired product (g mol}^{-1}\text{)}}{\text{total molar mass of all products (g mol}^{-1}\text{)}} \times 100$$

Summary

In this chapter you have been introduced to the vital skills of carrying out calculations concerned with amounts of substance using the concept of moles. These will be used regularly throughout the course, so it is essential to practice them regularly.

You can now check how well you can apply your skills and knowledge from Chapter 3, using the following resources:

3 Amount of substance: Checklist

3.1 STANDARD FORM AND SIGNIFICANT FIGURES

Specification references

- *M0.1 Recognise and use expressions in standard and ordinary form*
- *M0.4 Use calculators to find and use power, exponential and logarithmic functions*
- *M1.1 Use an appropriate number of significant figures*

Learning outcomes

After completing the worksheet you should be able to:

- convert between numbers in standard and ordinary form
- state numbers to a certain degree of accuracy.

Introduction

In the calculations you will be asked to perform as part of your AS studies you will need to be confident with both representing numbers in standard form and giving them to a certain number of significant figures.

When numbers are very large or very small they are written in **standard form**. In standard form a number is written in the format:

$$a \times 10^n \text{ where } 1 \leq a < 10 \text{ and } n \text{ is an integer.}$$

In an experiment, or from a calculation, you may only be able to give your answer with a certain amount of accuracy. This accuracy is shown by giving your answer to a certain number of **significant figures**.

Worked example: Standard form

Question

Express 0.00268 in standard form.

Answer

Step 1

Identify the value for '*a*.' In this case it will be 2.68.

Step 2

Work out how many places the decimal place must be moved to form this number.

0 . 0 0 2 6 8

The decimal place must move 3 places to the right to become 2.68.

This number of places is the value for the integer '*n*.' If the decimal point moves to the right '*n*' is negative. If the decimal place moves to the left '*n*' is positive.

Step 3

Substitute your values into the general format, $a \times 10^n$

Therefore in standard form 0.00268 is 2.68×10^{-3}.

Worked example: Significant figures

Question

Express 0.56480900 to 3 significant figures.

Answer

Step 1

Identify the numbers which are significant using the rules below:

Rule 1 Any number that isn't 0 is significant.

Rule 2 Any 0 that is between two numbers that are not 0 is significant.

Rule 3 Any 0 that is before all the non-zero digits is not significant.

Rule 4 Any 0 that is after all of the non-zero digits is only significant if there is a decimal point.

In this case the significant numbers are 0.**564 809** 00.

Step 2

Identify the three most significant figures. These are the significant numbers which are furthest to the left (have the biggest values), i.e., 0.**564** 809 00.

Step 3

Look at the next number. If this number is 5 or above, then round up. If this number is 4 or less, do not round up.

In this case the next number is 8, so we round up to 0.**565**.

Questions

1 This question is about expressing numbers in standard form.

a Express the following numbers in standard form. (*4 marks*)

i 0.0023

ii 1032

iii 275 000 0

iv 0.000528

b Write out the following numbers in ordinary form. (*4 marks*)

i 2.01×10^3

ii 5.2×10^{-2}

iii 8.41×10^2

iv 1.00×10^{-4}

c For each of the pairs of numbers below identify which is the bigger number. (*3 marks*)

i 1.43×10^{23} or 1.43×10^{24}

ii 5.16×10^{-3} or 5.16×10^{-4}

iii 12.4×10^{23} or 1.50×10^{24}

2 Express the following numbers to the number of significant figures indicated. (*6 marks*)

a 4.74861 to two significant figures

b 507980 to three significant figures

c 809972 to three significant figures

d 06.345 to three significant figures

e 7840 to three significant figures

f 0.007319 to three significant figures

3 Carry out the following calculations expressing the numbers in **standard form** to the degree of accuracy indicated: (*4 marks*)

a $(4.567 \times 10^{5}) \times (2.13 \times 10^{-3})$ to three significant figures

b $(1.567 \times 10^{3}) \div (2.245 \times 10^{-1})$ to four significant figures

c $(5.4 \times 10^{-1}) \div (2.7 \times 10^{-3})$ to one significant figure

d $(2.00 \times 10^{-2}) \times (2.00 \times 10^{-4})$ to three significant figures

ANSWERS

1 **a** **i** 2.3×10^{-3} (*1 mark*)
ii 1.032×10^{3} (*1 mark*)
iii 2.75×10^{6} (*1 mark*)
iv 5.28×10^{-4} (*1 mark*)
b **i** 2010 (*1 mark*)
ii 0.052 (*1 mark*)
iii 841 (*1 mark*)
iv 0.0001 (*1 mark*)
c **i** 1.43×10^{24} (*1 mark*)
ii 5.16×10^{-3} (*1 mark*)
iii 1.50×10^{24} (*1 mark*)

2 **a** 4.7 (*1 mark*)
b 508 000 (*1 mark*)
c 810 000 (*1 mark*)
d 6.35 (*1 mark*)
e 7840 (*1 mark*)
f 0.007 32 (*1 mark*)

3 **a** 9.73×10^{2} (*1 mark*)
b 6.980×10^{3} (*1 mark*)
c 2×10^{2} (*1 mark*)
d 4.00×10^{-6} (*1 mark*)

3.1 THE AVOGADRO CONSTANT

Learning outcomes

After completing the worksheet you should be able to:

- carry out calculations using the Avogadro constant
- carry out calculations using numbers in standard and ordinary form
- substitute numerical values into algebraic equations, and change the subject of equations
- report calculations to an appropriate number of significant figures.

Introduction

One mole of any substance contains the same number of particles as the number of atoms in 12 g of carbon-12. This number of particles is a huge number and is called the *Avogadro constant*. It has a value of 6.02×10^{23} and is given the units of mol^{-1} (per mole).

The relative atomic mass of an element in grams contains 6.02×10^{23} atoms or one mole of that element. The relative formula mass of a compound in grams contains 6.02×10^{23} particles (molecules or ions) or one mole of that compound. Therefore we use the term *molar mass* to describe the relative atomic or formula mass of a substance in grams and give it the unit g mol^{-1}.

To calculate the number of particles in a certain mass of a substance we can use the following equation.

$$\text{Number of particles} = \frac{\text{mass } m \text{ (g)}}{\text{molar mass } M \text{ (g mol}^{-1}\text{)}} \times 6.02 \times 10^{23} (\text{mol}^{-1})$$

Worked example

Question 1

How many molecules are there in 42.5 g of ammonia, NH_3?

Answer

Step 1

Calculate the molar mass of ammonia using the relative atomic masses of nitrogen and hydrogen from the periodic table.

Relative atomic masses: nitrogen 14.0, hydrogen 1.0

$NH_3 = (1 \times N) + (3 \times H) = (1 \times 14.0) + (3 \times 1.0) = 17.0 \text{ g mol}^{-1}$

Note: Remember to give all molar masses to one decimal place.

This means 17.0 g of ammonia contains 1 mol of ammonia or 6.02×10^{23} molecules.

Step 2

Substitute the values into the equation:

$$\text{amount, } n = \frac{42.5 \text{ g}}{17.0 \text{ g mol}^{-1}} \times 6.02 \times 10^{23} \text{ mol}^{-1}$$

$= 1.505 \times 10^{24}$

$= 1.51 \times 10^{24}$ (to 3 significant figures)

Note: You can only give your answer to the same degree of accuracy (significant figures) as the least accurate value used in the calculation. In this case to three significant figures.

Questions

1 **a** Calculate the molar mass of glucose, $C_6H_{12}O_6$. Give your answer to one decimal place. *(1 mark)*

b If the molar mass of glucose weighed out in grams contains 6.02×10^{23} molecules of glucose, calculate the number of molecules in *(3 marks)*

i 90 g of glucose

ii 360 g of glucose

iii 45 g of glucose.

2 Calculate the following:

Give all answers in standard form to the same number of significant figures as used for the information in the question. *(5 marks)*

a the number of atoms in 20.2 g of neon

b the number of atoms in 80.2 g of calcium

c the number of oxygen atoms in 48.0 g of oxygen

d the number of oxygen molecules in 49.6 g of oxygen gas

e the number of ions in 310 g of magnesium ions, Mg^{2}·.

3 Calculate the following:

Give all answers in standard form to the same number of significant figures as used for the information in the question. (*6 marks*)

- **a** the number of atoms of oxygen in 132 g of carbon dioxide, CO_2
- **b** the number of chloride ions in 129.9 g of iron(III) chloride, $FeCl_3$
- **c** the number of hydroxide ions in 198 g of barium hydroxide, $Ba(OH)_2$
- **d** the number of molecules of water in 150 g of hydrated copper sulfate, $CuSO_4{\bullet}5H_2O$
- **e** the number of molecules in 1 cm^3 of water (density of water = 1 g cm^{-3})
- **f** the number of atoms of helium in a balloon with a volume of 5 dm^3 (assume the density of helium to be 0.17 g dm^{-3}).

4 Calculate the mass in grams of the following:

- **a** 10 million atoms of gold (*1 mark*)
- **b** 1 molecule of water. (*1 mark*)

5 From OCR Chemistry A F321/01 Atoms, bonds and groups June 2012 (Question 1)

Solid sulfur exists as a lattice of S_8 molecules. Each S_8 molecule is a ring of eight atoms.

How many atoms of sulfur are there in 0.0210 mol of S_8 molecules? (*2 marks*)

ANSWERS

1 a $180.0\ g\ mol^{-1}$ *(1 mark)*

b i 3.01×10^{23} molecules *(1 mark)*

ii 1.204×10^{23} molecules *(1 mark)*

iii 1.505×10^{23} molecules *(1 mark)*

2 Students are asked to give all answers in standard form and to the same number of significant figures as used for the information in the question.

a $\frac{20.2\ g}{20.2\ g\ mol^{-1}} \times 6.02 \times 10^{23}\ mol^{-1} = 6.02 \times 10^{23}$ *(1 mark)*

b $\frac{80.2\ g}{40.1\ g\ mol^{-1}} \times 6.02 \times 10^{23}\ mol^{-1} = 1.20 \times 10^{24}$ *(1 mark)*

c $\frac{48.0\ g}{16.0\ g\ mol^{-1}} \times 6.02 \times 10^{23}\ mol^{-1} = 1.81 \times 10^{24}$ *(1 mark)*

d $\frac{49.6\ g}{32.0\ g\ mol^{-1}} \times 6.02 \times 10^{23}\ mol^{-1} = 9.33 \times 10^{23}$ *(1 mark)*

e $\frac{310\ g}{24.3\ g\ mol^{-1}} \times 6.02 \times 10^{23}\ mol^{-1} = 7.7 \times 10^{24}$ *(1 mark)*

3 Students are asked to give all answers in standard form and to the same number of significant figures as used for the information in the question

a $\frac{132\ g}{44.0\ g\ mol^{-1}} \times 6.02 \times 10^{23}\ mol^{-1} = 1.81 \times 10^{24}$ molecules of CO_2

$= 3.61 \times 10^{24}$ atoms of oxygen *(1 mark)*

b $\frac{129.9\ g}{162.3\ g\ mol^{-1}} \times 6.02 \times 10^{23}\ mol^{-1} = 4.818 \times 10^{23}$ particles of $FeCl_3$,

$= 1.445 \times 10^{24}$ chloride ions *(1 mark)*

c $\frac{198\ g}{171.3\ g\ mol^{-1}} \times 6.02 \times 10^{23}\ mol^{-1} = 6.96 \times 10^{23}$ particles of $Ba(OH)_2$

$= 1.39 \times 10^{24}$ hydroxide ions *(1 mark)*

d $\frac{150\ g}{249.6\ g\ mol^{-1}} \times 6.02 \times 10^{23}\ mol^{-1} = 3.62 \times 10^{23}$ particles of $CuSO_4{\bullet}5H_2O$,

$= 1.8 \times 10^{24}$ molecules of water *(1 mark)*

e 1 cm^3 of water has a mass of 1 g.

$\frac{1\ g}{18.0\ g\ mol^{-1}} \times 6.02 \times 10^{23}\ mol^{-1} = 3 \times 10^{22}$ molecules of water *(1 mark)*

f 5 dm^3 of helium has a mass of $0.17\ g\ dm^{-3} \times 5\ dm^3 = 0.85\ g$

$\frac{0.85\ g}{4.0\ g\ mol^{-1}} \times 6.02 \times 10^{23}\ mol^{-1} = 1.3 \times 10^{23}$ atoms of helium *(1 mark)*

4 a $(10000000 \times 197.0\ g\ mol^{-1}) \div 6.02 \times 10^{23}\ mol^{-1} = 3.27 \times 10^{-15}\ g$ *(1 mark)*

b $(1 \times 18.0\ g\ mol^{-1}) \div 6.02 \times 10^{23}\ mol^{-1} = 2.99 \times 10^{-23}\ g$ *(1 mark)*

5 From OCR Chemistry A F321/01 Atoms, bonds and groups Mark scheme June 2012 (Question 1)

Number of S_8 molecules in 0.0120 mol = $0.0120\ mol \times (6.02 \times 10^{23}\ mol^{-1})$

$= 7.224 \times 10^{21}$ molecules *(1 mark)*

No. of sulfur atoms = $(7.224 \times 10^{21}) \times 8$

$= 5.78 \times 10^{22}$ atoms *(1 mark)*

2.2 Determining the Formula of a Hydrated Salt

Background

Epsom salt, $MgSO_4{\bullet}7H_2O$, is an example of a *hydrated* salt. It contains *water of crystallisation*, which is responsible for the shape of the crystals.

When a hydrated salt is heated, the water of crystallisation evaporates and you are left with the *anhydrous* salt, which means without water. By recording the mass of the salt before and after heating, you can find out its formula by calculating the number of moles of anhydrous salt and water and then finding out the simplest ratio between them. In this experiment you will heat two hydrated salts and then use your results to determine their formula.

Safety

Wear eye protection.

- Hydrated copper(II) sulfate is HARMFUL
- Hydrated barium chloride is TOXIC

Equipment and materials

- Bunsen burner
- tripod
- pipe-clay triangle
- heatproof mat
- spatula
- tongs
- balance (accurate to at least **two** decimal places)
- crucible
- hydrated barium chloride ($BaCl_2{\bullet}xH_2O$) and hydrated copper(II) sulfate ($CuSO_4{\bullet}xH_2O$)

Method

Record all of your results in your results table to **two** decimal places. Whilst you are waiting for experiment 1 to cool, begin experiment 2.

Experiment 1 – finding the formula of hydrated copper(II) sulfate

1 Set up the equipment as shown in the diagram.

2 Weigh an empty crucible.

3 Add approximately 2 g of hydrated copper(II) sulfate ($CuSO_4•xH_2O$) to the crucible and reweigh.

4 Place the crucible on the pipe-clay triangle and heat *gently* for 1 minute, then *strongly* for 5 minutes.

5 Leave to cool for at least 5 minutes, and reweigh the crucible and its contents.

6 Heat the crucible again, strongly for a further minute, then leave to cool and reweigh.

7 Repeat step **6** until the mass remains constant.

8 Stop heating if a red colouration appears in the white powder.

Experiment 2 – finding the formula of hydrated barium chloride

1 Set up the equipment as shown in the diagram.

2 Weigh an empty crucible.

3 Add approximately 2 g of hydrated barium chloride ($BaCl_2•xH_2O$) to the crucible and reweigh.

4 Place the crucible on the pipe-clay triangle and heat *gently* for 1 minute, then *strongly* for 5 minutes.

5 Leave to cool for at least 5 minutes, and reweigh the crucible and its contents.

6 Heat the crucible again, strongly for a further minute, then leave to cool and reweigh.

7 Repeat step **6** until the mass remains constant.

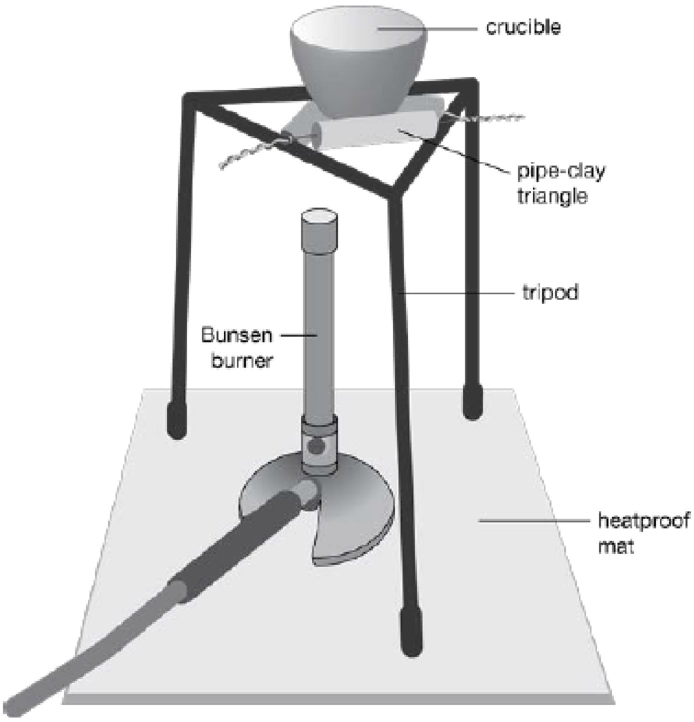


Figure 1 *Experimental set-up*

Results

Construct two results tables, such as Table 1 and Table 2 in which to record your results. Using your *final* mass for the contents of the crucible, calculate the mass of the water lost and the anhydrous salt remaining.

Table 1 *Example results table for experiment 1 – hydrated copper(II) sulfate*

Mass of crucible / g	
Mass of crucible and hydrated salt / g	
Mass of crucible and salt after heating (1) / g	
Mass of crucible and salt after heating (2) / g	
Mass of crucible and salt after heating (3) / g	
Mass of anhydrous salt remaining / g	
Mass of water removed / g	

Table 2 *Example results table for experiment 2 – hydrated barium chloride*

Mass of crucible / g	
Mass of crucible and hydrated salt / g	
Mass of crucible and salt after heating (1) / g	
Mass of crucible and salt after heating (2) / g	
Mass of crucible and salt after heating (3) / g	
Mass of anhydrous salt remaining / g	
Mass of water removed / g	

Questions

Use your data sheet for the atomic mass values.

1 For each experiment:

a Calculate the number of moles of anhydrous salt left after heating. (*2 marks*)

b Calculate the number of moles of water lost during heating. (*2 marks*)

c Deduce the simplest *whole number* ratio of the anhydrous salt : water and hence the formula of the hydrated salt. (*2 marks*)

2 Suggest why it is important to keep heating the salt until the mass remains constant. (*4 marks*)

3 A student decided to see if this was an accurate experiment and tried it using the hydrated salt $CoCl_2{\bullet}6H_2O$. He heated the salt and left it to cool. Here are his results.

Mass of crucible / g	35.64
Mass of crucible and hydrated salt / g	37.84
Mass of hydrated salt / g	2.20
Final mass of crucible and salt after heating / g	36.91
Mass of anhydrous salt remaining / g	
Mass of water removed / g	

a Complete the missing results in the table. (*1 mark*)

b Calculate the formula of the hydrated salt. (*3 marks*)

c Is it close to the real value? If not, suggest a reason why. (*1 mark*)

SAMPLE DATA

If 2 g of hydrated copper sulfate are used: ONLY 1 SET OF RESULTS

Mass of anhydrous salt = 1.28 g

Mass of water = 0.72 g **USE THIS DATA FOR Q1**

FOLLOW UP

Questions

1 Construct the formula of these hydrated salts, showing the water of crystallisation.

a $CoCl_2O_6H_{12}$ (*1 mark*)

b $Na_2CO_{13}H_{20}$ (*1 mark*)

c $AlN_3O_{18}H_{18}$ (*1 mark*)

2 A hydrated salt has the formula $Ca(NO_3)_2{\bullet}xH_2O$ and a molar mass of 236.1 g mol^{-1}.

a State the value of *x*. (*2 marks*)

b Construct an equation to show what happens when this salt is dehydrated. Include state symbols. (*2 marks*)

3 A student heated a sample of hydrated iron(II) sulfate, $FeSO_4{\bullet}xH_2O$. 1.84 g of water was removed and the anhydrous iron(II) sulfate has a mass of 2.22 g.

State the formula of the hydrated salt. (*3 marks*)

4 Another student heated 3.10 g of a sample of hydrated strontium chloride, $SrCl_2{\bullet}xH_2O$. After heating, the mass of the anhydrous salt was 1.80 g. Find the formula of the hydrated salt. (*3 marks*)

5 A hydrated salt of aluminium sulfate, $Al_2(SO_4)_3{\bullet}xH_2O$ contains 48.63 % of water by mass. Find its formula. (*4 marks*)

ANSWERS

Example data

3 marks are available for calculating each formula – see below.

If 2 g of hydrated copper sulfate are used:

Mass of anhydrous salt = 1.28 g

Moles of anhydrous salt = $\frac{1.28}{159.6}$

$= 8.0201 \times 10^{-3}$ (*1 mark*)

Mass of water = 0.72 g

Moles of water = $\frac{0.72}{18}$

$= 0.04$ (*1 mark*)

Divide each number of moles by the smallest number

Ratio of anhydrous salt : water = 1 : 4.99 or 1 : 5 (nearest whole number)

Formula of hydrated salt = $CuSO_4{\cdot}5H_2O$ (*1 mark*)

Answers for method sheet

1 All dependent on results. See above for example data.
For example, depending on values achieved:
$CuSO_4 \bullet 5H_2O(s) \rightarrow CuSO_4(s) + 5H_2O(g)$
$BaCl_2 \bullet 2H_2O(s) \rightarrow BaCl_2(s) + 2H_2O(g)$

2 $CuSO_4 \bullet 5H_2O$; $BaCl_2 \bullet 2H_2O$. To ensure all the water evaporates. *(1 mark)*

3 Here are his results.

Mass of crucible / g	35.64
Mass of crucible and hydrated salt / g	37.84
Mass of hydrated salt / g	2.20
Final mass of crucible and salt after heating / g	36.91
Mass of anhydrous salt remaining / g	1.27
Mass of water removed / g	0.93

a See above *(1 mark)*

b Moles of anhydrous salt = $\frac{1.27}{129.9}$

$= 9.777 \times 10^{-3}$ *(1 mark)*

Moles of water = $\frac{0.93}{18}$

$= 0.051\,67$ *(1 mark)*

Ratio of anhydrous salt : water = 5.28
This is 5 (to the nearest whole number) so formula would be $CoCl_2 \bullet 5H_2O$ *(1 mark)*

c Less than real value – should have been heated for longer as not all the water has evaporated. *(1 mark)*

Answers for follow up sheet

1 Work out the formula of these hydrated salts, showing the water of crystallisation.

a $CoCl_2 \bullet 6H_2O$ *(1 mark)*

b $Na_2CO_3 \bullet 10H_2O$ *(1 mark)*

c $Al(NO_3)_3 \bullet 9H_2O$ *(1 mark)*

2 **a** Molar mass of $Ca(NO_3)_2 = 164.1$ *(1 mark)*

$236.1 - 164.1 = 72$ *(1 mark)*

$\frac{72}{18} = 4$, so the formula is $Ca(NO_3)_2 \bullet 4H_2O$ *(1 mark)*

b $Ca(NO_3)_2 \bullet 4H_2O(s) \rightarrow Ca(NO_3)_2(s) + 4H_2O(g)$ *(1 mark for equation, 1 mark for state symbols)*

3.2 FINDING THE FORMULA OF A PRODUCT

Background

In order to write a balanced equation you have to know how many moles of each of your reactants will react to form your products. In this practical you will determine the products of the reaction and balance the equation based on the results you get.

This is an example of a precipitation reaction and you will determine, from the amount of solid precipitate produced, the amount (in moles) of your reactants that have reacted.

The reaction of potassium iodide with lead nitrate is a simple precipitation reaction. It can be described by the word equation:

potassium iodide + lead nitrate → lead iodide + potassium nitrate

This activity will build upon the work you have been doing in Chapter 2: *Atoms, ions, and compounds* such as:

- calculating amounts of substance from mass and molar mass
- calculating amounts of substance from concentrations and volumes of solutions
- deducing the formulae of ionic substances
- deducing the reacting ratios of substances in reactions (stoichiometry).

Safety

- Chemical splash-proof eye protection should be worn at all times.
- Wash hands after experiment.
- Both lead nitrate and lead iodide are classed as TOXIC over concentrations of 0.01 mol dm^{-3} and are considered harmful to the environment. They are both cumulative poisons (they build up in your system with prolonged exposure). Do not ingest or inhale the dust and do not dry the yellow solid lead iodide. Give them to the technician for disposal.
- Make sure that when using a centrifuge the tube masses are balanced before switching on.

Equipment and materials

- chemical splash-proof eye protection
- 1 mol dm^{-3} lead nitrate – TOXIC
- 1 mol dm^{-3} potassium iodide
- two 5 cm^3 graduated pipettes
- pipette fillers
- eight test tubes in a rack
- centrifuge
- balance accurate to 2 decimal places
- distilled water
- ruler with millimetre graduations

Method

1. Set up the eight test tubes in a rack, ensuring that you label them. Add 5 cm^3 of potassium iodide solution to each tube using a graduated pipette.
2. Starting with the left-hand tube add 0.5 cm^3 of lead nitrate solution.
3. Move along the rack of tubes increasing the amount of lead nitrate by 0.5 cm^3 each time, e.g. 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0 cm^3.
4. Add 3.5, 3.0, 2.5, 2.0, 1.5, 1.0, 0.5 cm^3 of water into the first seven tubes and check that all the tubes have the same mass before they are placed in the centrifuge.
5. Centrifuge the tubes for same length of time and record, on a graph like Figure 1, the height of the precipitate formed in each tube.

Example data (idealised)

Volume of lead nitrate / cm^3	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Height of precipitate formed / mm	3	6	9	12	15	15	15	15

Results

Record the height of the precipitate formed in each tube and construct a graph like Figure 1 to show these data.

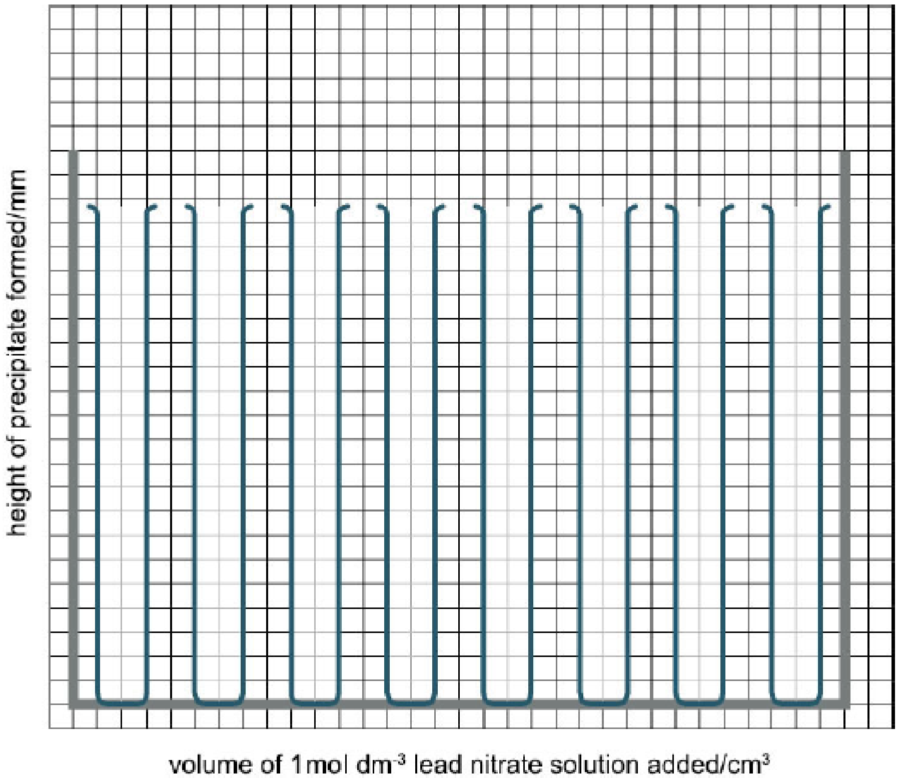


Figure 1 *Results of experiment*

Questions

1. State the volume of lead nitrate added at which the lead nitrate stops reacting with the potassium iodide. *(1 mark)*
2. Calculate how many moles of potassium iodide there are in 5 cm^3 of 1 mol dm^{-3} solution. *(2 marks)*
3. Calculate how many moles of lead nitrate are added to each 0.5 cm^3 sample. *(2 marks)*
4. State the mole ratio of potassium iodide to lead nitrate. *(1 mark)*
5. Find potassium in the periodic table. Use this information to predict what ion potassium will generate, when it forms compounds. *(2 marks)*
6. Find iodine in the periodic table. Use this information to predict what ion iodine will generate, when it forms compounds. *(2 marks)*
7. Deduce the formula of potassium iodide. *(1 mark)*
8. Construct a balanced symbol equation for the reaction, including state symbols, (given that the formula equation for lead nitrate is $Pb(NO_3)_2$). *(2 marks)*

FOLLOW UP

Task

In '3.2 Practical: *Finding the formula of a product*', you carried out an experiment to measure the reaction of potassium iodide with lead nitrate. You determined that the reaction occurred in a 2:1 ratio (this is called the reaction ratio, or stoichiometry), and found that the formula equation for the reaction was:

$$2KI\ (aq) + Pb(NO_3)_2\ (aq) \rightarrow PbI_2\ (s) + 2\ KNO_3\ (aq)$$

The lead iodide formed was a solid. You measured the amount of solid formed, in order to have been able to work out the reacting molar ratio (the stoichiometry) of the reaction.

In this first set of questions, you will consider two closely related examples of substitution reactions, involving a precipitation of a solid product. Can you calculate the stoichiometry of the reactions, and deduce the formula equations for them?

Questions

1 The reaction of sodium hydroxide with copper(II) sulfate is a precipitation reaction, forming a precipitate of copper(II) hydroxide. The word equation for the reaction is:

copper(II) sulfate + sodium hydroxide → copper(II) hydroxide + sodium sulfate

5 cm^3 of 1 mol dm^{-3} copper sulfate solution was added to eight centrifuge tubes. Solutions of 1 mol dm^{-3} sodium hydroxide were then added to each tube. The volumes of sodium hydroxide and the depth of the precipitate formed can be seen in Table 1.

Table 1 *Example results*

Volume of sodium hydroxide / cm^3	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
Height of precipitate formed / mm	4	8	12	16	21	20	20	21

a State the volume of sodium hydroxide added at which the sodium hydroxide stops reacting with the copper(II) sulfate. (*1 mark*)

b Calculate how many moles of copper sulfate were added to each tube. (*2 marks*)

c Calculate how many moles of sodium hydroxide were needed to react completely with the copper(II) sulfate. (*2 marks*)

d State the reacting molar ratio of copper(II) sulfate to sodium hydroxide. (*1 mark*)

e Construct a balanced symbol equation for the reaction of copper(II) sulfate with sodium hydroxide, including state symbols. (*1 mark*)

2 The reaction of barium chloride with aluminium sulfate is a precipitation reaction, forming a precipitate of barium sulfate. The word equation for the reaction is:

aluminium sulfate + barium chloride → aluminium chloride + barium sulfate

4 cm^3 of 1 mol dm^{-3} aluminium sulfate solution was added to eight centrifuge tubes. Solutions of 1 moldm^{-3} barium chloride were then added to each tube. The volumes of barium chloride and the depth of the precipitate formed can be seen in Table 2.

Table 2 *Example results*

Volume of barium chloride / cm^3	3.0	6.0	9.0	12.0	15.0	18.0	21.0	24.0
Height of precipitate formed / mm	2	4	6	8	8	8	8	8

a State the volume of barium chloride added at which the barium chloride stops reacting with the ammonium sulfate. (*1 mark*)

b Calculate how many moles of ammonium sulfate were added to each tube. (*2 marks*)

c Calculate how many moles of barium chloride were needed to react completely with the aluminium sulfate. (*2 marks*)

d State the reacting molar ratio of aluminium sulfate to barium chloride. (*1 mark*)

e Construct a balanced symbol equation for the reaction of aluminium sulfate with barium chloride, including state symbols. (*2 marks*)

3 Sodium phosphate, Na_3PO_4, is a salt that can be prepared by reacting phosphoric(V) acid, H_3PO_4, with sodium hydroxide, NaOH.

A student prepared a solution of Na_3PO_4 by reacting 12.5 cm^3 of 0.100 mol dm^{-3} H_3PO_4 with 0.200 mol dm^{-3} NaOH.

a Calculate the amount, in moles, of H_3PO_4 in 12.5 cm^3 of 0.100 mol dm^{-3} H_3PO_4. (*1 mark*)

b The equation for the preparation of Na_3PO_4 from NaOH and H_3PO_4 is shown below.

$$3NaOH\ (aq) + H_3PO_4\ (aq) \rightarrow Na_3PO_4\ (aq) + 3H_2O\ (l)$$

Calculate the volume of 0.200 mol dm^{-3} NaOH that reacts exactly with 12.5 cm^3 of 0.100 mol dm^{-3} H_3PO_4. (*1 mark*)

This question has been adapted from a question in an OCR GCE Chemistry A paper from May 2013 (F321/01 Atoms, Bonds and Groups) (Q3 c, parts ii) and iii))

4 A student was given a sample of an unknown Group 2 metal chloride.

- The student dissolves 2.86 g of the chloride in water.
- The student adds excess aqueous silver nitrate.
- 8.604 g of solid silver chloride, AgCl, forms.

a Calculate the amount, in moles, of AgCl that forms.

The molar mass of AgCl = 143.4 g mol^{-1}. (*1 mark*)

b Deduce the amount, in moles, of the Group 2 chloride that the student dissolves.

Hence deduce the relative atomic mass and the identity of the Group 2 metal.

Give the relative atomic mass to one decimal place. You must show your working. (*3 marks*)

This question has been adapted from a question in an OCR GCE Chemistry A paper from May 2012 (F321/01 Atoms, Bonds and Groups) (Q4 c)

ANSWERS

Example data (realistic)

Volume of lead nitrate / cm^3	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Height of precipitate formed / mm	4	7	10	13	16	16	16	16

Answers for method sheet

1 2.5 cm^3, as the height of the precipitate has reached a maximum value at this point. (*1 mark*)

2 Amount (moles) = concentration × volume (*1 mark*)

$$= 1 \times \frac{5}{1000}$$

$$= 5 \times 10^{-3}$$ (*1 mark*)

3 Amount (moles) = concentration × volume (*1 mark*)

$$= 1 \times \frac{0.5}{1000}$$

$$= 5 \times 10^{-4}$$ (*1 mark*)

4 2:1, as only 2.5 x 10^{-3} moles of lead nitrate are needed to react with the 5 x 10^{-3} moles of KI. (*1 mark*)

5 Potassium is found in Group 1 of the periodic table. (*1 mark*)
It will generate a +1 ion, K^+ when it forms compounds. (*1 mark*)

6 Iodine is found in Group 7 of the periodic table. (*1 mark*)
It will generate a −1 ion, I^- when it forms compounds. (*1 mark*)

7 KI (from the K^+ and I^-, the charges on the ions will cancel each other out) (*1 mark*)

8 $2KI\,(aq) + Pb(NO_3)_2\,(aq) \rightarrow PbI_2\,(s) + 2KNO_3\,(aq)$ (*1 mark for correct species and balancing, 1 mark for state symbols*)

Answers for follow up sheet

1 **a** 10.0 cm^3, as the height of the precipitate has reached a maximum value, at this point (*1 mark*)

b Amount (moles) = concentration × volume (*1 mark*)

$$= 1 \times \frac{5}{1000}$$

$$= 5 \times 10^{-3}$$ (*1 mark*)

c Amount (moles) = concentration × volume (*1 mark*)

$$= 1 \times \frac{10}{1000}$$

$$= 1 \times 10^{-2}$$ (*1 mark*)

d 1:2 (*1 mark*)

e $CuSO_4\,(aq) + 2\,NaOH\,(aq) \rightarrow Cu(OH)_2\,(s) + Na_2SO_4\,(aq)$ (*1 mark*)

2 The reaction of barium chloride with aluminium sulfate is a substitution reaction, forming a precipitate of barium sulfate. The word equation for the reaction is:

aluminium sulfate + barium chloride → aluminium chloride + barium sulfate

4 cm^3 of 1 mol dm^{-3} aluminium sulfate solution was added to eight centrifuge tubes. Solutions of 1 mol dm^{-3} barium chloride were then added to each tube. The volumes of barium chloride and the depth of the precipitate formed can be seen in the table below::

Volume of barium chloride / cm^3	3.0	6.0	9.0	12.0	15.0	18.0	21.0	24.0
Height of precipitate formed / mm	2	4	6	8	8	8	8	8

a 12.0 cm^3, as the height of the precipitate has reached a maximum value at this point. *(1 mark)*

b Amount (moles) = concentration × volume *(1 mark)*

$$= 1 \times \frac{4}{1000}$$

$$= 4 \times 10^{-3}$$ *(1 mark)*

c Amount (moles) = concentration × volume *(1 mark)*

$$= 1 \times \frac{12}{1000}$$

$$= 4 \times 10^{-2}$$ *(1 mark)*

d 1:3 *(1 mark)*

e $Al_2(SO_4)_3\ (aq) + 3\ BaCl_2\ (aq) \rightarrow 2\ AlCl_3\ (aq) + 3\ BaSO_4\ (s)$ *(1 mark for correct species and balancing, 1 mark for state symbols)*

3 **a** Amount (moles) = concentration × volume *(1 mark)*

$$= 0.1 \times \frac{12.5}{1000}$$

$$= 1.25 \times 10^{-3}$$ *(1 mark)*

b Reaction ratio of sodium hydroxide to phosphoric(V) acid is 3:1

Number of moles of sodium hydroxide reacting = $1.25 \times 10^{-3} \times 3$

$= 3.75 \times 10^{-3}$

Concentration of sodium hydroxide = 0.200 mol dm^{-3}

$$\text{Volume of sodium hydroxide used} = \frac{\text{amount}}{\text{concentration}}$$

$$= 1.25 \times \frac{10^{-3}}{0.2}$$

$= 0.01875\ dm^3$*

$= 0.01875 \times 1000$

$= 18.75\ cm^3$*

(Either answer is acceptable for 1 mark)*

This question has been adapted from an OCR GCE Chemistry A paper from May 2013 (F321/01 Atoms, Bonds and Groups) (Q3 c, parts ii) and iii))

4 **a** $$\text{Amount of AgCl} = \frac{\text{mass}}{\text{molar mass}}$$

$$= \frac{8.604}{143.4}$$

$= 0.06$ *(1 mark)*

b The unknown metal is a Group 2 chloride, so it will form substances with the formula, MCl_2.

The chloride will react with $AgNO_3$ in a 1:2 reaction ratio:

MCl_2 (aq) + $2AgNO_3$ (aq) → 2AgCl (s) + $M(NO_3)_2$ (aq)

Therefore we can calculate the number of moles of MCl_2 in the original sample as:

$\frac{0.06}{2} = 0.03$ *(1 mark)*

We can now calculate the molar mass of the original MCl_2 sample:

$$M_r (MCl_2) = \frac{\text{mass}}{\text{amount}}$$

$$= \frac{2.86}{0.03}$$

$= 95.3$ g mol^{-1}

And then go on, to calculate the atomic mass of the unknown metal, M, by subtracting the mass of the two chloride ions in the compound:

$M_r (M) = 95.3 - 71 = 24.3$ g mol^{-1} *(1 mark)*

And identify the unknown metal as magnesium, Mg *(1 mark)*

This question has been adapted from an OCR GCE Chemistry A paper from May 2012 (F321/01 Atoms, Bonds and Groups) (Q4 c)

3.3 Units and Concentration

Learning outcomes

After completing the worksheet you should be able to:

- recognise and make use of appropriate units in calculations
- state the concentration of a substance in solution in units of mol dm^{-3}
- carry out calculations using concentration, volume and amount of substance
- report answers to an appropriate number of significant figures.

Introduction

The concentration of a solution is defined in units of moles per cubic decimetre (mol/dm^3), which is called molar concentration. Since $\frac{1}{dm^3}$ can also be represented as dm^{-3} the unit of concentration can also be represented by mol dm^{-3}.

By looking at the units of concentration of mol dm^{-3} we can see that the equation for determining the concentration of a solution must be;

$$\text{Concentration } c \text{ (mol dm}^{-3}) = \frac{\text{amount } n \text{ (mol)}}{\text{volume } V \text{ (dm}^3)}$$

When calculating the concentration of a solution the volume must be given in units of dm^3. Therefore we need to be able to readily convert between units of m^3, dm^3 and cm^3 in order to correctly give the concentration of a solution. Figure 1 shows how to do this.

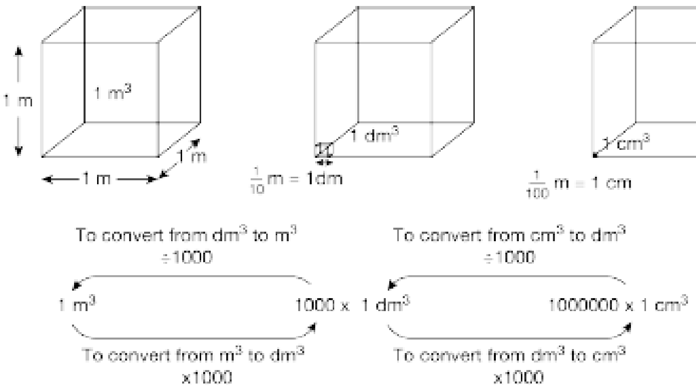


Figure 1 *Converting between units of volume*

Worked example

Question

Determine the concentration of a solution in which 0.0158 mol of sodium chloride is dissolved in 25 cm^3 of water.

Answer

Step 1

Change the volume to dm^3 by dividing by 1000:

25 cm^3 = 0.025 dm^3

Step 2

Substitute the values into the equation remembering to use the units to help:

$$\text{Concentration (mol/dm}^3\text{)} = \frac{0.015 \text{ mol}}{0.025 \text{ dm}^3}$$

$$= 0.632 \text{ mol dm}^{-3}$$

$$= 0.63 \text{ mol dm}^{-3} \text{ (to two significant figures)}$$

Remember you can only give your final answer to the same degree of accuracy (significant figures) as the least accurate value used in the calculation. In this case, to two significant figures.

Questions

1 Calculate following volumes, in terms of the units given: (*8 marks*)

- **a** 12.2 cm^3 into dm^3
- **b** 0.015 cm^3 into dm^3
- **c** 132 dm^3 into cm^3
- **d** 0.054 dm^3 into cm^3
- **e** 25 dm^3 into m^3
- **f** 0.48 m^3 into dm^3
- **g** 25 cm^3 into m^3
- **h** 381 m^3 into cm^3.

2 Give the concentrations of the following aqueous solutions in mol dm^{-3}.
Give all final answers to an appropriate degree of accuracy. (7 marks)

- **a** 2.46 mol dissolved in 2.50 dm^3
- **b** 0.005 00 mol dissolved in 24.6 cm^3
- **c** 1.5 mol dissolved in 0.020 cm^3
- **d** 63.2 mol dissolved in 2.00 m^3
- **e** 0.021 mol dissolved in 4.5×10^{-3} m^3
- **f** 81.9 g of calcium carbonate, $CaCO_3$, dissolved in 34.1 cm^3
- **g** 23.4 g of hydrated copper sulfate, $CuSO_4{\cdot}5H_2O$ dissolved in 2.5 dm^3.

3 Calculate the following. *Give all final answers to an appropriate degree of accuracy.*

a The amount of substance in moles in: (*3 marks*)

i 0.025 dm^3 of a 0.100 mol dm^{-3} solution

ii 24.3 cm^3 of a 0.150 mol dm^{-3} solution

iii 1.8×10^{-3} m^3 of a 1.28 mol dm^{-3} solution.

b The mass of solid in each of the following solutions: (*3 marks*)

i 0.0186 dm^3 of a 0.012 mol dm^{-3} solution of NaOH

ii 36.3 cm^3 of a 4.21 mol dm^{-3} solution of $Ca(OH)_2$

iii 1.23×10^{-3} m^3 of a 0.254 mol dm^{-3} solution of $NaHCO_3$.

4 *From OCR Chemistry A Atoms, bonds and groups F321/01 Jan 2013 (Question 5)*

Borax, $Na_2B_4O_7 \bullet 10H_2O$ can be used to determine the concentration of acids such as dilute HCl.

A student prepares 250 cm^3 of a 0.0800 mol dm^{-3} solution of borax in water in a volumetric flask.

Calculate the mass of borax crystals, $Na_2B_4O_7 \bullet 10H_2O$, needed to make up 250 cm^3 of 0.0800 mol dm^{-3} solution. (*3 marks*)

ANSWERS

Answers

1 a $0.0122\ dm^3$ *(1 mark)*

b $0.000\ 015\ dm^3$ or $1.5 \times 10^{-5}\ dm^3$ *(1 mark)*

c $132\ 000\ cm^3$ *(1 mark)*

d $54\ cm^3$ *(1 mark)*

e $0.025\ m^3$ *(1 mark)*

f $480\ dm^3$ *(1 mark)*

g $0.000\ 025$ or $2.5 \times 10^{-5}\ m^3$ *(1 mark)*

h $381\ 000\ 000\ cm^3$ or $3.81 \times 10^8\ cm^3$. *(1 mark)*

2 a $\frac{2.46\ mol}{2.50\ dm^3} = 0.984\ mol\ dm^{-3}$ (to 3 significant figures) *(1 mark)*

b $24.6\ cm^3 = 0.0246\ dm^3$;
$\frac{0.005\ mol}{0.0246\ dm^3} = 0.203\ mol\ dm^{-3}$ (to 3 significant figures) *(1 mark)*

c $0.02\ cm^3 = 2 \times 10^{-5}\ dm^3$
$\frac{1.5\ mol}{2 \times 10^{-5}\ dm^3} = 75000\ mol\ dm^{-3}$ (to 2 significant figures) *(1 mark)*

d $2\ m^3 = 2000\ dm^3$
$\frac{63.2\ mol}{2000\ dm^3} = 0.0316\ mol\ dm^{-3}$ (to 3 significant figures) *(1 mark)*

e $4.5 \times 10^{-3}\ m^3 = 4.5\ dm^3$
$\frac{0.021\ mol}{4.5\ dm^3} = 0.047\ mol\ dm^{-3}$ (to 2 significant figures) *(1 mark)*

f $\frac{81.9\ g}{100.1\ g\ mol^{-1}} = 0.818\ mol$

$34.1\ cm^3 = 0.0341\ dm^3$
$\frac{0.818\ mol}{0.0341\ dm^3} = 24.0\ mol\ dm^{-3}$ (to 3 significant figures) *(1 mark)*

h $\frac{23.4\ g}{249.6\ g\ mol^{-1}} = 0.0938\ mol$

$\frac{0.0938\ mol}{2.5\ dm^3} = 0.038\ mol\ dm^{-3}$ (to 2 significant figures). *(1 mark)*

3 a i $0.025\ dm^3 \times 0.100\ mol\ dm^{-3} = 0.0025\ mol$ *(1 mark)*

ii $24.3\ cm^3 = 0.0243\ dm^3$
$0.0243\ dm^3 \times 0.150\ mol\ dm^{-3} = 3.65 \times 10^{-3}\ mol$ (to 3 significant figures) *(1 mark)*

iii $1.8 \times 10^{-3}\ m^3 = 1.8\ dm^3$
$1.8\ dm^3 \times 1.28\ mol\ dm^{-3} = 2.3\ mol\ dm^{-3}$ (to 2 significant figures) *(1 mark)*

b i $0.0186\ dm^3 \times 0.012\ mol\ dm^{-3} = 2.23 \times 10^{-4}\ mol$
$2.23 \times 10^{-4}\ mol \times 40.0\ g\ mol^{-1} = 8.9 \times 10^{-3}\ g$ (to 2 significant figures) *(1 mark)*

ii $36.3\ cm^3 = 0.0363\ dm^3$

$0.0363\ dm^3 \times 4.21\ mol\ dm^{-3} = 0.153\ mol$

$0.153\ mol \times 74.1\ g\ mol^{-1} = 11.3\ g$ (to 3 significant figures) (*1 mark*)

iii $1.23 \times 10^{-3}\ m^3 = 1.23\ dm^3$

$1.23\ dm^3 \times 0.254\ mol\ dm^{-3} = 0.312\ mol$

$0.312\ mol \times 84.0\ g\ mol^{-1} = 26.2\ g$ (to 3 significant figures). (*1 mark*)

4 From OCR Chemistry A Atoms, bonds and groups F321/01 Jan 2013 (Question 5)

5(c)	Moles of $Na_2B_4O_7 \cdot 10H_2O$ needed = $0.0800\ mol\ dm^{-3} \times 0.25\ dm^3 = 0.02$ mol Molar mass of $Na_2B_4O_7 \cdot 10H_2O$ = $381.2\ g\ mol^{-1}$ Mass of $Na_2B_4O_7 \cdot 10H_2O$ needed = $0.02\ mol \times 381.2\ g\ mol^{-1} = 7.62\ g$ (to 3 significant figures)	3	If there is an alternative answer, check to see if there is any ECF credit possible using working below ALLOW 381 DO NOT ALLOW 380 ALLOW 0.0800 x [molar mass of borax] correctly calculated for 2nd mark (ie mass of borax in 1000 cm^3) ALLOW $\frac{\text{mass of borax in 1000 cm}^3}{4}$ correctly calculated for 3rd mark ALLOW calculator value or rounding to three significant figures or more IGNORE (if seen) a second rounding error

3.4 How does our understanding of chemicals benefit sustainability?

Introduction

Earth is home to approximately 7 billion people. Of these, approximately a quarter have no access to healthcare, education or even clean water. Yet, the world's population continues to increase – possibly by another 3 billion people in the next 50 years – putting ever more pressure on Earth's natural resources.

A key approach to dealing with this situation is to encourage economic growth, in developed but more so in developing countries. However, economic growth often depends on the use of natural resources, depleting them further whilst also increasing environmental pollution. It is, therefore, increasingly important that we develop in a way that can meet our needs without harming the ability of future generations' ability to meet their needs. This is known as known as sustainable development.

In this task you will explore the work that chemists are doing to reduce the amount of waste produced in industrial chemical reactions and processes. You will look at different ways chemists can understand the amount of product produced and investigate methods that may increase the quantity of product and reduce the amount of waste.

Learning outcomes

After completing this worksheet you should be able to:

- understand why chemists need to understand the efficiency of chemical reactions
- calculate percentage atom economy and percentage yield
- apply learning to solve real-world problems.

Background

Many chemical reactions and processes involve changing a raw material into a useful product. For environmental as well as financial reasons, it is important that as much of the product as possible is made from the raw material available.

To help achieve this, chemists use the percentage yield of a chemical reaction. The percentage yield is a comparison of the theoretical maximum yield, calculated using a balanced equation, and the actual yield. A yield of 100% implies no product has been lost while a yield of 0% that none has been made.

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

Atom economy is another tool chemists use to help understand the efficiency of a reaction. It allows us to calculate the theoretical percentage of wasted atoms in a reaction. That is, the mass atoms of the desired product as a proportion of the mass of all products, including those which will be discarded

$$\text{Atom economy} = \frac{\text{sum of molar masses of all desired products}}{\text{sum of molar masses of all products}} \times 100\%$$

Example

We can calculate the atomic economy for production of zinc chloride by the reaction of zinc with hydrochloric acid. First, we need to write a balanced symbol equation for the reaction:

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

Mr of H_2 = 1 + 1

= 2

Mr of $ZnCl_2$ = 65 + 35.5 + 35.5

= 136

$$\text{Atom economy} = \frac{136}{136 + 2} \times 100\%$$

= 98.55%

Task

The production of quicklime (calcium oxide) for use in cement, by a thermal decomposition of limestone (calcium carbonate) is an example of an industrial chemical process:

$$\text{calcium carbonate} \xrightarrow{825°C} \text{calcium oxide} + \text{carbon dioxide}$$

Mining and extraction of raw materials from ore is another example of an industrial chemical process. It is an intensive and heavily polluting process so it is important to be efficient in producing a usable product from it. Two methods to extract titanium from titanium ore (TiO_2) are:

1 Using magnesium to displace the titanium –

$$TiO_2 + 2Mg \rightarrow Ti + 2MgO.$$

2 Electrolysis –

$$TiO_2 \rightarrow Ti + O_2$$

You have been asked by two companies to evaluate the environmental impact of their manufacturing processes.

Questions

Enviro-Lime, a company that synthesises calcium oxide that is able to produce 61 kg of calcium oxide using 125 kg of calcium carbonate.

1 Write a balanced symbol equation for the thermal decomposition of limestone to produce calcium oxide. (*1 mark*)

2 Calculate the relative molecular mass, M_r for the raw material, product and waste product for this process. (*3 marks*)

3 Suggest why this process may be an environmental concern. (*2 marks*)

4 Calculate the percentage yield of *Enviro-Lime*'s process. (*3 marks*)

5 Calculate the percentage atom economy for this process. (*3 marks*)

6 Suggest why both percentage atom economy and percentage yield are necessary to assess the sustainability of a chemical reaction or process. (*2 marks*)

Mole Minerals is a company which has recently found deposits of titanium ore but is unsure which method of producing titanium to adopt. They are keen to maximise the amount of titanium they can produce both for environmental and financial reasons.

7 Which method of producing titanium from its ore is more sustainable?

- **a** Calculate percentage atom economy for both reactions. (*2 marks*)
- **b** Suggest what other information might be useful in making your judgement. (*2 marks*)
- **c** Oxygen is a useful product and can be sold. Explain the affect this would have on atom economy. (*1 mark*)

ANSWERS

Teacher notes

- Percentage yield and atom economy are important tools to help us understand the environmental impact of chemical reactions and processes.
- $\text{Percentage yield} = \dfrac{\text{actual yield}}{\text{theoretical yield}} \times 100\%$
- $\text{Atom economy} = \dfrac{\text{sum of molar masses of all desired products}}{\text{sum of molar masses of all products}} \times 100\%$
- Concern about sustainability has been driven by:
  - the increasing scarcity of the natural resources we depend upon;
  - the continuing increase in the global population;
  - the need for economic growth in developing countries; and
  - recognition of the impact of industrialisation on the environment.
- *Stretch:* Encourage more able learners to work independently, identifying other industrial processes which have been improved by identifying the percentage yield or atom economy.

They could be asked to look at the production of ibuprofen as an example of multi-stage reactions.

- *Support:* Less able learners could be supported by working through the example on the student sheet or by working through questions 1–5 in small groups or as a class. An equation sheet and the M_r for the reactants and products could be provided to support learners that find multi-step calculations challenging.
- Students should be familiar with the lime cycle and the extraction of titanium from prior learning. They should be familiar with relative molecular mass, M_r and be able to write balanced equations.
- Students may need access to a calculator.

Answers

1 $CaCO_3$ (s) → CaO (s) + CO_2 (g). (*1 mark*)

2 M_r $CaCO_3$ = 100.1 (*1 mark*)

M_r CaO = 56.1 (*1 mark*)

M_r CO_2 =44.0 (*1 mark*)

3 Award a maximum of two marks from the following, or any other sensible suggestion:

- mining may damage natural environments (*1 mark*)
- exhaust supplies of a natural resource (*1 mark*)
- produces CO_2 which is a greenhouse gas and may contribute to climate change. (*1 mark*)

4 Actual yield = 61 kg

Theoretical yield should be the same number of moles as there are in 125 g calcium carbonate

Moles of calcium carbonate = mass/*Mr*

$$= \frac{125}{100.1}$$

= 1.249 (*1 mark*)

Mass of calcium oxide = moles × *Mr*

= 1.249 × 56.1

= 70.05 (*1 mark*)

$$\text{Percentage yield} = \frac{61}{70.05} \times 100\%$$

= 87%. (*1 mark*)

5 Sum of molar masses of all desired products = 56.1 (*1 mark*)

Sum of molar masses of all products = 56.1 + 44.0

= 100.1 (*1 mark*)

$$\text{Atom economy} = \frac{56.1}{100.1} \times 100\%$$

= 56%. (*1 mark*)

6 Award a maximum of two marks from the following:

- a reaction may have a high percentage yield but still produce a lot of waste product – this can only be identified by calculating percentage atom economy (*1 mark*)
- percentage atom economy is theoretical and does not account for losses due to systematic or random errors. (*1 mark*)

7 The electrolysis method, because it has a higher percentage atom economy:

a Mg displacement

$$\text{Atom economy} = \frac{48}{128} \times 100\%$$

$= 38\%$ (*1 mark*)

Electrolysis

$$\text{Atom economy} = \frac{48}{80} \times 100\%$$

$= 60\%$ (*1 mark*)

b Award a maximum of two marks for any of the following:

- percentage yield (*1 mark*)
- environmental impact of mining (*1 mark*)
- value or usefulness of oxygen and magnesium oxide (*1 mark*)

c It would mean that the atom economy for the electrolysis method would be 100%. (*1 mark*)

3.4 Atom Economy

Learning outcomes

After completing the worksheet you should be able to:

- calculate the atom economy of a reaction using balanced equations
- rearrange and solve equations involving atom economy calculations

This worksheet builds on understanding from Topic 3.4: Reacting quantities and Topic 3.5: Percentage yield and atom economy.

Introduction

'Per cent' means out of 100. A percentage is therefore a number or ratio expressed as a fraction of 100.

The percentage atom economy of a reaction is a way to measure the amount of atoms wasted when making a chemical. It compares the mass of all the atoms in the desired product, to the masses of all the atoms that go into the reaction. It is an indication of how much waste is produced and hence how 'green' the process is. We can express the percentage atom economy of a reaction using the equation:

$$\text{Percentage atom economy, \%} = \frac{\text{sum of molar masses of all desired products}}{\text{sum of molar masses of all products}} \times 100\%$$

A percentage atom economy of 100% means that every atom in the reactants is used in the product.

Worked example

Question

Iron is extracted from iron oxide by reduction with carbon. The equation for the reaction is:

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

Carbon monoxide is created as an unwanted by-product of this reaction.

Calculate the percentage atom economy for this process.

Answer

Step 1

Calculate the sum of the molar masses of the desired products.

$= 2 \times$ Fe atoms $= 2 \times 55.8\ g\ mol^{-1}$

$= 111.6\ g\ mol^{-1}$

Step 2

Calculate the sum of the molar masses of *all* the products.

Molar mass of CO $= 12.0\ g\ mol^{-1} + 16.0\ g\ mol^{-1} = 28.0\ g\ mol^{-1}$

Therefore, the sum of the molar masses of *all* the products.

$= 2Fe + 3CO$

$= (2 \times 55.8\ g\ mol^{-1}) + (3 \times 28.0\ g\ mol^{-1})$

$= 195.6\ g\ mol^{-1}$

Step 3

Substitute the values into the equation for percentage atom economy.

$$\text{Percentage atom economy, } \% = \frac{111.6\ g\ mol^{-1}}{195.6\ g\ mol^{-1}} \times 100\%$$

$= 57.1\%$ (to 3 significant figures)

Questions

Give all answers to *three* significant figures.

1 Calculate the atom economy of each of the processes below.

a The production of hydrogen by the reaction of methane with water: (*2 marks*)

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

b The extraction of titanium from titanium chloride with magnesium: (*2 marks*)

$$TiCl_4 + 2Mg \rightarrow Ti + 2MgCl_2$$

c The production of copper from the reduction of copper carbonate with carbon: (*2 marks*)

$$2CuCO_3 + C \rightarrow 2Cu + 3CO_2$$

d The production of hydrogen by the reaction of zinc with hydrochloric acid.

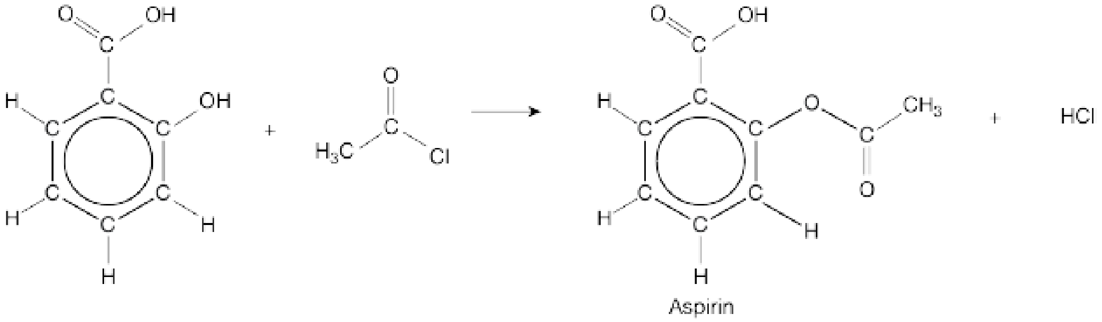
You should be able to produce your own balanced equation for this reaction. (*3 marks*)

2 Ethanol, C_2H_5OH, is produced from the fermentation of glucose, $C_6H_{12}O_6$. The only other product of the reaction is carbon dioxide.

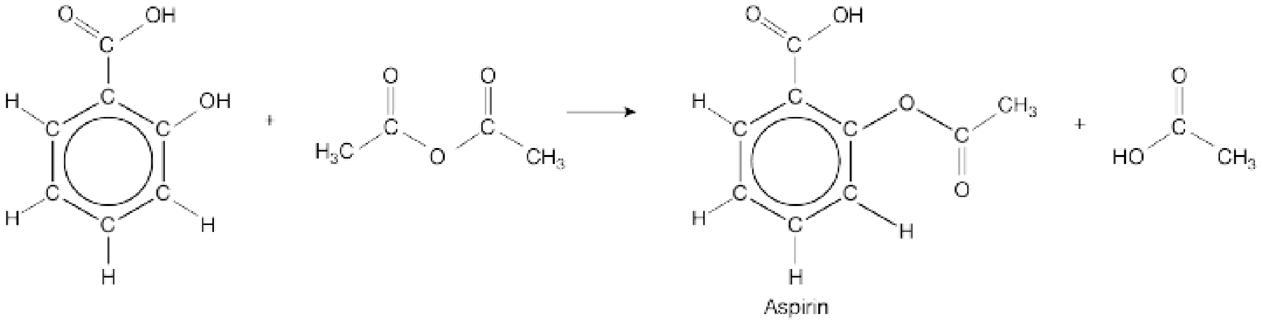
Calculate the atom economy of this process. (*3 marks*)

3 Aspirin can be made by the acylation of salicylic acid using either ethanoyl chloride or ethanoic anhydride. The equations for the two reactions are shown below:

Acylation with ethanoyl chloride:



Acylation with ethanoic anhydride:



Calculate the atom economy of both processes and hence determine which process has the lower atom economy. *(3 marks)*

4 *From OCR Chemistry A Chains, energy and resources F322 January 2011 (Question 2)*

Butyl ethanoate is an ester used as a flavouring.

The ester can be synthesised from butan-1-ol by two different processes.

Process 1 is a one-step process that involves a reversible reaction.

$$CH_3CH_2CH_2CH_2OH + CH_3COOH \leftrightharpoons CH_3COOCH_2CH_2CH_2CH_3 + H_2O$$

The percentage yield for **process 1** is 67.1%

The atom economy for **process 1** is 86.6%

Show that the atom economy for **process 1** is 86.6%. *(2 marks)*

ANSWERS

1 **a** Sum of molar masses of desired product (hydrogen) = $3 \times 2.0\ \text{g mol}^{-1}$

$= 6.0\ \text{g mol}^{-1}$

Sum of molar masses of all products = $(1 \times 28.0\ \text{g mol}^{-1}) + (3 \times 2.0\ \text{g mol}^{-1})$

$= 34.0\ \text{g mol}^{-1}$

$$\text{Percentage atom economy} = \frac{6.0\ \text{g mol}^{-1}}{34.0\ \text{g mol}^{-1}} \times 100\%$$

$= 17.6\%$

(*1 mark for correct calculation, 1 mark for answer*)

b Sum of molar masses of desired product (titanium) = $1 \times 47.9\ \text{g mol}^{-1} = 47.9\ \text{g}$

Sum of molar masses of all products = $(1 \times 47.9\ \text{g mol}^{-1}) + (2 \times 190.6\ \text{g mol}^{-1}) = 238.5\ \text{g mol}^{-1}$

$$\text{Percentage atom economy} = \frac{47.9\ \text{g mol}^{-1}}{238.5\ \text{g mol}^{-1}} \times 100\% = 20.1\%$$

(*1 mark for correct calculation, 1 mark for answer*)

c) Sum of molar masses of desired product (copper) = $2 \times 63.5\ \text{g mol}^{-1} = 127.0\ \text{g mol}^{-1}$

Sum of molar masses of all products = $(2 \times 63.5\ \text{g mol}^{-1}) + (3 \times 44.0\ \text{g mol}^{-1}) = 259.0\ \text{g mol}^{-1}$

$$\text{Percentage atom economy} = \frac{127.0\ \text{g mol}^{-1}}{259.0\ \text{g mol}^{-1}} \times 100\% = 49.0\%$$

(*1 mark for correct calculation, 1 mark for answer*)

d) $Zn + 2\ HCl \rightarrow ZnCl_2 + H_2$ (*1 mark for equation*)

Sum of molar masses of desired product (hydrogen) = $1 \times 2.0\ \text{g mol}^{-1} = 2.0\ \text{g mol}^{-1}$

Sum of molar masses of all products = $(1 \times 136.4\ \text{g mol}^{-1}) + (1 \times 2.0\ \text{g mol}^{-1}) = 138.4\ \text{g mol}^{-1}$

$$\text{Percentage atom economy} = \frac{2.0\ \text{g mol}^{-1}}{138.4\ \text{g mol}^{-1}} \times 100\% = 1.45\%$$

(*1 mark for correct calculation, 1 mark for answer*)

2 $C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$ (*1 mark for equation*)

Sum of molar masses of desired product (ethanol) = $2 \times 46.0\ \text{g mol}^{-1} = 92.0\ \text{g mol}^{-1}$

Sum of molar masses of all products = $(2 \times 46.0\ \text{g mol}^{-1}) + (2 \times 44.0\ \text{g mol}^{-1}) = 180.0\ \text{g mol}^{-1}$

$$\text{Percentage atom economy} = \frac{92.0\ \text{g mol}^{-1}}{180.0\ \text{g mol}^{-1}} \times 100\% = 51.1\%$$

(*1 mark for correct calculation, 1 mark for answer*)

3 Acylation with ethanoyl chloride;

$C_7H_6O_3 + C_2H_3OCl \rightarrow C_9H_8O_4 + HCl$

Sum of molar masses of desired product (aspirin) = $1 \times 180.0\ \text{g mol}^{-1} = 180.0\ \text{g mol}^{-1}$

Sum of molar masses of all products = $(1 \times 180.0\ \text{g mol}^{-1}) + (1 \times 36.5\ \text{g mol}^{-1}) = 216.5\ \text{g mol}^{-1}$

$$\text{Percentage atom economy} = \frac{180.0\ \text{g mol}^{-1}}{216.5\ \text{g mol}^{-1}} \times 100\% = 83.1\%$$

(*1 mark*)

Acylation with ethanoic anhydride;

$C_7H_6O_3 + C_4H_6O_3 \rightarrow C_9H_8O_4 + CH_3COOH$

Sum of molar masses of desired product (aspirin) = 1 × 180.0 g mol^{-1} = 180.0 g mol^{-1}

Sum of molar masses of all products = (1 × 180.0 g mol^{-1}) + (1 × 60.0 g mol^{-1}) = 240.0 g mol^{-1}

Percentage atom economy = $\frac{180.0 \text{ g mol}^{-1}}{240.0 \text{ g mol}^{-1}} \times 100\% = 75.0\%$ (*1 mark*)

The production of aspirin by the acylation of aspirin with ethanoic anhydride has the lower atom economy. (*1 mark*)

4 *From OCR Chemistry A Chains, energy and resources Mark scheme F322 January 2011 (Question 2)*

Answer	Marks	Guidance
(Mr of all reactants or Mr of all products) is 134.0 OR 134 OR (Mr of desired product) is 116.0 OR 116 Atom economy $= \frac{116.0}{134.0} \times 100\%$	2	Remember the marks are for the working out and not for the answer IGNORE lack of decimal place in answer ALLOW correct expressions to calculate the Mr or the atom economy eg Atom economy $= \frac{(6\times12)+(12\times1)+(2\times16)}{116+8} \times 100\%$

3.4 Balancing Equations

Introduction

The *stoichiometry* of a reaction is the whole number ratio in which reactants react and products are produced. We show this stoichiometry for any reaction in a balanced symbol equation. For example the balanced symbol equation for the complete combustion of ethane is:

$$2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$$

This means that the ethane and oxygen combine in a molar ratio of 2:7 in the reaction and carbon dioxide and water are produced in a molar ratio of 4:6. At GCSE you might have been taught that only whole numbers can be used to balance symbol equations. However as we now know that we are talking about the number of moles of species and not individual species it is equally correct to show this balanced symbol equation as;

$$C_2H_6 + 3\frac{1}{2}O_2 \rightarrow 2CO_2 + 3H_2O$$

What is important is that the reactants and products are shown in the correct ratio. We use this ratio when calculating amounts of substances reacting.

Worked example

Question

Balance the symbol equation below.

$$Mg_3N_2 + H_2O \rightarrow MgO + NH_3$$

Answer

Step 1

Write out the number of atoms of each element in the reactants and products in the equation as it currently stands:

$Mg_3N_2 + H_2O$		→	$MgO + NH_3$	
Reactants		→	**Products**	
Mg	3		Mg	1
N	2		N	1
H	2		H	3
O	1		O	1

Step 2

Choose one element to balance. Add a big number in front of any of the species until the number of the element in question is the same on either side of the arrow. Remember you cannot change the formula of any species. It is usually easiest to start by choosing an element that is in only one of the reactant species, and generally leave hydrogen and oxygen until later.

In this case we will start by balancing the 'Mg' atoms. By adding a 3 before the MgO we also change the number of 'O' atoms on the right:

$Mg_3N_2 + H_2O$		→	$3\ MgO + NH_3$	
Reactants		→	**Products**	
Mg	3		Mg	~~1~~ 3
N	2		N	1
H	2		H	3
O	1		O	~~1~~ 3

Step 3

Work through each of the elements in turn, balancing the number of atoms on either side of the equation. You may need to also go back and revisit elements that were previously balanced.

In this case we will balance the 'N' atoms followed by the 'H' and finally 'O' atoms.

Balance the 'N' atoms by adding a 2 before the ammonia;

$Mg_3N_2 + H_2O$		→	$3\ MgO + \mathbf{2}\ NH_3$	
Reactants		→	**Products**	
Mg	3		Mg	~~1~~ 3
N	2		N	~~1~~ 2
H	2		H	~~3~~ 6
O	1		O	~~1~~ 3

Balance the 'H' atoms by adding a 3 before the H_2O on the left. This also balances out the 'O' atoms.

$Mg_3N_2 + \mathbf{3}\ H_2O$		→	$3\ MgO + 2\ NH_3$	
Reactants		→	**Products**	
Mg	3		Mg	~~1~~ 3
N	2		N	~~1~~ 2
H	~~2~~ 6		H	~~3~~ 6
O	~~1~~ 3		O	~~1~~ 3

The final balanced symbol equation is therefore;

$Mg_3N_2 + 3H_2O \rightarrow 3MgO + 2NH_3$

Questions

1 Balance the equations below, by balancing the atoms in the order suggested;

a $CH_4 + O_2 \rightarrow CO_2 + H_2O$: balance C, then H, then O

b $KClO_4 \rightarrow KCl + O_2$: balance K, then Cl, then O (*2 marks*)

2 Balance the equations below;

a $Cl_2O_7 + H_2O \rightarrow HClO_4$

b $Ca(OH)_2 + H_3PO_4 \rightarrow Ca_3(PO_4)_2 + H_2O$

c $Al + H_2SO_4 \rightarrow Al_2(SO_4)_3 + H_2$

d $Fe_2O_3 + C \rightarrow Fe + CO_2$ (*4 marks*)

3 Balance the equations below.

HINT. Balance the equations as far as you can using the rules and then increase the reactant species containing the unbalanced atoms 1 mole at a time until the whole equation balances.

a $Cu + HNO_3 \rightarrow Cu(NO_3)_2 + NO_2 + H_2O$

b $S + HNO_3 \rightarrow H_2SO_4 + NO_2 + H_2O$ (*2 marks*)

ANSWERS

Answers

1 **a** $CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$ (*1 mark*)

b $KClO_4 \rightarrow KCl + 2\ O_2$ (*1 mark*)

2 **a** $Cl_2O_7 + H_2O \rightarrow 2\ HClO_4$ (*1 mark*)

Balance in the order Cl, H, O

b $3\ Ca(OH)_2 + 2\ H_3PO_4 \rightarrow Ca_3(PO_4)_2 + 6\ H_2O$ (*1 mark*)

Balance in the order Ca, P, H, O

c $2\ Al + 3\ H_2SO_4 \rightarrow Al_2(SO_4)_3 + 3\ H_2$ (*1 mark*)

Balance in the order Al, S, H, O

d $2\ Fe_2O_3 + 3\ C \rightarrow 4\ Fe + 3\ CO_2$ (*1 mark*)

Balance in the order Fe, C, O

3 **a** $Cu + 4\ HNO_3 \rightarrow Cu(NO_3)_2 + 2\ NO_2 + 2\ H_2O$ (*1 mark*)

Balance in the order Cu, N, H, O

b $S + 6\ HNO_3 \rightarrow H_2SO_4 + 6\ NO_2 + 2\ H_2O$ (*1 mark*)

Balance in the order S, N, H, O

4 AQA answer

$OF_2 + H_2O \rightarrow O_2 + 2\ HF$ (*1 mark*)

OCR answer

$N_2H_4 + 2\ NH_2Cl \rightarrow 2\ NH_4Cl + N_2$ (1 mark for N_2; 1 mark for NH_4Cl and balancing)

3.4 Percentage Yield

Learning outcomes

After completing the worksheet you should be able to:

- use balanced equations to calculate percentage yields, actual and theoretical yields based on data given
- rearrange and solve equations involving percentage yield calculations.

This worksheet builds on understanding from Topic 3.1: Amount of substance and the mole.

Introduction

'Per cent' means out of 100. A percentage is therefore a number or ratio expressed as a fraction of 100.

The percentage yield of a reaction expresses the amount of product you actually made (*actual yield*) compared with the amount you theoretically could make (*theoretical yield*) as a percentage. This can be shown by the equation below

$$\text{Percentage yield, } \% = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%$$

The yields referred to in this equation can be expressed either as a number of moles or as a mass, but identical units must be used for both the actual and theoretical yields. You must compare like for like.

Worked example

Question 1

Ammonium sulfate is produced by the reaction of ammonium hydroxide and sulfuric acid:

$$2NH_4OH + H_2SO_4 \rightarrow (NH_4)_2SO_4 + 2H_2O$$

If the theoretical yield of ammonium sulfate was 114 g and the actual yield 111 g, calculate the percentage yield of the reaction.

Answer

As both the actual and theoretical yield for this reaction are given in the question, simply substitute the values into the equation:

$$\text{Percentage yield} = \frac{111\,\text{g}}{114\,\text{g}} \times 100\%$$

$$= 97.36\%$$

$$= 97.4\% \text{ (to 3 significant figures)}$$

Question 2

Titanium is produced by the reduction of titanium chloride with sodium. The equation for the reaction is:

$$TiCl_4 + 4Na \rightarrow Ti + 4NaCl$$

Calculate the percentage yield for the reaction if 28 g of titanium was produced from the reduction of 138 g of $TiCl_4$.

Answer

Step 1

Calculate the number of moles in 138 g of $TiCl_4$ (molar mass = 189.9 g mol^{-1}):

$$\text{Moles} = \frac{138\text{ g}}{189.9\text{ g mol}^{-1}} = 0.7267\text{ mol}$$

Note: Carry intermediate numbers through as accurately as you can using the 'Ans' function on your calculator. Record intermediate values in working to 1 significant figure more than you intend to give the final answer.

Step 2

Use the stoichiometric ratio of $TiCl_4$ to Ti to determine the number of moles of Ti that should theoretically be produced by this number of moles of $TiCl_4$:

1 mol $TiCl_4$: 1 mol of Ti

Therefore the *theoretical yield* of Ti is 0.7267 mol.

Step 3

Calculate the *actual yield* of Ti by finding the number of moles in 28 g of Ti:

$$\text{Moles} = \frac{28\text{ g}}{47.9\text{ g mol}^{-1}} = 0.584\text{ mol}$$

Step 4

Substitute the values for the theoretical and actual yield into the equation.

$$\text{Percentage yield} = \frac{0.5846 \text{ mol}}{0.7267 \text{ mol}} \times 100\%$$

$$= 80.4\%$$

$$= 80\% \text{ (to 2 significant figures)}$$

Questions

1 Calculate the percentage yields for each of the reactions below, given the actual and theoretical yields.

a $CuO + C \rightarrow Cu + CO_2$ *(1 mark)*

Actual yield of Cu: 2.6 mol   Theoretical yield of Cu: 3.2 mol

b $CuCO_3 + H_2SO_4 \rightarrow CuSO_4 + H_2O + CO_2$ *(1 mark)*

Actual yield of $CuSO_4$: 104 g   Theoretical yield of $CuSO_4$: 112 g

c $CuO + 2HCl \rightarrow CuCl_2 + H_2O$ *(2 marks)*

Actual yield of $CuCl_2$: 56 g   Theoretical yield of $CuCl_2$: 0.63 mol

2 Magnesium reacts with oxygen as shown in the equation below:

$$2Mg + O_2 \rightarrow 2MgO$$

Calculate the percentage yield of the reaction, given that burning 2.32 g of magnesium produced 2.39 g of magnesium oxide. *(4 marks)*

3 Aluminium is produced by the electrolysis of aluminium oxide. The equation for the reaction is:

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

Calculate the percentage yield for the reaction if 1078 g of aluminium oxide produced 539 g of aluminium. *(4 marks)*

4 $CuO + H_2SO_4 + 4H_2O \rightarrow CuSO_4{\bullet}5H_2O$

Calculate the mass of hydrated copper sulfate produced from 21.9 g of copper oxide if the percentage yield for the reaction was 82.1%. *(4 marks)*

5 *From OCR Chemistry A Chains, energy and resources F322/01 January 2013 (Question 5a)*

Chloroethene CH_2CHCl is made from 1,2-dichloroethane CH_2ClCH_2Cl.

$$CH_2ClCH_2Cl \rightarrow CH_2CHCl + HCl$$

A chemical plant uses 19.80 tonnes of 1,2-dichloroethane to make 11.25 tonnes of chloroethane.

Calculate the percentage yield of chloroethene. *(3 marks)*

(1 tonne = 1.00×10^6 g)

ANSWERS

Answers

1 **a** Percentage yield $= \dfrac{2.6 \text{ mol}}{3.2 \text{ mol}} \times 100\%$

$= 81\%$

b Percentage yield $= \dfrac{104 \text{ g}}{112 \text{ g}} \times 100\%$

$= 93\%$

c Theoretical yield of Copper in g = 0.63 mol × 134.5 g mol^{-1} = 85 g

Percentage yield = $\dfrac{56 \text{ g}}{85 \text{ g}}$ × 100% = 66.1% = 66% (to 2 significant figures)

2 Number of moles of magnesium, Mg = $\dfrac{2.32 \text{ g}}{24.3 \text{ g mol}^{-1}}$ = 0.09547 mol

Number of moles of magnesium oxide, MgO theoretically this could make = 0.09547 mol

Actual number of moles of magnesium oxide, MgO made = $\dfrac{2.39 \text{ g}}{40.3 \text{ g mol}^{-1}}$

= 0.05930 mol

Percentage yield = $\dfrac{0.05930 \text{ mol}}{0.09547 \text{ mol}}$ × 100% = 62.1% (to 3 significant figures)

3 Number of moles in 1078 g of aluminium oxide, Al_2O_3 = $\dfrac{1078 \text{ g}}{102.0 \text{ g mol}^{-1}}$ = 10.57 mol

Number of moles of aluminium, Al theoretically this could make = 10.57 × 2 = 21.14 mol

Number of moles of aluminium, Al actually made = $\dfrac{539 \text{ g}}{27.0 \text{ g mol}^{-1}}$ = 19.96 mol

Percentage yield = $\dfrac{19.96 \text{ mol}}{21.14 \text{ mol}}$ × 100% = 94.4% (to 3 significant figures)

4 Number of moles in 21.9 g of copper oxide, CuO = $\dfrac{21.9 \text{ g}}{79.5 \text{ g mol}^{-1}}$ = 0.2755 mol

Number of moles of hydrated copper sulfate, $CuSO_4 \cdot 5H_2O$ this could theoretically make = 0.2755 mol

82.1% = $\dfrac{\text{actual yield in moles}}{0.2755 \text{ mol}}$ × 100

Actual yield $= 0.2755 \text{ mol} \times \dfrac{82.1}{100}$

Actual yield = 0.2261 mol

Actual mass of hydrated copper sulfate, $CuSO_4 \cdot 5H_2O$ produced

= 0.2261 mol × 249.6 g mol^{-1}

= 56.5 g (to 3 significant figures)

5 *From OCR Chemistry A Chains, energy and resources Mark scheme F322/01 January 2013 (Question 5)*

Answer	Marks	Guidance
Number of moles in 19.80 tonnes of 1, 2-dichloroethane $n = \frac{19.80 \times (1.00 \times 10^6\ g)}{99.0\ g\ mol^{-1}}$ $= 200000$ mol Number of moles of chloroethene could theoretically be made = 200000 mol Number of moles of chloroethene actually made $n = \frac{11.25 \times (1.00 \times 10^6\ g)}{62.5\ g\ mol^{-1}}$ $= 180000$ mol $\text{Percentage yield} = \frac{180000\ mol}{200000\ mol} \times 100\%$ $= 90\%$	3	IF there is an alternative answer, check to see if there is any ECF credit possible using working below. ALLOW approach based on mass for 2nd and 3rd marks Theoretical mass of chloroethene = 200000 × 62.5 OR 12500000 (g) OR 1.25 × 107 (g) ALLOW approach based on grams rather than tonnes ALLOW ECF throughout from wrong Mr value(s) with final % yield to 2 or more significant figures DO NOT ALLOW final mark for an answer above 100%

3.4 Ratios and Amount of Substance

Introduction

When an equation is balanced it gives us information about the amount of substances that react together and that are produced.

For example, look at the balanced equation for the reaction between magnesium and hydrochloric acid;

$$Mg(s) + 2\ HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$$

From the equation we know that 1 mol of Mg reacts with 2 mol of HCl to give 1 mol of $MgCl_2$ and 1 mol of H_2 gas. The magnesium reacts with the acid in a 1 : 2 molar ratio.

You'll notice that the total number of moles of reactant does not equal the total number of moles of product. This is because some species may contain more moles of certain atoms than others. For example, 1 mol of HCl contains 1 mol of Cl atoms whereas 1 mol of $MgCl_2$ contains 2 mol of Cl atoms. When balancing an equation we balance the number of individual atoms.

Worked example

Question

Calculate the mass of carbon monoxide needed to produce 11.2 g of iron from the reduction of iron oxide. The equation for the reaction is given below.

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

Answer

Step 1

Calculate the number of moles in 11.2 g of iron;

$$\text{Moles} = \frac{11.2\ \text{g}}{55.8\ \text{g mol}^{-1}} = 0.2007\ \text{mol}$$

Note: Carry intermediate numbers through as accurately as you can and where possible use the 'Ans' function on your calculator. In this example intermediate values have been written down to one significant figure more than you are going to give the final answer to, but have been carried through on the calculator using the 'Ans' function.

Step 2

Use ratios to determine the number of moles of carbon monoxide required to produce this number of moles of iron. The ratio of CO to Fe is:

3 mol CO : 2 mol of Fe

Divide both sides by 2 to find out how much CO is needed for 1 mol of Fe:

1.5 mol CO : 1 mol Fe

Multiply both sides by 0.2007 to find out how much CO is needed for 0.2007 mol of Fe:

0.3011 mol CO : 0.2007 mol Fe

Step 3

Convert the number of moles of CO into a mass of CO:

$$0.3011 \text{ mol} \times 28.0 \text{ g mol}^{-1} = 8.430 \text{ g} = 8.43 \text{ g (to 3 significant figures)}$$

Give your final answer to the same degree of accuracy as the least accurate value given in the question. In this case 3 significant figures.

Questions

1 Sodium hydrogen carbonate can be neutralised by an excess of sulfuric acid as shown by the equation below:

$$2\ NaHCO_3 + H_2SO_4 \rightarrow Na_2SO_4 + 2\ H_2O + 2\ CO_2$$

a Calculate the number of moles in 105 g of $NaHCO_3$. (*1 mark*)

b Hence calculate the amount in moles of Na_2SO_4 which will be produced by the neutralisation of this sample of $NaHCO_3$. (*1 mark*)

c State the mass of Na_2SO_4 which will therefore be produced by this sample of $NaHCO_3$. (*1 mark*)

2 Lead nitrate will react with potassium iodide in a very unusual solid–solid reaction. The equation for the reaction is:

$$Pb(NO_3)_2 + 2\ KI \rightarrow PbI_2 + 2\ KNO_3$$

Calculate the mass of lead iodide that will be produced by the reaction of 14.1 g of potassium iodide with an excess of lead nitrate. (*3 marks*)

3 Solid copper can be prepared from copper oxide by its reaction with ammonia. The equation for the reaction is:

$$3\ CuO + 2\ NH_3 \rightarrow 3\ Cu + N_2 + 3\ H_2O$$

Calculate the mass of copper oxide which would react with 0.425 g of ammonia. (*3 marks*)

4 In a propane gas burner, the propane fuel undergoes complete combustion. Calculate the mass of oxygen required for the complete combustion of 62 g of propane. (*3 marks*)

5 Tin chloride exists as a hydrated salt. It can be dehydrated on heating:

$$SnCl_2{\bullet}xH_2O \rightarrow SnCl_2 + x\ H_2O$$

If during the dehydration of a sample of hydrated tin chloride, 118.6 g of anhydrous tin chloride and 22.5 g of water are produced, calculate the value of x and hence state the formula of hydrated tin chloride. (*3 marks*)

6 Zinc chloride exists as a hydrated salt. It can be dehydrated on heating;

$$ZnCl_2{\bullet}xH_2O \rightarrow ZnCl_2 + x\ H_2O$$

If 19.4 g of water are produced by the dehydration of 56.2 g of the hydrated salt, calculate the value of x and hence state the formula of hydrated zinc chloride. (*4 marks*)

ANSWERS

1 **a** moles of $NaHCO_3 = \frac{105\text{ g}}{84.0\text{ g mol}^{-1}} = 1.25\text{ mol}$ (*1 mark*)

b 2 $NaHCO_3$: 1 Na_2SO_4, ∴ 1 $NaHCO_3$: 0.5 Na_2SO_4 and
∴ 1.25 mol $NaHCO_3$: 0.625 mol Na_2SO_4 (*1 mark*)

c 0.625 mol × 142.1 g mol^{-1} = 88.81 g = 88.8 g (to 3 significant figures) (*1 mark*)

2 No. of moles in 14.1 g of KI = $\frac{14.1\text{ g}}{166.0\text{ g mol}^{-1}} = 0.08494\text{ mol}$ (*1 mark*)

2KI : 1PbI_2, therefore moles of PbI_2 produced = $\frac{0.08494\text{ mol}}{2} = 0.04247\text{ mol}$ (*1 mark*)

Mass of PbI_2 produced = 0.04247 mol × 461.0 g mol^{-1} = 19.57 g = 19.6 g
(to 3 significant figures) (*1 mark*)

3 No. of moles in 0.425 g of NH_3 = $\frac{0.425\text{ g}}{17.0\text{ g mol}^{-1}} = 0.025\text{ mol}$ (*1 mark*)

3 CuO : 2 NH_3, therefore moles of CuO needed = $\frac{0.025}{2} \times 3 = 0.0375\text{ mol}$ (*1 mark*)

Mass of CuO needed = 0.0375 mol × 79.5 g mol^{-1} = 2.981 g = 2.98 g (to 3 significant figures). (*1 mark*)

4 $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$ (*1 mark*)

No. of moles in 62 g of propane = $\frac{62\text{ g}}{44.0\text{ g mol}^{-1}} = 1.409\text{ mol}$ (*1 mark*)

1 C_3H_8 : 5 O_2, therefore moles of O_2 needed = 1.409 mol × 5 = 7.045 mol (*1 mark*)
Mass of O_2 needed = 7.045 mol × 32.0 g mol^{-1} = 225 g = 230 g (to 2 significant figures). (*1 mark*)

5 No. of moles in 118.6 g of $SnCl_2$ = $\frac{118.6\text{ g}}{189.7\text{ g mol}^{-1}} = 0.6252\text{ mol}$ (*1 mark*)

No. of moles in 22.5 g of H_2O = $\frac{22.5\text{ g}}{18.0\text{ g mol}^{-1}} = 1.25\text{ mol}$ (*1 mark*)

If 1 $SnCl_2$: x H_2O = 0.625 mol $SnCl_2$: 1.25 mol H_2O = 1 mol $SnCl_2$: 2 mol H_2O then x = 2
The formula for hydrated tin chloride is $SnCl_2{\bullet}2H_2O$. (*1 mark*)

6 Mass of anhydrous $ZnCl_2$ produced = 56.2 g – 19.4 g = 36.8 g (by the conservation of mass rule).

No. of moles in 36.8 g of $ZnCl_2$ = $\frac{36.8\text{ g}}{136.4\text{ g mol}^{-1}} = 0.2697\text{ mol}$ (*1 mark*)

No. of moles in 19.4 g of H_2O = $\frac{19.4\text{ g}}{18.0\text{ g mol}^{-1}} = 1.077\text{ mol}$ (*1 mark*)

If 1 $ZnCl_2$: x H_2O = 0.2697 mol $ZnCl_2$: 1.077 mol H_2O = 1 $ZnCl_2$: 3.99 H_2O then x = 4
The formula for hydrated zinc chloride is $ZnCl_2{\bullet}4H_2O$. (*1 mark*)

3.4 Investigating carbon dioxide absorption

Learning outcomes

After completing the worksheet you should be able to:

- perform calculations using amount of substance in moles involving mass, gas volume, solution volume, and concentration
- use stoichiometry in equations to enable these calculations to be carried out
- calculate in standard form.

Background

Carbon dioxide is produced by the burning of fossil fuels. The percentage of carbon dioxide in the atmosphere is increasing and this increase is expected to lead to significant changes to the Earth's climate. One strategy to limit the increase could be to capture some of the carbon dioxide already in the air and then to store it in a suitable location, such as in rock formations. Passing air through a fine mist of sodium hydroxide solution to form sodium carbonate could be one way of capturing it; the sodium carbonate can be transported and treated to release the carbon dioxide.

Equation 1 shows how sodium hydroxide solution absorbs carbon dioxide to form sodium carbonate solution.

Equation 1: $2NaOH(aq) + CO_2(g) \rightarrow Na_2CO_3(aq) + H_2O(l)$

Equations 2, 3, and 4 show how the sodium carbonate solution is treated to form calcium carbonate solid and how this can be heated to release carbon dioxide gas, and regenerate the calcium hydroxide used in the treatment.

Equation 2: $Na_2CO_3(aq) + Ca(OH)_2(s) \rightarrow 2NaOH(aq) + CaCO_3(s)$

Equation 3: $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

Equation 4: $CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(s)$

The process would need to be carried out on a very large scale in order to have any effect on the carbon dioxide concentration in the air. Calculations can be done to estimate the amounts of sodium hydroxide solution needed and the masses of calcium carbonate which would need to be transported.

A similar reaction is used to absorb carbon dioxide in closed environments such as on the International Space Station (ISS). Here, carbon dioxide breathed out by astronauts is absorbed by lithium hydroxide solid in a reversible, exothermic reaction.

Equation 5: $2LiOH(s) + CO_2(g) \rightarrow Li_2CO_3(s) + H_2O(l)$

Careful calculations must be carried out to ensure that enough lithium hydroxide is present in the system to absorb all the carbon dioxide produced.

An alternative is to use the compound lithium peroxide, Li_2O_2. This reacts with carbon dioxide as shown in Equation 6.

Equation 6: $2Li_2O_2\ (s) + 2CO_2(g) \rightarrow 2Li_2CO_3(s) + O_2\ (g)$

Peroxides are powerful oxidising agents, and can increase the rate of combustion of organic materials such as paper, wood and fabrics.

Questions

1 This question is about the carbon dioxide absorption system used on board the International Space Station (ISS). This typically has about six astronauts on board at any one time. On average, a human being breathes out about 450 dm^3 of carbon dioxide each day.

a **i** Calculate the typical number of moles of carbon dioxide breathed out per day by astronauts on the ISS. *(2 marks)*

ii Use Equation 4 to calculate the mass of lithium hydroxide needed to absorb this volume of carbon dioxide. 1 mole of any gas occupies 24.8 dm^3 at 25 °C and 1 atmosphere. You can assume that these are the conditions in the ISS. *(3 marks)*

iii Lithium hydroxide solid is used to absorb carbon dioxide. Carbon dioxide absorption often uses other absorbants such as sodium hydroxide solution or potassium hydroxide solid. Discuss the advantages of lithium hydroxide solid as an absorbant in the ISS over these alternatives. *(3 marks)*

b Cargo, including replacement lithium hydroxide, is sent up to the ISS about every 3 weeks.

i How much lithium hydroxide should be sent up on each cargo shipment? Comment on your answer. *(2 marks)*

ii Use information in the introductory passage to suggest one way in which this amount could be reduced. *(1 mark)*

2 Some spacecraft use a system based on a lithium peroxide absorbant (Li_2O_2) to remove carbon dioxide, instead of lithium hydroxide.

a By considering the mass of carbon dioxide removed by 1 kg of absorbant, explain why lithium peroxide is sometimes preferred to lithium hydroxide to absorb carbon dioxide in a spacecraft. *(3 marks)* b Use information from the background material to explain one other advantage and one other disadvantage of the use of lithium peroxide in a spacecraft. (*4 marks*)

3 This question is about the proposal to absorb carbon dioxide in the air by absorbing it in sodium hydroxide solution.

The atmosphere currently contains approximately 3×10^{15} kg of carbon dioxide. It would only make sense to use methods such as this one on a large scale if it can reduce the amount of carbon dioxide in the atmosphere by a significant proportion – say 5%.

a **i** Calculate what mass (in g) of carbon dioxide would need to be absorbed in order to achieve this 5% reduction. (*1 mark*)

ii Use Equation 1 to find the amount, in moles, of sodium hydroxide solution needed to do this. (*2 marks*)

b One study has suggested using sodium hydroxide in the absorbers at a concentration of 7.2 mol dm^{-3}, since this helps to avoid water loss during the absorption.

i Calculate the volume of sodium hydroxide needed to achieve a 5% reduction in carbon dioxide. (*1 mark*)

ii How many Olympic-sized swimming pools would be needed to contain this volume of sodium hydroxide?(One Olympic-sized swimming pool has a volume of 2.5×10^6 dm^3.) (*1 mark*)

4 Absorption of this carbon dioxide could take place in a number of locations – say 1000 – and over a period of 100 years. Scientists must consider whether the scale of the whole operation would be realistic on this timescale. Use your answer to question **3** along with information from Equations 2, 3, and 4 to discuss whether or not you think that this proposal could be a realistic possibility. (*6 marks*)

ANSWERS

1 a i Volume of carbon dioxide produced per day = 6 × 450

= 2700 dm^3 *(1 mark)*

Moles of carbon dioxide produced = 112.5 *(1 mark)*

ii Moles of lithium hydroxide needed = 112.5 *(1 mark)*

M_r of lithium hydroxide = 23.9 *(1 mark)*

Mass of lithium hydroxide = 112.5 × 23.9

= 2689 g OR 2.69 kg *(1 mark)*

iii Reducing the mass of the absorbant needed will be very important, since it will all need to be carried up by cargo rocket to the ISS. *(1 mark)*

Lithium hydroxide has a very low M_r compared to sodium hydroxide or potassium hydroxide, *(1 mark)*

so a smaller mass will be needed to absorb the same number of moles of carbon dioxide. Water used to form the solution would also need to be carried up to the ISS. *(1 mark)*

b i Each cargo shipment would need to carry sufficient lithium hydroxide for about 21 days = 2.69 × 21

= 56.4 kg. *(1 mark)*

(Allowing a 10% safety margin this would be 60 kg or the mass of a single astronaut, so this is probably a feasible amount to carry.) *(1 mark)*

ii One way of reducing the amount needed would be to reverse the reaction to reform lithium hydroxide. This would require energy, which could probably be harnessed from sunlight. *(1 mark)*

2 a Mass of carbon dioxide removed by 1 kg Li_2O_2 = 961 g *(1 mark)*

Mass of carbon dioxide removed by 1 kg LiOH = 920.5 g *(1 mark)*

Li_2O_2 is favoured because less mass needs to be carried up into space. *(1 mark)*

b Advantage: reaction with carbon dioxide generates oxygen *(1 mark)*

which could be breathed by astronauts. *(1 mark)*

Disadvantage: peroxides oxidise organic material *(1 mark)*

this could cause fires on the spacecraft. *(1 mark)*

3 a i 5% of 3×10^{15} kg = 1.5×10^{14} kg

= 1.5×10^{17} g. *(1 mark)*

ii This is $\frac{1.5\times10^{17}}{44}$ = 3.4×10^{15} mol carbon dioxide. *(1 mark)*

Number of moles of sodium hydroxide needed = 6.8×10^{15} mol. *(1 mark)*

b i Volume of 7.2 mol dm^{-3} sodium hydroxide needed = $\frac{6.8\times10^{15}}{7.2}$

= 9.5×10^{14} dm^3. *(1 mark)*

ii Number of swimming pools needed = $\frac{9.5\times10^{14}}{2.5\times10^{6}}$

= 3.8×10^{8}. *(1 mark)*

Question	Answer	Marks	Guidance
4	**Level 3 (5–6 marks)** Correctly estimates number of swimming pools needed per location per year, clearly linked to reasoned conclusion about feasibility. AND Discusses a range of other factors (2 or 3) clearly linked to a stated conclusion about feasibility of proposal. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Makes an estimate of number of swimming pools needed per location per year/day with some attempt to link to feasibility of proposal. AND Discusses a small number of other factors (1 or 2) which may not all be linked to a stated conclusion about feasibility of proposal. *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Makes some progress in making an estimate of number of swimming pools needed per location per year/day although this may not be linked to a conclusion about feasibility. AND Other factors (1 or 2) are mentioned briefly but are not likely to be linked to a stated conclusion about feasibility of proposal. *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** *No response or no response worthy of credit.*	6	Calculation Per location: 3.8×10^5 pools needed over 100 years. Each year 3.8×10^3 pools or each day about 10 pools. Other factors to discuss: However NaOH can be regenerated by Equation 2. This will generate large masses of calcium carbonate, $CaCO_3$ which will need to be transported (this could be calculated). Energy will be needed to release the carbon dioxide again. Large volume of rock formations will be needed to contain this carbon dioxide.

Checklist

Amount of substance

Specification reference	Checklist questions	
2.1.1 e	Can you use the terms *relative molecular mass*, *Mr*, and *relative formula mass* and their calculation from relative atomic masses?	☐
2.1.3 a i	Can you explain and use the term *amount of substance*?	☐
2.1.3 a ii	Can you explain and use the term *mole* (symbol 'mol'), as the unit for amount of substance?	☐
2.1.3 a iii	Can you explain and use the term the *Avogadro constant*, N_A (the number of particles per mole, 6.02×10^{23} mol^{-1})?	☐
2.1.3 a iv	Can you explain and use the term *molar mass* (mass per mole, units g mol^{-1})	☐
2.1.3 a v	Can you explain and use the terms molar gas volume (gas volume per mole, units dm^3 mol^{-1})?	☐
2.1.3 b i	Can you use the terms: empirical formula (the simplest whole number ratio of atoms of each element present in a compound)	☐
2.1.3 b ii	Can you use the terms: molecular formula (the number and type of atoms of each element in a molecule)?	☐
2.1.3 c	Can you calculate empirical and molecular formulae, from composition by mass or percentage compositions by mass and relative molecular mass?	☐
2.1.3 d	Can you explain the terms *anhydrous*, *hydrated* and *water of crystallisation*?	☐
2.1.3 d	Can you calculate the formula of a hydrated salt from given percentage composition, mass composition or based on experimental results?	☐

Specification reference	Checklist questions	
2.1.3 e i	Can you perform calculations, using amount of substance (in moles), involving mass?	☐
2.1.3 e ii	Can you perform calculations, using amount of substance (in moles), involving gas volume?	☐
2.1.3 e iii	Can you perform calculations, using amount of substance (in moles), involving solution volume and concentration?	☐
2.1.3 f	Can you give the ideal gas equation: $pV = nRT$?	☐
2.1.3 g	Can you use stoichiometric relationships in calculations?	☐
2.1.3 h i	Can you use calculations to determine the percentage yield of a reaction or related quantities?	☐
2.1.3 h ii	Can you use calculations to determine the atom economy of a reaction?	☐
2.1.3 i	Can you describe the techniques and procedures required during experiments requiring the measurement of mass, volumes of solutions and gas volumes?	☐
2.1.3 j	Can you describe the benefits for sustainability of developing chemical processes with a high atom economy?	☐