

Mastering Maths

for A Level Edexcel Chemistry

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Teacher's Introduction

Chemistry students sometimes find the mathematical skills required for success at A Level a challenge, especially when expected to apply them to the context of Chemistry. The new A Level exams have set a much higher bar for the level of maths skills required, and have, therefore, provided an increased level of challenge. The key aim of this resource is to allow students to master the core mathematical skills **so you can focus on the Chemistry!**

Some sections are relatively basic, and serve to boost confidence and eradicate any bad habits. Others will provide even the brightest students with the opportunity to practise the more challenging mathematical skills. All chemical contexts are explained, so that these sheets may be used at any time in the course. Some will be beneficial right at the start of Year 12, while others will provide support for Year 13 students who are dropping maths marks in the run-up to the final exams.

The resource includes a table mapping each basic maths skill outlined in the exam board's published list to each specification point where the skill is found. The required mathematical skills are driven by the Department for Education. The assessment marks of quantitative skills in both AS and A Level papers will comprise a minimum of 20% of the required mathematical skills for Chemistry (Level 2 or above).

Skills Sections

Each section covers all the core mathematical skills mentioned in the exam board's published requirements list. Some skills are treated relatively briefly (e.g. mathematical symbols), while others are given several sections (e.g. rearranging equations).

Each section contains:

- mathematical guidance on the skill
- worked examples, including examples in a chemical context
- a mix of simple questions and in-context questions to practise the relevant skill

Diagnostic Test

This section includes a diagnostic test that is designed to give an assessment of students' comfort with different mathematical skills. This could be used at the start of Year 12 to gain a flavour of different students' background knowledge and ability.

The test indicates the mathematical skills tested in each question, and, therefore, specific skills with which the students are still struggling can be identified.

December 2017

Update v1.1, January 2024:

- Page 13 – 2.605 in solution for b) corrected to 3.605
- Page 64 – 35.9 corrected to 35.7 in first line of answer to Uncertainty I question 3

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*resulting from minor specification changes, suggestions from teachers and peer reviews, or occasional errors reported by customers

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MATHS SKILLS LIST

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Maths skill (skills in bold are tested at A Level only)		Chapter / Diagnostic test number	
Arithmetic and numerical computation			
0.0	Recognise and make use of appropriate units in calculation	2 & 3	Units
0.1	Recognise and use expressions in decimal and ordinary form	1	Decim
0.2	Use ratios, fractions and percentages	5, 6 & 7	Fracti Perce Scalin
0.3	Estimate results		Test
0.4	Use calculators to find and use power, exponential and logarithmic functions	Appendix 1	Using
Handling data			
1.1	Use an appropriate number of significant figures	4	Signifi
1.2	Find arithmetic means	8	Calcu
1.3	Identify uncertainties in measurements and use simple techniques to determine uncertainty when data are combined	9 & 10	Uncer
Algebra			
2.1	Understand and use the symbols: =, <, <<, >>, >, $\propto$, $\sim$, equilibrium sign	11	Math
2.2	Change the subject of an equation	12, 13, 14	Using
2.3	Substitute numerical values into algebraic equations using appropriate units for physical quantities		
2.4	Solve algebraic equations		
2.5	Use logarithms in relation to quantities that range over several orders of magnitude	15	Logar
Graphs			
3.1	Translate information between graphical, numerical and algebraic forms	16	Const
3.2	Plot two variables from experimental or other data		
3.3	Determine the slope and intercept of a linear graph	17, 18	Analy Equat
3.4	Calculate rate of change from a graph showing a linear relationship		
3.5	Draw and use the slope of a tangent to a curve as a measure of rate of change		
Geometry and trigonometry			
4.1	Use angles and shapes in regular 2D and 3D structures	19	Shape
4.2	Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects		
4.3	Understand the symmetry of 2D and 3D shapes		

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SPECIFICATION LINKS – I

Chapter in this resource	MS	Specification Re
Units I	0.0	5.1.1 Titration calculation
Units II		10.4 Equilibrium constant
		13B.19 Gibbs equations
Decimals and Standard Form	0.1	1.7 Mole calculations 12.1.2 pH calculations 12.1.1 K_w
Fractions, Percentages and Ratios	0.2	5.1.4 Percentage yield & atom economy 5.6 Balancing equations
Percentage Mass, Purity and Yield		5.1.4 Percentage yield & atom economy 5.5 Percentage by mass
Scaling Quantities		5.5 Percentage by mass
Using a Calculator	0.4	1.7 Mole calculations p 12.20 Buffers
Significant Figures	1.1	1.7 Mole calculations 5.5 $pV = nRT$ 5.1.1 Titration calculation
Calculating Means	1.2	1.10 Mass spectrometry 5.1.1 Titration calculation
Uncertainty I	1.3	5.1.1 Titration calculation
Uncertainty II		
Mathematical Symbols	2.1	10.4 K_c 12.9 K_a
Using Equations I	2.2 2.3 2.4	16.1 Rate constant 10.4 K_c
Using Equations II		8.8 Hess' Law
Using Equations III		12.8 pH 12.1.3 pK_a and pK_w
Logarithms	2.5	12.8 pH 12.1.3 pK_a and pK_w 16.1.2 Arrhenius
Constructing Graphs	3.1 3.2	16.1 Rates Concentration–time graphs
Rearranging Equations to the Form $y = mx + c$	3.3	5.5 $pV = nRT$ 13B.19 Gibbs equations 16.1.2 Arrhenius equation
Analysing Graphs	3.4 3.5	9.3 Initial rates
Shapes in Chemistry	4.1 4.2 4.3	2.1.1 Shapes and bond 6A.7 Stereoisomerism 15.1.3 Transition metals

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Be comfortable with using both decimals and standard form, and converting between

Chemists need to be able to manage large and small numbers. Sometimes the size make them difficult to use in calculations.

[illegible]

When doing calculations, it is a lot easier to write these numbers in standard form. decimal point, and gives the size of the number as a power of 10.

Numbers in standard form are written as:

$a \times 10^x$

where a is a number from 1 to 9, and x is the number of decimal places the decimal

If the decimal point moves to the **left** then x is a **positive number**. If the decimal point moves to the **right** then x is a **negative number**.

For example:

$$\underbrace{156000000.0}_{8} = 1.56 \times 10^8$$

The d
move
so x =

$$\underbrace{0.000429}_{4} = 4.29 \times 10^{-4}$$

The d
move
so x =

To convert from standard form to a decimal, you move the decimal x times in the opposite direction of the above.

For example:

$$3.78 \times 10^{-5} = \underbrace{000003.78}_{5} = 0.0000378$$

Rounding a number is a way of shortening numbers so they are easier to use in calculations. Numbers can be rounded to different numbers of decimal places (d.p.).

4.563	
3 d.p.	4.563
2 d.p.	4.56 ←
1 d.p.	4.6
0 d.p.	5

4.56 is closer to 4.5, so it is rounded to 4.5 when rounding to the nearest tenth.

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Standard form on your calculator

To be able to make calculations involving standard form, you will need to know how to use standard form on your calculator.

Standard form button $\boxed{\times 10^x}$

Here are some examples of how to use this button:

$\boxed{3} \boxed{\cdot} \boxed{5} \boxed{\times 10^x} \boxed{4}$

which inputs 3.5×10^4

$\boxed{4} \boxed{\times 10^x} \boxed{3} \boxed{\times} \boxed{6} \boxed{\times 10^x} \boxed{5}$

which inputs the calculation $4 \times 10^3 \times 6 \times 10^5$

WORKED EXAMPLE

A nanotube has a radius of 5×10^{-8} m and is 2.693×10^{-3} m long.

- Write the length of the nanotube as a decimal to 4 decimal places.
- The formula for the volume of the nanotube is $\pi \times r^2 \times l$, where r is the radius and l is the length. Calculate the volume of the nanotube using the following calculation on your calculator to find the volume in standard form.

$$\pi \times (5 \times 10^{-8})^2 \times 2.693 \times 10^{-3}$$

Solution

- $2.693 \times 10^{-3} = 0.002693$ (move the decimal place 3 places to the right)
 0.0027 (round up to 2 significant figures)
- $2.115077254 \times 10^{-17}$ (in standard form)
 $= 2.12 \times 10^{-17}$ (rounded down to 3 significant figures)

PRACTICE QUESTIONS

- Write the following in standard form:
 - 4 250 000 J
 - 0.012 m
 - 623 000 000 000 s
 - 0.0000007896 kg
- Write the following numbers out in full:
 - 6.72×10^{-6} mol
 - 7.59×10^4 atoms
 - 9.91×10^{-4} mol dm⁻³
 - 8.143×10^2 cm³
- Round the following to the given number of decimal places (d.p.):
 - 2.465 g to 2 d.p.
 - 7.9623 g to 3 d.p.
 - 3.14159 g to 3 d.p.
 - 0.956 g to 1 d.p.
- A drug developer dissolves a mass of 1.6289 g of a new drug in a volume of 200 cm³ of water.
 - Write down the mass in grams of the new drug dissolved in the water to 2 d.p.
 - Calculate the concentration of the drug solution in g m⁻³, by dividing the mass by the volume. Give your answer in standard form.
- A reaction has a percentage yield of 13 % and a theoretical yield of 0.20 g of product. Calculate the actual yield in g using the formula.

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

Give your answer in standard form.

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UNITS 1 – COMMON UNITS AND

LEARNING OUTCOME

Understand different units, convert between them, and understand why it is important

THEORETICAL OVERVIEW

Types of unit

In Chemistry, common measurements include length, volume and mass. You will also eventually come across other measurements, such as energy and momentum. The table on the right shows some common units for different types of measurement.

Type of measurement	
length	cm
mass	g
volume	cm ³ dm ³
temperature	°C
time	s

Converting between units

To do a calculation, you might need to convert the values you are given into other units, like converting volumes given in cm³ into dm³, or masses from kg to g. In Chemistry, converting between units often involves multiplying or dividing by powers of 10.

The different prefixes represent different powers of 10.

To convert to prefixes which are **larger** / higher powers of 10, you need to **divide** by 10 for every difference in the power.

To convert to numbers which are **smaller** / negative powers of 10, you need to **multiply** by 10 for every difference in the power.

For example, **centimetres** (10⁻²) are 100 times smaller than a metre.

$$1 \text{ cm} = 0.01 \text{ m}$$

$$100 \text{ cm} = 1 \text{ m}$$

To convert centimetres to metres, divide the value in centimetres by 100 (10²).

To convert metres to centimetres, multiply by 100.

$$\begin{array}{c} \div 100 \\ \curvearrowright \\ 1.3 \text{ cm} = 0.013 \text{ m} \\ \curvearrowleft \\ \times 100 \end{array}$$

Whether it's metres, grams or litres, converting between the different prefixes works the same way. For example, a **kilo**gram is 1000 times (or 10³ times) bigger than a gram.

$$1 \text{ kg} = 1000 \text{ g}$$

$$1 \text{ g} = 0.001 \text{ kg}$$

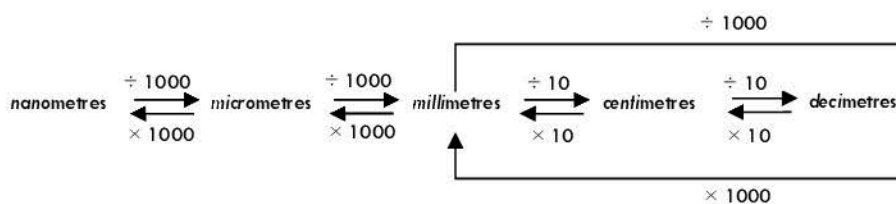
$$\begin{array}{c} \div 1000 \\ \curvearrowright \\ 4.8 \text{ g} = 0.0048 \text{ kg} \\ \curvearrowleft \\ \times 1000 \end{array}$$

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Here is a summary of some common conversions for metres, which are identical for



WORKED EXAMPLES

'Convert 149 kiloseconds to milliseconds.'

$149 \times 10^6 = 149\,000\,000$ ms (10^{-3}) are 10^6 times smaller

'Convert 289 nanometers to millimeters.'

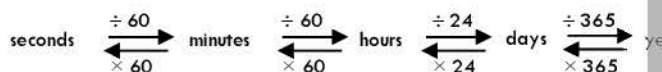
$289 \div 10^6 = 0.000289$ mm are 10^6 times smaller

Time and temperature

You may be more used to temperature in $^{\circ}\text{C}$, but temperature can also be measured in Kelvin (K). To convert between temperatures in $^{\circ}\text{C}$ and K, add 273.

Time is usually measured in seconds in Chemistry. You can multiply or divide to convert between different units of time.

Here is a summary of some common conversions for time:



Units in equations

To use equations, it may be necessary to convert values into suitable units for the equation. Equations should use values in SI units, i.e. moles (mol), pascals (Pa), metres cubed (m^3), and kelvin (K).

WORKED EXAMPLE

A student is recording how temperature changes during an experiment, and records the following. Draw a second table which has values in SI units.

Temperature ($^{\circ}\text{C}$)	Time (min)
21	3:20
29	2:50
38	2:10
47	1:50

Solution

Temperature (K)	Time (s)
$21 + 273 = 294$	$3 \times 60 + 20 = 200$
$29 + 273 = 302$	$2 \times 60 + 50 = 170$
$38 + 273 = 311$	$2 \times 60 + 10 = 130$
$47 + 273 = 320$	$1 \times 60 + 50 = 110$

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PRACTICE QUESTIONS

1. Convert the following quantities:
 - a) 40 m into km
 - b) 0.025 kg into mg
 - c) 180 s in min
 - d) a temperature of 25 °C into K
 - e) 2.45×10^{-7} m into nm
 - f) 0.26×10^{12} J into GJ
 - g) 4.65×10^{22} nm into km
 - h) 684 000 pm in nm
2. Convert the values to the correct base SI units for the ideal gas equation $pV = nRT$:
 - a) $p = 20 \text{ kPa}$, $n = 120 \text{ mmol}$, $T = 0 \text{ }^{\circ}\text{C}$
 - b) $p = 100 \text{ kPa}$, $n = 20 \text{ mmol}$, $T = 20 \text{ }^{\circ}\text{C}$
 - c) $p = 40 \text{ MPa}$, $n = 1450 \text{ } \mu\text{mol}$, $T = 40 \text{ }^{\circ}\text{C}$
3. The heat generated by a reaction, q , is calculated from mass, heat capacity and change in temperature:
 $q = mc\Delta T$
 $m = \text{mass in g}$, $c = \text{specific heat capacity in } \text{J g}^{-1} \text{K}^{-1}$, $T = \text{change in temperature in } ^{\circ}\text{C}$

Convert the values to the correct units for the following data:

- a) $m = 0.250 \text{ kg}$
- b) $m = 4.50 \times 10^6 \text{ mg}$
- c) $c = 0.142 \text{ kJ g}^{-1} \text{K}^{-1}$
- d) $T = 320 \text{ }^{\circ}\text{C}$
- e) $m = 30.0 \text{ mg}$
- f) $c = 129 \text{ J kg}^{-1} \text{K}^{-1}$

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UNITS II – UNITS WITH P

LEARNING OUTCOME

Understand units with powers, and convert between them.

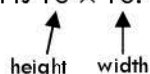
Converting units with powers

Units for area (e.g. m^2) and volume (e.g. m^3) have powers (i.e. 2 and 3). It is more c with multiple dimensions. It may surprise you that 1 m^3 is 1 000 000 times larger than 1 cm^3 .

Areas

Square 2 has 10 times the width and height of square 1.
However, square 2 does **not** have 10 times the area of square 1.
Square 2 has **100 times the area** of square 1.

This is 10 squared (10^2) which is 10×10 .

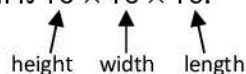


1 dm^2
square 1

Volumes

Cube 2 has 10 times the width, height and depth of cube 1.
However, cube 2 does **not** have 10 times the volume of cube 1.
Cube 2 has **1000 times the volume** of cube 1.

This is 10 cubed (10^3) which is $10 \times 10 \times 10$.



1 dm^3
cube 1

To convert a value in m^3 to a value in dm^3 , you have to multiply by 1 000, and divide for the reverse calculation.

e.g.

$$3 \text{ m}^3 = 3000 \text{ dm}^3$$

$\div 1000$
 mm^3 $\longleftrightarrow$
 $\times 1000$

WORKED EXAMPLES

1 'Convert 400 cm^3 to dm^3 .'

This is going from a smaller unit to a larger unit, so we need to divide.

$$400 \div 10^3 = 0.4 \text{ dm}^3$$

2 'Convert $8.2 \times 10^{-17} \text{ m}^2$ to nm^2 '

This is going from a larger unit to a smaller unit, so we need to multiply.

$$8.2 \times 10^{-17} \times (10^9)^2 = 8.2 \times 10^{-17} \times 10^{18} = 82 \text{ nm}^2$$

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Inverse units

Inverse units include units such as 'per gram' and 'per mole'. These are represented as ' $/\text{g}$ ' or ' $/\text{mol}$ ', or more commonly at A Level, ' g^{-1} ' and ' mol^{-1} '.

These are important for working with compound units, which are made up of two or more different units, like metres per second (m s^{-1}), or grams per mole (g mol^{-1}).

When converting between inverse units, the conversion works the other way round to

To go from a **smaller** unit to a **larger** unit you need to **multiply**.
To go from a **larger** unit to a **smaller** unit you need to **divide**.

For example, to go from grams to kilograms, you multiply by 1000. But to convert per gram to per kilogram, you divide by 1000.

WORKED EXAMPLE

'Convert 950 s^{-1} to ms^{-1} .'

This is going from a smaller unit to a larger unit so we need to divide.

$$950 \div 10^3 = 0.950 \text{ ms}^{-1}$$

Converting concentrations

Concentrations can be given in either mol dm^{-3} or g dm^{-3} . To convert between them use the mole equation (which you will meet in your course if you don't know it already)

$$\text{moles} = \frac{\text{mass}}{M_r}, \text{ so}$$

$$\text{mole concentration (mol dm}^{-3}\text{)} = \frac{\text{mass concentration (g dm}^{-3}\text{)}}{M_r}$$

WORKED EXAMPLE

'Convert 0.20 g dm^{-3} into mol dm^{-3} for H_2SO_4 '

Solution

$$M_r \text{ of } \text{H}_2\text{SO}_4 = 2 \times 1 + 32.1 + 4 \times 16 = 98.1$$

$$\text{Concentration (mol dm}^{-3}\text{)} = \frac{0.20}{98.1}$$

$$= 0.00204 \text{ mol dm}^{-3}$$

WORKED EXAMPLE

'Convert $0.320 \text{ mol dm}^{-3}$ into g dm^{-3} for NaCl .'

Solution

$$M_r \text{ of NaCl} = 23.0 + 35.5 = 58.5$$

$$\text{Concentration (g dm}^{-3}\text{)} = \text{Concentration (mol dm}^{-3}\text{)} \times M_r$$

$$= 0.320 \times 58.5$$

$$= 18.72 \text{ g dm}^{-3}$$

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PRACTICE QUESTIONS

- How many times bigger is:
 - 1 m^3 than 1 dm^3 ?
 - 10 m^3 than 1 dm^3 ?
 - a cube with sides 2 cm long than a cube with sides 1 cm long?
 - 2 m^2 than 1 m^2 ?
 - 5 m^2 than 10 cm^2 ?
- Convert the following quantities:
 - 5 m^3 into mm^3
 - 3 cm^3 into m^3
 - 20 m^2 into dm^2
 - 100 m^2 into mm^2
 - $8.8 \times 10^{-17} \text{ mm}^3$ into km^3
 - 24.55 cm^3 in dm^3
 - 0.250 dm^3 in cm^3
 - 3.0 J g^{-1} into J kg^{-1}
 - 18 mol cm^{-3} into mol dm^{-3}
- Convert the following concentrations:
 - 4.60 g dm^{-3} into mol dm^{-3} for KNO_3
 - $0.500 \text{ mol dm}^{-3}$ into g dm^{-3} for NaOH
 - 11.3 g dm^{-3} into mol dm^{-3} for MgSO_4
 - $0.350 \text{ mol dm}^{-3}$ into g dm^{-3} for Na_2CO_3
- In a titration experiment, the mean titre was recorded as 23.38 cm^3 . Convert it into dm^3 .
- 'A gas at 25°C and a pressure of 150 kPa occupies a volume of 30 dm^3 .
Convert all of these values into suitable units for use in the ideal gas equation.'

The ideal gas equation is:

$$pV = nRT$$

where: p = pressure in Pa (Pascals)
 V = volume in m^3
 n = amount of gas in moles
 $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
 T = temperature in K

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Use and understand significant figures, and give an appropriate number of significant

 $0.\overline{142857}142857142857142\dots$ 

WORKED EXAMPLE

The equation for the thermal decomposition of calcium carbonate into calcium oxide is the following:



In an experiment, 4.36758 g of CaCO_3 decomposes into 3.605 g of CaO .

- Give the mass of CaCO_3 used to 3 significant figures.
- All of the mass lost is due to CO_2 leaving the flask. Calculate the mass of CO_2 produced, using the unrounded numbers and then appropriate number of significant figures.

Solution

- The first 3 significant figures are 4.36, but the next digit is a 7 (above 5) so you round up to 4.37 (to 3 significant figures).
- The mass of CO_2 evolved = $4.36758 - 3.605 = 1.76258$ g. Remember that this is only valid until the end.

The smallest number of significant figures used in the calculation is 4, so the final answer is to 4 significant figures.

$$= 1.763 \text{ g}$$

PRACTICE QUESTIONS

- Round the following numbers to the given number of significant figures:
 - 76 489 to 2 s.f.
 - 0.0061 283 to 3 s.f.
 - 18 990 to 3 s.f.
 - 0.010034 to 2 s.f.
 - 0.0034067 to 4 s.f.
 - 1.9999 to 4 s.f.
- The number of moles of a substance can be calculated using:

$$\text{number of moles} = \frac{\text{mass}}{\text{molar mass}}$$

Calculate the number of moles of the following substances, giving your answers to the correct number of significant figures:

- Mass of $\text{MgCO}_3 = 16.35$ g, molar mass of $\text{MgCO}_3 = 84.3 \text{ g mol}^{-1}$
- Mass of $\text{CoCl}_2 = 77$ g, molar mass of $\text{CoCl}_2 = 129.9 \text{ g mol}^{-1}$
- Mass of $\text{CaCO}_3 = 160.0$ g, molar mass of $\text{CaCO}_3 = 100.1 \text{ g mol}^{-1}$

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FRACTIONS, PERCENTAGES AND RATIOS

LEARNING OUTCOME

Use and convert between fractions, percentages and ratios.

THEORETICAL OVERVIEW

Fractions, percentages and ratios

Fractions, percentages and ratios are different ways of representing proportions.

$$\text{Fractions} \\ \frac{\text{number}}{\text{total number}}$$

$$\text{Percentages} \\ \frac{\text{number}}{\text{total number}} \times 100$$

WORKED EXAMPLE

A water molecule has the chemical formula H_2O , so it consists of two hydrogen atoms and one oxygen atom. There are three atoms in the molecule overall. You can express this information using fractions, percentages or ratios.

Fractions

The fraction of atoms which are hydrogen atoms is:

$$\frac{\text{number of hydrogen atoms}}{\text{total number of atoms}} = \frac{2}{3}$$

Percentages

The fraction of atoms which are hydrogen atoms is:

$$\frac{\text{number of hydrogen atoms}}{\text{total number of atoms}} \times 100 = 66.7 \%$$

Each of these representations contains all of the relevant information to describe the

Converting between fractions, percentages and ratios

As well as being able to calculate fractions, percentages and ratios, it is useful to be able to convert between them.

Fractions and percentages

To convert $\frac{3}{4}$ into a percentage, multiply the fraction by 100:

$$\frac{3}{4} \times 100 = 75 \%$$

It is not always easy to convert from a percentage to a fraction, but some percentages that are useful to recognise are:

$$5 \% \\ \frac{1}{20}$$

$$10 \% \\ \frac{1}{10}$$

$$20 \% \\ \frac{1}{5}$$

$$25 \% \\ \frac{1}{4}$$

$$33.33... \% \\ \frac{1}{3}$$

$$50 \% \\ \frac{1}{2}$$

Ratios and fractions

Imagine grains of salt and sand in the ratio 2:3. There are 2 grains of salt for every 3 grains of sand.

The fraction of salt is:

$$\frac{2}{2+3} = \frac{2}{5}$$

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Ratios and percentages

To convert a ratio into a percentage, do both of the conversions above, i.e.

1. Convert the ratio to a fraction
2. Multiply by 100.

WORKED EXAMPLE

For a glass that contains ice and water in the ratio of 5:3:

1. Use the ratio to find the fraction of the glass that contains water: $\frac{\text{water}}{\text{ice} + \text{water}}$
2. Multiply the fraction of water by 100 to get the percentage of the glass that contains water.

$$\frac{3}{8} \times 100 = \frac{300}{8} = 37.5\%$$

So the glass is 37.5 % water.

Simplifying

There are different ways of writing the same fraction or ratio, and some fractions or ratios are simplified. For example, $\frac{3}{6}$ and $\frac{1}{2}$ are equal (they are both 50 %). $\frac{1}{2}$ is a simplified version of $\frac{3}{6}$.

Fractions and ratios are normally written in their *simplest form*. To simplify a fraction or ratio, the numbers are divisible by the same number, e.g. 9 and 6 are both divisible by 3. If there are no more common divisors.

For example:

- a fraction of $\frac{4}{6}$ (divide top and bottom by 2) is written as $\frac{2}{3}$
- a ratio of 3:6:12, (divide all numbers by 3) is written as 1:2:4

WORKED EXAMPLE

'Aspirin is a molecule derived from the bark of the willow tree, commonly used as a painkiller. It has the chemical formula $\text{C}_9\text{H}_8\text{O}_4$.

- a) What fraction of the atoms in an aspirin molecule is oxygen atoms?
- b) What is this as a percentage?
- c) What is the ratio of carbon atoms to other atoms?

- a) The fraction of oxygen atoms in aspirin is the number of oxygen atoms (4) divided by the total number of atoms (21).

$$\frac{\text{number of oxygen atoms}}{\text{total number of atoms}} = \frac{4}{9+8+4} = \frac{4}{21}$$

- b) Then to get a percentage you need to multiply the fraction of oxygen atoms by 100: $\frac{4}{21} \times 100 = 19.0476... = 19\% \text{ oxygen (to the nearest whole number).}$

- c) To calculate the number of atoms that aren't carbon, you subtract the number of carbon atoms from the total number of atoms:

$$\text{number of carbon atoms} = 9$$

$$\text{number of atoms that aren't carbon} = 21 - 9 = 12$$

$$\text{ratio of carbon atoms to other atoms} = 9:12$$

$$= 3:4$$

← simplify (divide both sides by 3)

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PRACTICE QUESTIONS

- Write the following as decimals:
 - 45 %
 - $\frac{1}{5}$
 - 0.3 %
 - $\frac{0.7}{3.5}$
 - $\frac{5}{12}$
- Write the following as percentages to 1 d.p.:
 - $\frac{5}{7}$
 - $\frac{6}{23}$
 - $\frac{9}{10}$
 - $\frac{7}{9}$
 - $\frac{42}{100}$
- Write the following as their simplest fractions:
 - 25 %
 - 125 %
 - 30 %
 - 60 %
 - 55 %
- There are two isotopes of chlorine, ^{35}Cl and ^{37}Cl , which exist in the ratio 3:1.
 - What fraction of chlorine isotopes are ^{37}Cl ?
 - What percentage of chlorine isotopes are ^{37}Cl ?
- Simplify each of the following formulae to give its empirical formula:
 - C_2H_4
 - $\text{C}_6\text{H}_{12}\text{O}_6$
- In the chemical SO_3 , 60 % of the mass is due to the three oxygen atoms, and 40 % is due to one S atom. Express the mass of SO_3 as a ratio of 'mass due to S : mass due to O'.

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PERCENTAGE MASS, PURITY

LEARNING OUTCOME

Calculate purity and yield as percentages.

THEORETICAL OVERVIEW

Purity

In Chemistry, pure materials are substances which only contain one element or compound. However, many gold rings also contain **impurities**, such as copper, to make the ring more durable.

The purity of a gold ring could be expressed by mass.
For example, a gold ring with a mass of 3.0 g might have:

Mass (g)

From this data, you can calculate the **purity** of each element.

$$\text{Purity (\%)} = \frac{\text{mass of element}}{\text{total mass of ring}} \times 100$$

WORKED EXAMPLE

'What is the percentage purity of gold in the ring described above?'

$$\text{Percentage purity of gold} = \frac{1.5 \text{ g}}{3.0 \text{ g}} \times 100 = 50 \%$$

Answer is given
the values

WORKED EXAMPLE

'A chemist dissolved 60 g of a lump of metal ore containing different metals in an acid solution was filtered to leave the only metal which didn't react with the acid were obtained, what is the percentage of the rock which is gold?'

$$\text{Percentage purity of gold} = \frac{0.70 \text{ g}}{60 \text{ g}} \times 100 = 1.2 \%$$

Answer is given
the values

Percentage by mass

Percentage by mass tells you how much of a compound is one type of element. It is calculated as follows:

$$\text{Percentage by mass (\%)} = \frac{\text{relative formula mass of element} \times \text{number of elements}}{\text{relative formula mass of compound}} \times 100$$

WORKED EXAMPLE

'What is the percentage by mass of O in CaSO_4 ?'

Relative formula mass of O = 16.0 and there are 4 in the formula

$$\text{Relative formula mass of } \text{CaSO}_4 = 40.1 + 32.1 + 4 \times 16.0 = 136.1$$

$$\text{Percentage by mass (\%)} = \frac{16.0 \times 4}{136.1} \times 100 = 47.0 \%$$

WORKED EXAMPLE

'What is the percentage by mass of Mg in $\text{Mg}(\text{OH})_2$?'

Relative formula mass of Mg = 24.3

$$\text{Relative formula mass of } \text{Mg}(\text{OH})_2 = 24.3 + (16 + 1) \times 2 = 58.3$$

$$\text{Percentage by mass (\%)} = \frac{24.3}{58.3} \times 100 = 41.7 \%$$

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Yield

Percentages are also used in Chemistry to represent the yield of a reaction. In a reaction, reactants form desired products. However, some reactants will form side-products or won't react.



If some of the reactants form side-products, this decreases the yield.

To calculate percentage yield:

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

- The actual yield is the mass of product **actually made** in the reaction.
- The theoretical yield is the mass of the product which **could have been made** if all the reactants reacted to form the desired products.

WORKED EXAMPLE

'A student performs a reaction and forms 3.4 g of MgSO_4 . The theoretical mass of MgSO_4 that could have been formed from the reactants is 6.5 g. Find the percentage yield of this reaction.'

$$\begin{aligned} \text{percentage yield} &= \frac{\text{actual yield}}{\text{theoretical yield}} \times 100 \\ &= \frac{3.4}{6.5} \times 100 \\ &= 52\% \end{aligned}$$

PRACTICE QUESTIONS

- Calculate the following as percentages:
 - The purity of copper in 40 g of wire containing 36 g of copper
 - The purity of iron in 20 g of steel containing 15 g of iron
- Calculate the following percentage yields:
 - Actual yield of HNO_3 : 1.2 g
Theoretical yield of HNO_3 : 3.0 g
 - Actual yield of BaCl_2 : 28 g
Theoretical yield of BaCl_2 : 56 g
 - Actual yield of NH_3 : 4.1 g
Theoretical yield of NH_3 : 6.7 g
- Calculate the following percentages by mass:
 - Ca in CaCO_3
 - Mg in MgSO_4
 - Na in NaOH
 - H in Ca(OH)_2
 - Fe in $\text{Fe}_2(\text{SO}_4)_3$

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SCALING QUANTITIES

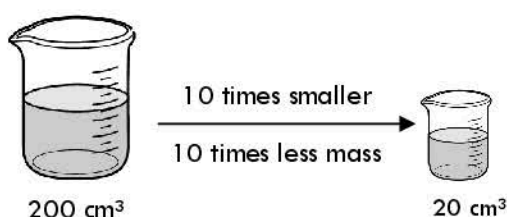
LEARNING OUTCOME

Scale up and down when doing extended calculations.

THEORETICAL OVERVIEW

Scaling up and down

In Chemistry it can be important to scale a quantity up or down in proportion to another.



The trick is to a) divide by the original amount so you know how much there is in, e.g. 1 cm³, then multiply by the new amount to find out how much there is at the end.

WORKED EXAMPLE 1

'5.0 g of a substance is dissolved in 200 cm³. 15 cm³ samples are taken. What mass of substance is in each sample?'

200 cm³ contains 5.0 g

1 cm³ contains $\frac{5}{200} = 0.025$ g

15 cm³ contains 0.375 g

The mass of substance in the samples is: $\frac{5}{200} \times 15 = 0.375$ g

divide
multiply

WORKED EXAMPLE 2: MASS

'30% of a sample weighs 0.48 g. How much does 100% weigh?'

The mass of the whole sample is:

$\frac{0.48}{30} \times 100 = 1.6$ g

divide
then multiply

WORKED EXAMPLE 3: MASS IN A SOLUTION

'0.4 dm³ of a solution contains 3.6 g of a substance. What mass is found in 0.9 dm³ of the solution?'

The number of grams in 0.9 dm³ is:

$\frac{3.6}{0.4} \times 0.9 = 8.1$ g

divide
multiply

WORKED EXAMPLE 4: SCALING DOWN

You can use the exact same method to scale down and work out the value of a smaller quantity.

'If 90% of the mass of a substance is 27 g, find the mass of 80 % of the substance.'

The mass of 80 % of the substance is:

$\frac{27}{90} \times 80 = 24$ g

divide
multiply

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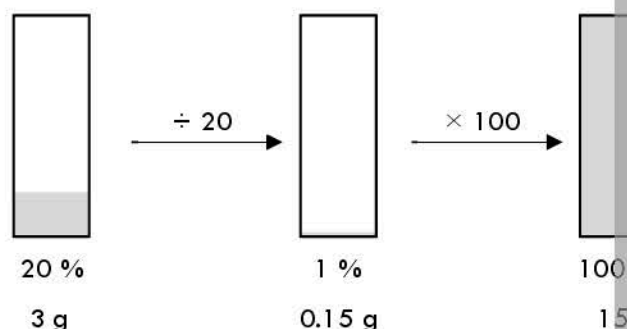
Scaling purity and yields

If you know the percentage purity or yield, you can use it to scale up to find the total mass.

Imagine a reaction with an actual yield of 3 g, and a percentage yield of 20 %.

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

You can find out the theoretical yield by dividing the mass by 20 (to find the mass of 1 %) and then multiplying by 100 (to find the mass of 100 %). This diagram might help visualise the process:



The theoretical yield is, therefore, 15 g.

This concept can also be shown by rearranging the equation for percentage yield:

$$\begin{aligned} \text{percentage yield} &= \frac{\text{actual yield}}{\text{theoretical yield}} \times 100 \\ \text{theoretical yield} \times \text{percentage yield} &= \text{actual yield} \times 100 && \begin{array}{l} \text{multiply by} \\ \text{divide by} \end{array} \\ \text{theoretical yield} &= \frac{\text{actual yield}}{\text{percentage yield}} \times 100 \end{aligned}$$

Adding numbers to the calculation:

$$\begin{aligned} \text{theoretical yield} &= \frac{\text{actual yield}}{\text{percentage yield}} \times 100 \\ &= \frac{3}{20} \times 100 && \begin{array}{l} \text{In} \\ \text{by} \\ 100 \end{array} \\ &= 15 \text{ g} \end{aligned}$$

Identifying 'x'

It is possible to find the value of 'x' in a chemical formula given the relative formula mass and the percentage by mass of the element.

To do this, find the relative formula mass of the compound by scaling the relative formula mass of the element by the percentage by mass.

WORKED EXAMPLE

'A salt with formula FeCl_x contains 44.0 % Fe by mass. Find the value of x.'

$$\text{Relative formula mass} = \frac{55.8}{44} \times 100 = 126.8$$

$$\text{Relative formula mass of } \text{Cl}_x = 126.8 - 55.8 = 71.0$$

$$\text{Relative formula mass of Cl} = 35.5$$

$$\text{Value of } x = \frac{71.0}{35.5} = 2, \text{ so the salt is } \text{FeCl}_2$$

scaling up the relative formula mass of Fe

taking away the mass of Fe from the relative formula mass; the remainder must be due to Cl

each Cl has a mass of 35.5

FeCl_2 has a RFM of 71.0 (x2)

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WORKED EXAMPLE

'A salt contains manganese ions and oxide ions. 53.4 % of the formula mass is due to manganese. Manganese has a relative atomic mass of 54.9. The formula of the salt is MnO_x , where x is a whole number. What is x ?'

The formula can be determined by finding the relative formula mass of the salt, so:

- Calculate the relative formula mass of the salt
- Determine the value of x from your answer to a)

Solution

a) Relative formula mass of $\text{MnO}_x = \frac{54.9}{53.4} \times 100 = 102.8$

b) Relative mass of $\text{O}_x = 102.8 - 54.9 = 47.9$.

Relative mass of O = 16

value of $x = \frac{47.9}{16} = 2.99$

x must be a whole number, so round up to $x = 3$

scaling up the relative atomic mass

taking away the mass of the manganese ion from the relative formula mass to find the mass due to oxygen

each O has a mass of 16

MnO_3 has a M_r of 102.8

PRACTICE QUESTIONS

- 14 % of a sample has a mass of 0.56 g. Work out the mass of the following:
 - 60 % of the sample
 - 85 % of the sample
 - 3 % of the sample
- 1.36 dm³ of a solution contains 0.17 g of a substance. Work out how many dm³ of the solution contains 1.0 g of the substance. Give your answers to 2 significant figures.
 - 1 gram of the substance
 - 1.75 grams of the substance
 - 34 g of the substance
 - 0.1 grams of the substance
- A reaction has a predicted percentage yield of 26.0 % and produces 18.0 g of ammonia. Work out the theoretical yield of ammonia.
- A sample of a rock is found to contain 25 % aluminium by mass. The total mass of the rock is 120 g. Work out the mass of aluminium in the rock.
- A reaction with a percentage yield of 75 % produces 3.3 g of a desired product. Work out the theoretical yield of the reaction in g.
- A salt has the formula MCl . The metal ion is unknown but can be determined by finding the relative formula mass of the salt. Cl^- ions have a relative formula mass of 35.5 and make up 40 % of the mass of the salt.
 - Find the relative formula mass of the salt, MCl .
 - Using a periodic table, determine the identity of the metal, M.
- A salt has the formula M_2O_3 . O^{2-} ions have a relative formula mass of 16.0 and make up 30 % of the relative formula mass.
 - Find the relative formula mass of the salt, M_2O_3 .
 - Using a periodic table, determine the identity of the metal, M.

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CALCULATING MEAN

LEARNING OUTCOME

Calculate mean averages and weighted means by selecting appropriate values from given data.

THEORETICAL OVERVIEW

Repeating experiments

It is common in Chemistry to repeat an experiment and take an average of the results. If you repeat the experiment several times, the result will be more **accurate**.

Means

To calculate the mean average, you add up the numbers and divide by the number of numbers.

The mean of the numbers 1–4 is:

$$\frac{1 + 2 + 3 + 4}{4} = 2.5$$

Outliers (anomalies)

You might repeat an experiment to find a more accurate value. However, sometimes the data you have collected might have an outlier.

Repeat number 2 is an outlier and should be removed when calculating the mean:

$$\text{mean} = \frac{2.3 + 2.3 + 2.4 + 2.2}{4} = 2.3 \text{ s}$$

Titration

Titration is a common example of a repeated experiment in Chemistry. There are often several titration data.

1. Only include 'concordant' results in the mean calculation. These are results which are close to each other.
2. You sometimes see a 'rough' result. This isn't included in the mean as it is used to find the endpoint required, and often is a lot higher than the results that follow.
3. The mean for a titration may be required to 1 or 2 decimal places.

WORKED EXAMPLE

	Rough	Titration 1	Titration 2
Volume of acid used (cm ³)	19.00	18.10	18.20

The rough is not used in the mean, and titration 2 is discarded as it is not concordant with titration 1 and 3. Concordant titres are titration 1 and 3.

The mean of these results is: $\frac{18.10 + 18.20}{2} = 18.15 \text{ cm}^3$

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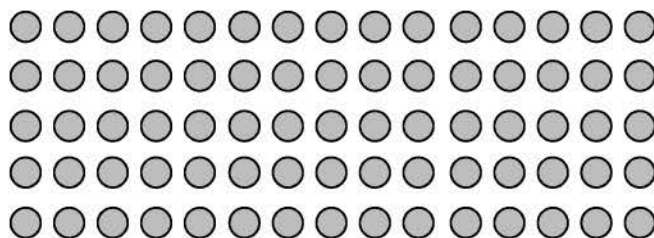
Weighted means

The data in the table shows the mass of different isotopes and what percentage of chlorine atoms are in each isotope.

For the data in the table, it isn't correct to say the average mass is

$\frac{35 + 37}{2} = 36$, because there are three times as many atoms of ^{35}Cl as there are atoms of ^{37}Cl .

Instead, you have to calculate the **weighted mean**. Imagine you had 100 chlorine ^{37}Cl .



To find the weighted mean, calculate the mean of the 100 atoms

$$\frac{(75 \times 35) + (25 \times 37)}{100} = 35.5$$

The weighted average mass of different isotopes of an element is called the **relative atomic mass** (A_r) of the element. This is the correct relative atomic mass of chlorine to 1 d.p.

WORKED EXAMPLE

'A sample of a meteorite contains three different isotopes of iron, with the abundances shown in the table.'

Use a weighted mean calculation to find the relative atomic mass of iron in the sample.'

Solution

Calculate the weighted mean by multiplying the mass number of each isotope of iron by its 'weight', then dividing by 100 %:

$$\frac{(7 \times 54) + (90 \times 56) + (3 \times 57)}{100} = 55.9$$

Isotope

^{35}Cl

^{37}Cl

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PRACTICE QUESTIONS

- Calculate the mean of the following sets of data:
 - The whole numbers 1–10
 - 5, 4, 2, 8
 - 6.5, 6.2, 6.6, 6.9
 - 250, 300, 280, 310, 260
 - 0.06, 0.02, 0.05, 0.02
- Calculate the mean volume titrated from the following titration data to the given number of decimal places. Remember that in titrations you only use concordant results to calculate the mean.

- a) To 1 d.p.

Titration	Rough	1	2
Volume titrated (cm ³)	16.10	14.60	14.20

- b) To 2 d.p.

Titration	Rough	1	2
Volume titrated (cm ³)	21.05	19.15	19.40

- c) To 1 d.p.

Titration	Rough	1	2
Volume titrated (cm ³)	14.45	13.20	13.50

- Calculate the relative atomic mass for each of the following samples to 1 d.p., in the worked example.
 - | Isotope | Mass | Abundance (%) |
|------------------|------|---------------|
| ²³⁴ U | 234 | 2.00 |
| ²³⁵ U | 235 | 2.00 |
| ²³⁸ U | 238 | 96.00 |

- b)

Isotope	Mass	Abundance (%)
³⁵ Cl	35.0	75.00
³⁷ Cl	37.0	25.00

- c)

Isotope	Mass	Abundance (%)
⁶ Li	6.00	8.00
⁷ Li	7.00	92.00

- d)

Isotope	Mass	Abundance (%)
⁵⁰ Cr	50.0	9.00
⁵² Cr	52.0	84.00
⁵³ Cr	53.0	7.00

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UNCERTAINTY

LEARNING OUTCOME

Understand the concept of uncertainty, and be able to calculate uncertainty for different measurements, and for experiments, such as titrations.

THEORETICAL OVERVIEW

In an experiment, the readings made can never be exact. The true amount can always be slightly higher or lower than the value given. The amount of 'inexactness' is called the uncertainty.

Readings

A reading is one value recorded in an experiment. The value from a thermometer, on a balance or on a burette are all readings.

The uncertainty in a reading from many pieces of apparatus is half the distance between the lines. For example, if a thermometer has a reading every 1 °C (the distance between lines is 1 °C), then the uncertainty in a reading is 0.5 °C.

This means that for a temperature of 48 °C, the temperature could be as high as 48.5 °C or as low as 47.5 °C.

Writing uncertainties

Uncertainties can be written in the form 'reading ± uncertainty'. This is called the **absolute uncertainty**.

For a temperature of 48 °C with an uncertainty of 0.5 °C, you would write:

$$48 \pm 0.5 \text{ }^{\circ}\text{C}$$

NB The uncertainty is half the distance between the lines

Measurements

A measurement is the combination of two readings.

For example, you can measure a temperature change by taking two **readings** and then subtracting them.

Reading 1	Reading 2	Measurement
Start temperature	End temperature	Temperature change
18 °C	25 °C	

The actual values for readings 1 and 2 are 0.5 °C above or below the written value.

This table shows the maximum and minimum temperature change that could have occurred.

	Start temperature	End temperature
Maximum change	17.5 °C	25.5 °C
Minimum change	18.5 °C	24.5 °C

Another way to show the result is like this:

Start temperature	End temperature
$18 \pm 0.5 \text{ }^{\circ}\text{C}$	$25 \pm 0.5 \text{ }^{\circ}\text{C}$

The absolute uncertainty in the measurement (the temperature change) is ±1. It is the sum of the uncertainties in the two readings.

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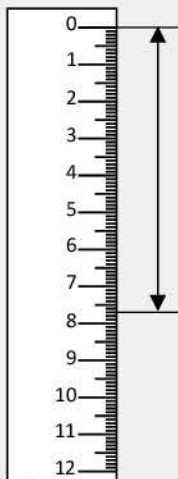
WORKED EXAMPLE

A value from a ruler is actually a measurement, not a reading, because there are two readings: one at the value, and one at zero.

$$7.7 \pm 0.1 \text{ cm}$$

or

$$77 \pm 1 \text{ mm}$$



When taking a measurement:

- the **smallest** value
- the **uncertainty** at the top
- the **uncertainty** at the bottom

$$0.5 + 0.5 = 1.0$$

WORKED EXAMPLE

'Two chemicals are needed for a reaction and are weighed out.'

What is the uncertainty in their combined mass?

The uncertainty in a digital balance is written on the balance. For the readings shown:



- The value for the combined mass in the reaction is $2.93 + 1.67 = 4.60$
- The uncertainty for the total mass is $2 \times 0.01 = 0.02 \text{ g}$
- The value for the mass used in the reaction is written as $4.60 \pm 0.02 \text{ g}$

Repeated measurements

Repeating an experiment multiple times and finding the mean result is a method used to reduce uncertainty. Uncertainty is calculated differently for repeated experiments.

When finding the uncertainty from repeat experiments, you find the value of **half the range** is the difference between the highest and the lowest value.

WORKED EXAMPLE

'Find the mean of the following volumes, giving the uncertainty in your answer.'

Reading	1	2	3
Volume (cm ³)	21.2	21.3	21.3

The result for this data is:

$$\text{Mean} = \frac{21.2 + 21.3 + 21.3 + 21.2}{4}$$

$$\text{Half the range} = \frac{21.3 - 21.2}{2}$$

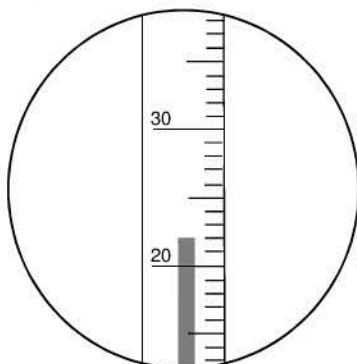
$$\text{Mean} = 21.25 \pm 0.05 \text{ cm}^3$$

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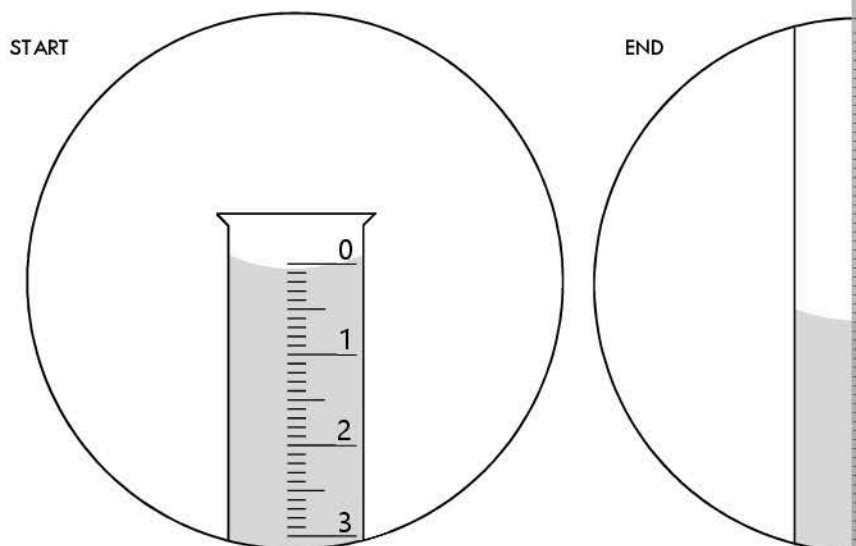


PRACTICE QUESTIONS

- Write down the value with the absolute uncertainty of the following measurements:
 - A volume of 23.0 cm^3 measured in a measuring cylinder with 1 cm^3 markings
 - A 12.0 cm object measured with a ruler with 0.1 cm markings
 - A temperature change of 16°C measured with a thermometer with 1°C markings
 - A volume change of 19.50 cm^3 measured in a burette with markings every 0.10 cm^3
 - A mass change given by a digital balance with an uncertainty of 0.01 g giving a start mass as 3.25 g and end mass as 4.50 g
 - The temperature from the following thermometer:



- The measurement from the following burette readings:



- Calculate the mean result from the following data:

Reading	1	2	3	
Temperature ($^\circ \text{C}$)	25.2	24.8	26.2	

- Calculate the absolute uncertainty of the mean result using the repeated readings.
- Calculate the mean value with absolute uncertainty to 1 decimal place for the following data:

Reading	1	2	3	
Mass (g)	34.3	38.1	33.2	3

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UNCERTAINTY IN

LEARNING OUTCOME

Calculate percentage uncertainty and handle uncertainty in data from titrations.

THEORETICAL OVERVIEW

Percentage uncertainty

An uncertainty of ± 0.1 m is low for a value of a kilometre, but high for a value of a metre. Percentage uncertainty in a measurement is useful, as it compares the uncertainty to the value.

The percentage uncertainty of a measurement is calculated using:

$$\text{percentage uncertainty} = \frac{\text{uncertainty}}{\text{value}} \times 100\%$$

WORKED EXAMPLE

For this value:

$$21.25 \pm 0.05 \text{ cm}^3$$

The percentage uncertainty is:

$$\frac{0.05}{21.25} \times 100\% = 0.235\%$$

Overall uncertainty

Here is some titration data:

Titration	Rough	1	2
Final reading (cm ³)	24.50	49.10	25.20
Initial reading (cm ³)	0.05	24.50	0.25
Titre (cm ³)	25.45	24.60	24.95

There are two main sources of error in a titration experiment.

Divisions	Volume
Burettes have 0.1 cm³ divisions. - The uncertainty in the initial reading is ± 0.05 cm³. - The uncertainty in the final reading is ± 0.05 cm³. The uncertainty of each measurement is 0.10 cm³.	Another factor adds to the uncertainty in the volume of a drop. The uncertainty in the volume of a drop is ± 0.05 cm³.

So the overall uncertainty in the mean titre is the uncertainties added up: ± 0.15 cm³

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WORKED EXAMPLE

'A student conducts a titration and obtains the following results:

Titration	Rough	1	2
Final reading (cm ³)	22.00	42.85	21.25
Initial reading (cm ³)	0.10	22.00	0.05
Titre (cm ³)	22.00	20.85	21.20

Calculate the percentage uncertainty in the average titre value.'

Solution

The first two values within 0.1 cm³ of each other are averaged to find the average titre value:

$$\frac{21.20 + 21.10}{2} = 21.15 \text{ cm}^3$$

Then, to calculate the percentage uncertainty in this value:

$$\begin{aligned} \text{percentage uncertainty} &= \frac{\text{uncertainty}}{\text{value}} \times 100\% \\ &= \frac{0.15 \text{ (uncertainty in the mean titre)}}{21.15} \times 100 \\ &= 0.709\% \text{ (3 s.f.)} \end{aligned}$$

PRACTICE QUESTIONS

- Calculate the percentage uncertainty of the following readings.
 - $12.50 \pm 0.50 \text{ mm}$
 - $42.60 \pm 0.10 \text{ }^\circ\text{C}$
 - $28.50 \pm 0.15 \text{ cm}^3$
 - $49.4 \pm 1.0 \text{ g}$
 - $1542 \pm 5 \text{ mL}$
 - $0.130 \pm 0.050 \text{ dm}^3$
- Calculate the percentage uncertainty in the average titre values for the following factors from judging each reading and from the uncertainty in judging the end point.

Titration	Rough	1	2	3
Initial reading (cm ³)	0.00	0.00	0.00	0.10
Final reading (cm ³)	27.00	26.05	26.15	26.85
Titre (cm ³)				

b)

Titration	Rough	1	2	3
Initial reading (cm ³)	0.10	0.55	0.25	0.20
Final reading (cm ³)	27.10	26.05	26.05	26.05
Titre (cm ³)				

c)

Titration	Rough	1	2	3
Initial reading (cm ³)	0.05	0.20	0.30	0.25
Final reading (cm ³)	23.95	22.80	22.70	22.75
Titre (cm ³)				

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MATHEMATICAL SYMBOLS

LEARNING OUTCOME

Be able to use the symbols $<$, $<<$, $>$, $>>$, $\propto$ and $\sim$.

THEORETICAL OVERVIEW

Greater than ($>$) and less than ($<$)

The symbol points towards the smaller number: $2 < 5$

These symbols can be rearranged in a similar way to an equals sign $=$.

For example:

$$x - 3 < 5$$

You can solve this as if it was an equation:

$$x < 8$$

Add 3 to both sides

The only difference is when reversing equations. You have to swap the symbol around.

$$\begin{aligned} x &< 2 \\ 2 &> x \end{aligned}$$

WORKED EXAMPLE

'A chemist started with 5 g of impure material containing calcium carbonate, which he reacted with hydrochloric acid. The material also contained impurities, some of which also reacted with the acid.'

The chemist dissolved the material in hydrochloric acid, and found that 0.5 g of impurities were left.

Write an expression for the mass of calcium carbonate (X).

$X + 0.5 < 5$ because the 5 g included 0.5 g of impurity

$X < 4.5$ g

Much greater or less than: $<<$ and $>>$

$<<$ means much less than $>>$ means much greater than

For example: $5\,000\,000\,000\,000\,000 >> 5$

Approximately equal: $\sim$

For example: $5.001 \sim 5$

A quantity called K_c tells us whether there are more reactants or more products left in a reaction. $K_c = \frac{\text{products}}{\text{reactants}}$

$K_c >> 1$ means that the amount of the products is much greater than the amount of the reactants.

$K_c << 1$ means that the amount of the reactants is much greater than the amount of the products.

$K_c \sim 1$ means that the amounts of reactants and products are about equal.

Directly proportional: $\propto$

This symbol means that as the value of one side of an equation increases, so does the value of the other side.

$$y \propto x$$

Therefore, if y is doubled, x is also doubled. If x is divided by 10, y is also divided by 10.

Another way of writing this is using an equals symbol, using 'k' which is a constant (a number that doesn't change when x and y change):

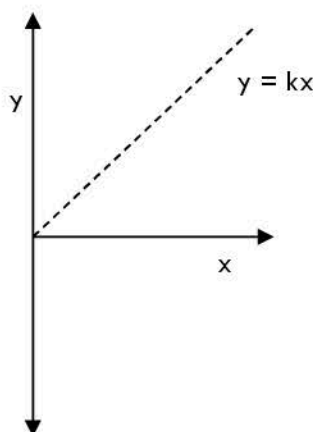
$$y = kx$$

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If k is positive
 x increases proportionally as y increases



If k is negative
 x decreases proportionally as y increases



A Chemistry example is the ideal gas equation, where, in a constant volume of gas:

pressure $\times$ volume $\propto$ temperature

$$pV \propto T$$

which can also be rearranged to:

$$p \propto \frac{T}{V}$$

From this, you can tell that:

- doubling the temperature doubles the volume (if pressure is constant)
- doubling the volume halves the pressure (if temperature is constant)

Directly proportional to x^2

y can also be proportional to x^2 :

$$y = kx^2$$

which means that when x is multiplied by a factor (e.g. x doubles), y is multiplied by quadruples).

change in x	change in y
$\times 2$	$\times 2^2 = \times 4$
$\times 3$	$\times 3^2 = \times 9$
$\times 4$	$\times 4^2 = \times 16$
$\times \frac{1}{2}$	$\times (\frac{1}{2})^2 = \times \frac{1}{4}$

PRACTICE QUESTIONS

- Write the following statements using the correct symbols:
 - 2 cm^3 is greater than 1 cm^3
 - 4000 mg is less than 4300 mg
 - A K_c of 4000 is much greater than 0.003
 - The number of moles is proportional to pressure
- For the expression $pV \propto nT$:
 - What happens to V as n doubles, assuming that p and T stay the same?
 - What happens to V as T halves, assuming p and n stay the same?
 - What happens to T as n doubles, assuming p and V stay the same?
 - What happens to n if p is doubled and V and T stay the same?
 - What happens to T if p and V are both halved and n stays the same?
 - What happens to V if p , n and T are all tripled?
- Sketch a graph of the following expressions:
 - a vs b for ' $a \propto b$ '
 - pV vs T for $pV \propto T$
 - Rate vs $[Y]$ for $\text{Rate} \propto [X][Y]^2[Z]$

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USING EQUATIONS

REARRANGING SIMPLE EQUATIONS

LEARNING OUTCOME

Use and rearrange simple equations to calculate values for physical quantities.

THEORETICAL OVERVIEW

Substituting values

In Chemistry, equations are used to calculate values from other values. The following situation 'y is 5 times bigger than x':

$$y = 5x$$

When $x = 3$, the equation can be used to calculate that $y = 15$:

$$y = 5 \times 3 = 15$$

Rearranging equations

If you know the value of y and want to find x.

The equation can be rearranged:

$$y = 5x$$

$$\frac{y}{5} = x$$

divide both sides by 5

The key to rearranging equations is that if you do something to one side of the equation, you must do the same to the other side.

Rearranging and substituting

Some equations are more complex because they contain more variables (letters). Consider the ideal gas law, which describes the relationships between pressure, volume and temperature. Rearrange the ideal gas equation to find volume using the following equation:

$$pV = nRT$$

Though there are more variables in the ideal gas equation, you can rearrange and substitute values the same way.

So if you know that $p = 1 \times 10^5 \text{ Pa}$, $n = 1 \text{ mol}$, $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$, and $T = 273 \text{ K}$, substitute this information into the equation, and then substitute in this information to find V:

$$pV = nRT$$

$$V = \frac{nRT}{p}$$

divide both sides by p

$$V = \frac{1 \times 8.31 \times 273}{1 \times 10^5}$$

substitute values

$$V = 0.023 \text{ m}^3$$

perform calculation

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WORKED EXAMPLE

'The ideal gas equation is:

$$pV = nRT$$

where: p = pressure in Pa (Pascals)

V = volume in m^3

n = amount of gas in moles

$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$

T = temperature in K

3.00 moles of a gas are stored in a 0.250 m^3 container at 273 K . Calculate the pressure on the walls of the container.'

Solution

$$pV = nRT \xrightarrow[\text{dividing by } V]{\text{rearrange by}} p = \frac{nRT}{V} \xrightarrow{\text{substitute in}} p = \frac{3 \times 8.31 \times 273}{0.25} = 27223.56 \text{ Pa} (= 27.2 \text{ kPa})$$

PRACTICE QUESTIONS

1. The rate of a reaction can be calculated using the equation:

$$\text{rate} = \frac{\text{concentration of reactant used}}{\text{reaction time}}$$

Rearrange the equation to show how the concentration of reactant used depends on reaction time.

2. Rearrange the following equations to make x the subject of the equation:

a) $d = 2x$

b) $wA = yx$

c) $24 = 6x$

3. Rearrange the following equations to make moles the subject of the equations:

a) $\text{moles} \times M_r = \text{mass}$

b) $24,000 \times \text{moles} = \text{volume}$

c) $\text{concentration} = \frac{\text{moles}}{\text{volume}}$

4. The ideal gas equation is:

$$pV = nRT$$

a) Rearrange the equation to make p the subject.

b) Rearrange the equation to make T the subject.

c) Rearrange the equation to make n the subject.

5. Find the volume in cm^3 of 0.75 moles of gas using the equation: $\text{moles} = \frac{V \text{ (in cm}^3\text{)}}{24\,000}$

6. Find the value of ΔT for $q = mc\Delta T$ where: $m = 150 \text{ g}$, $c = 4.18 \text{ J g}^{-1} \text{ K}^{-1}$ and $q = 1250 \text{ J}$

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USING EQUATIONS II – EQ

WITH +, −, × AND

LEARNING OUTCOME

Make variables the subject of an equation in equations involving multiplications, division

THEORETICAL OVERVIEW

Equations are a really useful way of looking at the relationships between quantities. For example, this equation tells you how the quantity y depends on the quantity x .

$$y = 5x + 3$$

But what if you want to know how x depends on y ? To see this, you have to **rearrange** the equation to make x the subject:

$$y = 5x + 3$$

$$y - 3 = 5x$$

The second step is to then get the x completely on its own. At the moment, you have $5x$ on the right-hand side of the equation, so divide both sides by 5.

$$\frac{y-3}{5} = x$$

This equation can be written the other way around:

$$x = \frac{y-3}{5}$$

Now that you have rearranged the equation, you can substitute a value of y straight into the equation for x , e.g. when $y = 13$:

$$x = \frac{13-3}{5} = \frac{10}{5} = 2$$

WORKED EXAMPLE

'An experiment measuring the volume of gas produced gave the following data'

Repeat	1	2	3	4
Gas produced (cm ³)	214	216	211	212

A student calculated the mean value as 212 cm³. Find the value of x .'

Solution

The mean value is given by:

$$\frac{214 + 216 + 211 + x}{4} = 212 \quad \text{which we can simplify to} \quad \frac{641 + x}{4}$$

Rearrange the formula to make x the subject, and calculate the value.

$$\frac{641 + x}{4} = 212$$

$$641 + x = 212 \times 4$$

$$x = 212 \times 4 - (641)$$

$$= 207 \text{ cm}^3$$

multiply both sides by 4

subtract 641 from both sides

perform the calculation

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PRACTICE QUESTIONS

1. Make x the subject of the following equations:

- a) $y = \frac{x+5}{3}$
 b) $y = 6x - 9$
 c) $y = mx + c$
 d) $y = \frac{4}{x}$
 e) $9x + 2 = 7x + 2y$
 f) $4y + 2x + 3 = 2y + 6x - 1$
 g) $3yx = 1$
 h) $4xy + 8 = 4y - 4$

2. For the following data, a student calculated the mean to be 8 cm^3 :

Repeat	1	2	3	4
Volume (cm^3)	x	10	8	7

Find the value of x (repeat 1).

3. For the following data, a student calculated the mean to be 29.4 g :

Repeat	1	2	3	4
Mass (g)	30.2	x	28.7	30.0

Find the value of x (repeat 2).

4. The relative atomic mass of an element can be calculated using:

$$\text{relative atomic mass} = \frac{\text{total of (mass of an isotope} \times \text{abundance)}}{100}$$

A sample of neon was calculated to have a relative atomic mass of 20.2 using

Mass of isotope	Abundance of isotope
20	90
Y	10

Calculate the mass of the second isotope 'y' using the equation above.

5. The energy change of a reaction can be estimated using the formula:

$$\text{energy change} = \text{bonds broken} - \text{bonds formed}$$

Bond	Energy / kJ mol^{-1}
H-H	436
O=O	498
H-O	?
H-Cl	?
Cl-Cl	242

- a) Find the energy of the H-Cl bond given that the following reaction has an energy change of -184 kJ mol^{-1}
 BONDS BROKEN $2 \times \text{H-H} + 2 \times \text{Cl-Cl} \rightarrow 2 \times \text{H-Cl}$
 b) Find the energy of the H-O bond given that the following reaction has an energy change of -484 kJ mol^{-1}
 BONDS BROKEN $2 \times \text{H-H} + \text{O=O} \rightarrow 2 \times \text{H-O-H}$

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USING EQUATIONS III – EQ WITH POWERS AND R

LEARNING OUTCOME

Rearrange equations containing powers and roots.

THEORETICAL OVERVIEW

Some equations in Chemistry are quite complex, and can be hard to rearrange. For example, the volume of a sphere is given by:

$$V = \frac{4\pi r^3}{3}$$

where r is the radius of, for instance, a spherical nanoparticle.

To make r the subject of the equation:

$$\begin{array}{l} V = \frac{4\pi r^3}{3} \quad \leftarrow \text{multiply both sides by 3} \\ 3V = 4\pi r^3 \\ \frac{3V}{4\pi} = r^3 \quad \leftarrow \text{divide both sides by } 4\pi \\ \sqrt[3]{\frac{3V}{4\pi}} = r \quad \leftarrow \text{take the cube root} \end{array}$$

Now r is the subject of the equation, so the equation can be used to easily calculate the radius of a spherical nanoparticle.

*The cube root finds the number which, multiplied by itself three times, gives that number. For example $\sqrt[3]{27} = 3$ because $3 \times 3 \times 3 = 27$.

WORKED EXAMPLE

'The kinetic energy of an ion in a mass spectrometer is given by:

$$KE = \frac{1}{2}mv^2$$

Rearrange the formula to make v the subject.'

Solution

$$\begin{array}{l} KE = \frac{1}{2}mv^2 \quad \leftarrow \text{multiply both sides by 2} \\ 2KE = mv^2 \\ \frac{2KE}{m} = v^2 \quad \leftarrow \text{divide both sides by } m \\ \sqrt{\frac{2KE}{m}} = v \quad \leftarrow \text{take the square root} \end{array}$$

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PRACTICE QUESTIONS

- Given that $a = 2$ and $b = 3$, find c for each of the following equations:
 - $c = a^b + b^2$
 - $cb = b^a$
 - $c^2 = b^a$
 - $abc = \frac{b^2}{a}$
 - $a^2b^2 = 5 + b^3 + c^2$
 - $a^2c^3 = b^3 + a^2 + 1$
- Make x the subject of the following equations:
 - $y = \frac{1}{2}x^2$
 - $y = \frac{4\pi}{x^2}$
 - $y = \sqrt{\frac{x}{4}}$
 - $y = z(3x)^3$
- Square brackets are used to represent concentration in equations, e.g. $[\text{Cl}^-]$ means concentration. K_c is a way of measuring how much of the reactants has been converted to products.
 - Make $[\text{H}^+]$ the subject of the equation: $K_c = \frac{[\text{CH}_2(\text{COO})_2^{2-}][\text{H}^+]^2}{[\text{CH}_2(\text{COOH})_2]}$ and then calculate $[\text{H}^+]$.
 $[\text{CH}_2(\text{COO})_2^{2-}] = 1.200 \text{ mol dm}^{-3}$
 $[\text{CH}_2(\text{COOH})_2] = 0.500 \text{ mol dm}^{-3}$
 $K_c = 2.04 \times 10^{-6} \text{ mol}^2 \text{ dm}^{-6}$
 - Make $[\text{H}_2]$ the subject of the equation: $K_c = \frac{[\text{NH}_3]^2}{[\text{N}_2][\text{H}_2]^3}$ and then calculate $[\text{H}_2]$.
 $[\text{NH}_3] = 0.040 \text{ mol dm}^{-3}$
 $[\text{N}_2] = 0.12 \text{ mol dm}^{-3}$
 $K_c = 1.45 \times 10^{-4} \text{ mol}^{-2} \text{ dm}^6$
- The kinetic energy, KE , of an ion in a mass spectrometer is given by $\text{KE} = \frac{1}{2}mv^2$.
 - Find the value of m in kg when $v = 45\,100 \text{ m s}^{-1}$ and $\text{KE} = 6.77 \times 10^{-16} \text{ J}$.
 - Find the value of v in m s^{-1} when $m = 9.27 \times 10^{-26} \text{ kg}$ and $\text{KE} = 1.00 \times 10^{-16} \text{ J}$.
- The rate of the reaction between NO and H_2 is given by $\text{Rate} = k[\text{NO}]^2[\text{H}_2]$, where Rate is in $\text{mol dm}^{-3} \text{ s}^{-1}$.
 - Calculate the value of k given that:
 $\text{Rate} = 1.95 \times 10^{-8} \text{ mol dm}^{-3} \text{ s}^{-1}$ when $[\text{NO}] = 8.1 \times 10^{-3} \text{ mol dm}^{-3}$ and $[\text{H}_2] = 3.1 \times 10^{-3} \text{ mol dm}^{-3}$.
 - Calculate the value of $[\text{NO}]$ for the same reaction when:
 $\text{Rate} = 3.52 \times 10^{-7} \text{ mol dm}^{-3} \text{ s}^{-1}$ and $[\text{H}_2] = 3.1 \times 10^{-3} \text{ mol dm}^{-3}$.

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LOGARITHMS

LEARNING OUTCOME

Understand how and why logarithms are used, and use them in calculations.

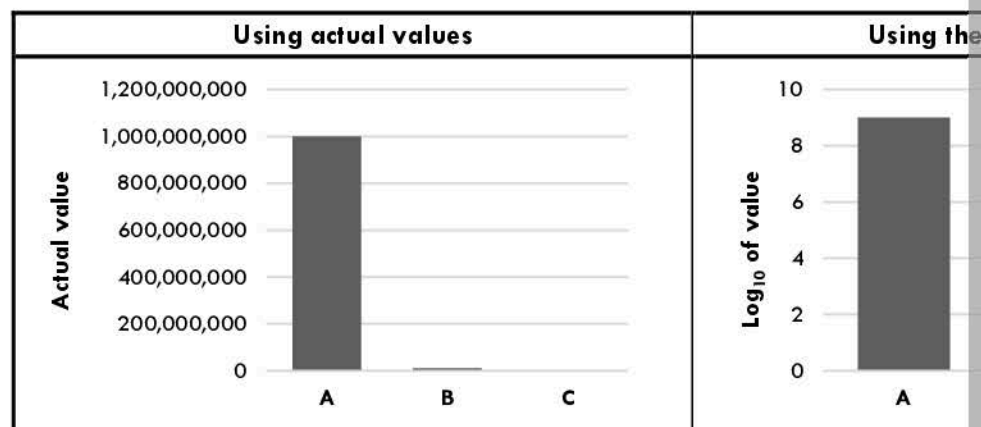
THEORETICAL OVERVIEW

Why logarithms are useful

Numbers can get very big or very small in Chemistry. Sometimes this makes it difficult to compare them.

This data is plotted on the graphs below. These two graphs are plotting the same data using logarithms to make comparing the numbers easier.

Number	Value	Log ₁₀ of the value
A	1 000 000 000	9
B	1 000 000	6
C	1 000	3



As you can see, the left-hand graph is not useful for comparing the size of B and C, A. This means it isn't possible to see any patterns. By 'taking logs' of each of the values we can see that A is much bigger than B and C, **and that C is smaller than B**.

Mathematics of log₁₀

Rule 1

The log₁₀ of a number is the power you need to raise 10 to get that number.

$$\log_{10}(10^x) = x$$

For example:

$$\begin{aligned}\log_{10}(1000) &= \log_{10}(10^3) = 3 \\ \log_{10}(10000) &= \log_{10}(10^4) = 4\end{aligned}$$

Rule 2

This is also related. Raising 10 to the power of a log gives the number that is 'logged'. So, 10 to the power of the logged number.

$$10^{\log(a)} = a$$

For example:

$$10^{\log(9)} = 9$$

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A Chemistry example where numbers are hard to compare is in acidity.

The pH scale is a way of representing these concentrations in a way that makes the

From this table, you can see how pH relates to the concentration. The equation for

To work out the concentration from the pH:

WORKED EXAMPLES

- ### Solution

Solution

difficult step: see rule 2 above if this do



Mathematics of natural logs, ln

Many relationships in nature, including Chemistry, have an **exponential** pattern. This is expressed as e^x .

ln, or $\log_e$, is an important type of logarithm because of the relationship:

$$\ln(e^x) = x$$

Chemistry example: Arrhenius equation

The only equation in A Level Chemistry which includes e is the Arrhenius equation:

$$k = A \times e^{\frac{-E_a}{RT}}$$

This equation links the activation energy (E_a) and the temperature (T) to the rate constant called the Arrhenius constant (A).

Using log rules, the equation can also be expressed as:

$$\ln k = \ln A - \frac{E_a}{RT}$$

This can be used to find values for E_a and A using a graph when the value of k is known (see separate section).

WORKED EXAMPLE

'The value of $\ln A$ in a reaction was found by a graphical method to be 14.9.'

Find the value of A for this reaction.'

Solution

$$\begin{aligned} A &= e^{\ln A} \\ &= e^{14.9} \\ &= 2.96 \times 10^6 \end{aligned}$$

PRACTICE QUESTIONS

- Use a calculator to find the following values to 4 significant figures:
 - $10^{3.2}$
 - $\log(120\,000)$
 - $\log(0.0005)$
 - $10^{-0.038}$
 - $\log(10^{-4})$
 - $10^{\log(3)}$
- Calculate the value of x to 4 significant figures.
 - $\log(x) = 3$
 - $\log(x) = 8.4$
 - $10^x = 0.002$
 - $10^x = 7.43$
 - $10^{(x+3)} = 0.00567$
- The table shows the values of the first eight ionisation energies of aluminium.
 - Use log rules to calculate the missing values.

ionisation energy number	1	2	3	4	5
ionisation energy (kJ mol^{-1})	577	1816	2744		8009
$\log_{10}(\text{ionisation energy})$	2.7612			4.0636	

- Explain why using logs is useful in this situation.
- By rearranging the equation $k = A \times e^{\frac{-E_a}{RT}}$, find the value of k for a reaction with

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CONSTRUCTING GRAPHS

LEARNING OUTCOME

Use experimental data to plot representative graphs and draw a line of best fit.

THEORETICAL OVERVIEW

The following example will walk you through the steps of constructing a graph. This example shows data for a solid which is heated and decomposes, losing mass.

independent variable
the variable chosen by the person doing the experiment

Time (s)	Mass (g)
10	0.88
20	0.79
30	0.70
40	0.63
50	0.49
60	0.37

dependent variable
the mass of the solid which is lost

1. Choosing the axes

The independent variable goes on the x-axis, which in this case is time, as you have **chosen** the times at which to measure the mass. As the mass measured **depends** on the time at which it is measured, mass is the **dependent variable**, and so goes on the y-axis.

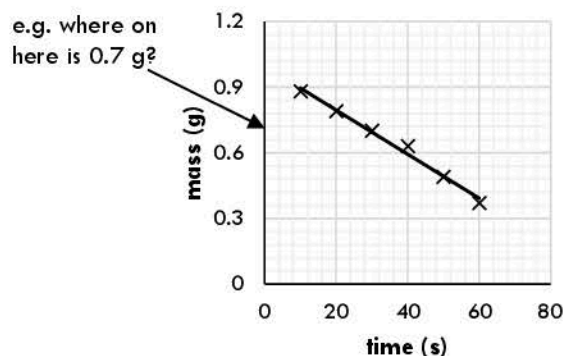
When labelling your axes, always make sure you write the **units** of each variable.

2. Choose a scale for each axis

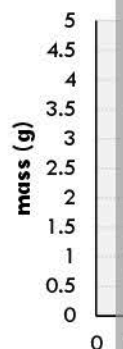
- The scale must be regular.
- The data must cover at least half the page.
- The data must all fit on the scale!
- Each large square should be a round number.

Bad examples:

Divisions are difficult to judge because the major grid lines are every 0.3 g on the y-axis.



Poor use of the y-axis



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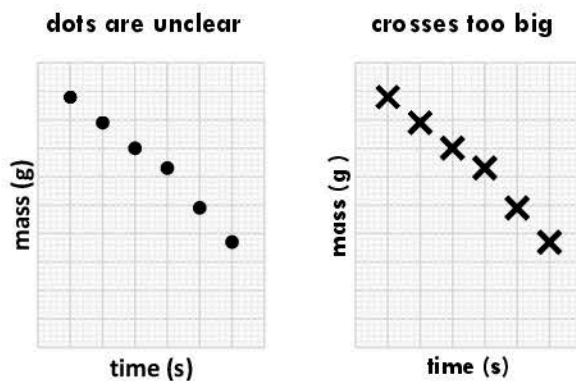


3. Plot the points

To plot a point, imagine two lines coming from the x- and y-axes at the correct values. The point where these two imaginary lines cross is where you plot your data point.

Use a small $\times$ to represent each data point.

Examples of bad points plotted:

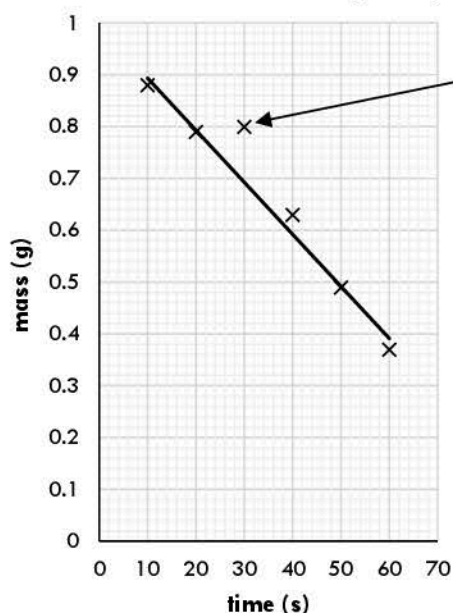


4. Draw a line or curve of best fit

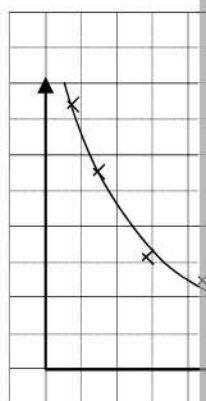
Depending on the data being plotted, a curved or straight best-fit line is used to show the trend. You should look at the data to judge which is appropriate. Sometimes two straight lines are needed, **do not do dot-to-dot**.

You should aim to have an equal number of data points on each side of the line.

Straight lines – use a ruler to draw through the points



Curved lines – smooth free



Curves can be tricky to draw. It is a temptation to go back and draw 'sketchy' double lines. This is not acceptable.

Lines do not have to go through the origin (0,0) but sometimes it makes sense for the data. For example, when timing how far something travels in a given time, you know it hasn't travelled anywhere at time zero.

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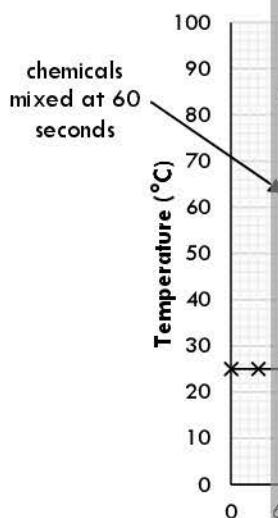


Two lines of best fit (temperature change)

To find the temperature change of a reaction, a specific method is used. The temperature is recorded before and after the reaction occurs. Two straight lines of best fit are drawn and **extrapolated** to the time at which mixing occurred.

A vertical line is drawn at the time the chemicals are mixed, and the temperature change is recorded as the place where the two lines cross.

The temperature change is $87 - 25 = 62\text{ }^{\circ}\text{C}$.



PRACTICE QUESTIONS

1. Using graph paper, plot graphs for the data and draw an accurate line of best fit.

- a) An experiment monitoring the decrease in mass of calcium carbonate as it thermally decomposes over time.

Time (s)	Mass of CaCO_3 (g)
0	5.00
10	4.25
20	3.79
30	3.00
40	2.16
43	1.87

- b) An experiment monitoring the amount of CO_2 produced by a reaction over time.

Time (s)	Volume of CO_2 (cm^3)
0	0.0
10	46.5
20	62.3
30	66.3
40	77.2
50	79.3

- c) An experiment measuring the rate of reaction between hydrochloric acid and calcium carbonate over 90 s. Use the data to draw a line of best fit and extrapolate to $t = 90$.

Time (s)
0
30
60
90
120
150
180
210
240
270

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ANALYSING GRAPHS

LEARNING OUTCOME

Read data values from graphs, calculate the gradient and y-intercept of the line of best fit, and calculate the rate of change at a given point on a curved line of best fit.

THEORETICAL OVERVIEW



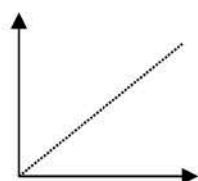
Reading data from a graph

Reading data from a graph is very similar to plotting data on a graph. To find the mass at a certain time, imagine lines going directly up from the time (x-axis), and directly across from the line of best fit. The place where the imaginary line crosses the y-axis gives the mass.

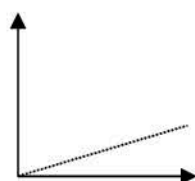
For example, to find the mass at 25 s, draw an imaginary line up from 25 s, and across to the y-axis. The mass at 25 s is 0.74 g.

Slopes of graphs

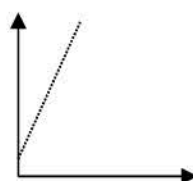
The slope of the line can tell you how quickly the concentration changes. In other words, it tells you the **rate** at which the concentration is changing. A steeper slope shows a higher rate.



positive, starts at the origin



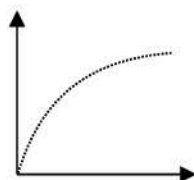
positive, low rate



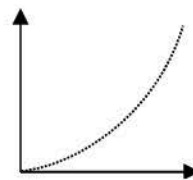
positive, high rate



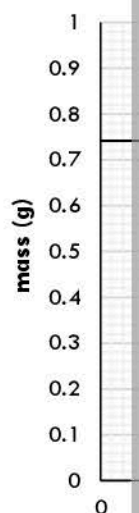
negative rate



curved, tending to a gradient of 0



curved with increasing gradient (e.g. exponential)



Calculating the gradient

To obtain a value for this rate of change, you have to calculate the gradient of the line. Choose two points on the line, and find the difference between the two y-values and the two x-values.

$$\text{gradient} = \frac{\text{difference in } y}{\text{difference in } x}$$

The two points should be far apart, but within the data range.

WORKED EXAMPLE

The gradient of the graph in the top right of the page is:

$$\begin{aligned} \text{gradient} &= \frac{\text{change in mass}}{\text{change in time}} = \frac{\text{mass}_2 - \text{mass}_1}{\text{time}_2 - \text{time}_1} \\ &= \frac{0.50 - 0.74}{49 - 20} \\ &= -0.010 \text{ g s}^{-1} \end{aligned}$$

When you have a gradient, **think** about whether it is positive or negative.

Upwards slope = positive gradient
Downwards slope = negative gradient

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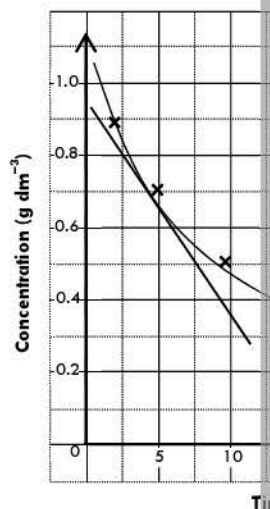
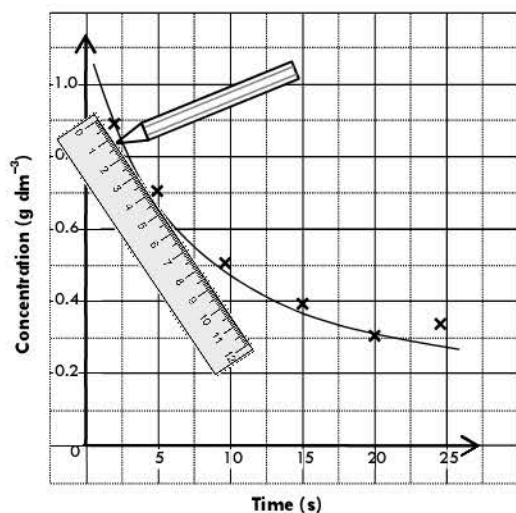


Calculating rate of change from a curved graph

If you have a curved line of best fit, the gradient is different at different points on the curve.

To calculate the gradient at a point on the curve, you can draw a tangent to the curve. A tangent is a straight line that touches the curve only once. To do this, position a ruler on the curve so that it only touches the curve once.

The tangent has the same gradient as the curve at the point where the tangent touches the curve. The gradient of the line is normal.



Changing gradients

In many graphs, the steepness of the gradient tells you how fast the reaction is occurring.

As the reaction slows down, the gradient changes. Later in the experiment, the slope is less steep.

For this graph, we can compare the two gradients to see how much the reaction has slowed down.



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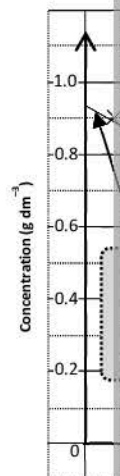
y-intercept

The **y-intercept** of a line is the point where the line crosses the y-axis. In order to work this out, you need to **extrapolate** back from the line of best fit to the axis.

The y-intercept gives you the y-value when the x-value is 0. In this graph, the y-axis tells you the concentration (y-value) at the beginning of the experiment ($x = 0$). In other words, it will tell you the **initial concentration**.

Sometimes, it is possible to read the y-intercept straight from the graph. In this case you can see that the line of best fit crosses the y-axis at approximately 0.92 g dm^{-3} .

This means that the concentration was 0.92 g dm^{-3} before the experiment started.



Calculating the y-intercept

Sometimes the y-intercept won't be visible on the graph, so you will need to calculate the formula of a straight line:

$$\text{any y-value} \rightarrow y = mx + c \leftarrow \text{any x-value}$$

Choose any point on the line of best fit. From the graph above, we can choose the gradient of the line, so $m = -0.020$ (which we calculated on the previous page). c is the y-intercept (which we are trying to calculate).

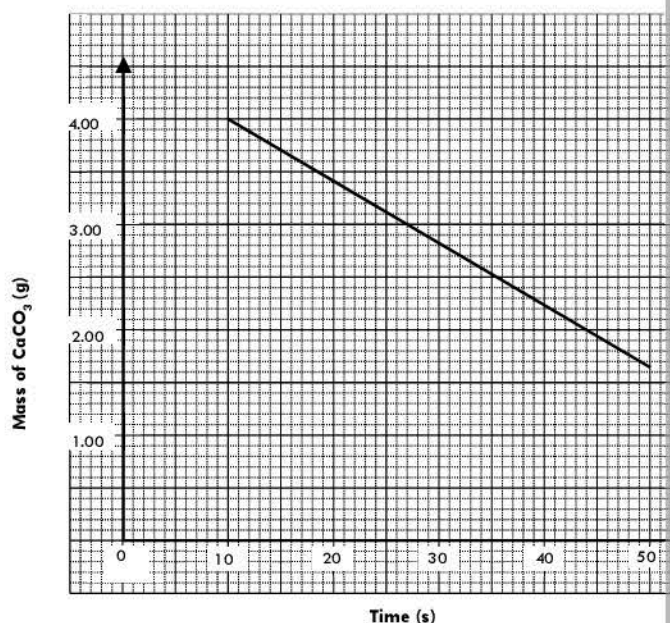
Rearrange the equation and substitute in the values to calculate c :

$$c = y - mx$$

$$\begin{aligned} c &= 0.45 - (-0.020 \times 23) \\ &= 0.91 \text{ g dm}^{-3} \end{aligned}$$

PRACTICE QUESTIONS

1. For the following graph, find:
 - a) The mass at 20 s
 - b) The mass at 35 s
 - c) The time when the mass is 3.00 g
 - d) The change in mass between 10 and 40 s

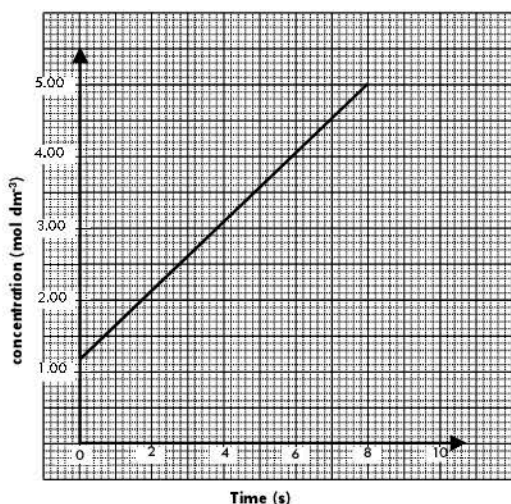


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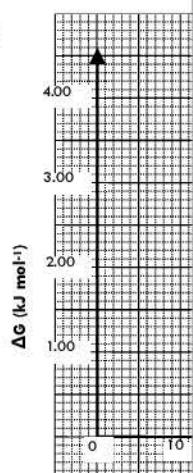


2. For each of the following graphs, calculate the gradient and y-intercept:

a)

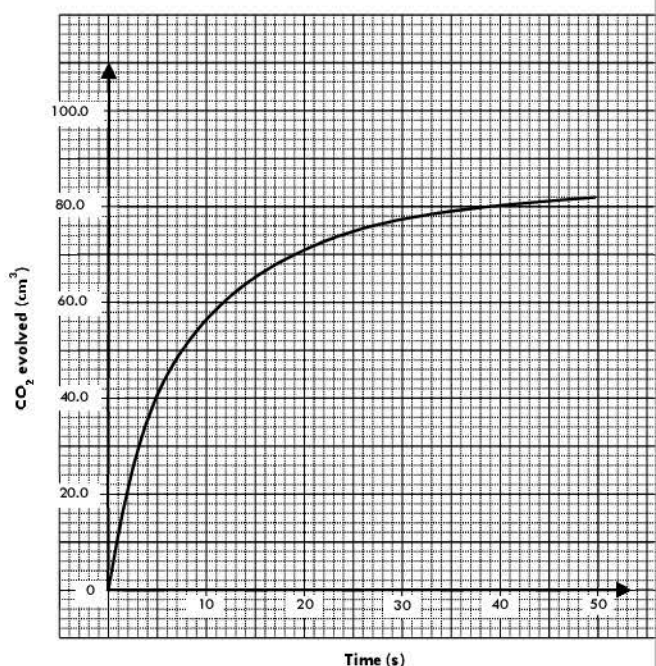


b)



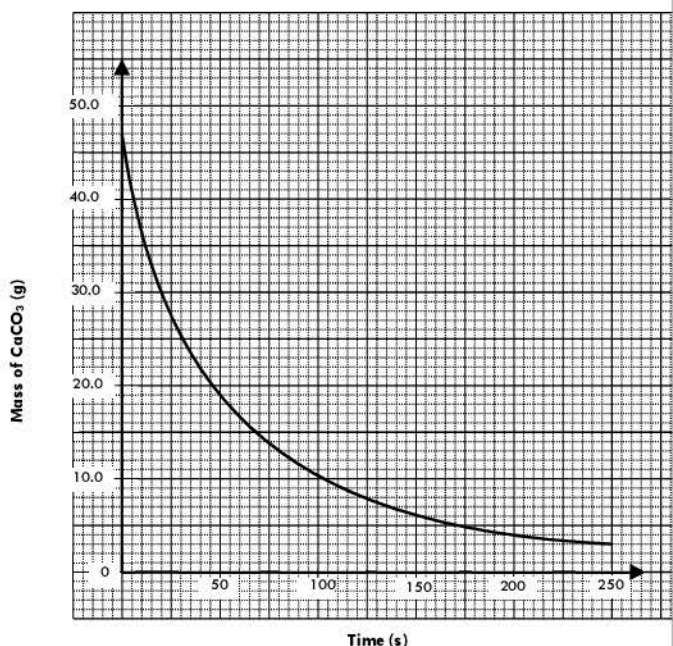
3. Calculate the gradient of the tangent for the following graph:

- a) at 30 s
b) at 10 s



4. Calculate the gradient of the tangent for the following graph:

- a) at 100 s
b) at 50 s



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REARRANGING EQUATION

FORM $y = mx + c$

LEARNING OUTCOME

Rearrange equations to the form $y = mx + c$, and then use graphs to find gradient

THEORETICAL OVERVIEW



Equations in the form $y = mx + c$ give straight-line graphs.

The equation $\Delta G = \Delta H - T\Delta S$ is called the Gibbs equation. The equation can be rearranged easily to the form $y = mx + c$:

$$y = mx + c$$

$$\Delta G = (-\Delta S)T + \Delta H$$

y-intercept = c

Remind

If a graph of ΔG vs T is plotted, then you can find from the graph the values of:

- gradient = $m = -\Delta S$
- y-intercept = $c = \Delta H$

ΔH is the enthalpy change (the energy change due to bond breaking and forming). Unit = kJ mol^{-1}

ΔS is the entropy change which can be + or -, so the slope could be positive or negative. Unit = $\text{J mol}^{-1} \text{K}^{-1}$

ΔG is the free energy change. A negative ΔG means the reaction is feasible. Unit = kJ mol^{-1}

WORKED EXAMPLE: GIBBS FREE ENERGY

Plot the following data and use the graph to find the values of ΔS and ΔH .

T / K	G / kJ mol^{-1}
100	3810
150	2710
200	1610
250	510
300	-590
350	-1690

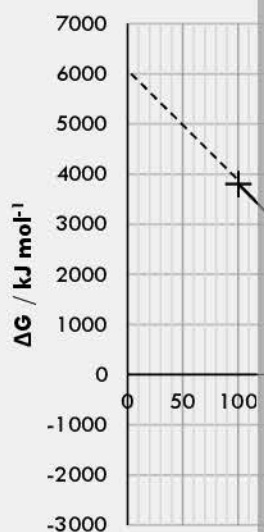
Calculating the gradient:

$$-\Delta S = \frac{(0) - (3000)}{(275) - (135)} = -21.4$$

$$\Delta S = 21.4 \text{ kJ mol}^{-1} \text{K}^{-1} = 21400 \text{ J mol}^{-1} \text{K}^{-1}$$

Extrapolate the line back to the y-axis to find the y-intercept:

$$\Delta H = 6000 \text{ kJ mol}^{-1}$$



Alternat
y-interc
and c =

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WORKED EXAMPLE: IDEAL GAS LAW

'A gas with an unknown number of moles (n) is compressed in a container. As the pressure increases. The temperature is held constant at 298 K.

- a) Use the data given to calculate T/V for each volume.
 b) Then rearrange the equation $pV = nRT$, and plot p against $\frac{T}{V}$, to find the value of R is $8.314 \text{ J K}^{-1} \text{ mol}^{-1}$.

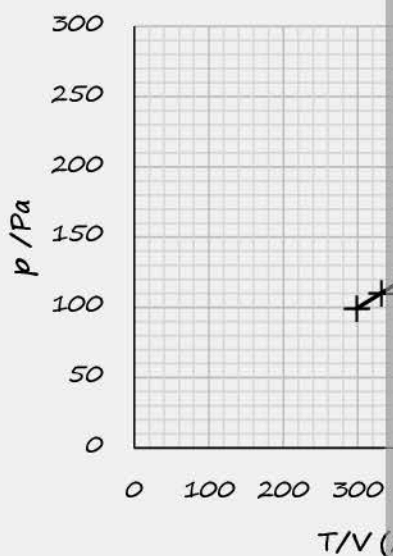
Rearrange the equation to the form $y = mx + c$:

$$pV = nRT \rightarrow p = nR \frac{T}{V} (+0)$$

$y = mx (+c)$
 $\downarrow \quad \downarrow \quad \downarrow$
 $p \quad nR \quad \frac{T}{V} (+0)$

This equation doesn't have a 'c' part, so the y-intercept will be at 0. The gradient is nR against T/V . Don't forget that T is 298 K.

V / m^3	T/V	p / Pa
1.000	298	99.1
0.900	331	110
0.800	373	124
0.700	426	142
0.600	497	165
0.500	596	198
0.400	745	248



$$\text{Gradient (m)} = \frac{200 - 100}{600 - 300} = 0.333$$

$$\text{Gradient} = nR, \text{ so } n = \frac{\text{Gradient}}{R}$$

$$n = \frac{0.333}{0.314} = 0.0401 \text{ mol}$$

Rearranging with exponentials and logs: Arrhenius equation

The Arrhenius equation is $k = Ae^{\frac{-E_A}{RT}}$.

Log rules can be used to rearrange this equation into the form $y = mx + c$.

$$k = Ae^{\frac{-E_A}{RT}}$$

take the natural log of both sides

$$\ln k = \ln(A \times e^{\frac{-E_A}{RT}})$$

Use $\ln(J \times K) = \ln J + \ln K$

$$\ln k = \ln A + \ln e^{\frac{-E_A}{RT}}$$

Use $\ln(e^x) = x$

$$\ln k = \frac{-E_A}{RT} + \ln A$$

This is now in the form:

$$\ln k = \frac{-E_A}{R} \times \frac{1}{T} + \ln A$$

$y = mx + c$
 $\swarrow \quad \downarrow \quad \searrow$
 $\ln k \quad \frac{-E_A}{R} \quad \frac{1}{T} \quad \ln A$

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WORKED EXAMPLE

'Use the data below to find the missing data, and then plot $\ln k$ against $\frac{1}{T}$ to find $R = 8.314 \text{ kJ mol}^{-1} \text{ K}^{-1}$.'

T / K	k / s ⁻¹	1/T	ln k
300	4.67×10^{-4}	0.00333	-7.67
310	8.69×10^{-4}	0.00323	-7.05
320	1.55×10^{-4}	0.00313	-6.47
330	2.69×10^{-3}	0.00303	-5.92
340	4.49×10^{-3}	0.00294	-5.41

Solution*Gradient*

$$\text{gradient} = \frac{(-7.5) - (-5.5)}{0.0033 - 0.00296} = -5882$$

$$\text{gradient} = -\frac{E_A}{R}, \text{ so } E_A = -\text{gradient} \times R$$

$$E_A = 5882 \times 8.314 = 49\,000 \text{ kJ mol}^{-1}$$

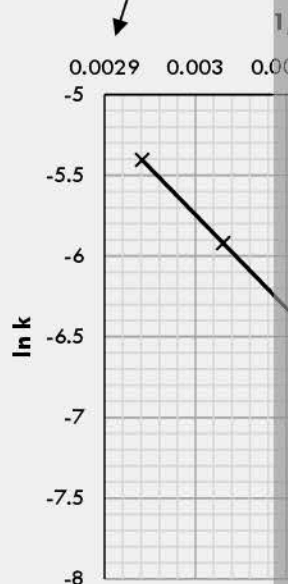
y-intercept

$$\ln k = \frac{-E_A}{RT} + \ln A$$

$$\begin{aligned} \text{so } \ln A &= \ln k + \frac{E_A}{RT} \\ &= -7.67 + \frac{49\,000}{8.314 \times 300} \\ &= 11.9 \end{aligned}$$

$$A = e^{11.9} = 1.53 \times 10^5$$

Tip: We can't just extrapolate the y-axis to find the y intercept level with $x = 0$.



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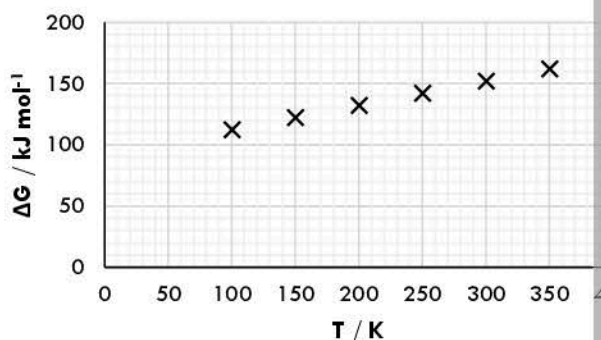


PRACTICE QUESTIONS

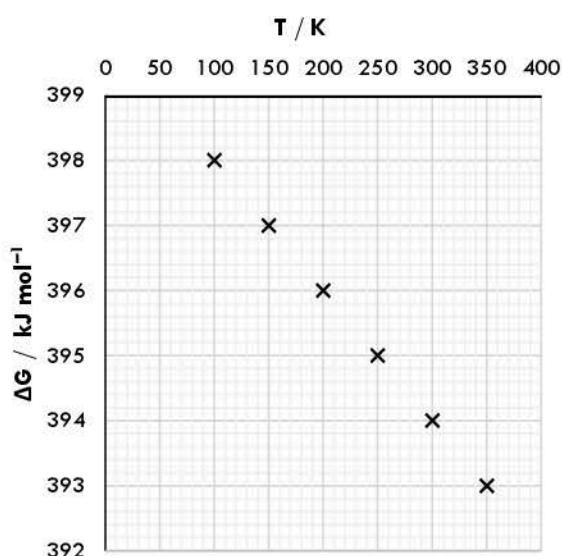
1. Use the following graphs of ΔG vs T to find the values of ΔH and ΔS .

$$\Delta G = \Delta H - T\Delta S$$

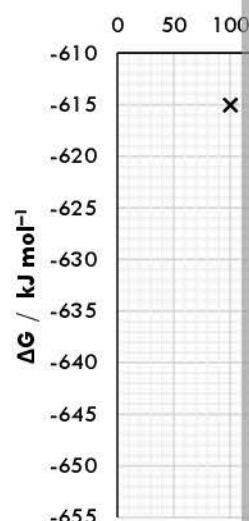
a)



b)



c)



2. Draw a graph of the following to find the stated values:

a) p vs T/V to find n ($pV = nRT$). $T = 298$ K.

V / m ³	p / Pa	T/V K m ⁻³
50.0	15.0	
40.0	19.0	
30.0	25.0	
20.0	37.0	
10.0	74.0	
5.0	149.0	

b) $\ln k$ against $1/T$ to find E_a and A , using a rearranged version of the equation

T / K	k / s ⁻¹	1/T / K ⁻¹	ln k
300	1.70×10^{-8}		
400	4.23×10^{-5}		
500	4.61×10^{-3}		
600	1.05×10^{-1}		
700	9.82×10^{-1}		

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SHAPES IN CHEMIS

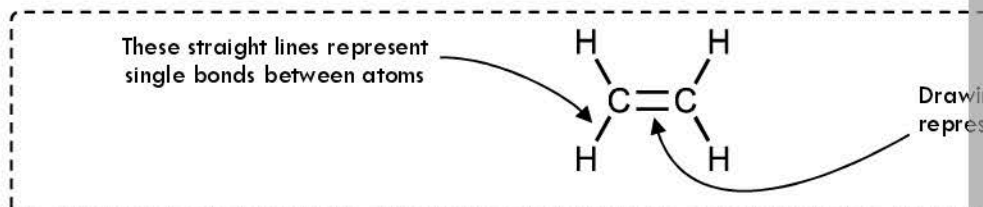
LEARNING OUTCOME

Draw the structures of molecules with different shapes, bond angles and orders of s

THEORETICAL OVERVIEW

2D molecules

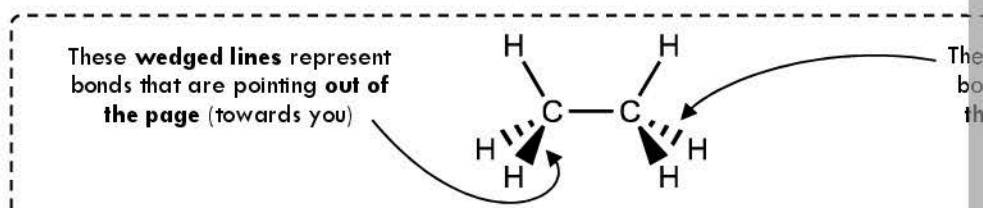
Here is an example of a 2D diagram of a molecule.



This is the simplest way of representing molecules. Each line between atoms repre

Wedge-and-dash diagrams

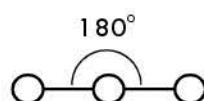
In reality, molecules are not 2D – they are 3D. It is possible to draw the 3D layout of molecules using **wedged** and **dashed** lines:



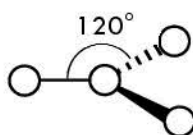
Using wedged and dashed lines, you can represent the structures of many basic molecules. You can use molecular modelling kits, or even just cocktail sticks.

Bond angles

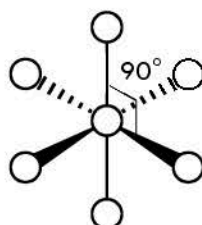
Different molecular structures have different **bond angles** (the angle between bonds). The bond angles in these basic molecular structures.



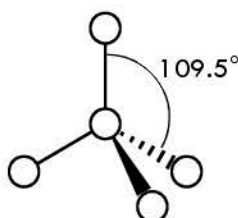
linear



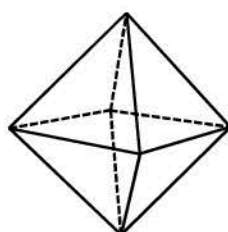
trigonal planar



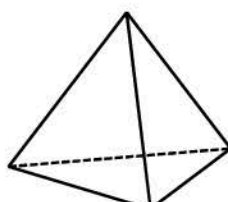
octahedral



tetrahedral



octahedron



tetrahedron

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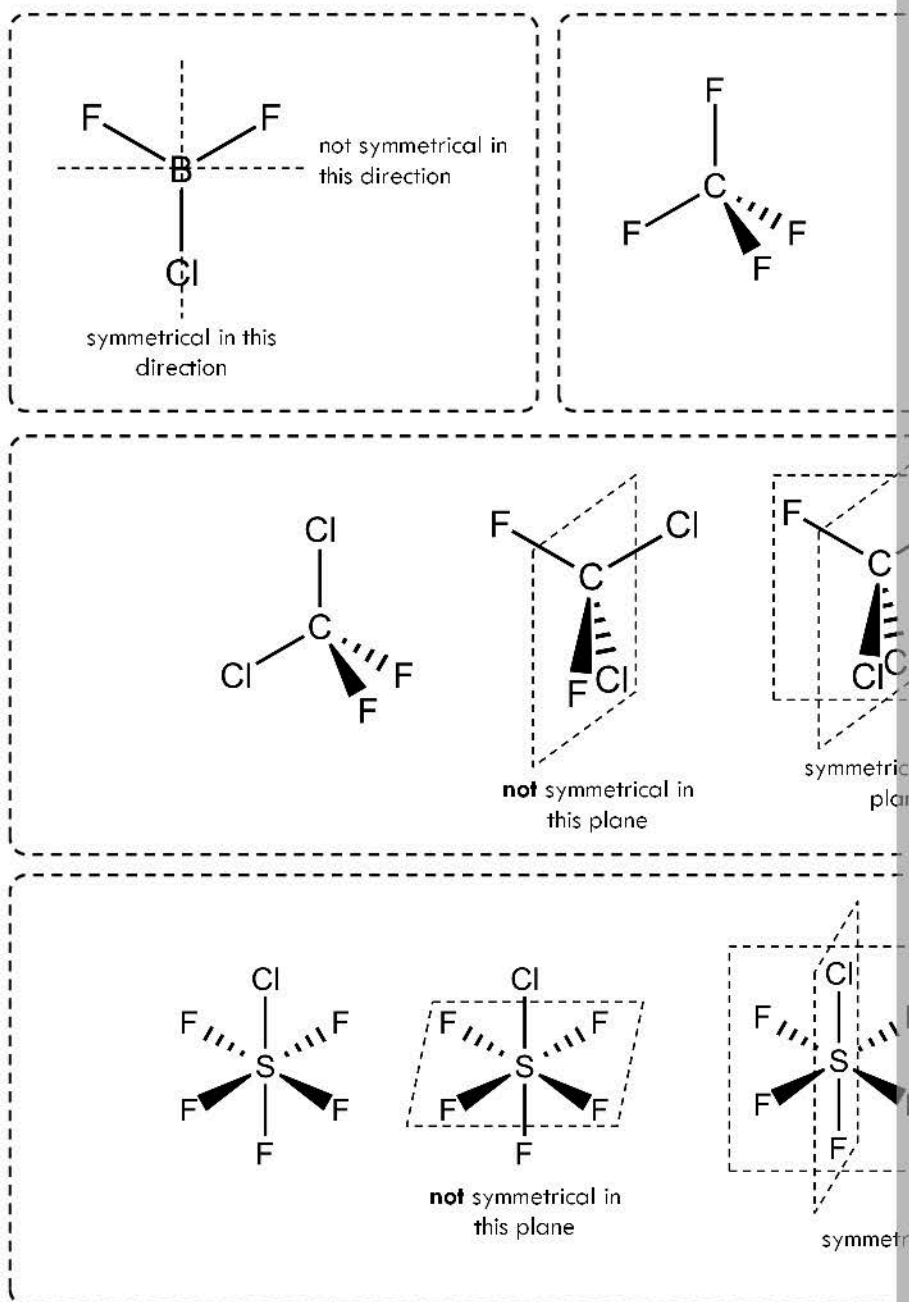
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Symmetry

As well as bond angles, another important feature of molecular structure is **symmetry**. Using a 3D representation of a molecule, you can work out whether it is **symmetrical**.

Technique
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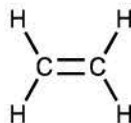
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PRACTICE QUESTIONS

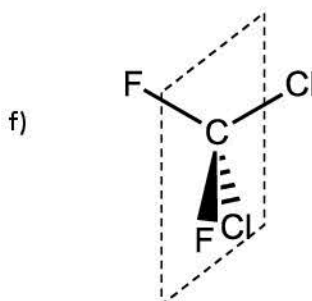
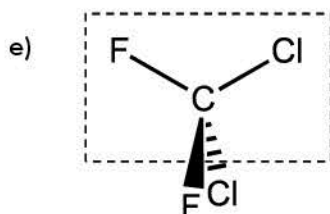
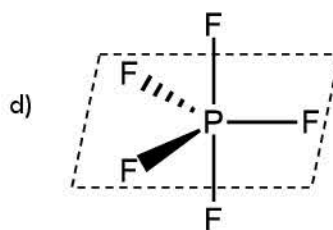
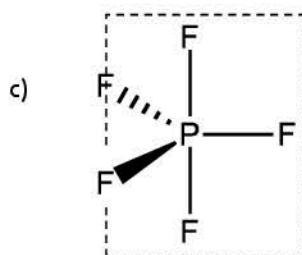
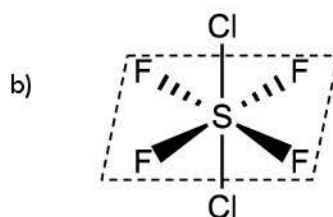
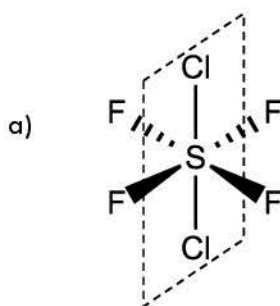
1. Methane has the formula CH_4 . It contains a central carbon with four hydrogen atoms bonded to it. Draw the 3D geometry of methane.
- a) Draw methane in 3D.
- b) Identify the bond angle in methane from its geometry.

2. This molecule is ethene:



Represent ethene as a 3D diagram, with the carbon–hydrogen bonds in and out of the plane of the paper.

3. State whether the following molecules are symmetrical in the planes shown.



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APPENDIX – USING A CALCULATOR

LEARNING OUTCOME

Use your calculator to make calculations involving powers, standard form, exponential growth and decay.

THEORETICAL OVERVIEW



Powers

Powers mean that a number is multiplied by itself.

For example:

$$3^3 = 3 \times 3 \times 3 = 27$$

$$10^5 = 10 \times 10 \times 10 \times 10 \times 10 = 100\,000$$

To calculate 2^5 , write:

$$2 \text{ } y^x \text{ } 5 \text{ } =$$

Roots

Roots are the opposite of powers.

$$\sqrt[3]{64} = 4, \text{ because } 4 \times 4 \times 4 = 64$$

To calculate $\sqrt[3]{64}$, write:

$$3 \text{ } \sqrt{\text{ }} \text{ } 64 \text{ } =$$

Logarithms

A logarithm is the opposite of '10 to the power of'. It tells you how many times you multiply 10 by itself to get a certain number.

$$\log 1000 = 3$$

This is because $10^3 = 10 \times 10 \times 10 = 1000$

To find the log of 1000 on a calculator, type:

$$\log 1000 =$$

e

e is a number which comes up in a few equations in Chemistry. It is a number, similar to π , with 2.7183 to 4 decimal places.

The e^x button works in the same way as the power button, so to calculate e^2 , you type:

$$e^x 2 =$$

Natural logarithms

Some equations will include $\ln$, which is called the natural logarithm. To find the natural log of 8, type:

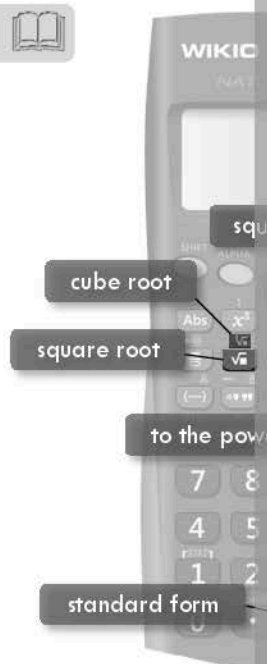
$$\ln 8 =$$

Standard form

Standard form is a way of representing numbers, especially very large or very small numbers.

To write 5×10^7 , type:

$$5 \text{ } 10^x \text{ } 7 \text{ } =$$



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WORKED EXAMPLE

'The rate constant, k , can be calculated from the Arrhenius equation:

$$k = Ae^{\frac{-E_a}{RT}}$$

Where: k is the rate constant

A is a constant,

E_a is the activation energy,

R is the universal gas constant, which has the value $8.314 \times 10^{-3} \text{ kJ mol}^{-1} \text{ K}^{-1}$

T is the temperature (in kelvin).

Calculate k when

$$A = 2.13 \times 10^9$$

$$E_a = 111000$$

$$T = 300 \text{ K}$$

Solution

To calculate this, type:

$(2.13 \times 10^9) \times (e^{\frac{-111000}{(8.314 \times 10^{-3} \times 300)}})$

which should give an answer of 2.04×10^{-10} .

PRACTICE QUESTIONS

1. Calculate the following:

a) $4^5 - 5^4$

b) $\log 10\,000\,000$

c) $8.95 \times 10^7 \div 1.41 \times 10^9$

d) $\ln(e^{5^2})$

e) $e^{4^2-3^2}$

f) $\log 63$

g) 6^{8-3^2}

h) $(9.49 \times 10^{-6}) \div (3.23 \times 10^{-7})$

i) $\log(4.5) - e^7$

j) $3^2 + e^2 + (\log(3))^2$

2. Using the Arrhenius equation from the worked example, calculate k for the following:

a) $E_a = 52,100 \text{ J mol}^{-1}$

$T = 313 \text{ K}$

$A = 15.6$

$R = 8.314 \text{ J K}^{-1} \text{ mol}^{-1}$

b) $E_a = 35\,600 \text{ J mol}^{-1}$

$T = 612 \text{ K}$

$A = 9.40$

$R = 8.314 \text{ J K}^{-1} \text{ mol}^{-1}$

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APPENDIX – DIAGNOSTIC

1. a) Write 0.000432 in standard form.
b) Write the number 9.045×10^2 out in full.
c) Round 7.5654 to 3 significant figures.
d) A reaction starts at 12°C and ends at 23.7°C . Write the temperature difference to 3 significant figures.
2. a) Convert 3 minutes 45 seconds into seconds.
b) Convert 0.24 km into m.
3. a) Convert 0.20 dm^3 into mm^3 .
b) Convert 200 cm^3 into dm^3 .
c) Convert 32 s^{-1} into ms^{-1} .
d) Convert 3 kg mol^{-1} into g mol^{-1} .
4. a) How many significant figures does the number 0.00693 have?
b) Write 45.298 to 4 significant figures.
5. a) Write the ratio 12:42 as a fraction in its simplest form.
b) Write the fraction $\frac{4}{5}$ as a decimal.
c) Write the percentage 60 % as a fraction in its simplest form.
6. a) A 87.2 g piece of rock contains 34.5 g aluminium by mass. Calculate the percentage by mass of Al in the rock.
b) Find the percentage by mass of C in CO_2 .
c) Calculate the percentage yield of a reaction with actual yield 4.80 g and theoretical yield 6.00 g.
7. a) A 120 cm^3 solution contains 3.40 g. How much mass is in 77.0 cm^3 of the solution?
b) A salt with the formula VO_x contains 61.4 % vanadium. Determine the formula of the salt.
8. a) Calculate the mean of the following values: 5.5, 5.6, 5.7, 5.6
b) Calculate the mean titre from the following titres:

	Titre			
	Rough	1	2	3
start volume / cm^3	0.00	0.45	0.05	0.5
end volume / cm^3	30.70	29.45	29.45	29.4
volume of acid / cm^3				

- c) Sulfur has the following composition of isotopes: ^{32}S 95.00 %, ^{33}S 00.75 %
Calculate the relative atomic mass of sulfur.
9. Calculate the percentage uncertainty in a reading of 12.45 g on an analogue balance.
10. Calculate the uncertainty in a titre of 23.35 cm^3 measured on a burette with 0.1 cm^3 graduations. Assume errors due to the volume of a drop.
11. a) Sketch a graph to show the relationship between Rate and $[\text{H}^+]$ for the expression $\text{Rate} \propto [\text{H}^+]^2$.
b) For the expression $\text{Rate} \propto [\text{H}^+]^2$, describe the effect on the rate if $[\text{H}^+]$ is tripled.
12. a) Rearrange the equation $pV = nRT$ to make R the subject of the formula.
b) Rearrange the equation $y = \frac{x+9}{3}$ to make x the subject of the formula.
c) Find the value of T when $p = 100,000\text{ Pa}$, $V = 0.0430\text{ m}^3$, $n = 2.50\text{ mol}$.
13. a) In the equation $\Delta G = \Delta H - T\Delta S$. Find the value of ΔS when $\Delta G = -120\text{ kJ mol}^{-1}$ and $T = 150\text{ K}$.
b) An experiment with three measurements has a mean result of 23.45 cm^3 . Measurement 1 = 23.40 and measurement 2 = 23.60. Determine the value of measurement 3.

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14. a) Find the value of $[A]$ in mol dm^{-3} for the equation $\text{Rate} = k[A]^3[B]$ when $R = 0.0400 \text{ dm}^3 \text{ mol}^{-3} \text{ s}^{-1}$ and $[B] = 0.100 \text{ mol dm}^{-3}$.
 b) Rearrange the formula $V = \frac{4\pi r^3}{3}$ to find the value of r when $V = 32.0 \text{ m}^3$.
15. a) Use a calculator to find the value of $\log(13000)$.
 b) Given that $\text{pH} = -\log[\text{H}^+]$, find the pH of a solution with $[\text{H}^+] = 0.000320$.
16. a) Plot a graph of the following data. Add a trend line.

time / s	rate / $\text{mol dm}^{-3} \text{ s}^{-1}$
0	0.521
60	0.452
120	0.401
180	0.345
240	0.201

- b) Plot a graph of the following data. Add a trend line.

time / s	concentration / mol dm^{-3}
60	0.0533
120	0.0487
180	0.115
240	0.161
300	0.146
360	0.293
420	0.344
480	0.557
540	0.936
600	1.58

17. a) Find the gradient of the line of best fit for the graph in 16 a.
 b) Find the gradient of the tangent at 400 s for the graph in 16 b.
18. Plot a graph of the following data to find the value of E_a , given that $\ln k = \ln A - \frac{E_a}{RT}$.

T / K	k / s^{-1}	1/T / K^{-1}	$\ln k$
300	7.63×10^2		
400	2.81×10^3		
500	6.14×10^3		
600	1.03×10^4		
700	1.50×10^4		

19. a) Draw the molecule SF_6 in 3D using wedge-and-dash lines. It has octahedral geometry.
 b) Identify the bond angle in SF_6 .

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DIAGNOSTIC TEST ANSWERS

1. a) 4.32×10^{-4}
b) 904.5
c) 7.57
d) $23.7 - 22 = 11.7$
 $= 12^\circ\text{C}$ (2 s.f.)
2. a) 225 s
b) $0.24 \times 10^3 = 240$ m
3. a) $0.20 \times (10^2)^3 = 200\,000$ mm³
b) $200 \div 10^3 = 0.2$ dm³
c) $32 \div 10^3 = 0.032$ ms⁻¹
d) $3 \times 10^3 = 3000$ g mol⁻¹
4. a) 3
b) 45.30
5. a) $\frac{2}{7}$
b) 0.8
c) $\frac{3}{5}$
6. a) $\frac{34.5}{87.2} \times 100 = 39.6\%$
b) $\frac{12}{12 + 16 \times 2} \times 100 = 27.3\%$
c) $\frac{4.8}{9.3} \times 100 = 51.6\%$
7. a) $\frac{3.4}{120} \times 77 = 2.18$ g
b) relative formula mass of V = 50.9
relative formula mass of VO_x = $\frac{50.9}{61.4} \times 100 = 82.9$
relative formula mass of O_x = $82.9 - 50.9 = 32$
 $x = \frac{32}{16} = 2$
Salt is VO₂
8. a) $\frac{5.5 + 5.6 + 5.7 + 5.6}{4} = 5.6$
b)

	Titre			
	Rough	1	2	3
start volume / cm ³	0.00	0.45	0.05	0.55
end volume / cm ³	30.70	29.45	29.45	29.45
volume of acid / cm ³	30.70	29.00	29.40	28.90

 Mean titre = $\frac{29.00 + 28.90}{2} = 28.95$ cm³
 c) $\frac{(32 \times 95) + (33 \times 0.75) + (34 \times 4.25)}{100} = 32.09$
9. Percentage uncertainty = $\frac{0.01}{12.45} \times 100 = 0.08\%$
10. Uncertainty in a reading = 0.05 cm³
Uncertainty in a titre (measurement) = $0.05 \times 2 = 0.1$
 $\frac{0.1}{23.35} \times 100 = 0.43\%$

11. a) Ra

- b) multi

12. a) R =
b) x =
c) T

13. a) ΔS
b) $\frac{23.40}{23.40}$
x =

14. a) [A]

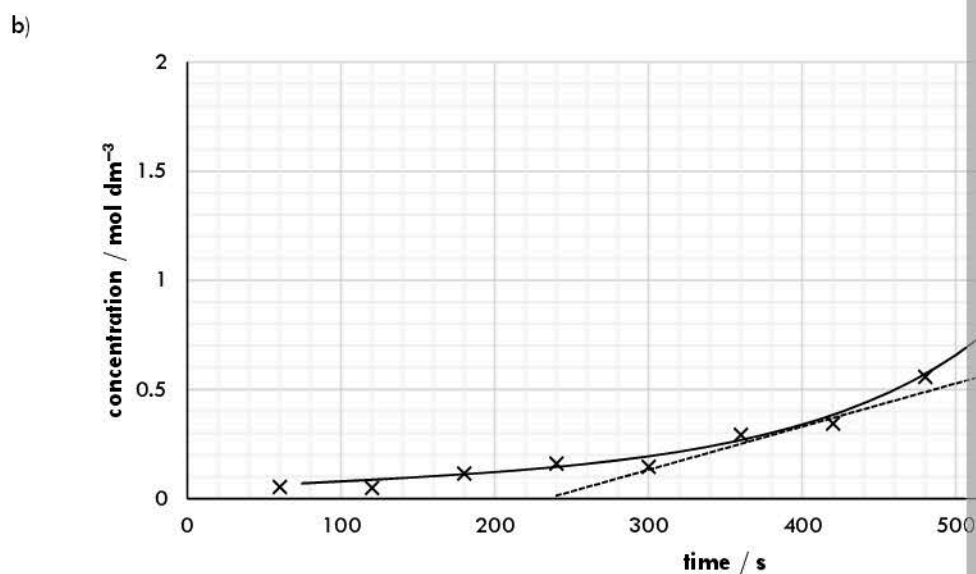
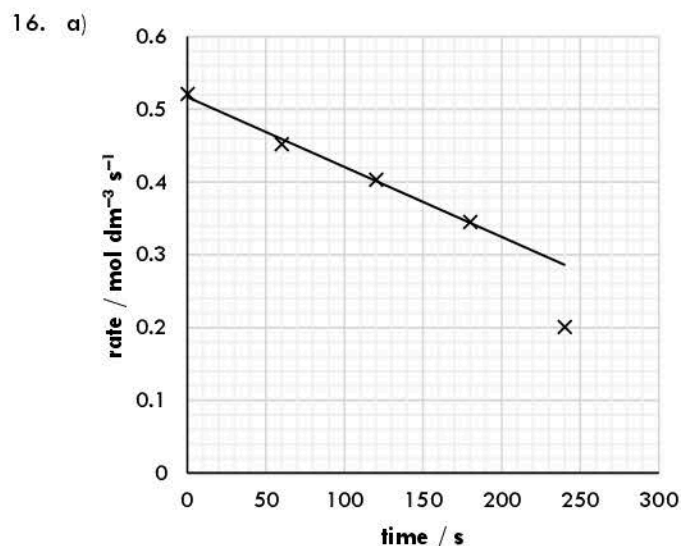
- b) r

15. a) 4.11
b) -log

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17. a) $\text{gradient} = \frac{0.29 - 0.52}{240 - 0}$
 $= -9.58 \times 10^{-4} \text{ mol dm}^{-3} \text{ s}^{-1}$

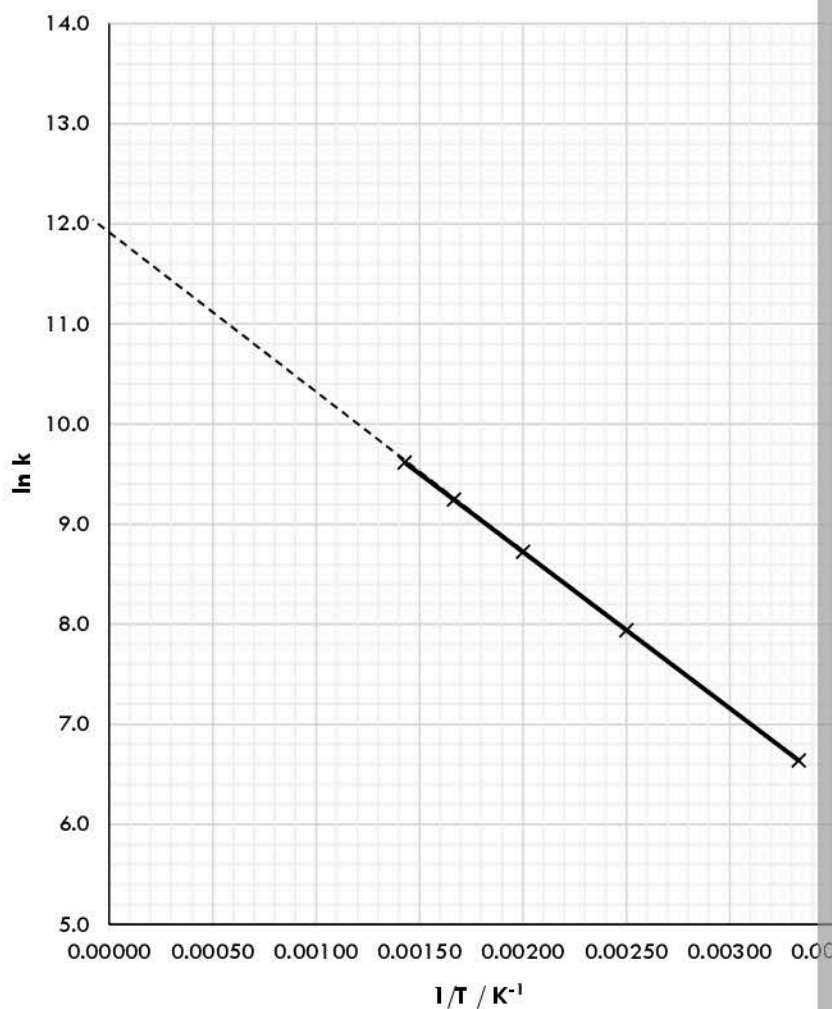
b) $\text{Gradient} = \frac{0.9 - 0.1}{680 - 300} = 0.00211 \text{ mol dm}^{-3} \text{ s}^{-1}$ (allow between 0.00191 and 0.00231)

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18.

T / K	k / s ⁻¹	1/T / K ⁻¹	ln k
300	7.63×10^2	0.00333	6.64
400	2.81×10^3	0.00250	7.94
500	6.14×10^3	0.00200	8.72
600	1.03×10^4	0.00167	9.24
700	1.50×10^4	0.00143	9.62



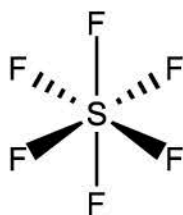
$$\text{y-intercept} = \ln A = 11.9$$

$$A = e^{11.9} = 147\,000$$

$$\text{Gradient} = \frac{9-7}{0.0018-0.0031} = -1538 = \frac{-E_a}{R}$$

$$E_a = 1538 \times 8.314 = 13\,000 \text{ J mol}^{-1}$$

19. a)



b) 90°

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PRACTICE QUESTIONS A

Decimals and Standard Form

- $4.25 \times 10^6 \text{ J}$
 - $1.2 \times 10^{-2} \text{ m}$
 - $6.23 \times 10^{11} \text{ s}$
 - $7.896 \times 10^{-7} \text{ kg}$
- 0.00000672 mol
 - 75900 atoms
 - 0.000991 mol dm⁻³
 - 814.3 cm³
- 2.47 g
 - 7.962 g
 - 3.142 g
 - 1.0 g
- 1.63 g
 - $3.26 \times 10^{-1} \text{ g}$
- $$\frac{13 \times 0.2}{100} = 0.026 = 2.6 \times 10^{-2}$$

Units I – Common Units and Prefixes

- $\frac{40}{1000} = 0.04 \text{ km}$
 - $0.025 \times 10^6 = 25\,000 \text{ mg}$
 - $\frac{180}{60} = 3 \text{ min}$
 - $25 + 273 = 298 \text{ K}$
 - $2.45 \times 10^{-7} \times 10^9 = 245 \text{ nm}$
 - $\frac{0.26 \times 10^{12}}{10^9} = 260 \text{ GJ}$
 - $\frac{4.65 \times 10^{22}}{10^{12}} = 4.65 \times 10^{10} \text{ km}$
 - $\frac{684\,000}{1\,000} = 684 \text{ nm}$
- $p = 20 \times 10^3 = 20\,000 \text{ Pa}$
 $n = 120 \div 1000 = 0.120 \text{ mol}$
 $T = 0 + 273 = 273 \text{ K}$
- $p = 100 \times 10^3$
 $n = 20 \div 1000$
 $T = 20 + 273 =$
 - $p = 40 \times 10^6 =$
 $n = 1450 \div 10$
 $T = 40 + 273 =$
- $m = 0.250 \times 10$
 - $m = \frac{4.50 \times 10^6}{10^3} =$
 - $c = 0.142 \times 10$
 - $T = 320 + 273$
 - $m = \frac{30}{1000} = 0.03$
 - $c = 129 \div 10^3$

Units II – Units with Powers

- 1000 times
 - 10 000 times
 - $8 (2 \times 2 \times 2)$
 - 2 times
 - 5000 times
- $5 \times (10^3)^3 = 5\,000\,000\,000 \text{ mm}^3$
 - $3 \div (10^{-3})^3 = 3 \times 10^{-6} \text{ m}^3$
 - $20 \times (10)^2 = 2000 \text{ dm}^2$
 - $100 \times (10^3)^2 = 100\,000\,000 \text{ mm}^2$
 - $8.8 \times 10^{-17} \times (10^6)^3 = 88 \text{ km}^3$
 - 0.02455 dm³
 - 250 cm³
 - $3 \times 10^3 = 3000 \text{ J kg}^{-1}$
 - $18 \times 10^3 = 18\,000 \text{ mol dm}^{-3}$
- $4.6 \div (39.1 + 1)$
 - $0.5 \times (23 + 16)$
 - $11.3 \div (24.3 + 1)$
 - $0.35 \times (23 \times 2)$
- $23.38 \div 1000 = 0.02338$
- $p = 150 \text{ kPa} = 150\,000 \text{ Pa}$
 $V = 30 \text{ dm}^3 = 30 \div 1000 = 0.03 \text{ m}^3$
 $T = 25^\circ\text{C} = 25 + 273 = 298 \text{ K}$

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Significant Figures

- 76 000
 - 0.00613
 - 19000
 - 0.010
 - 0.003407
 - 2.000
- 0.194 mol (3 s.f.)
 - 0.59 mol (2 s.f.)
 - 1.598 mol (4 s.f.)

Fractions, Percentages and Ratios

- $45 \div 100 = 0.45$
 - $1 \div 5 = 0.2$
 - $0.3 \div 100 = 0.003$
 - $0.7 \div 3.5 = 0.2$
 - $5 \div 12 = 0.417$
- $5 \div 7 \times 100 = 71.4 \%$
 - $6 \div 23 \times 100 = 26.1 \%$
 - $9 \div 10 \times 100 = 90.0 \%$
 - $7 \div 9 \times 100 = 77.8 \%$
 - $42 \div 100 \times 100 = 42.0 \%$
- $1/4$
 - $5/4$
 - $3/10$
 - $3/5$
 - $11/20$
- $1 \div (1 + 3) = 1/4$
 - $1 \div 4 \times 100 = 25 \%$
- CH_2 (divide all r by 2)
 - CH_2O (divide all r by 2)
- $40:60 = 2:3$

Percentage Mass, Purity and Yield

- $\frac{36}{40} \times 100 = 90 \%$
 - $\frac{15}{20} \times 100 = 75 \%$
- $\frac{1.2}{3.0} \times 100 = 40 \%$
 - $\frac{28}{56} \times 100 = 50 \%$
 - $\frac{4.1}{6.7} \times 100 = 61 \%$
- $\frac{40.1}{40.1 + 12 + 3 \times 16} \times 100 = 36.1 \%$
 - $\frac{24.3}{24.3 + 32.1 + 4 \times 16} \times 100 = 20.7 \%$
 - $\frac{23.0}{23 + 16 + 1} \times 100 = 58.8 \%$
 - $\frac{2 \times 1}{40.1 + 2 \times (16 + 1)} \times 100 = 2.4 \%$
 - $\frac{2 \times 55.8}{2 \times 55.8 + 3 \times (32.1 + 16)} \times 100 = 15.2 \%$

Scaling Quantities

- $(0.56 \div 14) \times 60 = 2.4 \text{ g}$
 - $(0.56 \div 14) \times 85 = 3.4 \text{ g}$
 - $(0.56 \div 14) \times 3 = 0.12 \text{ g}$
- $(1.36 \div 0.17) \times 1 = 8.0 \text{ dm}^3$
 - $(1.36 \div 0.17) \times 1.74 = 14 \text{ dm}^3$
 - $(1.36 \div 0.17) \times 34 = 270 \text{ dm}^3$
 - $(1.36 \div 0.17) \times 0.1 = 0.80 \text{ dm}^3$
- percentage yield = $\frac{\text{actual yield}}{\text{theoretical yield}} \times 100$

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

= $\frac{18}{26} \times 100$

= 69.2 g
- $(40 \div 25) \times 100 = 160 \%$
- theoretical yield
- $(35.5 \div 47.6) \times 100 = 74.6 \%$
 - $74.6 - 35.5 = 39.1$
formula mass of M is K
- $16 \times 3 = 48$
 $(48 \div 47.1) \times 100 = 101.9$
 $101.9 - 48 = 53.9$
 $53.9 \div 2 = 27.0$
 - M is Al as Al has a relative atomic mass of 27.0

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Calculating Means

- $\frac{1+2+3+4+5+6+7+8+9+10}{10} = 5.5$
 - $\frac{5+4+2+8}{4} = 4.75$
 - $\frac{6.5+6.2+6.6+6.9}{4} = 6.55$
 - $\frac{250+300+280+310+260}{5} = 280$
 - $\frac{0.06+0.02+0.05+0.02}{4} = 0.0375$
- $\frac{14.60+14.50}{2} = 14.6 \text{ cm}^3$
 - $\frac{19.40+19.45}{2} = 19.43 \text{ cm}^3$
 - $\frac{13.20+13.30}{2} = 13.3 \text{ cm}^3$
- $\frac{(234 \times 2) + (235 \times 2)}{100}$
 - $\frac{(35 \times 75) + (37 \times 25)}{100}$
 - $\frac{(6 \times 8) + (7 \times 92)}{100}$
 - $\frac{(50 \times 9) + (52 \times 84)}{100}$

Uncertainty I

- $23.0 \pm 0.5 \text{ cm}^3$
 - $12.0 \pm 0.1 \text{ cm}$ (uncertainty is 0.05×2 as two readings are taken)
 - $16 \pm 1 \text{ }^\circ\text{C}$
 - $19.50 \pm 0.10 \text{ cm}^3$
 - $2 \times 0.01 \text{ g} = 0.02 \text{ g}$
 $4.50 - 3.25 = 1.25 \text{ g}$
 $1.25 \pm 0.02 \text{ g}$
 - $22.0 \pm 0.5 \text{ }^\circ\text{C}$
 - $45.60 - 0.05 = 45.55$
 $0.05 \times 2 = 0.10$
 $45.55 \pm 0.10 \text{ cm}^3$
- $\frac{25.2+24.8+26.2}{4}$
 - $\pm 0.7 \text{ }^\circ\text{C}$
- $\frac{34.3+38.1+33.2+37.1}{4}$
 $(38.1 - 33.2) \div 2 =$
 $35.7 \pm 2.5 \text{ g}$

Uncertainty II

- $\frac{0.5}{12.5} \times 100 = 4.0 \%$
 - $\frac{0.1}{42.6} \times 100 = 0.23 \%$
 - $\frac{0.15}{28.5} \times 100 = 0.53 \%$
 - $\frac{1}{49.4} \times 100 = 2.0 \%$
 - $\frac{5}{1542} \times 100 = 0.3 \%$
 - $\frac{0.05}{0.13} \times 100 = 38 \%$

2. a)

Titration	Rough	1	2	3
Initial reading (cm ³)	0.00	0.00	0.00	0.10
Final reading (cm ³)	27.00	26.05	26.15	26.85
Titre (cm ³)	27.00	26.05	26.15	26.75

$$\text{Mean titre} = \frac{26.05 + 26.15}{2} = 26.10$$

$$\frac{0.15}{26.1} \times 100 = 0.56 \%$$

b)

Titration
Initial reading (cm ³)
Final reading (cm ³)
Titre (cm ³)

$$\text{Mean titre} = \frac{25.8}{2}$$

$$\text{Uncertainty} = \frac{0.1}{25}$$

c)

Titration
Initial reading (cm ³)
Final reading (cm ³)
Titre (cm ³)

$$\text{Mean titre} = \frac{22.4}{2}$$

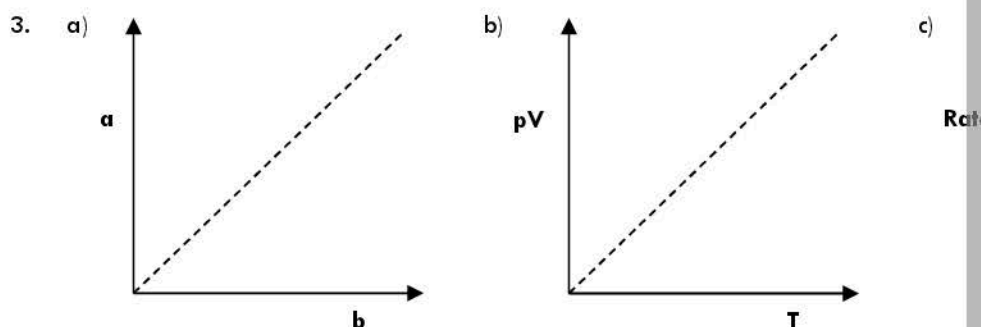
$$\text{Uncertainty} = \frac{0.1}{22}$$

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Mathematical Symbols

- $2 \text{ cm}^3 > 1 \text{ cm}^3$
 - $4000 \text{ mg} < 4300 \text{ mg}$
 - $4000 \gg 0.003$
 - moles $\propto$ pressure
- Doubles (both sides increase proportionally)
 - Halves (both sides decrease proportionally)



Using Equations I – Rearranging Simple Equations

- concentration of reactant used = rate $\times$ reaction time
- $x = d/2$
 - $x = wA/y$
 - $x = 4$
- $$\text{moles} = \frac{\text{mass}}{M_r}$$

$$\text{moles} = \frac{\text{volume}}{24\,000}$$

$$\text{moles} = \text{concentration} \times \text{volume}$$
- $p = \frac{nRT}{V}$
 - $T = \frac{pV}{nR}$
 - $n = \frac{pV}{RT}$
- $$V = \text{moles} \times 24\,000$$

$$= 0.75 \times 24\,000$$

$$= 18\,000 \text{ cm}^3$$
- $$\Delta T = \frac{Q}{mc}$$

$$= \frac{2000}{150 \times 4.18}$$

$$= 3.19 \text{ K}$$

Using Equations II – Equations with +, −, $\times$ and $\div$

- $x = 3y - 5$
 - $x = \frac{y+9}{6}$
 - $x = \frac{y-c}{m}$
 - $x = \frac{4}{y}$
 - $x = y - 1$
 - $x = \frac{y+2}{2}$ or $x = \frac{y}{2} + 1$
 - $x = \frac{1}{3y}$
 - $x = \frac{y-3}{y}$ or $x = 1 - \frac{3}{y}$
- $$\text{Mean} = \frac{x + 10 + 8 + 7}{4} = 8$$

$$x + 10 + 8 + 7 = 8 \times 4 = 32$$

$$x = 32 - (10 + 8 + 7)$$

$$x = 7 \text{ cm}^3$$
- $$\text{Mean} = \frac{30.2 + x + 28.7 + 30.0}{4} = 29.4$$

$$x + 30.2 + 28.7 + 30.0 = 29.4 \times 4 = 117.6$$

$$x = 117.6 - (30.2 + 28.7 + 30.0)$$

$$x = 28.7 \text{ g}$$
- $$20.2 = \frac{(20 \times 90) + (Y \times 100)}{100}$$

$$20.2 \times 100 = (20 \times 90) + Y$$

$$2020 - 1800 = Y$$

$$\frac{220}{10} = Y$$

$$Y = 22$$
- $$492 = 2 \times 436 + 2 \times \text{H-Cl}$$

$$\text{H-Cl} = \frac{2 \times 492 - 2 \times 436}{2}$$

$$= 43$$
 - $$-482 = 2 \times 436 + 4 \times \text{H-O}$$

$$\text{H-O} = \frac{2 \times 436 + 4 \times 482}{4}$$

$$= 46$$

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Using Equations III – Equations with Powers and Roots

- $2^3 + 3^2 = 17$
 - $c = 3^2 \div 3$
 $= 3$
 - $c^2 = 3^2$
 $c = 3$ (or -3)
 - $c = \frac{b}{a^2}$
 $= \frac{3}{2^2} = \frac{3}{4}$
 $= 0.75$
 - $c = \sqrt{a^2 b^2 - b^3 - 5}$
 $= \sqrt{2^2 3^2 - 3^3 - 5}$
 $= \sqrt{4}$
 $= 2$ (or -2)
 - $c = \sqrt[3]{\frac{b^3 + a^2 + 1}{a^2}}$
 $= \sqrt[3]{\frac{3^3 + 2^2 + 1}{2^2}}$
 $= \sqrt[3]{8}$
 $= 2$
- $x = \sqrt{2y}$
 - $x = \sqrt{\frac{4\pi}{y}}$
 - $x = 4y^2$
 - $x = \sqrt[3]{\frac{y}{27z}}$ or $x = \frac{\sqrt[3]{y}}{3}$
- $[H^+] = \sqrt[2]{\frac{[CH_3(COO)]}{[CH_3(CO)]}}$
 $= \sqrt[2]{\frac{0.5 \times 2.0}{1.0}}$
 $= 9.22 \times 10^{-2} \text{ mol dm}^{-3}$
 - $[H_2] = \sqrt[3]{\frac{[NH_3]^2}{[N_2] \times K_p}}$
 $= \sqrt[3]{\frac{0.010^2}{0.12 \times 1.0}}$
 $= 4.5 \text{ mol dm}^{-3}$
- $m = 2 \times \frac{K.E.}{v^2}$
 $= 2 \times \frac{6.77 \times 10^{-17}}{45^2}$
 $= 6.66 \times 10^{-21} \text{ kg}$
 - $v = \sqrt{\frac{2 K.E.}{m}}$
 $= \sqrt{\frac{2 \times 1.00 \times 10^{-17}}{9.27 \times 10^{-31}}}$
 $= 46400 \text{ m s}^{-1}$
- $k = \frac{\text{Rate}}{[NO]^2[H_2]}$
 $= 0.048 \text{ s}^{-1} \text{ mol}^{-2} \text{ dm}^6$
 - $[NO] = \sqrt{\frac{\text{Rate}}{k[H_2]}}$
 $= \sqrt{\frac{3.52 \times 10^{-4}}{0.048 \times 1.00}}$
 $= 0.049 \text{ mol dm}^{-3}$

Logarithms

- 1585
 - 5.079
 - 3.301
 - 0.9162
 - 4.000
 - 3.000
- 1000
 - 2.512×10^8
 - 2.699
 - 0.8710
 - 5.246

3. a)

ionisation energy number	1	2	3	4	5
ionisation energy (kJ mol ⁻¹)	577	1816	2744	11 577	14 840
log(ionisation energy)	2.7612	3.2591	3.4384	4.0636	4.1713

- b) Values span a large range
It makes the values easier to compare / plot on a graph

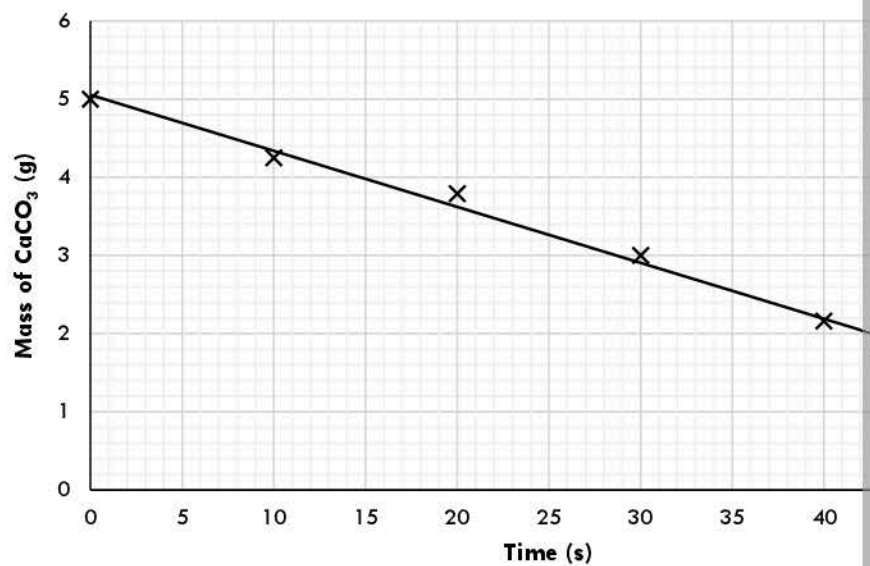
4. $k = Ae^{\frac{-E_a}{RT}}$
 $\ln k = \ln A - \frac{E_a}{RT}$
 $= 7.65 - 16.4$
 $= -8.75$
 $k = e^{-8.75}$
 $= 1.58 \times 10^{-4}$

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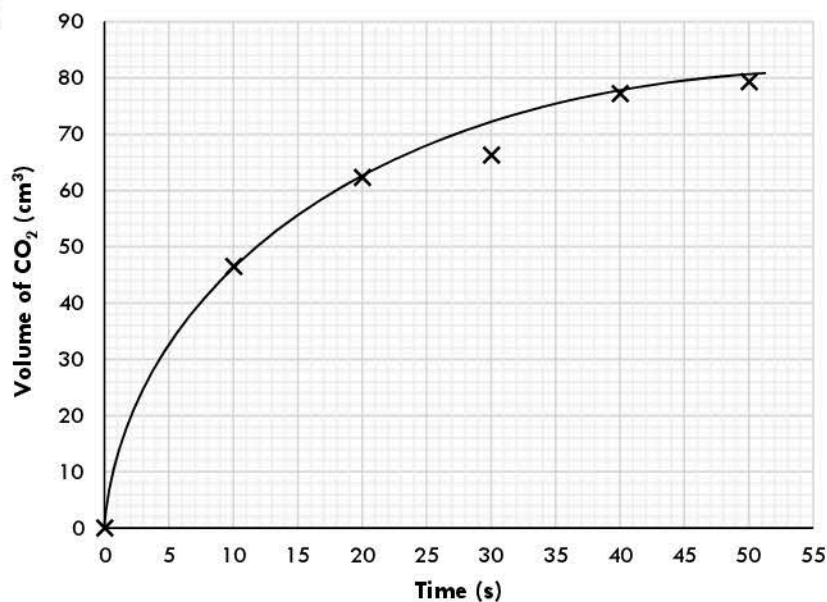


Constructing Graphs

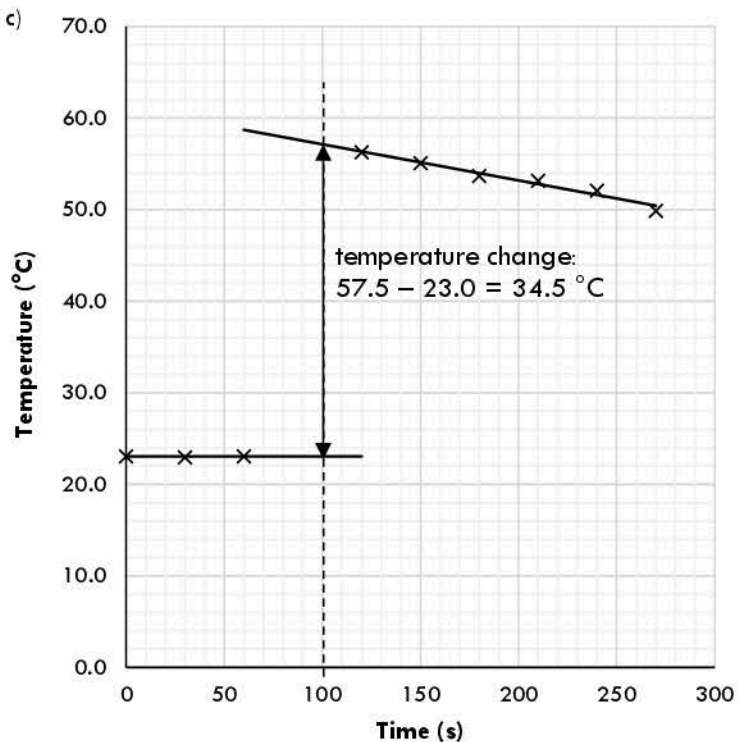
1. a)



b)



c)



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Analysing Graphs

- 3.40 g
 - 2.50 g
 - 27 s
 - $4.00 - 2.25 = 1.75$ g
- $\text{Gradient} = \frac{5.0 - 1.2}{8 - 0} = 0.48 \text{ mol dm}^{-3} \text{ s}^{-1}$
 $y\text{-intercept} = 1.2 \text{ mol dm}^{-3}$
 - $\text{Gradient} = \frac{2 - 3.5}{35 - 25} = -0.15 \text{ kJ mol}^{-1} \text{ K}^{-1}$
 $y = -0.15x + c$, so $c = y + 0.15x$

 When $y = 2$, $x = 35$
 $c = 2 + 0.15 \times 35 = 7.25 \text{ kJ mol}^{-1}$
- $\frac{80 - 34}{20 - 0} = 2.3 \text{ cm}^3$
 - $\frac{84 - 65}{45 - 0} = 0.42 \text{ cm}^3$
- $\frac{0 - 22}{190 - 0} = -0.12$
 - $\frac{0 - 30}{125 - 5} = -0.25$

Rearranging Equations to the Form $y = mx + c$

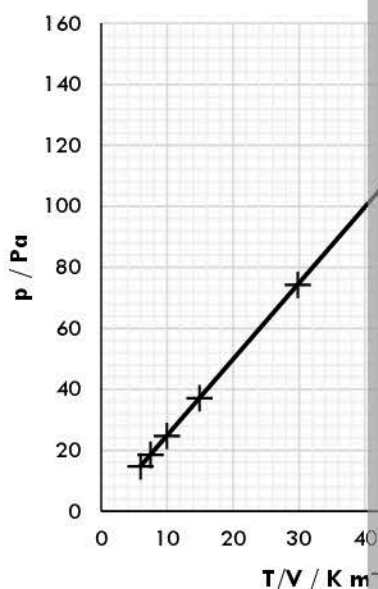
- $-\Delta S = \frac{(200) - (150)}{350 - 100} = 0.200$
 $\Delta S = -0.200 \text{ kJ mol}^{-1} \text{ K}^{-1} (= 200 \text{ J mol}^{-1} \text{ K}^{-1})$
 $\Delta H = \Delta G + T\Delta S$
 $= 110 + 100 \times (-0.2)$
 $= 90 \text{ kJ mol}^{-1}$
 - $-\Delta S = \frac{(393) - (398)}{350 - 100} = -0.020$
 $\Delta S = 0.020 \text{ kJ mol}^{-1} \text{ K}^{-1} (= 20 \text{ J mol}^{-1} \text{ K}^{-1})$
 $\Delta H = \Delta G + T\Delta S$
 $= 398 + 100 \times 0.020$
 $= 400 \text{ kJ mol}^{-1}$

2. a)

V / m^3	p / Pa	$T/V \text{ K m}^{-3}$
50.0	15.0	5.96
40.0	19.0	7.45
30.0	25.0	9.93
20.0	37.0	14.9
10.0	74.0	29.8
5.00	149.0	59.6

$$nR = \frac{(150) - (17)}{60 - 6} = 2.46$$

$$n = \frac{2.46}{8.314} = 0.296 \text{ mol}$$

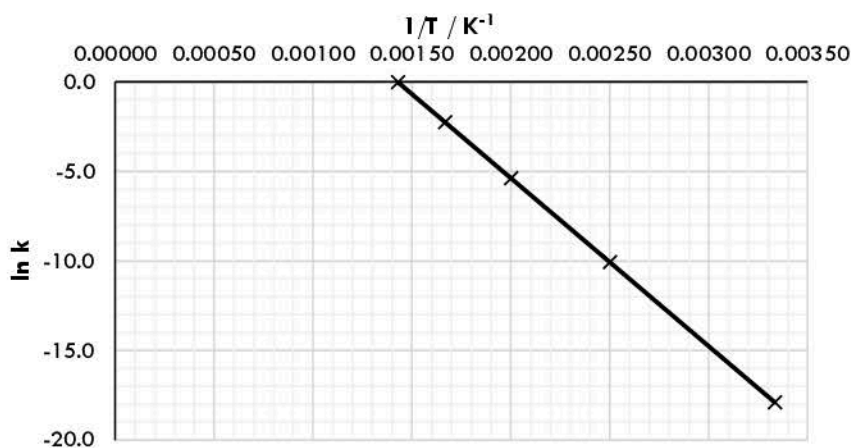


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b)

T / K	k / s ⁻¹	1/T / K ⁻¹	ln k
300	1.70 × 10 ⁻⁸	0.00333	-17.9
400	4.23 × 10 ⁻⁵	0.00250	-10.1
500	4.61 × 10 ⁻³	0.00200	-5.38
600	1.05 × 10 ⁻¹	0.00167	-2.25
700	9.82 × 10 ⁻¹	0.00143	-0.0178



$$-E_a/R = \frac{-18 - 0}{0.00332 - 0.00143} = -9523$$

$$E_a = 9523 \times 8.314 = 79\,180 \text{ J mol}^{-1}$$

$$\ln k = \frac{-E_a}{RT} + \ln A$$

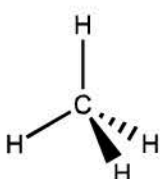
$$\begin{aligned} \text{so } \ln A &= \ln k + \frac{E_a}{RT} \\ &= -10 + \frac{79\,180}{8.314 \times 400} \\ &= 13.8 \end{aligned}$$

$$A = e^{13.8} = 994\,000 \text{ (} = 9.94 \times 10^5 \text{)}$$

Note: calculating A requires raising in gradient will lead to large diff

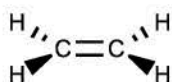
Shapes in Chemistry

1. a)



b) 109.5°

2.



3.

- a) yes
- b) yes
- c) yes
- d) yes
- e) no
- f) no

Using a Calculator

1. a) 399

b) 7

c) 0.0635

d) 25

e) 1096.6

f) 1.799

g) 0.16667

h) 29.381

i) -1096.0

j) 16.617

- 2. a) k = 15.6 ×
- = 3.15 ×
- b) k = 9.40 ×
- = 8.60 ×

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