CHAPTER

19 Science inquiry skills in chemistry

This chapter covers the skills needed to successfully plan, conduct and evaluate results from experiments and investigations in chemistry.

For investigations, you will sometimes need to develop inquiry questions and hypotheses. When conducting experiments and investigations you will consider risk assessments, ethical concerns and the identification, measurement and control of variables. Uncertainty and error are common to all experimental work, and you will identify causes of random and systematic error, and describe how the effects of these errors can be reduced.

The chapter also describes how best to represent your data, and explains how to analyse your results, including using mathematical models. You also be shown ways to effectively communicate conclusions using appropriate scientific language, nomenclature and scientific notation.

Science inquiry skills

- identify, research and refine questions for investigation; propose hypotheses; and predict possible outcomes
- design investigations, including the procedure(s) to be followed, the materials required, and the type and amount of primary and/or secondary data to be collected; conduct risk assessments; and consider research ethics
- conduct investigations safely, competently and methodically for the collection of valid and reliable data, including: acid-base properties, using acid-base volumetric analysis techniques, effects of changes to equilibrium systems, and constructing electrochemical cells
- conduct investigations safely, competently and methodically for the collection of valid and reliable data, including properties of organic compounds containing different functional groups and using chemical synthesis processes
- represent data in meaningful and useful ways, including using appropriate graphic representations and correct units and symbols; organise and process data to identify trends, patterns and relationships; identify sources of random and systematic error and estimate their effect on measurement results; and select, synthesise and use evidence to make and justify conclusions
- interpret a range of scientific texts, and evaluate processes, claims and conclusions by considering the quality of available evidence, including confidence intervals in secondary data; and use reasoning to construct scientific arguments
- communicate to specific audiences and for specific purposes using appropriate language, nomenclature and formats, including scientific reports

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19.1 Questioning

DEVELOPING AIMS AND QUESTIONS, FORMULATING HYPOTHESES AND MAKING PREDICTIONS

The inquiry question, aim and hypothesis for an investigation are interlinked (Figure 19.1.1). It is important to note that each of these can be refined as the planning of the investigation continues.

FIGURE 19.1.1 There may be many elements to an investigation. Taking a step-by-step approach will help the process and assist in completing a solid and worthwhile investigation.

Inquiry questions and hypotheses

An inquiry question defines what is being investigated. For example, What is the relationship between the pH of an acidic solution and the rate of reaction with a metal?

A **hypothesis** is a prediction based on previous knowledge and evidence or observations that attempts to answer the inquiry question. For example: Decreasing the pH of the solution will increase the rate of the reaction of hydrochloric acid solution with marble chips.

It is important that you can interpret what an inquiry question is asking you to do. To do this:

- identify a 'guiding' word, such as *who*, *what*, *where*, *why*
- link the guiding word to command verbs that are often used in senior high school such as *identify*, *describe*, *compare*, *contrast*, *distinguish*, *analyse*, *evaluate* and *create*.

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Table 19.1.1 gives examples of inquiry questions that could be investigated.

TABLE 19.1.1 How to interpret an inquiry question

Guiding word	Example inquiry questions	What are you being asked to do? What are the command verbs?
What	**What** difference can replacing standard galvanic cells with hydrogen fuel cells make to society and the environment?	Identify and describe specific examples, evidence, reasons and analogies from a variety of possibilities. *Identify* and *describe*.
Where	**Where** would you use redox reactions to treat water supplies?	Identify and describe giving reasons for a place or location. *Identify* and *describe*.
How	**How** are metals extracted from their ores using redox reactions? **How** do buffer solutions maintain the pH of blood in our bodies? **How** do different types of bonding within proteins respond to changes in the pH of the environment?	Identify and describe in detail a process or mechanism. Give examples using evidence and reasons. *Identify* and *describe*.
Why	**Why** are some acids weak and some strong? **Why** are some industrial processes carried out at conditions that do not produce the fastest possible reaction?	Explain in detail the causes, reasons, mechanisms and evidence for. *Identify* and *describe*.
Would	**Would** a weak base react as an acid when mixed with a solution of a strong base?	Evaluate. Justify, giving reasons for and against (using evidence, analogies, comparisons). *Evaluate*, *assess*, *justify*.
Is/are	**Are** all carboxylic acids weak? **Is** potassium metal the strongest reducing agent known?	Evaluate. Justify, giving reasons and evidence. *Evaluate*, *assess*, *justify*.
On what basis	**On what basis** are the strength of acids compared?	Evaluate. Justify using reasons and evidence. Evaluate, assess, justify.
Can	**Can** we use physical methods to protect reactive metals from corrosion?	Evaluate and assess. Is it possible? Give reasons, suggest possible alternatives. *Evaluate*, *assess*, *justify*, *create*.
Do/does	**Does** the rate of corrosion of a metal depend on its group on the periodic table?	Evaluate. Justify using reasons and evidence for and against. *Evaluate*, *assess*, *justify*.
Should	**Should** cars be made from polymers instead of metals?	Evaluate advantages and disadvantages, implications and limitations. Make a judgement. *Evaluate*, *assess*, *justify*, *create*.
Might	What type of power source **might** we use for vehicles in the future?	Evaluate. Justify, giving reasons for and against (using evidence, analogies, comparisons). *Evaluate*, *assess*, *justify*, *compare*, *contrast*, *create*.

Formulating a question

If you are required to formulate a question, it is good practice to research the topic to be investigated. You should become familiar with the relevant scientific concepts and key terms.

During this research, write down questions or correlations as they arise.

Compile a list of possible ideas. Do not reject ideas that initially might seem improbable. Use these ideas to generate questions that are answerable.

Before constructing a hypothesis, formulate a question that needs an answer. This question will lead to a hypothesis when:

- the question is confined to measurable variables
- a prediction is made based on knowledge and experience.

Evaluating your question

Once a question has been chosen, stop to evaluate the question before progressing. The question may need further refinement or even further investigation before it is suitable as a basis for investigation. A major planning point is to not attempt something that is not possible to complete in the time available or with the resources on hand. For example, it might be difficult to create a specific piece of specialist equipment in the school laboratory of if experiments take too long it may be impossible to conduct sufficient trials in the time allocated.

To evaluate the question, consider the following:

- Relevance: Is the question related to the appropriate course content?
- Clarity and measurability: Can the question be framed as a clear hypothesis?

If the question cannot be stated as a specific hypothesis, then it is going to be very difficult to complete the investigation.

- Time frame: Can the question be answered within a reasonable period of time? Is the question too broad?
- Knowledge and skills: Do you have a level of knowledge and the laboratory skills that will allow the question to be explored?
- Practicality: Are resources, such as laboratory equipment and materials, likely to be readily available?
- Safety and ethics: Consider the safety and ethical issues associated with the question you will be investigating. If there are issues, can they be addressed?

Sourcing information

Once you have selected a topic, the next step is to source reliable information. Some of the steps involved in sourcing information are:

- identifying key terms
- sourcing information
- evaluating the credibility of sources
- evaluating experimental data/evidence.

Sources can be:

- **primary sources**—original sources of data and evidence; for example, articles containing research findings that have been published in peer-reviewed scientific journals or research presented at a scientific conference.
- **secondary sources**—analyses and interpretations of primary sources; for example, textbooks, magazine articles and newspaper articles.

Some of the sources that may contain useful information are listed in Table 19.1.2.

TABLE 19.1.2 Useful sources of primary and secondary information

Primary sources of information	Secondary sources of information
journal articles from peer-reviewed journals, such as *Nature*	newspaper articles and opinion pieces
global databases, statistics and surveys	magazine articles; examples of reputable science magazines include: • *Cosmos* • *Double Helix* (CSIRO) • *New Scientist* • *Popular Science* • *Scientific American*
laboratory work	government reports
computer simulations and modelling	

Hypothesis

A hypothesis is a prediction that is based on evidence and prior knowledge. A hypothesis often takes the form of a proposed relationship between two or more variables in a cause and effect relationship; or in other words, 'If X is done, then Y will occur.'

Here are some examples of hypotheses:

- The buffering capacity of a buffer solution will depend on the relative amounts of the acid and its salt added to make the buffer.
- The pH of a sample of wine is directly related to the concentration of tartaric acid ion the wine.
- The cell potential of a galvanic cell will double if the concentrations of the electrolytes in the half-cells are doubled.

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Variables

An investigation can test a good scientific hypothesis and the hypothesis will be supported or refuted. To be a testable hypothesis, it should be possible to measure both what is changed or carried out and what will happen. The factors that are monitored during an experiment or investigation are called the **variables**. An experiment or investigation determines the relationship between variables by measuring the results.

There are three categories of variables:

- The **independent variable** is the variable that is determined by the researcher (the one that is selected and changed).
- The **dependent variable** is the variable that may change in response to a change in the independent variable. This is the variable that will be measured or observed.
- **Controlled variables** are all the variables that must be kept constant during the investigation.

Note that you should only test one variable at a time, otherwise it cannot be stated that the changes in the dependent variable are the result of changes in the independent variable.

Qualitative and quantitative variables

Variables are either qualitative or quantitative, with further subsets in each category.

- **Qualitative** variables can be observed but not measured. They can only be sorted into groups or categories such as brightness, type of material, colour of flame.
- **Quantitative** variables can be measured. Mass, volume, temperature, pH and time are all examples of quantitative data.
  - Discrete variables consist of only integer numerical values, not fractions; for example, the number of protons in an atom, the number of atoms of each element in a compound and the number of cells in a battery.
  - Continuous variables allow for any numerical value within a given range; for example, the measurement of temperature, volume, mass, pH and conductivity.

Formulating a hypothesis

Once the inquiry question is confirmed, formulating a hypothesis comes next. A hypothesis requires a proposed relationship between two variables. It should predict that a relationship exists or does not exist.

Identify the two variables in your question. State the independent and dependent variables.

For example: If I do/change this (independent variable), then this (dependent variable) will happen.

A good hypothesis should:

- be a statement
- be based on information contained in the research question (purpose)
- be worded so that it can be tested in the experiment
- include an independent and a dependent variable
- include variables that are measurable.

The hypothesis should also be falsifiable. This means that a negative outcome would disprove it. For example, the hypothesis that all apples are round cannot be proved beyond doubt, but it can be disproved—in other words, it is falsifiable. In fact, only one square apple is needed to disprove this hypothesis. Unfalsifiable hypotheses cannot be proved by science. These include hypotheses on ethical, moral and other subjective judgements.

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Worked example 19.1.1

DEVELOPING A HYPOTHESIS

Develop a hypothesis and identify variables for investigating the rate of the reaction between marble chips and hydrochloric acid	
Thinking	**Working**
Write inquiry question	What is the relationship between the concentration of the acid and reaction rate?
Identify the independent variable	concentration of hydrochloric acid solution
Identify the dependent variable	the mass lost during the first 30 seconds of the reaction
Identify the controlled variables	starting temperature of hydrochloric acid volume of hydrochloric acid mass of the marble chips surface area of the marble chips
Write a potential hypothesis	For a constant particle size of marble chips and volume of hydrochloric acid, if the concentration of the hydrochloric acid solution is halved, the rate of reaction will halve.

Worked example: Try yourself 19.1.1

DEVELOPING A HYPOTHESIS

In this example, a student decided to investigate how the cell voltage was related to the concentration of the silver ions in the following galvanic cell. The set up for the experiment is shown in figure 19.1.2.

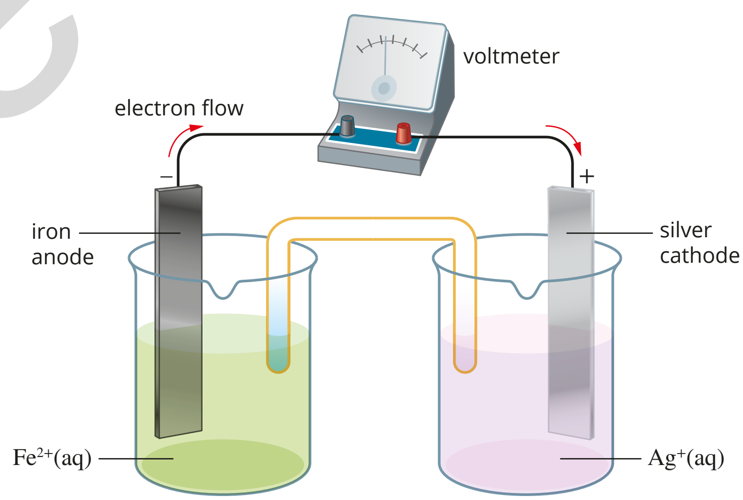

FIGURE 19.1.2 A diagram of the cell containing Fe/Fe^{2+} and Ag/Ag^{+} half-cells.

Develop a hypothesis and identify variables for investigating how the voltage of the galvanic cell is affected by the concentration of the silver ions in the silver nitrate solution.

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19.1 Review

SUMMARY

- By utilising data from primary and/or secondary sources, you will better understand the context of your investigation to create an informed inquiry question.
- A hypothesis is a prediction based on previous knowledge and evidence or observations that attempts to answer the research question. For example: If the surface area of magnesium is increased, the rate of reaction of that magnesium and dilute hydrochloric acid will increase.
- Once a question has been chosen, evaluate the question before progressing. The question may need further refinement or even further investigation before it is suitable as a basis for an achievable and worthwhile investigation.
- There are three categories of variables:
  - The independent variable is the variable that is controlled by the researcher.
  - The dependent variable is the variable that may change in response to a change in the independent variable. This is the variable that will be measured or observed.
  - Controlled variables are all the variables that must be kept constant during the investigation.

KEY QUESTIONS

1 Scientists make observations from which a hypothesis is stated and this is then experimentally tested.
  a Define ‘hypothesis’.
  b How are theories and principles different from a hypothesis?

2 For each of the following hypotheses, select the dependent variable.
  a If more sodium hypochlorite is added to a swimming pool, the pH of the pool water will increase.
  b The voltage produced by a commercial cell will decrease over time.
  c The amount of dissolved carbon dioxide in the ocean will vary dependent on temperature.
  d Hydrogen peroxide solution will decompose more quickly if acid is added

3 In an experiment a student uses the following range of values to describe colours of indicators: yellow, blue, red and green.
What type of measurement is the variable ‘colour’?

4 Which of the following methods is likely to be the most accurate, quantitative method for measuring the pH of water?
  A Using pH paper (e.g. litmus paper)
  B Using universal indicator and a colour chart
  C Using a calibrated pH meter at a particular temperature
  D Using a conductivity meter

5 Give the correct term that describes an experiment with each of the following conditions.
  a The experiment addresses the hypothesis and aims.
  b The experiment is repeated and consistent results are obtained.
  c Appropriate equipment is chosen for the desired measurements.

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19.2 Planning investigations

Once you have formulated your hypothesis, you will need to plan and design your investigation. Taking the time to carefully plan and design a practical investigation before beginning will help you to maintain a clear and concise focus throughout. Preparation is essential. This section is a guide to some of the key steps that should be taken when planning and designing an investigation.

DEVELOPING THE METHOD

The method of your investigation is a step-by-step procedure.

Ensuring accuracy

When designing the method, you must ensure that it ensures a valid, reliable and accurate investigation.

Validity

Validity refers to whether an experiment or investigation is in fact testing the set hypothesis and aims. Is the investigation obtaining data that is relevant to the question?

To ensure an investigation is valid, it should be designed so that only one variable is being changed at a time. The remaining variables must remain constant so that meaningful conclusions can be drawn about the effect of each variable in turn.

To ensure validity, carefully determine:

- the independent variable: the variable that will be changed, and how it will change
- the dependent variable: the variable that will be measured
- the controlled variables: the variables that must remain constant, and how they will be maintained.

Reliability

Reliability refers to the notion that if the experiment is repeated many times, the results obtained should be consistent.

It is important to determine how many times the experiment needs to be replicated (see Figure 19.2.1). Many scientific investigations lack sufficient repetition to ensure that the results can be considered reliable and repeatable.

- Repeat readings: repeat each reading (at least three times if possible), record each measurement and then average the measurements. This reduces systematic errors and allows random errors to be identified. If a reading differs too much from the rest (known as an outlier), discard it before averaging.
- Sample size: where there might be differences in construction or manufacture of a sample, there should be various samples with the same conditions in the same experiment. The greater the sample size the more reliable the data.
- Repeats: if possible repeat the experiment on a different day. Don't change anything. If the results are not the same, think about what could have happened. For example, was the equipment faulty, or were all the controlled variables correctly identified? Repeat the experiment a third time to confirm which run was correct. Repeat an experiment as many times as possible; three is a good number but, if time and resources allow, aim for five.

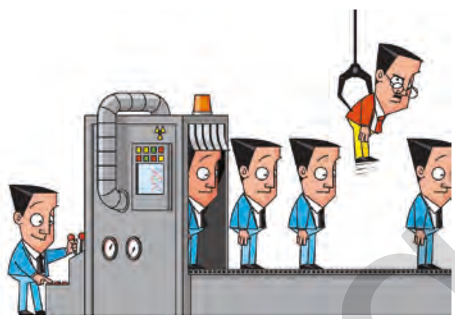

FIGURE 19.2.1 Replication increases the reliability of your investigation. It ensures that if anyone repeats the investigation they will obtain similar data.

In some situations, it may be appropriate to conduct a **control experiment**. The control is an identical experiment carried out at the same time, except that in the control experiment the independent variable is not changed.

When the controls do not behave as expected, the data obtained from an experiment or observation is not reliable.

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Accuracy and precision

In science and statistics, the terms 'accuracy' and 'precision' have very specific and different meanings:

- **Accuracy** is the ability to obtain the correct measurement. To obtain accurate results, you must minimise systematic errors.
- **Precision** is the ability to consistently obtain the same measurement. To obtain precise results, you must minimise random errors.

To understand more clearly the difference between accuracy and precision, think about firing arrows at an archery target (Figure 19.2.2). Accuracy is being able to hit the bullseye, whereas precision is being able to hit the same spot every time you shoot. If you hit the bullseye every time you shoot, you are both accurate and precise (Figure 19.2.2a). If you hit the same area of the target every time but not the bullseye, you are precise but not accurate (Figure 19.2.2b). If you hit the area around the bullseye each time but don't always hit the bullseye, you are accurate but not precise (Figure 19.2.2c). If you hit a different part of the target every time you shoot, you are neither accurate nor precise (Figure 19.2.2d).

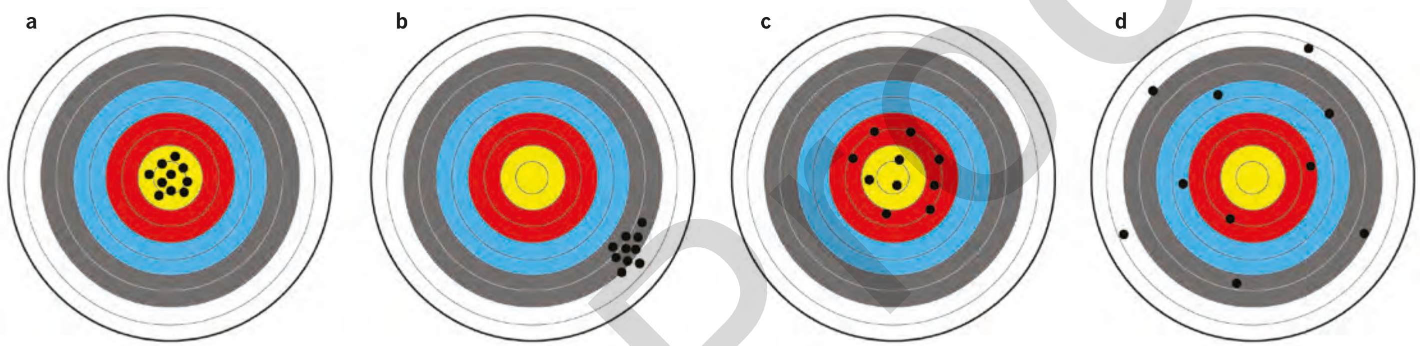

FIGURE 19.2.2 Examples of accuracy and precision: (a) both accurate and precise, (b) precise but not accurate, (c) accurate but not precise, and (d) neither accurate nor precise.

Applying this idea to a chemistry situation, if you are timing the rate of reaction by stopping a stopwatch when 100 mL of gas has been released, and the you get consistent results but you are always stopping the stopwatch too early, your results are precise but not accurate.

Uncertainty

When scientists take a measurement, the measurement is always subject to variations in accuracy and precision. The goal when taking measurements is to get as close as possible to 'true' or 'correct value. The **uncertainty** is the how far an experimental quantity might be from the true value. It can be calculated, or estimated and is often represented as a percentage. For example, if the uncertainty was described as ±1%, it means that measurement is likely to be no more than 1% above or below the 'true' value of the quantity that is being measured.

In this course you are not required to calculate uncertainties, but it is a good idea to consider uncertainty when planning experiments and later, when you come to evaluate your results.

Confidence intervals

A **confidence interval** is a range of values that's likely to include the 'true' value. This is similar to the uncertainty, which is usually written as a ± number, as shown above. However, the confidence interval is written as a range, such as pH 12.1 – 12.5. These numbers are called the (upper and lower) confidence limits. Confidence intervals are normally accompanied by a confidence level, expressed as a percentage.

For example, if the confidence interval for the pH is 12.1 – 12.5 and the confidence level is 95%, this means that the researcher has estimated that there is a 95% change of the true value of the pH being somewhere between 12.1 and 12.5.

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Confidence intervals vary dependent on the sample size. The greater the sample size, the smaller the confidence interval. In fact, there is a mathematical relationship – the confidence interval will be inversely proportional to the square root of the sample size. This means, for example, if you were to increase the sample size by a factor of 4, the confidence interval would halve. When considering using secondary data, it is useful to consider confidence intervals as they give an indication of the accuracy of the data.

Recording numerical data

Reasonable steps to ensure the accuracy of the investigation include considering:

- the unit in which the independent and dependent variables will be measured
- the instrument that will be used to measure the independent and dependent variables.

Select and use appropriate equipment, materials and methods. For example, select equipment that measures to greater precision to reduce uncertainty and repeat the measurements to confirm them.

When using measuring instruments, the number of significant figures and decimal places you use is determined by how precise your measurements are.

This depends on the scale, accuracy and precision of the instrument and technique you are using. For example, a burette is has an uncertainties of ±0.02 mL.

Raw data is the information that is recorded directly from observation. When this is processed, for example calculating a mean or subtracting one value from another, the resulting information is called **processed data**. When you record raw data and report processed data, use the number of significant figures available from your equipment or observation. Using either a greater or smaller number of significant figures can be misleading. For example, Table 19.2.1 shows measurements of 3 titres to two decimal place (3 significant figures). The data was entered into a spreadsheet to calculate the **mean**, which was displayed with 3 decimal places. You would record the mean as 19.52 mL, not 19.517 mL, because two decimal places is the precision limit of the instrument. Recording 19.517 g would be an example of false precision.

TABLE 19.2.1 AN example of false precision in a data calculation.

Trial	1	2	3	Mean
Volume (mL)	19.45	19.55	19.55	19.517

Data analysis

Data analysis is part of the method. Consider how the data will be presented and analysed. A wide range of analysis tools are available. For example, tables organise data so that patterns can be established and graphs can show relationships and comparisons. In fact, preparing an empty table showing the data that needs to be obtained will help in the planning of the investigation.

Sourcing appropriate equipment and materials

When designing your investigation, you will need to decide on the materials, technology and instrumentation that will be used to carry out your investigation. It is important to find the right balance between items that are easily accessible and those which will give you accurate results. When conducting your investigation, it will be important to take note of the precision of your chosen instrumentation and how this affects the accuracy and validity of your results.

Modifying the method

The method may need modifying as the investigation is carried out. The following actions will help to determine any issues in the method and how to modify them:

- Record everything.
- Be prepared to make changes to the approach.
- Note any difficulties encountered and the ways they were overcome. What were the failures and successes? Every test carried out can contribute to the understanding of the investigation as a whole, no matter how much of a disaster it may first appear.

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If the expected data is not obtained, don't worry. As long as it can be critically and objectively evaluated, the limitations of the investigation are identified and further investigations proposed, the work is worthwhile.

COMPLYING WITH ETHICAL AND SAFETY GUIDELINES

Ethical considerations

When planning an investigation, researchers should always identify all possible ethical considerations and evaluate their necessity or ways that can reduce or mitigate them.

Ethical issues might include:

- How can this affect wider society?
- Does one party benefit over another; for example, one individual, a group of individuals or a community?
- Is there a risk of harm (physical or mental) to people involved in the research?
- Does it prevent anyone from gaining their basic needs?
- How can this impact on future ethical decisions or issues?
- Does the research cause damage to the environment?
- Does the research cause harm to other living things?

In reality, school chemistry investigations generally will have minor ethical issues, if any, but these should be considered in your planning.

Safety in practical experiments and investigations

While planning for an investigation, it is important for your safety and the safety of others that the potential risks are considered (Figure 19.2.3).

Everything we do has some risk involved. Risk assessments are performed to identify, assess and control hazards. Always identify the risks and control them to keep everyone safe.

FIGURE 19.2.3 When planning an investigation you need to identify, assess and control hazards.

To identify risks think about:

- the activity that will be carried out
- the equipment or chemicals that will be used.

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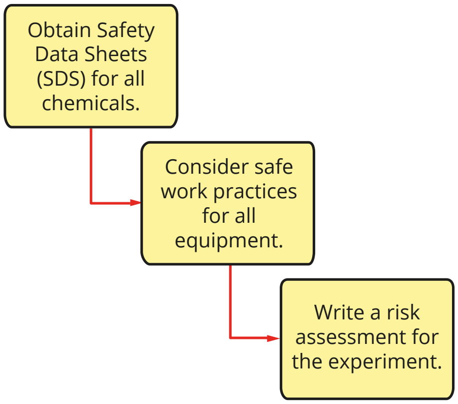

FIGURE 19.2.4 Steps involved in identifying risks.

The following hierarchy of risk controls is organised from the most effective to least effective:

1. *Elimination:* Eliminate dangerous equipment, procedures or substances.
2. *Substitution:* Find different equipment, procedures or substances to use that will achieve the same result, but have less risk associated.
3. *Isolation:* Ensure there is a barrier between the person and the hazard. Examples include physical barriers such as guards in machines, or fume hoods to work with volatile substances.
4. *Administrative controls:* Provide guidelines, special procedures, warning signs and safe behaviours for any participants.
5. *Personal protective equipment (PPE):* Wear safety glasses, lab coats, gloves and respirators etc. where appropriate, and provide these to other participants.

Figure 19.2.4 shows a flow chart of how to consider and assess the risks involved in a research investigation.

Chemical codes

The chemicals at school or at the hardware shop have a warning symbol on the label. These are **chemical (HAZCHEM) codes**. Some common codes and their meanings are shown in Figure 19.2.5.

HAZCHEM INTERPRETATION

NUMBER			
1		Water Jets	
2		Water Fog	
3		Foam	
4		Dry Agent	
FIRST LETTER			
P	V	Full Protective Clothing*	DILUTE
R		Full Protective Clothing*	DILUTE
S	V	Breathing Apparatus	DILUTE
S	V	Breathing Apparatus for Fire Only	DILUTE
T		Breathing Apparatus	DILUTE
T		Breathing Apparatus for Fire Only	DILUTE
W	V	Full Protective Clothing*	CONTAIN
X		Full Protective Clothing*	CONTAIN
Y	V	Breathing Apparatus	CONTAIN
Y	V	Breathing Apparatus for Fire Only	CONTAIN
Z		Breathing Apparatus	CONTAIN
Z		Breathing Apparatus for Fire Only	CONTAIN
SECOND LETTER			
E		Consider Evacuation	

Note V: Danger of violent reaction or explosion
* Full Protective Clothing includes Breathing Apparatus

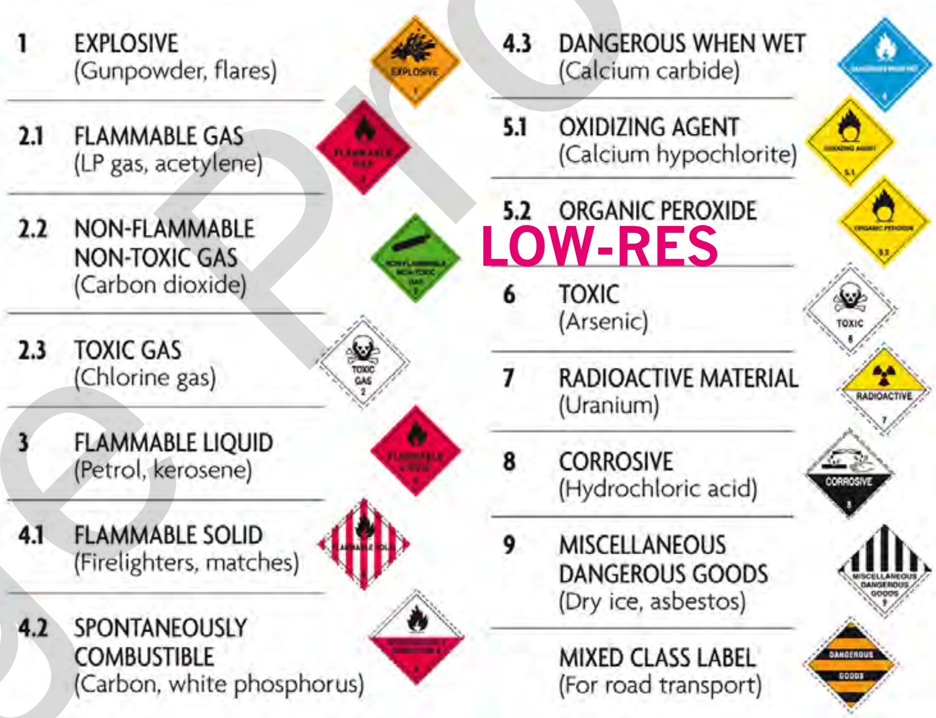

FIGURE 19.2.5 HAZCHEM signs.

Safety Data Sheets

Each chemical substance has an accompanying document called a **Safety Data Sheet (SDS)** (Figure 19.2.6), which was previously called a Material Safety Data Sheet (MSDS). An SDS contains important safety and first aid information about each chemical you commonly use in the laboratory. If the products of a reaction are toxic to the environment, you must pour your waste into a special container (not down the sink).

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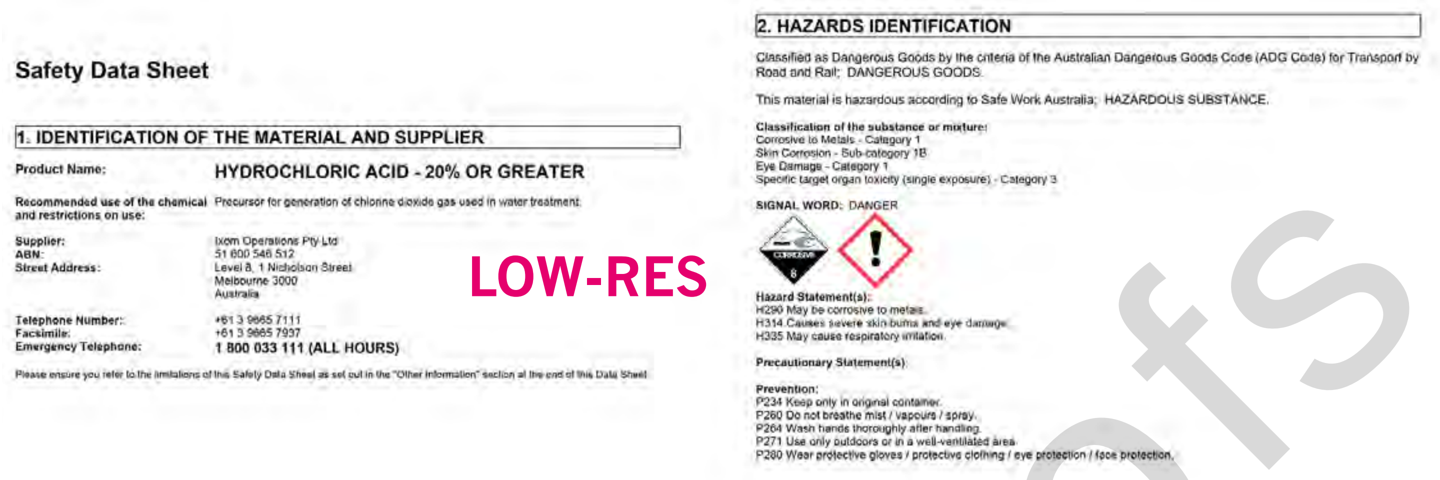

Safety Data Sheet

1. IDENTIFICATION OF THE MATERIAL AND SUPPLIER

Product Name: HYDROCHLORIC ACID - 20% OR GREATER

Recommended use of the chemical and restrictions on use: Precursor for generation of chlorine dioxide gas used in water treatment.

Supplier: Ixom Operations Pty Ltd
ABN: 51 600 546 512
Street Address: Level 8, 1 Nicholson Street
Melbourne 3000
Australia

Telephone Number: +61 3 9665 7111
Facsimile: +61 3 9665 7937
Emergency Telephone: 1 800 033 111 (ALL HOURS)

Please ensure you refer to the limitations of this Safety Data Sheet as set out in the "Other Information" section at the end of this Data Sheet

2. HAZARDS IDENTIFICATION

Classified as Dangerous Goods by the criteria of the Australian Dangerous Goods Code (ADG Code) for Transport by Road and Rail; DANGEROUS GOODS.

This material is hazardous according to Safe Work Australia; HAZARDOUS SUBSTANCE.

Classification of the substance or mixture:
Corrosive to Metals - Category 1
Skin Corrosion - Sub-category 1B
Eye Damage - Category 1
Specific target organ toxicity (single exposure) - Category 3

SIGNAL WORD: DANGER

Hazard Statement(s):
H290 May be corrosive to metals.
H314 Causes severe skin burns and eye damage.
H335 May cause respiratory irritation.

Precautionary Statement(s):

Prevention:
P234 Keep only in original container.
P260 Do not breathe mist / vapours / spray.
P264 Wash hands thoroughly after handling.
P271 Use only outdoors or in a well-ventilated area.
P280 Wear protective gloves / protective clothing / eye protection / face protection.

LOW-RES

FIGURE 19.2.6 Extracts of a Safety Data Sheet (SDS) for concentrated hydrochloric acid. The SDS alerts the reader to any potential hazards when using a substance, including appropriate measures to reduce risk of harm.

The SDS provides employers, workers and health and safety representatives with the necessary information to safely manage the risk of hazardous substance exposure.

Personal protective equipment

Everyone who works in a laboratory wears items that help keep them safe. This is called **personal protective equipment (PPE)** and includes:

- safety glasses
- shoes with covered tops
- disposable gloves when handling certain chemicals
- a disposable apron or a lab coat if there is risk of damage to clothing

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19.2 Review

SUMMARY

- The method of your investigation is a step-by-step procedure. When detailing the method, ensure it complies as a valid, reliable and accurate investigation.
- It is also important to determine how many times the experiment needs to be replicated. Many scientific investigations lack sufficient repetition to ensure that the results can be considered reliable and repeatable.
- Risk assessments must be carried out before conducting an investigation to make sure that when you carry out your investigation you and others are kept safe. If elements of your investigation are too high risk, you will need to revise your design.
- It is important to choose appropriate equipment for your experiment. Not just personal protective equipment (PPE) that will help keep you safe, but also selecting instrumentation that will give you accurate results.

KEY QUESTIONS

1 A journal article reported the materials and method used in order to conduct an experiment. The experiment was repeated three times, and all values were reported in the results section of the article. Repeating an experiment and reporting results supports:

a Validity
b Reliability
c Credibility
d Systematic errors

2 **a** Explain what is meant by the term 'control experiment'.
b Using an example, distinguish between independent and dependent variables.

3 You are conducting an experiment to determine the acidity of different samples of seawater. Identify
a the independent variable
b the dependent variable
c at least one controlled variable

4 You are conducting an experiment to determine the pH of a buffer solution. Discuss the accuracy of your results if you are
a using litmus paper or universal indicator
b recording the pH using a calibrated pH meter

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19.3 Reducing uncertainty in data

During the planning and conducting of an experiment or investigation, minimising potential error is an important consideration

ERRORS

Most practical experiments have errors associated with them. Errors can occur for a variety of reasons. Being aware of potential errors helps you to avoid or minimise them. For an investigation to be accurate, it is important to identify and record any errors.

There are two types of errors:

- systematic errors
- random errors.
- When considering whether an error is random or systematic, you have to consider the measurement that is made compared to the true value of the value being measured

Systematic errors

A **systematic error** will cause the measured error to be always above, or always below, the true value. It is an error that is consistent and will occur again if the investigation is repeated in the same way.

An example of a systematic error is if you were measuring the mass of a substance and on a piece of filter paper and you didn't take into account the mass of the filter paper. The mass recorded will always be higher than the true mass of just the substance being weighed. Another example would be if you were making up a standard solution from a primary standard, and when you transferred the initial solution from a beaker to a volumetric flask you didn't ensure that all the solution was transferred. In this case the concentration of the stock solution would always be less than the calculated value.

Systematic errors are usually a result of instruments that are not calibrated correctly or methods that are flawed.

Random errors

Random errors occur in an unpredictable manner and are generally small. They could give a value higher, or lower than the true value. Whenever a measuring device, whether it is a burette or an electric balance is used, random error will occur.

Note that mistakes are not classified as errors avoidable errors. Mistakes could include misreading the numbers on a scale or spilling a portion of a sample. A measurement that involves a mistake must be rejected and not included in any calculations, or averaged with other measurements of the same quantity.

Techniques for reducing error

Designing the method carefully, including selection and use of equipment, will help reduce errors. Determining the units of the data being collected and at what scale will help to select the correct equipment. Using the right unit and scale will ensure that measurements are more accurate and precise.

Significant figures

Significant figures are the numbers that convey meaning and precision. The number of significant figures used depends on the scale of the instrument. It is important to record data to the number of significant figures available from the equipment or observation. Using either a greater or smaller number of significant figures can be misleading.

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Review the following examples to learn more about significant figures:

- 15 has two significant figures
- 3.5 has two significant figures
- 3.50 has three significant figures
- 0.037 has two significant figures
- 1401 has four significant figures.

Significant figures in processed data

When adding or subtracting the sum or difference of a set of numbers should have as many numbers after the decimal as the least accurate in the set.

Adding: 5.0 + 3.21 + 1.2345 = 9.445 = 9.4 (because 5.0 has only one figure after the decimal point)

Subtracting: 19.8765 − 1.23 = 18.6465 = 18.64 (because 1.23.0 has only one figure after the decimal point)

When multiplying or dividing the answer has no more significant figures than the number with the least significant figures

Multiplying: 1.234 × 2.34 = 2.88756 = 2.89 (because 2.34 has only 3 significant figures)

Dividing: 34.56 ÷ 6.7 = 5.158208 = 5.2 (because 6.7 has only 2 significant figures)

Calibrated equipment

Some equipment, such as pH meters, need to be calibrated before use. Before carrying out the investigation, make sure the instruments or measuring devices are properly calibrated and are, in general, functioning correctly. Record the precision of glassware that you intend to use. If you are preparing a solution of known concentration you might have access to a volumetric flask which has less uncertainty associated with measurements compared the using a beaker (Figure 19.3.1).

FIGURE 19.3.1 Record the uncertainty for glassware and instruments. This pipette can dispense a volume (aliquot) of 25.00 ± 0.03 mL. When used correctly, the volume dispensed will be between 24.97 mL and 25.03 mL.

Correct use of equipment

Use the equipment properly. Ensure any necessary training has been done to use the equipment and that you have had an opportunity to practice using the equipment before beginning the investigation. Improper use of equipment can result in inaccurate, imprecise data with large errors, and the validity of the data can be compromised.

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Incorrect reading of measurements is a common misuse of equipment. Make sure all of the equipment required in the investigation can be used correctly and record the instructions in detail so they can be referred back to if the data doesn't appear correct.

Repeat trials

As discussed in Section 19.2, reliability is improved by repeating your experiment. Note that repeating trials will only reduce the effect of random errors. Repeating a flawed method will not reduce the effect of the systematic error within that method. Therefore modifications to your procedure may need to be looked at before repeating the investigation to ensure all variables are being tested under the same conditions.

19.3 Review

SUMMARY

- It is essential that during the investigation, the following are recorded in the logbook:
  - all quantitative and qualitative data collected
  - the methods used to collect the data
  - any incident, feature or unexpected event that may have affected the quality or validity of the data.
- A systematic error will cause the measured error to always above, or always below the true value.
- Random errors could give a value higher, or lower than the true value.
- The number of significant figures used depends on the scale of the instrument used. It is important to record data to the number of significant figures available from the equipment or observation.

KEY QUESTIONS

1 What type of error is associated with:
   a inaccurate measurements?
   b imprecise measurements?

2 Identify whether each of the situations below is a mistake, systematic error or random error.
   a A student washed a burette with distilled water immediately before use.
   b The volume of a solution of hydrochloric acid used in a titration was measured using a measuring cylinder.
   c A student sometimes forgot to re zero the balance between weighing samples of solid sodium carbonate when making a standard solution.

3 A scientist carries out a set of experiments, analyses the results and publishes them in a scientific journal. Other scientists in different laboratories repeat the experiment, but do not get the same results as the original scientist. Suggest three reasons that could explain this.

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19.4 Processing data and information

Once you have conducted your investigation and collected data, you will need to find the best way of collating it. This section is a guide to the different forms of representation that will help you to better understand your data.

Raw data is unlikely to be used directly to validate the hypothesis. However, raw data is essential to the investigation and plans for collecting the raw data should be made carefully. Consider the formulas or graphs that will be used to analyse the data at the end of the investigation. This will help to determine the type of raw data that needs to be collected in order to validate the hypothesis.

Once you have determined the data that needs to be collected, prepare a table in which to record the data.

The raw data that has been obtained should be presented in a way that is clear, concise and accurate. There are a number of ways of presenting data, including tables, graphs, flow charts and diagrams.

GRAPHS

In general, tables provide more detailed data than graphs, but it is easier to observe trends and patterns in data in graphical form than in tabular form.

Graphs are used when two variables are being considered and one variable is dependent on the other. The graph shows the relationship between the variables.

There are several types of graphs that can be used, including line graphs, bar graphs and pie charts. The best one to use will depend on the nature of the data.

General rules to follow when making a graph (see Figure 19.4.1) include the following:

- Keep the graph simple and uncluttered.
- Use a descriptive title.
- Represent the independent variable on the *x*-axis and the dependent variable on the *y*-axis.
- Make axes proportionate to the data.
- Clearly label axes with both the variable and the unit in which it is measured.

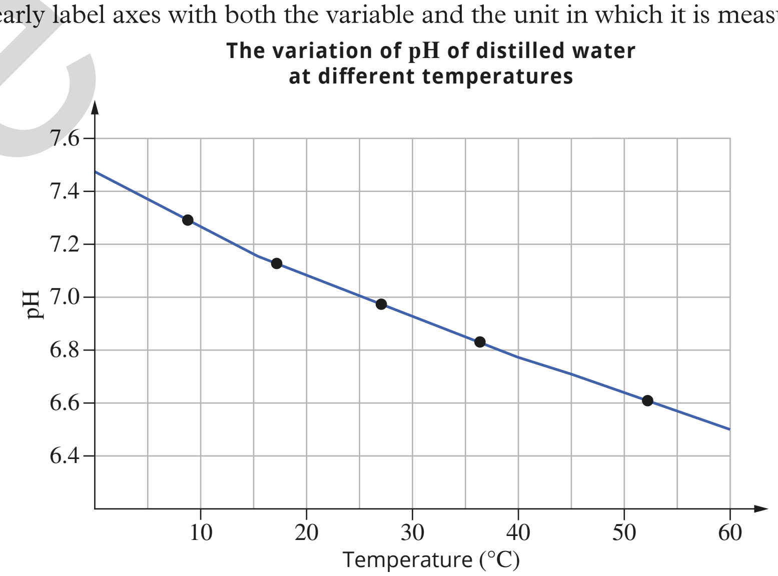

FIGURE 19.4.1 A graph is a better way to observe trends and patterns in data form

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Line graphs

Line graphs are a good way of representing continuous quantitative data. In a line graph, the values are plotted as a series of points on the graph. There are two ways of joining these points:

- A line can be ruled from each point to the next. It shows the overall trend; it is not meant to predict the value of the points between the plotted data.
- The points can be joined with a single smooth straight or curved line (see Figure 19.4.2). This creates a **trend line**, also known as a line of best fit. The line of best fit does not have to pass through every point but should go close to as many points as possible. It is used when there is an obvious trend between the variables.

Sometimes when the data is collected, there may be one point that does not fit with the trend and is clearly an error. This is called an **outlier**. An outlier is often caused by a mistake made in measuring or recording data. If there is an outlier, include it on the graph, but ignore it when adding a line of best fit.

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FIGURE 19.4.2 Caption to come

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19.4 Review

SUMMARY

- Consider how the data will be presented and analysed. A wide range of analysis tools could be used. For example, tables organise data so that patterns can be established and graphs can show relationships and comparisons.
- The simplest form of a table is a two-column format in which the first column contains the independent variable and the second column contains the dependent variable
- General rules to follow when making a graph include the following:
  - Keep the graph simple and uncluttered.
  - Use a descriptive title.
  - Represent the independent variable on the *x*-axis and the dependent variable on the *y*-axis.
  - Make axes proportionate to the data.
  - Clearly label axes with both the variable and the unit in which it is measured.

KEY QUESTIONS

1 How can the general pattern (trend) of a graph be represented once the points are plotted?

2 **a** Use the following values to plot a calibration curve to determine the concentration of nickel (as Ni^{2+}) in solutions of nicke(II) chloride using a colorimeter. The absorbance values were obtained during an experiment using a wavelength of light of 635 nm.

Standard concentration (mol L^{-1})	Absorbance of light at 635 nm
0.00	0.000
0.12	0.038
0.24	0.079
0.36	0.159
0.48	0.154
0.60	0.191

b From the graph you have drawn, select the data point that is an outlier.

c Define the term ‘outlier’.

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19.5 Analysing data and information

Now that the investigation has been conducted and data collected, it is time to draw it all together. You will now analyse your results to better understand the chemical processes behind them.

ANALYSING AND EVALUATING DATA

In the discussion, the findings of the investigation need to be analysed and interpreted.

- State whether a pattern, trend or relationship was observed between the independent and dependent variables. Describe what kind of pattern it was and specify under what conditions it was observed.
- Were there discrepancies, deviations or anomalies in the data? If so, these should be acknowledged and explained.
- Identify any limitations in the data you have collected. Perhaps a larger sample or further variations in the independent variable would lead to a stronger conclusion.

Trends in line graphs

Graphs are drawn to show the relationship, or trend, between two variables.

- Variables that change in linear or direct proportion to each other produce a straight, sloping trend line (Figure 19.5.1).
- Variables that change exponentially in proportion to each other produce a curved trend line (Figure 19.5.2).
- When there is an inverse relationship, one variable increases as the other variable decreases (Figure 19.5.3).
- When there is no relationship between two variables, one variable will not change even if the other changes (Figure 19.5.4).

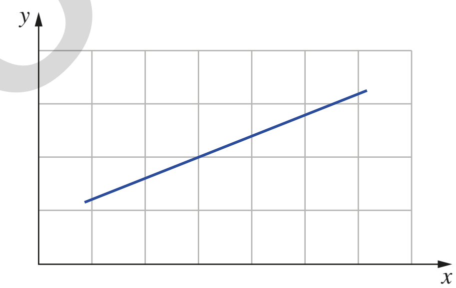

FIGURE 19.5.1 Trend line for variables that change in direct response to each other

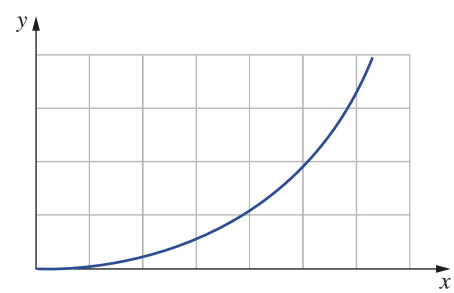

FIGURE 19.5.2 Variables that change in response to each other in a non-linear way

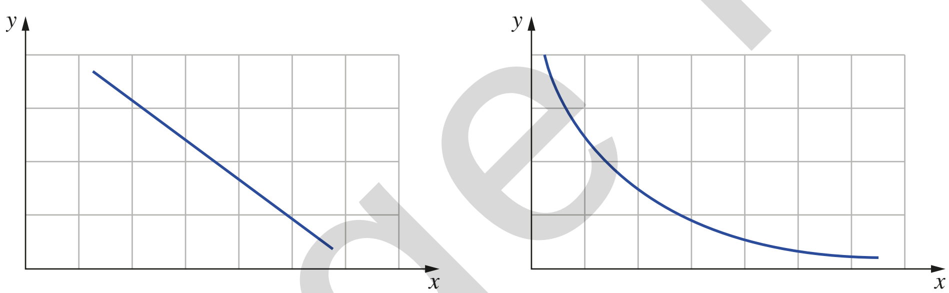

FIGURE 19.5.3 An inverse relationship in which one variable decreases in response to the other variable increasing. It may be (a) direct or (b) non-linear.

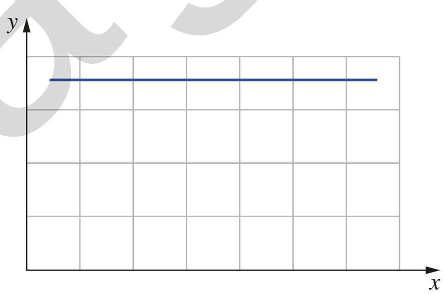

FIGURE 19.5.4 When two variables show no relationship, there is no trend in the data

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Remember that the results might be unexpected. This does not make the investigation a failure. However, the findings must be related to the hypothesis, aims and method.

Table 19.5.1 lists the types of graphs used for various examples.

TABLE 19.5.1 Examples of the types of graphs that could be used in your report

Type of graph	When to use	Example
Scatter graph	When showing quantitative data where one variable is dependent on another variable; draw a line of best fit to show the relationship between the two variables	Showing the relationship between the rate of a reaction and the concentration of acid.
Line graph	With continuous quantitative data	Concentration of dissolved oxygen at a particular location of a creek over a period of time
Bar graphs	When comparing data in an investigation with a qualitative independent variable	pH of water of seawater various locations,
Pie diagrams	When summarising qualitative data; to display proportions	Relative proportion of different pesticides in a sample of water

EVALUATING THE METHOD

It is important to discuss the limitations of the investigation method. Evaluate the method and identify any issues that could have affected the validity, accuracy, precision or reliability of the data. Sources of errors and uncertainty must also be stated in the discussion.

Once any limitations or problems in the methodology have been identified, recommend improvements on how the investigation could be conducted if repeated; for example, suggest how a journal article reported the materials could be minimised or eliminated.

Bias

Bias may occur in any part of the investigation method, including sampling and measurements.

Bias is a form of systematic error resulting from the researcher's personal preferences or motivations. There are many types of bias, including:

- poor definitions of both concepts and variables (for example, not defining pH)
- incorrect assumptions (for example, measuring pH of a solution without also measuring the temperature of the solution)
- errors in the investigation design and methodology (for example, taking water samples from more than one site)

Some biases cannot be eliminated, but should be addressed in the discussion.

Accuracy and precision

In the discussion, evaluate the degree of accuracy and precision of the measurements for each variable of the hypothesis. Comment on the uncertainties obtained.

When relevant, compare the chosen method with any other methods that might have been selected, evaluating the advantages and disadvantages of the selected method and the effect on the results.

Reliability

When discussing the results, indicate the range of the data obtained from replicates. Explain how the sample size was selected. Larger samples are usually more reliable, but short timeframes and scarce resources might have prevented multiple sets of data from being collected. Discuss whether the results of the investigation have been limited by the sample size.

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The control group is important to the reliability of the investigation. A control group helps determine if a variable that should have been controlled has been overlooked and might explain any unexpected results.

Error

Discuss any source of systematic or random error and suggest ways of improving the investigation.

CRITICALLY EVALUATING SOURCES OF INFORMATION

Not all sources are **credible**. When you have used primary of secondary data from information sources it is essential to critically evaluate the content and its origin. Questions you should always ask when evaluating a source include:

- Who created this source? What are the qualifications, expertise, reputation and affiliation of the authors?
- Why was it written?
- Where was the information published?
- When was the information published?
- Are conclusions supported by data or evidence?
- What is implied?
- What is omitted?
- Are any opinions or values being presented in the piece?
- Is the writing objectively and accurately describing a scientific concept or **phenomenon**?
- How might other people understand or interpret this message differently from me?

  When evaluating the validity or bias of websites consider its domain extension:
  - .gov stands for government
  - .edu stands for education
  - .org stands for non-profit organisations
  - .com stands for commercial/business

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19.5 Review

SUMMARY

- After completing your investigation you will need to analyse and interpret your data. A discussion of your results is required where the findings of the investigation need to be analysed and interpreted.
- State whether a pattern, trend or relationship was observed between the independent and dependent variables. Describe what kind of pattern it was and specify under what conditions it was observed.
- Where possible, create a mathematical model, for example, using Excel
- You can describe or calculate a trend line or to determine gradients of curves, to describe your data.
- Were there discrepancies, deviations or anomalies in the data? If so, these should be acknowledged and explained.
- Identify any limitations in the data collected. Perhaps a larger sample or further variations in the independent variable would lead to a stronger conclusion.
- It is important to discuss the limitations of the investigation method. Evaluate the method and identify any issues that could have affected the validity, accuracy, precision or reliability of the data. Sources of errors and uncertainty must also be stated in the discussion.
- When discussing the results, indicate the range of the data obtained from replicates. Explain how the sample size was selected. Larger samples are usually more reliable, but time and resources might have been scarce. Discuss whether the results of the investigation have been limited by the sample size.

KEY QUESTIONS

1 What relationship between the variables is indicated by a sloping linear graph?

2 What relationship exists if one variable decreases as the other increases?

3 What relationship exists if both variables increase or both decrease at the same rate?

4 What might cause a sample size to be limited in an investigation?

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19.6 Conclusions

Having analysed your results you can then apply them to chemical concepts in order to evaluate your conclusions. In this section you will learn how analysing your investigation leads to a better understanding of the underlying scientific principles of your research.

DISCUSSING RELEVANT CHEMICAL CONCEPTS

To make the investigation more meaningful, it should be explained within the right context, meaning the related chemical ideas, concepts, theories and models. Within this context, explain the basis for the hypothesis. For example, if you were studying the impact of dissolved carbon dioxide on the pH of sea water you could include the information in Table 19.6.1 in your discussion.

TABLE 19.6.1 Examples of how to include chemical concepts in your discussion

Key ideas	Example
Definitions of key terms	'pH', 'dissolved carbon dioxide' and 'seawater'
The source of carbon dioxide	Product from the combustion of fossil fuels
Relationship between variables	Dissolved carbon dioxide and pH of water, temperature was controlled in the experiment
Chemical principles	Dissolved carbon dioxide and formation of carbonic acid (H_2CO_3), including relevant equations
Sources of error	Reducing random error, by repeating measurements and calculating average

Relating your findings to a chemical concept

During the analysing stage of your investigation (Section 19.5), you were able to find trends, patterns and mathematical models of your results. This is the framework needed to discuss whether the data supported or refuted the hypothesis. Ask questions such as:

- Was the hypothesis supported?
- Has the hypothesis been fully answered? (If not, give an explanation of why this is so and suggest what could be done to either improve or complement the investigation.)
- Do the results contradict the hypothesis? If so, why? (The explanation must be plausible and must be based on the results and previous evidence.)

Be sure to discuss the broader implications of the findings. Implications are the bigger picture. Outlining them for the audience is an important part of the investigation. Ask questions such as:

- Do the findings lead to further questions?
- Can the findings be extended to another situation?
- Are there any practical applications for the findings?

DRAWING EVIDENCE-BASED CONCLUSIONS

A conclusion is usually written as a paragraph that links the collected evidence to the hypothesis and provides a justified response to the research question.

Indicate whether the hypothesis was supported or refuted and the evidence on which this decision is based (that is, the results). Do not provide irrelevant information. Only refer to the specifics of the hypothesis and the research question and do not make generalisations.

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Read the examples of poor and better conclusions in Table 19.6.2 and Table 19.6.3 for the hypothesis and research question shown.

TABLE 19.6.2 Examples of strong and weak conclusions to the hypothesis

Hypothesis: An increase in the temperature of pond water will result in a decrease in the measured pH of the water sample

Strong conclusion	Weak conclusion
An increase in temperature from 5°C to 40°C resulted in a decrease in the pH of the water from 7.4 to 6.8.	The pH of water decreased as temperature increased.

TABLE 19.6.3 Examples of strong and weak conclusions in response to the research question

Research question: Does temperature affect the pH of water?

Strong conclusion	Weak conclusion
Analysis of the results on the effect of an increase in temperature of water from 5°C to 40°C showed an inverse relationship in which the pH of water decreased from 7.4 to 6.7. These results support the current knowledge that an increase in water temperature results in a decrease in its pH.	The results show that temperature does affect the pH of water.

19.6 Review

SUMMARY

- To make the investigation more meaningful, it should be explained within the right context, meaning the related chemical ideas, concepts, theories and models. Within this context, explain the basis for the hypothesis.
- Indicate whether the hypothesis was supported or refuted and on what evidence this decision is based (that is, the results). Do not provide irrelevant information. Only refer to the specifics of the hypothesis and the research question and do not make generalisations.

KEY QUESTIONS

1 Which of the following would **not** support a strong conclusion to a report?
The concluding paragraphs:
A are relevant and provide evidence.
B are written in emotive language.
C include reference to limitations of the research.
D include suggestions for further avenues of research.

2 A procedure was repeated 30 times. How should the following statement be rewritten?
Many repeats of the procedure were conducted.

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19.7 Communicating

How you approach communicating your results will depend on the audience you want to reach. If you are communicating with a general audience you may want to discuss your investigation in the style of a news article or blog post. These types of communication don't use too much scientific language as you need to assume that your audience does not have a science background.

Throughout this course you will need to present your research using appropriate scientific language and notation. There are many different presentation formats that you can use, such as posters, oral presentations and reports. This section covers the main characteristics of effective science communication and report writing, including objectivity, clarity, conciseness and coherence.

STRUCTURING A REPORT

Your report should have a clear, logical structure.

Introduction:

- The first paragraph should introduce your topic and define key terms.

Body paragraphs:

- Each subsequent paragraph should cover one main idea.
- Use evidence to support statements.
- Avoid very long or very short paragraphs.

Conclusion:

- The final section should summarise the main findings.
- It should relate to the aim of the investigation.
- The conclusion should include limitations and should discuss implications and applications of the research and potential future research.

Analysing information relevant to your research investigation

Scientific research should always be objective and neutral. Any premise presented must be supported with facts and evidence to allow the audience to make its own decision. Identify the evidence supporting or contradicting each point you want to make. It is also important to explain connections between ideas, concepts, theories and models. Figure 19.7.1 lists the questions you need to consider when writing your investigation report.

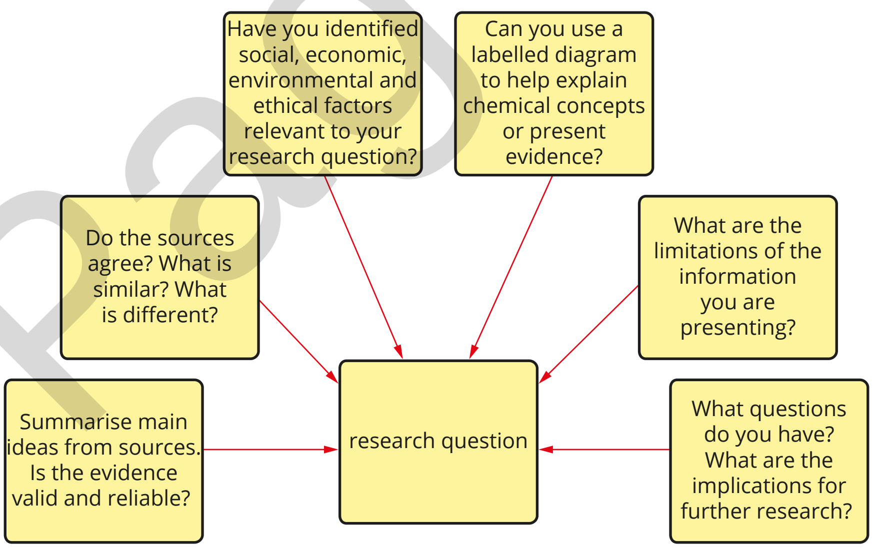

FIGURE 19.7.1 Discuss relevant information, ideas, concepts, implications and make sure your discussion is relevant to the question under investigation.

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WRITING FOR SCIENCE

Scientific reports are usually written in an objective or unbiased style. This is in contrast with English writing that most often uses the subjective techniques of rhetoric or persuasion. Read Table 19.7.1, which contrasts persuasive and scientific writing styles.

TABLE 19.7.1 Persuasive writing versus scientific writing styles

Persuasive writing examples	Scientific writing equivalent examples
Use of biased and subjective language Examples: The results were extremely bad, atrocious, wonderful etc. This is terrible because ... This produced a disgusting odour. Health crisis	**Use of unbiased and objective language** Examples: The results showed ... The implications of these results suggest ... The results imply ... This produced a foul odour. Health issue
Use of exaggeration Example: The object weighed a colossal amount, like an elephant.	**Use of non-emotive language** Example: The object weighed 256 kg.
Use of everyday or colloquial language Examples: The bacteria passed away. The results don't ... The researchers had a sneaking suspicion ...	**Use of formal language** Examples: The bacteria died. The results do not ... The researchers predicted/hypothesised/theorised ...

Consistent reporting narrative

Scientific writing can be written either in first-person or in third-person narrative. Your teacher may advise you on which to select. In either case, ensure that you keep the narrative point of view consistent. Read the examples of first-person and third-person narrative in Table 19.7.2.

TABLE 19.7.2 Examples of first-person and third-person narrative

First person	Third person
I put 50.0 g marble chips in a conical flask and then added 10.0 mL of 2.0 mol L^{-1} hydrochloric acid.	First, 50.0 g of marble chips was weighed into the conical flask and then 10.0 mL of 2.0 mol L^{-1} hydrochloric acid was added.
After I observed the reaction, I found that ...	After the reaction was completed, the results showed ...
My colleagues and I found ...	Researchers found ...

Qualified writing

Be careful of words that are absolute, such as *always*, *never*, *shall*, *will* and *proven*. Sometimes it may be more accurate and appropriate to use qualifying words, such as *may*, *might*, *possible*, *probably*, *likely*, *suggests*, *indicates*, *appears*, *tends*, *can* and *could*.

Concise writing

It is important to write concisely, particularly if you want to engage and maintain the interest of your audience. Use shorter sentences. Read Table 19.7.3, which shows some examples of more concise wording.

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TABLE 19.7.3 Examples of verbose and concise language

Verbose example	Concise example
Due to the fact that	Because
Smith undertook an investigation into ...	Smith investigated
It is possible that the cause could be ...	The cause might be ...
A total of five experiments	Five experiments
End result	Result
In the event that	If
Shorter in length	Shorter

REFERENCES AND ACKNOWLEDGEMENTS

All the quotations, documents, publications and ideas used in the investigation need to be acknowledged in the 'references and acknowledgments' section in order to avoid plagiarism and to ensure authors are credited for their work. References and acknowledgements also give credibility to the study and allow the audience to locate information sources should they wish to study it further. The standard referencing style used is the Amercian Psychological Association (APA) academic referencing style.

When referencing a book include in this order:

- author's surname and initials
- date of publication
- title
- publisher's name
- place of publication.

For example: Rickard, Greg, et al. (2016), *Pearson Science SB9* (2nd ed.), Pearson Education, Melbourne, Australia

When referencing a website include in this order:

- author's surname and initials, or name of organisation, or title
- year website was written or last revised
- title of webpage
- date website was accessed
- website address.
- For example: National Geographic (2015), 'Killer fungus that's devastating bats may have met its match', accessed 29 May 2015, from http://news.nationalgeographic.com/2015/05/150527-bats-white-nose-syndrome-treatment-conservation-animals-science

In-text citations

Each time you write about the findings of other people or organisations, you need to provide an in-text citation and provide full details of the source in a reference list. In the APA style, in-text citations include the first author's last name and date in brackets (author, date). List the full details in your list of references.

The following examples show the use of in-text citation.

It was reported that in testing of five pro-oxidant additives added to commonly manufactured polymers, none resulted in significant biodegradation after three years (Selke et al., 2015).

Or

Selke et al. (2015) reported that in testing of five pro-oxidant additives added to commonly manufactured polymers, none resulted in significant biodegradation after three years.

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The bibliographic details of the example above would be:

Selke, S., Auras, R., Nguyen, T.A., Aguirre, E.C., Cheruvathur, R., & Liu, Y. (2015). Evaluation of biodegradation—promoting additives for plastics. *Environmental Science & Technology*, *49*(6), 3769–3777.

MEASUREMENT AND UNITS

In every area of chemistry we have attempted to quantify the phenomena we study. In practical demonstrations and investigations we generally make measurements and process those measurements in order to come to some conclusions. Scientists have a number of conventional ways of interpreting and analysing data from their investigations. There are also conventional ways of writing numerical measurements and their units.

Table 19.7.4 presents the main quantities and units used in chemistry.

TABLE 19.7.4 Quantities and units used in chemistry

Quantity	Symbol for quantity	Unit
Mass	*m*	gram (g)
Volume	*V*	litre (L)
Amount of substance	*n*	mole (mol)
Molar mass	*M*	grams per mole ($g\,mol^{-1}$)
Relative molecular or formula mass	M_r	no units, relative to one atom of ^{12}C exactly
Relative atomic mass	A_r	no units, relative to one atom of ^{12}C exactly
Density	*d*	$g\,mL^{-1}$, $kg\,L^{-1}$
Molarity	c	moles per litre ($mol\,L^{-1}$)

Correct use of unit symbols

The correct use of unit symbols removes ambiguity, as symbols are recognised internationally. The symbols for units are not abbreviations and should not be followed by a full stop unless they are at the end of a sentence.

Upper-case letters are only used for the *symbols* of the units that are named after people. For example, the unit of energy is joule and the symbol is J. The joule was named after James Joule who was famous for studies into energy conversions. The exception to this rule is 'L' for litre. We do this because a lower-case 'l' looks like the numeral '1'.

The product of a number of units is shown by separating the symbol for each unit with a space. The division or ratio of two or more units can be shown in fraction form, using a slash, or using negative indices. Prefixes should not be separated by a space.

Table 19.7.5 provides some examples of correct and incorrect use of symbols for derived units.

TABLE 19.7.5 Some examples of the use of symbols for derived units.

Preferred	Incorrect
$g\,mol^{-1}$	$g\,mol^{-1}$
kPa	K Pa

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Units named after people can take the plural form by adding an 's' when used with numbers greater than one. Never do this with the unit symbols. It is acceptable to say 'two kilojoules' but it is wrong to write 2 kJs.

Numbers and symbols should not be mixed with words for units and numbers. For example, thirty grams and 30 g are correct while 30 grams and thirty g are incorrect.

Scientific notation

To overcome confusion or ambiguity, measurements are often written in scientific notation. Quantities are written as a number between one and ten and then multiplied by an appropriate power of ten. Note that 'scientific notation', 'standard notation' and 'standard form' all have the same meaning.

Examples of some values written in scientific notation are:

6.022×10^{23} particles

$25.25\,\text{mL} = 2.525 \times 10^{-2}\,\text{L}$

$0.00302\,\text{mol} = 3.02 \times 10^{-3}\,\text{mol}$

You should be routinely using scientific notation to express numbers. This also involves learning to use your calculator intelligently. Scientific and graphics calculators can be put into a mode whereby all numbers are displayed in scientific notation. It is useful when doing calculations to use this mode rather than frequently attempting to convert to scientific notation by counting digits on the calculator display.

An important reason for using scientific notation is that it removes ambiguity about the precision of some measurements. For example, a measurement recorded as 240 g could be a measurement to the nearest gram; that is, somewhere between 239.5 g and 240.5 g, or it could have been rounded up to the nearest 10 g. By writing this quantity as 2.40×10^2 g it makes it clear the accuracy of the value (in this case 3 significant figures).

Prefixes and conversion factors

Conversion factors should be used carefully. You should be familiar with the prefixes and conversion factors in Table 19.7.6. Note that the table gives all conversions as a multiplying factor.

TABLE 19.7.6 Prefixes and conversion factors.

Multiplying factor		Prefix	Symbol
1 000 000 000 000	10^{12}	tera	T
1 000 000 000	10^{9}	giga	G
1 000 000	10^{6}	mega	M
1 000	10^{3}	kilo	k
0.01	10^{-2}	centi	c
0.001	10^{-3}	milli	m
0.000 001	10^{-6}	micro	μ
0.000 000 001	10^{-9}	nano	n
0.000 000 000 001	10^{-12}	pico	p

Do not put spaces between prefixes and unit symbols.

It is important to give the symbol the correct case (upper or lower case). There is a big difference between 1 mm and 1 Mm.

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19.7 Review

SUMMARY

- A scientific report must include an introduction, body paragraphs and conclusion.
- The conclusion should include a summary of the main findings, a conclusion related to the issue being investigated, limitations of the research, implications and applications of the research, and potential future research.
- Scientific writing uses unbiased, objective, accurate, formal language. Scientific writing should also be concise and qualified.
- Visual support can assist in conveying scientific concepts and processes efficiently.
- Ensure you edit your final report.
- Scientific notation needs to be used when communicating your results.

KEY QUESTIONS

1 The variables molar mass, and molarity each have different units. Write the units for each of the following in correct notation.

a molar mass; grams per mole

b molarity; mole per litre

2 **a** Show how to convert mL into L.

b Discuss why you might need to convert between different multiplying factors, for example litres to millilitres.

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Chapter review

19

KEY TERMS

accuracy
chemical (HAZCHEM) codes
confidence interval
control experiment
controlled variable
credible
dependent variable
hypothesis
independent variable
mean
outlier
personal protective equipment (PPE)
phenomenon
precision
primary source
processed data
qualitative
quantitative
random error
raw data
reliability
Safety Data Sheet (SDS)
secondary source
significant figures
systematic error
trend line
uncertainty
validity
variable

1 Consider the following research question:
'Is the pH of water sampled from the Ningaloo Reef within acceptable limits?'
Identify each of the following as independent, dependent or controlled variables.
  a pH
  b Analytical technique, temperature of water sample, type of sampling container
  c Source and location of water

2 Match the following command verbs with their definitions:
describe**,** analyse, apply, create, identify, reflect, investigate.
  a Think deeply about.
  b Produce or make new.
  c Identify connections and relationships, interpret to reach a conclusion.
  d Observe, study, examine, inquire systematically in order to establish facts or derive conclusions.
  e Use knowledge and understanding in a new situation.
  f Recognise or indicate what or who.
  g Give a detailed account.

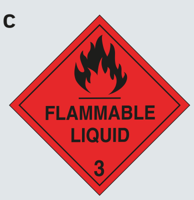
3 Consider the following hypothesis:
'The concentration of calcium ions in drinking water from the Perth desalination plant is greater than that of drinking water sourced from the Perth Hills.'
Name the independent, dependent and controlled variables for an experiment with this hypothesis.

4 What are the meanings of the following chemical codes?

a

b

c



5 Explain the terms 'accuracy' and 'validity.'

6 Identify whether the following are mistakes, systematic errors or random errors.
  a A student spills some solution during an experiment.
  b The reported measurements are above and below the true value.
  c A weighing balance has not been calibrated.

7 What relationship between variables is indicated by a straight trend line?

8 What factors should you consider to ensure you discuss the limitations of your method?

9 Explain the meaning of the term 'trend' in a scientific investigation and describe the types of trends that might exist.

10 What is meant by the 'limitations' of the investigation method?

11 What is the purpose of referencing and acknowledging documents, ideas and quotations in your investigation?

12 For the following source, what is the correct way to make an in-text citation in APA style?
Selke, S., Auras, R., Nguyen, T.A., Aguirre, E.C., Cheruvathur, R., & Liu, Y. (2015). Evaluation of biodegradation—promoting additives for plastics. *Environmental Science & Technology, 49*(6), 3796–3777.
  A However, Selke et al. (2015) did not find any significant difference in biodegradability.
  B However, Selke et al. did not find any significant difference in biodegradability[1].
  C However, Selke et al. did not find any significant difference in biodegradability (Selke, S., Auras, R., Nguyen, T.A., Aguirre, E.C., Cheruvathur, R., & Liu, Y. (2015). Evaluation of biodegradation—promoting additives for plastics. *Environmental Science & Technology, 49*(6), 3769–3777).
  D However, Selke et al. (2015) did not find any significant difference in biodegradability (Evaluation of biodegradation-promoting additives for plastics. *Environmental Science & Technology*).

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13 Convert 23.0 mL into L

14 A scientist designed and completed an experiment to test the following hypothesis:
'Increasing the concentration of the electrolyte in a hydrogen fuel cell would result in an increase in the voltage generated by the cell.'

- **a** What would be the independent, dependent and controlled variables in this investigation?
- **b** What data would be collected? Would it be qualitative or quantitative?
- **c** List the equipment that could be used and the type of precision expected for each item.
- **d** Explain the difference between raw data and processed data, using this hypothesis as an example. Sketch what you expect the graph of the results to look like if the scientist's hypothesis was correct.

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APPENDIX A Symbols, units and fundamental constants

TABLE 1 Units and symbols based on the SI system. Units listed in red are the arbitrarily defined fundamental units of the SI system

Quantity	Symbol for physical quantity	Corresponding SI unit	Symbol for SI unit	Definition of SI unit
Mechanics				
Volume	*V*	cubic metre	m^3	
Mass	*m*	kilogram	kg	fundamental unit
Density	*d*	—	$kg\ m^{-3}$	
Time	*t*	second	s	fundamental unit
Force	*F*	newton	N	$kg\ m\ s^{-2}$
Pressure	*P*	pascal	Pa	$N\ m^{-2}$
Energy	*E*	joule	J	N m
Electricity				
Electric potential difference	*V*	volt	V	$J\ A^{-1}\ s^{-1}$
Nuclear and chemical quantities				
Atomic number	*Z*	—	—	—
Neutron number	*N*	—	—	—
Mass number	*A*	—	—	*Z* + *N*
Amount of substance	*n*	mole	mol	fundamental unit
Relative atomic mass	A_r	—	—	—
Relative molecular mass	M_r	—	—	—
Molar mass	*M*	—	—	$kg\ mol^{-1}$
Molar volume	V_m	—	—	$m^3\ mol^{-1}$
Concentration	c	—	—	$mol\ m^{-3}$
Thermal quantities				
Temperature	*T*	kelvin	K	fundamental unit
Specific heat capacity	*C*	—	—	$J\ K^{-1}\ kg^{-1}$

TABLE 2 SI prefixes, their symbols and values

SI prefix	Symbol	Value
pico	p	10^{-12}
nano	n	10^{-9}
micro	μ	10^{-6}
milli	m	10^{-3}
centi	c	10^{-2}
deci	d	10^{-1}
kilo	k	10^{3}
mega	M	10^{6}
giga	G	10^{9}
tera	T	10^{12}

TABLE 3 Some physical constants

Description	Symbol	Value
Avogadro's constant	N_A	$6.022 \times 10^{23}\ mol^{-1}$
Charge of an electron	*e*	-1.60×10^{-19} C
Mass of electron	m_e	9.109×10^{-31} kg
Mass of proton	m_p	1.673×10^{-27} kg
Mass of neutron	m_n	1.675×10^{-27} kg
Gas constant	*R*	$8.31\ J\ K^{-1}\ mol^{-1}$
Ionic product for water	K_w	1.00×10^{-14} at 298 K
Molar volume of an ideal gas	V_m	
at 273 K, 100 kPa		$22.71\ L\ mol^{-1}$
Specific heat capacity of water	c	$4.18\ J^{-1}\ g^{-1}\ K^{-1}$
Density of water	*d*	$1.00\ g\ mL^{-1}$ at 298 K

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APPENDIX B Significant figures and standard form

SIGNIFICANT FIGURES

The number of significant figures a piece of data has indicates the precision of a measurement. For example, compare the following data:

- A jogger takes 20 minutes to cover 4 kilometres.
- A sprinter takes 10.21 seconds to cover 100.0 metres.

The sprinter's data has been measured more precisely than that of the jogger. This is indicated by the greater number of significant figures in the second set of data.

Which figures are significant?

A significant figure is an integer or a zero that follows an integer.

In the data above, the:

- distance '4 kilometres' has one significant figure
- time '20 minutes' has two significant figures (the zero follows the integer 2)
- 10.21 seconds and 100.0 metres each have four significant figures.

A zero that comes before any integers, however, is not significant. For example:

- the value 0.0004 has only one significant figure, whereas the value 0.0400 has three significant figures. The zeros that come before the integer 4 are not significant, whereas those that follow the integer are significant.

Using significant figures

In chemistry you will often need to calculate a value from a set of data. It is important to remember that the final value you calculate is only as precise as your *least precise piece of data*.

Addition and subtraction

When adding or subtracting values, the answer should have no more digits to the right of the decimal place than the value with the least number of digits to the right of the decimal place.

Example

12.78 mL of water was added to 10.0 mL of water. What is the total volume of water?

12.78 mL + 10.0 mL = 22.78 = 22.8 mL

Because one of the values (10.0 mL) has only one digit to the right of the decimal place, the answer will need to be adjusted so that it too has only one digit to the right of the decimal place.

Multiplication and division

When multiplying and dividing values, the answer should have no more significant figures than the value with the least number of significant figures.

Example

An athlete takes 3.5 minutes to complete four laps of an oval. What is the average time taken for one lap?

$$\text{Average time} = \frac{3.5 \text{ minutes}}{4} = 0.875 = 0.88 \text{ minutes}$$

Because the data (3.5 minutes) has only two significant figures, the answer will need to be adjusted to two significant figures so that it has the same degree of precision as the data. (Note: The 'four' is taken to indicate a precise number of laps and so is considered to have as many significant figures as the calculation requires. This applies to values that describe *quantities* rather than *measurements*.)

Rounding off

When adjusting the number of significant figures, if the integer after the last significant figure is equal to or greater than '5', then the last significant integer is rounded up. Otherwise, it is rounded down.

STANDARD FORM

A value written in standard form is expressed as a number equal to or greater than 1 and less than 10 multiplied by 10^x, where x is an integer. For example, when written in standard form:

- 360 becomes 3.6×10^2
- 0.360 becomes 3.60×10^{-1}
- 0.000456 becomes 4.56×10^{-5}.

Sometimes you will need to use standard form to indicate the precision of a value.

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APPENDIX C Table of relative atomic masses*

TABLE 1 Table of relative atomic masses*

Element name	Symbol	Atomic number	Relative atomic mass	Element name	Symbol	Atomic number	Relative atomic mass	Element name	Symbol	Atomic number	Relative atomic mass
Actinium	Ac	89	—	Germanium	Ge	32	72.63	Potassium	K	19	39.098
Aluminium	Al	13	26.9815	Gold	Au	79	196.9666	Praseodymium	Pr	59	140.9077
Americium	Am	95	—	Hafnium	Hf	72	178.49	Promethium	Pm	61	—
Antimony	Sb	51	121.76	Hassium	Hs	108	—	Protactinium	Pa	91	231.0359
Argon	Ar	18	39.948	Helium	He	2	4.00260	Radium	Ra	88	—
Arsenic	As	33	74.9216	Holmium	Ho	67	164.9303	Radon	Rn	86	—
Astatine	At	85	—	Hydrogen	H	1	1.0080	Rhenium	Re	75	186.21
Barium	Ba	56	137.33	Indium	In	49	114.82	Rhodium	Rh	45	102.9055
Berkelium	Bk	97	—	Iodine	I	53	126.9045	Roentgenium	Rg	111	—
Beryllium	Be	4	9.01218	Iridium	Ir	77	192.22	Rubidium	Rb	37	85.468
Bismuth	Bi	83	208.9804	Iron	Fe	26	55.845	Ruthenium	Ru	44	101.07
Bohrium	Bh	107	—	Krypton	Kr	36	83.80	Rutherfordium	Rf	104	—
Boron	B	5	10.81	Lanthanum	La	57	138.9055	Samarium	Sm	62	150.4
Bromine	Br	35	79.904	Lawrencium	Lr	103	—	Scandium	Sc	21	44.9559
Cadmium	Cd	48	112.41	Lead	Pb	82	207.2	Seaborgium	Sg	106	—
Caesium	Cs	55	132.9055	Lithium	Li	3	6.94	Selenium	Se	34	78.97
Calcium	Ca	20	40.08	Livermorium	Lv	116	—	Silicon	Si	14	28.086
Californium	Cf	98	—	Lutetium	Lu	71	174.967	Silver	Ag	47	107.868
Carbon	C	6	12.011	Magnesium	Mg	12	24.305	Sodium	Na	11	22.9898
Cerium	Ce	58	140.12	Manganese	Mn	25	54.9380	Strontium	Sr	38	87.62
Chlorine	Cl	17	35.453	Meitnerium	Mt	109	—	Sulfur	S	16	32.06
Chromium	Cr	24	51.996	Mendelevium	Md	101	—	Tantalum	Ta	73	180.9479
Cobalt	Co	27	58.9332	Mercury	Hg	80	200.59	Technetium	Tc	43	—
Copernicium	Cn	112	—	Molybdenum	Mo	42	95.95	Tellurium	Te	52	127.60
Copper	Cu	29	63.55	Neodymium	Nd	60	144.24	Terbium	Tb	65	158.9254
Curium	Cm	96	—	Neon	Ne	10	20.180	Thallium	Tl	81	204.384
Darmstadtium	Ds	110	—	Neptunium	Np	93	—	Thorium	Th	90	232.038
Dubnium	Db	105	—	Nickel	Ni	28	58.693	Thulium	Tm	69	168.9342
Dysprosium	Dy	66	162.50	Niobium	Nb	41	92.9064	Tin	Sn	50	118.71
Einsteinium	Es	99	—	Nitrogen	N	7	14.0067	Titanium	Ti	22	47.87
Erbium	Er	68	167.26	Nobelium	No	102	—	Tungsten	W	74	183.84
Europium	Eu	63	151.96	Osmium	Os	76	190.2	Uranium	U	92	238.0289
Fermium	Fm	100	—	Oxygen	O	8	15.9994	Vanadium	V	23	50.942
Flerovium	Fl	114	—	Palladium	Pd	46	106.4	Xenon	Xe	54	131.29
Fluorine	F	9	18.9984	Phosphorus	P	15	30.9738	Ytterbium	Yb	70	173.05
Francium	Fr	87	—	Platinum	Pt	78	195.08	Yttrium	Y	39	88.9058
Gadolinium	Gd	64	157.25	Plutonium	Pu	94	—	Zinc	Zn	30	65.38
Gallium	Ga	31	69.72	Polonium	Po	84	—	Zirconium	Zr	40	91.22

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* Based on the atomic mass of $^{12}C = 12$.
The values for relative atomic masses given in the table apply to elements as they exist in nature, without artificial alteration of their isotopic composition, and, further, to natural mixtures that do not include isotopes of radiogenic origin.

APPENDIX D

Common positive and negative ions and solubility of common ionic compounds in water

TABLE 1 Names and formulae of some common positive and negative ions

Positive ions (cations)						Negative ions (anions)			
+1		+2		+3		–1		–2	
Caesium	Cs^+	Barium	Ba^{2+}	Aluminium	Al^{3+}	Bromide	Br^-	Carbonate	CO_3^{2-}
Copper(I)	Cu^+	Cadmium(II)	Cd^{2+}	Chromium(III)	Cr^{3+}	Chloride	Cl^-	Chromate	CrO_4^{2-}
Gold(I)	Au^+	Calcium	Ca^{2+}	Gold(III)	Au^{3+}	Cyanide	CN^-	Dichromate	$Cr_2O_7^{2-}$
Lithium	Li^+	Cobalt(II)	Co^{2+}	Iron(III)	Fe^{3+}	Dihydrogen phosphate	$H_2PO_4^-$	Hydrogen phosphate	HPO_4^{2-}
Potassium	K^+	Copper(II)	Cu^{2+}			Ethanoate	CH_3COO^-	Oxalate	$C_2O_4^{2-}$
Rubidium	Rb^+	Iron(II)	Fe^{2+}	+4		Fluoride	F^-	Oxide	O^{2-}
Silver	Ag^+	Lead(II)	Pb^{2+}	Lead(IV)	Pb^{4+}	Hydrogen carbonate	HCO_3^-	Sulfide	S^{2-}
Sodium	Na^+	Magnesium	Mg^{2+}	Tin(IV)	Sn^{4+}	Hydrogen sulfide	HS^-	Sulfite	SO_3^{2-}
		Manganese(II)	Mn^{2+}			Hydrogen sulfite	HSO_3^-	Sulfate	SO_4^{2-}
		Mercury(II)	Hg^{2+}			Hydrogen sulfate	HSO_4^-		
		Nickel	Ni^{2+}			Hydroxide	OH^-	–3	
		Strontium	Sr^{2+}			Iodide	I^-	Nitride	N^{3-}
		Tin(II)	Sn^{2+}			Nitrite	NO_2^-	Phosphate	PO_4^{3-}
		Zinc	Zn^{2+}			Nitrate	NO_3^-		
						Permanganate	MnO_4^-		

TABLE 2 Solubility of common ionic compounds in water

Soluble ionic compounds		
Soluble in water (>0.1 mol dissolves per L at 25°C)	**Exceptions: insoluble (<0.01 mol dissolves per L at 25°C)**	**Exceptions: slightly soluble (0.01–0.1 mol dissolves per L at 25°C)**
Most chlorides (Cl^-), bromides (Br^-) and iodides (I^-)	AgCl, AgBr, AgI, PbI_2	$PbCl_2$
All nitrates (NO_3^-)	No exceptions	No exceptions
All ammonium (NH_4^+) salts	No exceptions	No exceptions
All sodium (Na^+) and potassium (K^+) salts	No exceptions	No exceptions
All ethanoates (CH_3COO^-)	No exceptions	No exceptions
Most sulfates (SO_4^{2-})	$SrSO_4$, $BaSO_4$, $PbSO_4$	$CaSO_4$, Ag_2SO_4
Insoluble ionic compounds		
Insoluble in water	**Exceptions: soluble**	**Exceptions: slightly soluble**
most hydroxides (OH^-)	NaOH, KOH, $Ba(OH)_2$, NH_4OH*, AgOH**	$Ca(OH)_2$, $Sr(OH)_2$
most carbonates (CO_3^{2-})	Na_2CO_3, K_2CO_3, $(NH_4)_2CO_3$	No exceptions
most phosphates (PO_4^{3-})	Na_3PO_4, K_3PO_4, $(NH_4)_3PO_4$	No exceptions
most sulfides (S^{2-})	Na_2S, K_2S, $(NH_4)_2S$	No exceptions

*NH_4OH does not exist in significant amounts in an ammonia solution. Ammonium and hydroxide ions readily combine to form ammonia and water.
**AgOH readily decomposes to form a precipitate of silver oxide and water.

Page Proofs

APPENDIX E Electrochemical series

half-reaction	$E°$ (volts)
$F_2(g) + 2e^- \rightleftharpoons 2F^-(aq)$	+ 2.89
$H_2O_2(aq) + 2H^+(aq) + 2e^- \rightleftharpoons 2H_2O(l)$	+ 1.76
$PbO_2(s) + SO_4^{2-}(aq) + 4H^+(aq) + 2e^- \rightleftharpoons PbSO_4(s) + 2H_2O(l)$	+ 1.69
$2HClO(aq) + 2H^+(aq) + 2e^- \rightleftharpoons Cl_2(g) + 2H_2O(l)$	+ 1.63
$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l)$	+ 1.51
$Au^{3+}(aq) + 3e^- \rightleftharpoons Au(s)$	+ 1.50
$HClO(aq) + H^+(aq) + 2e^- \rightleftharpoons Cl^-(aq) + H_2O(l)$	+ 1.49
$PbO_2(s) + 4H^+(aq) + 2e^- \rightleftharpoons Pb^{2+}(aq) + 2H_2O(l)$	+ 1.46
$Cl_2(g) + 2e^- \rightleftharpoons 2Cl^-(aq)$	+ 1.36
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightleftharpoons 2Cr^{3+}(aq) + 7H_2O(l)$	+ 1.36
$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l)$	+ 1.23
$Br_2(l) + 2e^- \rightleftharpoons 2Br^-(aq)$	+ 1.08
$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$	+ 0.80
$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$	+ 0.77
$O_2(g) + 2H^+(aq) + 2e^- \rightleftharpoons H_2O_2(aq)$	+ 0.70
$I_2(s) + 2e^- \rightleftharpoons 2I^-(aq)$	+ 0.54
$O_2(g) + 2H_2O(l) + 4e^- \rightleftharpoons 4OH^-(aq)$	+ 0.40
$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$	+ 0.34
$S(s) + 2H^+(aq) + 2e^- \rightleftharpoons H_2S(aq)$	+ 0.17
$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$	0 exactly
$Pb^{2+}(aq) + 2e^- \rightleftharpoons Pb(s)$	– 0.13
$Sn^{2+}(aq) + 2e^- \rightleftharpoons Sn(s)$	– 0.14
$Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)$	– 0.24
$Co^{2+}(aq) + 2e^- \rightleftharpoons Co(s)$	– 0.28
$PbSO_4(s) + 2e^- \rightleftharpoons Pb(s) + SO_4^{2-}(aq)$	– 0.36
$Cd^{2+}(aq) + 2e^- \rightleftharpoons Cd(s)$	– 0.40
$2CO_2(g) + 2H^+(aq) + 2e^- \rightleftharpoons H_2C_2O_4(aq)$	– 0.43
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	– 0.44
$Cr^{3+}(aq) + 3e^- \rightleftharpoons Cr(s)$	– 0.74
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	– 0.76
$2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$	– 0.83
$Mn^{2+}(aq) + 2e^- \rightleftharpoons Mn(s)$	– 1.18
$Al^{3+} + 3e^- \rightleftharpoons Al(s)$	– 1.68
$Mg^{2+}(aq) + 2e^- \rightleftharpoons Mg(s)$	– 2.36
$Na^+(aq) + e^- \rightleftharpoons Na(s)$	– 2.71
$Ca^{2+}(aq) + 2e^- \rightleftharpoons Ca(s)$	– 2.87
$Sr^{2+}(aq) + 2e^- \rightleftharpoons Sr(s)$	– 2.90
$Ba^{2+}(aq) + 2e^- \rightleftharpoons Ba(s)$	– 2.91
$K^+(aq) + e^- \rightleftharpoons K(s)$	– 2.94

Page Proofs

1. Transforming decimal notation to scientific notation

Scientists use scientific notation to handle very large and very small numbers.

For example, instead of writing 0.000 000 035, scientists would write 3.5×10^{-8}.

A number in *scientific notation* (also called standard form or power of ten notation) is written as:

$$a \times 10^{n}$$

where a is a number equal to or greater than 1 and less than 10, that is $1 \le a < 10$.

n is an integer (a positive or negative whole number).

n is the power that 10 is raised to and is called the index value.

To transform a very large or very small number into scientific notation:

Write the original number as a decimal number greater than or equal to 1 but less than 10.

Multiply the decimal number by the appropriate power of 10.

The index value is determined by counting the number of places the decimal point needs to be moved to form the original number again.

If the decimal point is moved n places to the right, n will be a positive number. For example:

$$51 = 5.1 \times 10^{1}$$

If the decimal point is moved n places to the left, n will be a negative number. For example:

$$0.51 = 5.1 \times 10^{-1}$$

You will notice from these examples that when large numbers are written in scientific notation, the 10 has a positive index value. When very small numbers are written in scientific notation, the 10 has a negative index value.

Practice questions

1 Match each number with its correct scientific notation.

Number	Scientific notation
0.002	2×10^{3}
2000	1.234×10^{-1}
0.1234	2×10^{-3}
12.34	1.234×10^{1}
123.4	1.234×10^{2}

2 Write 7.009×10^{-4} using decimal notation.

2. Identifying significant figures

When giving an answer to a calculation it is important to take note of the number of significant figures that you use.

You should give an answer that is as accurate as possible. However, an answer can't be more accurate than the data or the measuring device used to calculate it. For example, if a set of scales that measures to the nearest gram shows that an object has a mass of 56 g, then the mass should be recorded as 56 g, not 56.0 g. This is because you do not know whether it is 56.0 g, 56.1 g, 56.2 g or 55.8 g.

56 is a number with 2 significant figures. Recording to 3 significant figures (e.g. 56.0 g or 55.8 g) would not be scientifically 'honest'.

If this mass of 56 g is used to calculate another value it would also not be 'honest' to give an answer that has more than 2 significant figures.

Page Proofs

Determining to what number of significant figures to give an answer to depends on what kind of calculation you are doing.

If you are multiplying or dividing, use the smallest number of significant figures provided in the initial values.

If you are adding or subtracting, use the smallest number of decimal places provided in the initial values.

Working out the number of significant figures

The following rules should be followed to avoid confusion in determining how many significant figures are in a number.

1 All non-zero digits are always significant. For example, 21.7 has 3 significant figures.
2 All zeroes between two non-zero digits are significant. For example, 3015 has 4 significant figures.
3 A zero to the right of a decimal point and following a non-zero digit is significant. For example, 0.5700 has 4 significant figures.
4 Any other zero is not significant, as it will be used only for locating decimal places. For example, 0.005 has just 1 significant figure.

Practice questions

1 Which of the following is written to 2 significant figures?
 A 30.1
 B 0.000 40
 C 0.5
 D 5.12
2 George multiplied 1.22 by 1.364. Which of the options below shows the result of this multiplication with the correct number of significant figures?
 A 1.66
 B 1.664
 C 1.65
 D 1.7
3 How can 41 be written to 4 significant figures?
 A 00.41
 B 4100
 C 41.00
 D 4.100
4 Alex is getting ready to go for a bike ride. Alex's mass is 65.3 kg. The bicycle has a mass of 12.92 kg.
 a Calculate the combined mass of Alex and the bicycle. Give your answer to the correct number of significant figures.
  A 78
  B 78.2
  C 78.22
  D 78.3
 b Using the combined mass calculated in part (a) above, and the formula $F_{net} = ma$, calculate the force Alex needs to apply to achieve an acceleration of 1.250 m s^{-1}. Give your answer to the correct number of significant figures.

3. Calculating percentages

Scientists use percentages to express a ratio or fraction of a quantity.

To express one quantity as a percentage of another, use the second quantity to represent 100%.

Page Proofs

For example, expressing 6 as a percentage of 24 is like saying '6 is to 24 as x is to 100':

$$\frac{6}{24} = \frac{x}{100}$$
$$x = \frac{6}{24} \times 100$$
$$= 25\%$$

To calculate a percentage of a quantity, the percentage is expressed as a decimal then multiplied by the quantity.

For example, to calculate 40% of 20:

$$x = \frac{40}{100} \times 20$$
$$= 0.4 \times 20$$
$$= 8$$

Practice questions

1 What is 9 as a percentage of 12?
A 25%
B 50%
C 75%
D 30%

2 What is 25% of 24?
A 6.6
B 6
C 5
D 0.5

3 Which of the following values expresses 15 as a percentage of 120?
A 8%
B 5%
C 12.5%
D 0.125%

4. Converting between percentages and fractions

To write a percentage as a fraction, divide the percentage by 100.

For example:

$$25\% = \frac{25}{100}$$
$$= \frac{1}{4}$$

$\frac{25}{100}$ is not the simplest form of this fraction. If you divide both the numerator and the denominator by 25 (their highest common factor) then the fraction simplifies to $\frac{1}{4}$.

Whenever you give a fraction as an answer, always try and simplify it by dividing the numerator and denominator by the highest common factor.

To write a fraction as a percentage, multiply the fraction by 100%. In many cases it is easier to convert the fraction to a decimal number first.

For example:

$$\frac{1}{4} = 0.25 \times 100$$
$$= 25\%$$

Page Proofs

The value of the fraction or percentage has not changed. It is just being represented in a different way.

Practice questions

1 Choose the option that expresses $\frac{1}{5}$ as a percentage.
A 25%
B 20%
C 30%
D 50%

2 Match each percentage with its corresponding fraction.

Percentage	Fraction
0.2%	$\frac{7}{20}$
2.5%	$\frac{7}{40}$
17.5%	$\frac{1}{40}$
35%	$\frac{111}{250}$
44.4%	$\frac{1}{500}$

5. Changing the subject of an equation

Scientists use equations to represent relationships between variables. In an equation like $A = \pi r^2$, A is called the subject of the equation.

Sometimes the subject of the equation has to be changed in order to express the relationship in a more useful way. For example, if you need to find the radius of a circle, you would want r to be the subject of the equation above.

To change the subject of a simple equation, transpose the equation to leave the new subject on its own. In the example above, the equation needs to read

$r = \ldots$

Keep the equation balanced by performing the same operation to both sides of the equation to cancel operations being performed on the desired subject. Inverse operations (the opposite operation; for example dividing is the inverse of multiplying) will allow cancelling.

For example, make r the subject of the equation $A = \pi r^2$.

1 Divide both sides of the equation by π.

$$A = \pi r^2$$

$$\frac{A}{\pi} = \frac{\pi r^2}{\pi}$$

The π in the numerator and denominator on the right side of the equation cancel out, giving

$$\frac{A}{\pi} = r^2$$

Page Proofs

2 To cancel the squaring operation of r, take the square root of both sides of the equation.

$$\frac{A}{\pi} = r^2$$

$$\sqrt{\frac{A}{\pi}} = \sqrt{r^2}$$

The square and square root on the right side of the equation cancel out, giving

$$\sqrt{\frac{A}{\pi}} = r$$

3 r is now the subject of the equation.

$$r = \sqrt{\frac{A}{\pi}}$$

Practice questions

1 Rearrange the formula $A = \frac{2}{3}R$ to make R the subject.

A $R = \frac{2A}{3}$

B $R = \frac{A}{3}$

C $R = \frac{3A}{2}$

D $R = 6A$

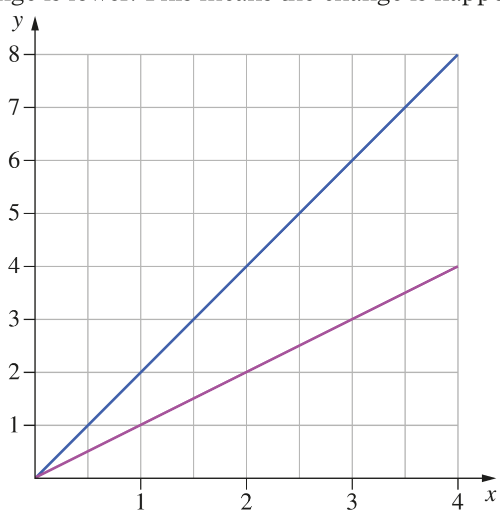
2 Rearrange the formula $y = 3\sqrt{\frac{p}{q}}$ to make p the subject.

6. Interpreting the slope of a linear graph

Scientists often represent a relationship between two variables as a graph. For directly proportional relationships, the variables are connected by a straight line, where the slope (or gradient) of the line represents the constant of proportionality between the two variables.

The slope or gradient of the line is defined as the ratio of change between two points in the vertical axis (ΔY), divided by the change between two points in the horizontal axis (ΔX). In other words, it measures the rate at which one variable (the dependent variable) changes with respect to the other (the independent variable).

The graph below has two straight lines with different slopes. The steeper slope (blue line) indicates that the rate of change is higher. This means the change is happening more quickly. On the other hand, the flatter slope (red line) indicates that the rate of change is lower. This means the change is happening more slowly.



Page Proofs

Practice questions

1 On a graph with two sloped lines, what does the steeper sloped line indicate?
A a faster rate of change
B a slower rate of change
C the same rate of change
D a much slower rate of change

2 The rate of change of a straight line on a graph is given by the:
A *y*-intercept
B *x*-intercept
C gradient
D area under the graph

7. Understanding mathematical symbols

Part of the language of science is using symbols to represent quantities or to give meanings. For example, the four symbols <, >, ≤ and ≥ are known as 'inequalities'.

The following mathematical symbols are commonly used in science.

Symbol	Meaning	Example	Explanation
<	less than	$2 < 3$	2 is less than 3
>	greater than	$6 > 1$	6 is greater than 1
≤	less than or equal to	$2x \leq 10$	$2x$ is less than or equal to 10
≥	greater than or equal to	$3y \geq 12$	$3y$ is greater than or equal to 12
$\sqrt{\ }$	square root	$\sqrt{4} = 2$	The square root of 4 is 2
Δ	change in (difference between)	Δt	change in t (time)
≈	approximately equal to	$\pi \approx 3.14$	π is approximately equal to 3.14
Σ	summation	$\sum_{i=1}^{4} i$	The sum of consecutive integers from 1 to 4, i.e. $1 + 2 + 3 + 4 = 10$

Practice questions

1 The symbol that means 'less than' is:
A <
B >
C ≤
D ≥

2 Which of these symbols is an inequality?
A ≈
B Δ
C $\sqrt{\ }$
D ≤

8. Understanding the difference between discrete and continuous data

Quantitative data forms the backbone of science. Scientists are constantly working with data—measuring, recording, analysing and interpreting it.

Quantitative data consists of numerical values that can either be discrete or continuous.

Discrete data is data that has a set of clearly defined values. For example, the number of students in a class would have a discrete set of possible data.

Continuous data is usually data that is measured in some way and can have an infinite number of values. For example, your height or weight would have a continuous set of possible data.

Page Proofs

The easiest way to distinguish between the two types of quantitative data is to ask, 'Is the data measured or counted?' If it is counted, the data set is discrete. If it is measured, the data set is continuous.

Practice questions

1 Which one of these data sets is continuous?
  A the number of cars parked in a street
  B the temperature of the air over a 24-hour period
  C the number of students at a school
  D the number of nails used to build a fence
2 Which one of these data sets is discrete?
  A the number of cars parked in a street
  B the temperature of the air over 24 hours
  C the heights of a team of footballers
  D the mass of a team of netballers

9. Calculating the mean, median and range of a data set

When handling data, scientists often look for ways to describe patterns in the data. Common terms used when analysing a set of data include the mean, median and range.

Mean: the *average* value in the data set. To calculate the mean, sum all the values in the data set and then divide this by the number of data values.

Median: the *middle* value in an ordered data set. To calculate the median, arrange the data set in ascending order and then count the number of data values. If the number of values is odd, the median is the middle value. If the number of values is even, calculate the median by adding the two middle values and dividing by 2, i.e. by calculating the average of the two middle numbers.

Range: the *spread* of values in the data set. To calculate the range, take the largest data value and then subtract the smallest data value.

Practice questions

1 The following set of data is recorded:
  44, 17, 21, 26, 42, 18
  Find the
  a mean
  b median
  c range.
2 The mass in kilograms of each student in a class of 25 students is recorded below. The combined mass of all the students is 1340 kg.
  Find the
  a mean
  b median
  c range.
  Students' weights: 67, 60, 41, 52, 39, 60, 42, 55, 55, 50, 46, 62, 48, 48, 56, 64, 55, 56, 59, 61, 41, 63, 53, 62, 45

10. Solving simple algebraic equations

To solve an equation means to find the values that make the equation true. Scientists manipulate equations and substitute in known variables in order to solve for the variable required.

For example, you can solve

$$a = \frac{F_{\text{net}}}{m}$$

Page Proofs

where F_{net} is the net force on the car, which is 2400 N

m is the mass of the car, which is 1200 kg

a is the acceleration of the car in m s^{-2}, which is unknown.

$$a = \frac{2400}{1200}$$
$$= 2\,\text{m s}^{-2}$$

Practice questions

1 Solve the equation $V = IR$ if $I = 3$ and $R = 9$.

A $V = 3$
B $V = 6$
C $V = 12$
D $V = 27$

2 Solve the equation and find the value of Q if $Q = mc\Delta T$, $m = 1.2$, $c = 4200$ and $\Delta T = 30$.

A $Q = 840$
B $Q = 25\,200$
C $Q = 126\,000$
D $Q = 6$

11. Completing calculations with more than one operation

Scientists often deal with complex calculations that can involve numerous operations within the one calculation. The order in which these operations are performed can affect the result of the calculation.

For example, the calculation $2 + 3 \times 4$ will give an incorrect answer of 20 if you calculate the $2 + 3$ part first, but it will give the correct answer of 14 if you calculate the 3×4 part first.

Scientists and mathematicians have agreed on a set order in which operations are carried out so that calculations are consistent. You can remember this order using the acronym 'BIDMAS':

- brackets
- indices (powers, square roots, etc.)
- division and multiplication
- addition and subtraction.

The operations present in a calculation are performed in the order shown in the list. If there are multiple instances of division and multiplication, or addition and subtraction, work from left to right.

For example, the 3×4 part in the original example would always be performed first, since multiplication is higher in the list than addition.

When dealing with scientific notation, it is important to keep each individual number complete. Use brackets to help do this, especially when dividing.

For example, when dividing 3.01×10^{21} by 6.02×10^{23}, brackets are used to keep the second number together.

If you used a calculator and entered $\frac{3.01\times10^{21}}{6.02\times10^{23}}$ (i.e. $3.01 \times 10^{21} \div 6.02 \times 10^{23}$), the answer would come out as 5.00×10^{43}. This is not the correct answer.

The correct answer is only obtained by entering $\frac{3.01\times10^{21}}{(6.02\times10^{23})}$. This time, the answer comes out correctly as 5.00×10^{-3}.

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Using the calculator's *EXP* button or the $x10^x$ button keeps the number and power of 10 together as one number and avoids the problems of using the number multiplied by 10^x. If your calculator does not have an *EXP* or $x10^x$ button, check the user manual. It may be that it is just labelled differently on your calculator. Alternatively, remember to always use brackets to keep the terms in the denominator together, as shown above.

Practice questions

1 What is 3.4×10^{-4} divided by 1.7×10^{-3}?
A 2×10^{-7}
B 2
C 20
D 0.2

2 Substitute $m = 1.4$, $d = 3.9$ and $c = 2.7$ into $W = 6m - 4(d + c)$ and solve for W.
A –4.5
B –18
C 34.8
D 26.7

12. Understanding the relationship between data, graphs and algebraic rules

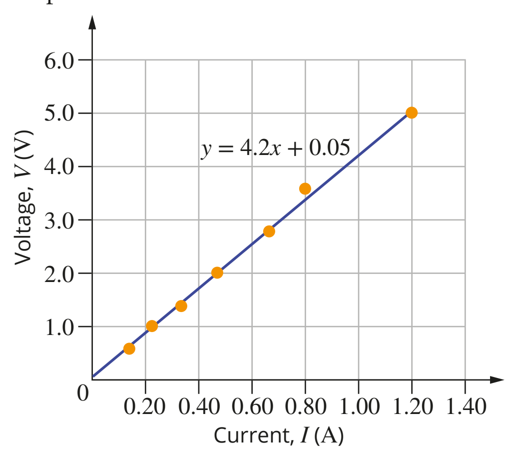
Scientists use graphs to analyse the data they collect from experiments. All graphs tell a story. The shape of the graph shows the relationship between the variables, and this relationship can be written algebraically and numerically. The horizontal axis is known as the x-axis and the vertical axis is known as the y-axis.

Once the algebraic rule is known, the values for one variable can be substituted and the values for the other variable can be calculated. These values can also be determined by reading them from the graph.

For example, when investigating how current and voltage vary across a light bulb, the following data was collected:

Current, *I* (A)	Voltage, *V* (V)
0.14	0.6
0.22	1.0
0.33	1.4
0.47	2.0
0.66	2.8
0.80	3.6
1.20	5.0

Graphing this data produced:



Page Proofs

The numerical values from the experiment are listed in the table and plotted on the graph. The algebraic relationship between the variables is given by the equation of the line:

$$y = 4.2x + 0.05$$

The value of the y-intercept is approximately zero, so assuming that the y-intercept is zero, and labelling the x-axis as current and the y-axis as voltage, the relationship can be written as:

$$y = 4.2 \times \text{current}$$

Using the appropriate symbols this can also be written as: $V = 4.2I$

Practice questions

1 If a graph had L on the y-axis and B on the x-axis and the equation of the straight line was $y = 3.7x$, what is the algebraic form of the graph?
  A $L = 3.7x$
  B $y = 3.7x$
  C $y = 3.7B$
  D $L = 3.7B$
2 If a relationship was written as $m = 5.9L$, what shape would the graph be and which variable would be plotted on which axis?
  A The graph would be non-linear, with m on the y-axis and L on the x-axis.
  B The graph would be non-linear, with m on the x-axis and L on the y-axis.
  C The graph would be linear, with m on the y-axis and L on the x-axis.
  D The graph would be linear, with m on the x-axis and L on the y-axis.

13. Recognising and using ratios

A ratio is the relationship between two numbers of the same kind. It could be the quantities in a recipe, the division of profits from a sale, or the number of different types of the same thing.

Scientists use ratios to compare quantities. This might be the numbers of atoms of different elements in a compound, or the number of primary and secondary windings of a transformer.

You can also use the principle of ratios to solve problems. For example, if 1 reaction produces 2.5 MeV of energy, then how much energy does 34 reactions produce?

The reaction-to-energy ratio of 1:2.5 should remain constant as the number of reactions increases. So you need to find the factor that 1 needs to be multiplied by to give 34:

$$1 \times 34 = 34$$

You then multiply the energy amount by the same factor:

$$2.5 \times 34 = 85\,\text{MeV}$$

You may also see ratios expressed as fractions.

Practice questions

1 If the primary coil of a transformer has 2400 windings and the secondary coil has 600 windings, what is the simplest ratio of primary to secondary windings?
  A 2400:600
  B 24:6
  C 12:3
  D 4:1

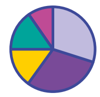
Page Proofs

14. Understanding pie charts, frequency graphs, and histograms

It is essential in science to collect data and arrange it in an orderly way. Tables are often used to organise data, which can then be displayed in a graph.

Pie charts

A pie chart is a circle that is divided into sectors. Each sector represents one item in the data set and is shown as a percentage or fraction of the total data set.



Frequency graphs and histograms

Frequency graphs and histograms are another way of representing data visually.

If data is discrete (i.e. can be counted), each column in a column graph will represent one category, e.g. ‘apples’ or ‘strawberries’. Often these columns have a gap between them.

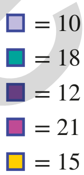
If the data is continuous (i.e. can be measured), such as the heights of the students in that class, each column will represent a range of possible heights, e.g. 140 to 160 cm, and there will be no gaps between the columns. These are called histograms.

Practice questions

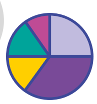
1 Choose the pie chart that correctly shows the data from Emmanuel’s poll of soccer fans.

Number of matches watched	10	12	15	18	21
Relative frequency (%)	25	35	15	15	10

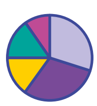
Matches watched:



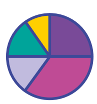
A



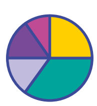
B



C

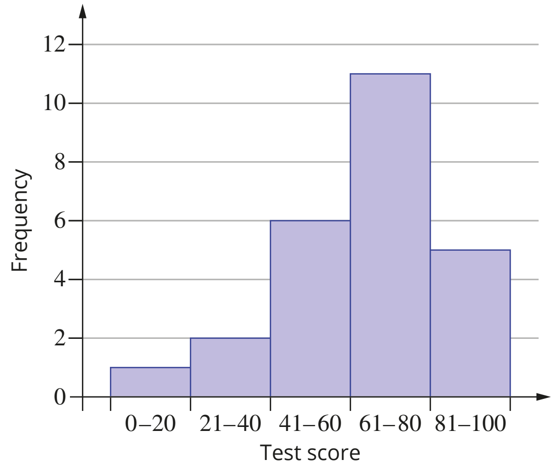


D



Page Proofs

2 A class of Year 11 Chemistry students had a test. A histogram of their test scores is shown below.



a How many students scored over 80?
b How many students scored below 40?
c How many student are in this class?

15. Using units in an equation to check for dimensional consistency

Scientists know that each term in an equation represents a quantity. The units used to measure that quantity are not used in the calculations. Units are only indicated on the final line of the solved equation.

For example, this is the equation for the area (A) of a rectangle of length (L) and width (W):

$$A = L \times W$$

If L has a value of 7 m and W has a value of 4 m, it is written:

$$\begin{aligned} A &= L \times W \\ &= 7 \times 4 \\ &= 28\,\text{m}^2 \end{aligned}$$

Note that the units are left out of the actual calculation on the second line and only included at the end, after the numerical answer.

You can use units to check the dimensional consistency of the answer. In the example above, the two quantities of L (length) and W (width) both have to be expressed in consistent units, in this case metres (m), to give an answer that is expressed in square metres ($\text{m} \times \text{m} = \text{m}^2$).

If you had made a mistake, and used the formula $A = L + W$ instead, the answer would be expressed in metres only. This is not the correct unit to express area, so you would know that was wrong.

Practice questions

1 Which formula has the correct dimensions for calculating volume in m^3?
A m × m
B m × s
C m × m × s
D m × m × m

Page Proofs

2 Which of these shows the correct substitution into $p = 2L + 2W$ using consistent units for $L = 3.5$ cm and $W = 240$ cm?
A $P = 2 \times 3.5 + 2 \times 240$
B $P = 2 \times 3.5 + 2 \times 24$
C $P = 2 \times 35 + 2 \times 240$
D $P = 2 \times 3.5 + 2 \times 2.4$

3 By using the equation $p = mv$ as a guide, select the correct units in which to measure momentum, p.
A m s
B m s^{-1}
C kg m s^{-1}
D kg m s^{-2}

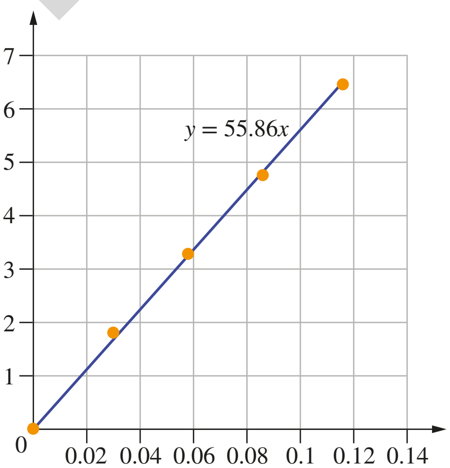
16. Understanding lines of best fit

When scientists observe that the points on a graph seem to form a straight line, then a line of best fit (or trendline) can be drawn through them. Computer programs such as Excel can fit a trendline to a data set; lines of best fit can also be drawn by hand onto a printed or drawn graph.

The line of best fit should pass as close as possible to as many of the points as possible (i.e. it should 'fit' the data closely). It may not pass exactly through any of the points, but once the line of best fit is drawn, the points should be spaced equally on each side, above and below the line. There should be no points very far away from the line, unless they are considered to be unreliable. Unreliable points are called 'outliers' and can be disregarded for the purposes of creating a line of best fit.

The gradient and y-intercept of the line (not the points) can be determined to find the relationship between the variables using the general equation for a straight line: $y = mx + c$.

For example:



Practice questions

1 Are the following statements true or false?
a All the points on a scatter plot must lie on the line of best fit.
b The line of best fit may pass through none of the points.
c The points of the scatter plot should lie close to the line of best fit.

2 Are the following statements true or false?
a A trendline is the same as a line of best fit.
b A line of best fit can only be drawn using a computer program such as Excel.
c Outliers should be included as normal points when considering where to draw a line of best fit.

Page proofs

Appendix F Maths Skills

1. Transforming decimal notation to scientific notation

1

0.002	2×10^{-3}
2000	2×10^{3}
0.1234	1.234×10^{-1}
12.34	1.234×10^{1}
123.4	1.234×10^{2}

0.002: Move the decimal point 3 places to the right which gives an index of –3, so 0.002 is written as 2×10^{-3}.
2000: Move the decimal point 3 places to the left which gives an index of +3, so 2000 is written as 2×10^{3}.
0.1234: Move the decimal point 1 place to the right which gives an index of –1, so 0.1234 is written as 1.234×10^{-1}.
12.34: Move the decimal point 1 place to the left which gives an index of +1, so 12.34 is written as 1.234×10^{1}.
123.4: Move the decimal point 2 places to the left which gives an index of +2, so 123.4 is written as 1.234×10^{2}.

2 The –4 index shows the decimal point has been moved 4 places to the right. Move it back 4 places to the left to give 0.000 700 9.

2. Identifying significant figures

1 B 0.000 40

2 A 1.66
When two numbers are multiplied, use the smallest number of significant figures in the initial values to give your answer. In George's multiplication, the answer is 1.66408, but as 1.22 has 3 significant figures, the correct answer is 1.66.

3 C 41.00
The zeroes to the right of the decimal point are significant. When writing an answer to a correct number of significant figures, you may need to use rounding if the initial answer has more figures (digits) than you need. These extra figures are called 'non-significant figures.' If the first non-significant figure is ≥5, you round up. If the first non-significant figure is <5, then do not round up. For example, if the initial answer for a calculation was 2.1259 but you only needed an answer to 3 significant figures, you would round it to 2.13. If the initial answer was 2.1241, then to 3 significant figures this becomes 2.12.

4 **a** B 78.2
When 65.3 is added to 12.92, the answer is 78.22, but only if it is assumed that 65.3 is actually 65.30. When adding or subtracting with significant figures, use the smallest number of significant figures provided in the initial values. As there is no way of knowing the accuracy of beyond 65.3, the answer should only be given to 3 significant figures, which is 1 decimal place, 78.2.

b When multiplying or dividing, use the smallest number of significant figures in the initial values to give your answer.

$$F_{net} = ma$$
$$= 78.2 \times 1.250$$
$$= 97.8$$

Since the mass value only has 3 significant figures, the answer should also only have 3 significant figures. Therefore, even though the calculated answer is 97.75, the answer to 3 significant figures is $97.8\,\text{m}\,\text{s}^{-1}$.

3. Calculating percentages

1 C 75%

$$\frac{9}{12} = \frac{x}{100}$$
$$x = \frac{9}{12} \times 100$$
$$= 75\%$$

2 B 6

$$x = \frac{25}{100} \times 24$$
$$= 0.25 \times 24$$
$$= 6$$

3 C 12.5%

$$\frac{15}{120} = \frac{x}{100}$$
$$x = \frac{15}{120} \times 100$$
$$= 12.5\%$$

4. Converting between percentages and fractions

1 B 20%
To write a fraction as a percentage, multiply the fraction by 100.

$$\frac{1}{5} = 0.2 \times 100$$
$$= 20\%$$

2

0.2%	$\frac{1}{500}$
2.5%	$\frac{1}{40}$
17.5%	$\frac{7}{40}$
35%	$\frac{7}{20}$
44.4%	$\frac{111}{250}$

To change a percentage to a fraction, divide by 100.

$$0.2\% = \frac{0.2}{100} = \frac{2}{1000} = \frac{1}{500}$$
$$2.5\% = \frac{2.5}{100} = \frac{25}{1000} = \frac{1}{40}$$
$$17.5\% = \frac{17.5}{100} = \frac{175}{1000} = \frac{35}{200} = \frac{7}{40}$$
$$35\% = \frac{35}{100} = \frac{7}{20}$$
$$44.4\% = \frac{44.4}{100} = \frac{444}{1000} = \frac{222}{500} = \frac{111}{250}$$

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5. Changing the subject of an equation

1 C

$R = \frac{3A}{2}$

Multiply both sides of the equation by 3

$3A = 3 \times \frac{2}{3}R$

$= 2R$

Divide both sides of the equation by 2

$\frac{3A}{2} = R$

Rewrite the equation so it reads

$R = \frac{3A}{2}$

2 $p = \frac{y^2 q}{9}$

Divide both sides of the equation by 3

$\frac{y}{3} = \sqrt{\frac{p}{q}}$

Square both sides

$\left(\frac{y}{3}\right)^2 = \frac{p}{q}$

Expand the brackets on the left

$\frac{y^2}{9} = \frac{p}{q}$

Multiply both sides by q

$\frac{y^2 q}{9} = p$

Rewrite the equation so it reads

$p = \frac{y^2 q}{9}$

6. Interpreting the slope of a linear graph

1 A. The steepness of the slope indicates the rate of change. A line with a steeper slope indicates a faster rate of change.

2 C. The gradient or slope of a linear graph indicates the rate of change.

7. Understanding mathematical symbols

1 A <. One way is to remember that the smaller end of the shape points toward the smaller number. For example, 3 < 6 means 3 is less than 6.

2 D ≤. The symbols <, >, ≤ and ≥ are all inequalities.

8. Understanding the difference between discrete and continuous data

1 B the temperature of the air over a 24-hour period.
If the data can be counted, the data set is discrete. If the data can be measured, the data set is continuous. The temperature of the air can be measured with a thermometer, so the data set is continuous.

2 A the number of cars parked in a street.
If the data can be counted, the data set is discrete. If the data can be measured, the data set is continuous. The number of cars parked in a street can be counted, so the data set is discrete.

9. Calculating the mean, median and range of a data set

1 **a** 44 + 17 + 21 + 26 + 42 + 18 = 168

$\frac{168}{6} = 28$

b Place the numbers in ascending order: 17, 18, 21, 26, 42, 44
As there is an even number of values, add the two middle values and divide by 2

$\frac{21+26}{2} = 23.5$

c 44 – 17 = 27

2 **a** $\frac{1340}{25} = 53.6$ kg

b 55 kg

c 67 – 39 = 28 kg

10. Solving simple algebraic equations

1 D $V = 27$
Substitute the values and solve the equation.
$V = 3 \times 9$
$= 27$

2 B $Q = 25\,200$
Substitute the values and solve the equation.
$Q = 0.2 \times 4200 \times 30$
$= 25\,200$

11. Completing calculations with more than one operation

1 D 0.2
The correct calculation, using brackets, is:

$\frac{3.4 \times 10^{-4}}{(1.7 \times 10^{-3})} = 0.2$

2 B –18
$W = 6 \times 1.4 - 4 \times (3.9 + 2.7)$
$= 6 \times 1.4 - 4 \times 6.6$
$= 8.4 - 26.4$
$= -18$

12. Understanding the relationship between data, graphs and algebraic rules

1 D. $L = 3.7B$
Substituting L for y and B for x gives $L = 3.7B$.

2 C. The graph would be linear, with m on the y-axis and L on the x-axis.
The graph would be linear as the equation is written in the form $y = mx + 0$ with m on the y-axis and L on the x-axis.

13. Recognising and using ratios

1 D 4:1
The primary to secondary ratio is 2400:600. Dividing both sides of the ratio by 600 simplifies it to 4:1.

14. Understanding pie charts, frequency graphs, and histograms

1 A

The largest sector of the pie chart is purple, representing the percentage of people who watched 12 matches (35%). The next in size is blue (10 matches, 25%), then green (18 matches, 15%) and yellow (15 matches, 15%). The smallest sector is red (21 matches, 10%).

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2 **a** 5
b 3
c 25
The height of the 81–100 column is 5. This shows 5 students scored over 80.
The heights of the 0–20 and 21–40 columns are 1 and 2. This shows that 3 students scored below 40.
If you add up the heights of all the columns (1 + 2 + 6 + 11 + 5 = 25), it tells you that there are 25 students in the class.

15. Using units in an equation to check for dimensional consistency

1 D m × m × m
2 D $P = 2 \times 3.5 + 2 \times 2.4$
Both units must be consistent.
Since 100 cm = 1 m the consistent units must be either
L = 3.5 m and W = 240 cm
or
L = 350 cm and W = 240 cm
The only correct combination is $P = 2 \times 3.5 + 2 \times 2.4$.

3 C kg m s^{-1}
The unit for momentum is taken from the unit for mass (kg) multiplied by the unit for velocity (m s^{-1}). Therefore, momentum is measured in kg m s^{-1}.

16. Understanding lines of best fit

1 **a** False.
b True.
c True.
2 **a** True.
b False.
c False.

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Glossary

A

accumulator A secondary, or rechargeable, electrochemical cell.

acid A substance capable of donating a hydrogen ion (proton) (Brønsted-Lowry theory).

acid–base reaction A reaction in which one substance, an acid, donates a hydrogen ion (proton) to another substance, a base.

acid rain Rainwater that has reacted with acidic emissions from industry and vehicles and has a pH less than 5.5.

acidic salt A salt that dissociates in aqueous solution and one of its ions donates a proton to water, producing hydronium ions.

acidic proton A proton that is donated to a base during an acid–base reaction.

acidic solution An aqueous solution in which the concentration of hydronium ions (H_3O^+) is greater than the concentration of hydroxide ions (OH^-). At 25°C, the pH of an acidic solution is less than 7.

acidification The decrease in pH that is occurring due to the absorption of carbon dioxide from the atmosphere.

acidity constant The equilibrium constant (K_a) for the ionisation/dissociation of an acid in aqueous solution. Also know as the acid dissociation constant.

activation energy The minimum energy required by reactants for a reaction to occur; symbol E_a. This energy is needed to break the bonds between atoms in the reactants to allow products to form.

active site The location on an enzyme's structure at which a reaction is catalysed. It is usually a hollow or a cavity in the protein structure, where the enzyme binds and interacts with the substrate.

actual yield The mass of product actually obtained during a chemical reaction. This will be less than or equal to the theoretical yield.

addition polymer A polymer that is formed by an addition reaction, where many monomers bond together by rearrangement of C=C double bonds without the loss of any atom or molecule. An addition polymer is made from unsaturated monomers.

addition polymerisation The process of forming a polymer by an addition reaction, where many monomers bond together by rearrangement of C=C double bonds without the loss of any atom or molecule.

addition reaction A reaction in which a molecule bonds to an unsaturated hydrocarbon, forming a single carbon–carbon bond. In this process, two reactant moleculesform a single product.

alcohol A homologous series of organic molecules that contains the hydroxyl (–OH) functional group.

aldehyde A homologous series of organic molecules which contains the carbonyl functional group, C=O, bonded to a hydrogen on one end of the molecule. Aldehydes can be recognised by the presence of a –CHO group at one end of a compound's condensed structural formula.

aliquot A fixed volume of liquid measured by a pipette.

alkali A substance capable of accepting a hydrogen ion (proton) (Brønsted-Lowry theory).

alkaline cell A commercial electrochemical cell with an alkaline electrolyte that is a moist paste rather than a solution.

alkane A saturated hydrocarbon that contains only single bonds; alkanes have a general formula of C_nH_{2n+2}.

alkene An unsaturated hydrocarbon containing one or more carbon–carbon double bonds. Alkenes with one double bond have the general formula C_nH_{2n}.

alkyl group A group obtained by removing a hydrogen atom from an alkane, with a general formula C_nH_{2n+1}; for example, methyl ($-CH_3$). Alkyl groups can be present as branches in organic compounds.

alloy A substance formed when other materials (e.g. carbon, other metals) are mixed with a metal.

α-amino acid A type of organic molecule that contains an amino group and a carboxylic acid group where the amino group is bonded to the carbon atom (the α-carbon atom) that is attached to the carboxyl group.

α-helix One type of secondary structure found in proteins. It has a spiral shape and it is maintained by hydrogen bonding between amino acid units in the chain

amphiprotic The ability to act as an acid (proton donor) and also as a base (proton acceptor).

amide A compound containing the $-CONH_2$ functional group.

amide functional group A functional group found in the homologous series of amides consisting of an amine group attached to a carbonyl group $-CONH_2$.

amine A homologous series of organic molecules that contains the amino ($-NH_2$) functional group.

amino acid The monomer molecule used to make proteins. Amino acids contains an amino ($-NH_2$) group and a carboxyl (–COOH) functional group.

amorphous region A region in a polymer in which molecules are tangled in a random arrangement.

anion A negatively charged ion, e.g. a chloride ion, Cl^-.

anioinic detergent A synthetic detergent where the active component is a negatively charged ion.

anode An electrode at which an oxidation reaction occurs.

atom economy A method of tracking the atoms in a reaction equation to calculate the mass of the atoms of reactants actually used to form products as a percentage of the total mass of the reactants. Atom economy can be calculated from the formula:

atom economy

$$= \frac{\text{molar mass of desired product}}{\text{molar mass of all products}} \times 100$$

average titre The average of concordant titres.

B

back titration A technique used when a sample containing an acid or base is unable to be analysed by direct titration. A known amount of base or acid is added in excess to the original sample. The amount of the original sample is calculated by using a titration to determine how much of the added chemical remains unreacted.

base A substance capable of accepting a hydrogen ion (proton).

base hydrolysis A hydroloysis reaction catalysed by a strong base, e.g. sodium hydroxide.

basic salt A salt that dissociates in aqueous solution and one of its ions accepts a proton to water producing hydroxide ions.

basic solution An aqueous solution in which $[H_3O^+] < [OH^-]$. For a basic solution at 25°C, pH > 7.

battery A combination of cells connected in series.

β-pleated sheet One of the two types of secondary structure found in proteins. It consists of polypeptide strands bonded laterally. The parallel groups of a polypeptide chain are twisted back on themselves, forming a pleated sheet. It is maintained by hydrogen bonding.

biodegradable Capable of being decomposed by bacteria or other living organisms.

biodiesel A fuel derived from vegetable oil or animal fat, consisting of long-chain alkyl esters. Biodiesel is typically made by reacting triglycerides with an alcohol.

bioethanol A fuel that can be produced from crops or other organic material. Examples of biofuels are ethanol from the fermentation of sugars, methane from animals, and biogas produced from plant and animal waste materials.

biofuel A fuel that can be produced from crops or other organic material. Examples of biofuels are ethanol from fermentation of sugars, methane from animals, and biogas produced from plant and animal waste materials.

biogas A mixture of gases produced by the breakdown of organic matter in the absence of oxygen.

bromothymol blue A widely used indicator. The indicator is yellow in acidic solutions and blue in basic solutions. In a neutral solution of pH 7, the colour of the indicator is green, midway between yellow and blue.

Brønsted–Lowry theory A theory that defines an acid as a proton (hydrogen ion) donor and a base as a proton acceptor. In the reaction $HCl(g) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$, HCl is the proton donor and is classified as an acid. H_2O is a proton acceptor and is classified as a base.

buffer capacity A measure of the effectiveness of a buffer solution to resist a change in pH when either a strong acid or strong base is added.

buffer solution A solution that resists change to pH when small quantities of an acid or a base are added. Buffers are composed of a weak acid and its conjugate weak base, or a weak base and its conjugate weak acid.

burette Glassware used for volumetric analysis to transfer a variable volume of solution accurately.

C

C-terminal The end of a protein or polypeptide with a free carboxyl group (–COOH).

calcification The precipitation of dissolved ions as calcium carbonate in the form of shells, corals and structures in marine organisms. Once they are formed, such structures are vulnerable to dissolution if concentrations of ions in the water change. High acidity levels limit the formation of corals and shells.

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carbon cycle The series of processes by which carbon compounds are interconverted in the environment, chiefly involving the incorporation of carbon dioxide into living tissue by photosynthesis and its return to the atmosphere through respiration, the decay of dead organisms, and the burning of fossil fuels.

carbon neutral A process that absorbs the same amount of carbon as it generates. The carbon dioxide absorbed from the atmosphere by a carbon neutral process compensates for the carbon dioxide produced by the process.

carbonyl functional group A functional group that consists of a carbon atom double bonded to an oxygen atom, –CO–. This group is present in aldehydes, ketones, carboxylic acids, amides and esters.

carboxyl functional group A functional group that consists of a hydroxyl group attached to the carbon of a carbonyl group, –COOH. This group is present in carboxylic acids.

carboxylate A salt of a carboxylic acid. Carboxylates contain the charged group $–COO^–$.

carboxylic acid A homologous series of organic molecules that contain the carboxyl functional group (–COOH).

catalyst A substance that increases the rate of a reaction but is not consumed in the reaction. The catalyst provides an alternative reaction pathway with a lower activation energy.

cathode An electrode at which a reduction reaction occurs.

cathodic protection Use of a low-voltage power supply to ensure that a reduction reaction occurs at a metal surface to prevent corrosion.

cation A positively charged ion.

chain isomer An isomer of an organic molecule caused by branching of the hydrocarbon chain.

closed system A system in which matter does not enter from or escape into the surroundings.

***cis* isomer** An isomer in which the highest priority groups attached to the carbons of a double bond are on the same side of the double bond plane.

***cis–trans* isomers** Isomers that occur when two different groups are attached to each carbon in a carbon-carbon double bond. They occur because there is restricted rotation around the carbon–carbon double bond.

climate change A change in global or regional climate patterns, in particular a change apparent from the mid to late 20th century onwards and attributed largely to the increased levels of atmospheric carbon dioxide produced by the use of fossil fuels.

collision theory A theoretical model that accounts for the rates of chemical reactions in terms of collisions between particles occurring during a chemical reaction.

combustion A rapid reaction with oxygen accompanied by the release of large amounts of energy.

concentrated solution A solution that has a relatively high ratio of solute to solvent.

concentration A measure of how much solute is dissolved in a specified volume of solution.

concentration fraction The ratio of concentrations of products to reactants in a reversible reaction, as expressed in the equilibrium law. It can also be called the reaction quotient.

concordant titres A set of titres that vary within a narrow range, ideally within 0.10 mL from highest to lowest of one another.

condensation polymer A polymer formed by a condensation reaction, involving the elimination of a small molecule (often water) when monomers bond together. For this to occur the monomers have functional groups at both ends of the molecule.

condensation polymerisation Formation of a polymer by condensation reactions.

condensation reaction A reaction in which two molecules link together by eliminating a small molecule, such as water.

condensed formula A simple representation of the structural formula of an organic molecule. A condensed structural formula shows the atoms connected to each carbon atom, but not all the bonds, e.g. $CH_3CH_2CH_3$.

conjugate acid The conjugate acid of a base contains one more hydrogen ion (proton) than the base, e.g. HCl is the conjugate acid of $Cl^–$.

conjugate acid–base pair An acid and its conjugate base. The conjugate base contains one less hydrogen ion (proton) than the acid.

conjugate base The conjugate base of an acid contains one less hydrogen ion (proton) than the acid, e.g. $Cl^–$ is the conjugate base of HCl.

conjugate redox pair An oxidising agent and the product that is formed when the oxidising agent gains electrons. e.g. Cu^{2+}/Cu are a conjugate redox pair. Alternatively, it may be considered as a reducing agent and the product that is formed when the reducing agent loses electrons. e.g. $Cl^–/Cl_2$ are a conjugate redox pair.

contact process The process used for the industrial production of sulfuric acid.

copolymer A polymer that is made from two or more monomers.

cross-link A covalent bond between different chains of atoms in a polymer or other complex molecule.

crude oil A mixture of hydrocarbons that originates from the remains of prehistoric marine micro-organisms. The organisms have been broken down by high temperatures and pressures over millions of years.

crystalline region A region where polymer molecules line up parallel to each other and pack closely together.

D

decalcification The removal or loss of calcium or calcium compounds.

denaturation The change of the secondary or tertiary structure of proteins, often caused by heat or a change in the pH of the surroundings.

detergent A synthetic compound that acts as a surfactant, used for cleaning.

dilution The addition of a solvent to a solution to reduce its concentration.

dilution factor The ratio of the final volume to the aliquot volume.

dimer A chemical structure formed from two similar sub units; for example, paired carboxylic acids that form hydrogen bonds with each other.

dipeptide An organic molecule that has been produced by the condensation reaction between two amino acids.

diprotic acid An acid that can ionise in water to form two H_3O^+ ions.

direct corrosion Direct reaction with oxygen in the air to form a metal oxide, e.g. the reaction of magnesium with oxygen is written as $Mg(s) + O_2(g) \rightarrow 2MgO(s)$.

dispersion force A very weak force of attraction between molecules due to temporary dipoles induced in the molecules. The temporary dipoles are the result of random fluctuations in the electron density.

displace The transfer of electrons from an element to a positive ion which results in the ion leaving the solution as an element, e.g. when zinc is placed in a solution of copper(II) ions the displacement reaction is $Cu^{2+}(aq) + Zn(s) \rightarrow Zn^{2+}(aq) + Cu(s)$.

dry corrosion See *direct corrosion.*

dynamic equilibrium A point in a chemical reaction when the rate of the forward reaction is equal to the rate of the reverse reaction.

E

E number A code number used to identify food additives.

ecosystem A biological community of interacting organisms and their physical environment.

elastomer A rubbery material composed of long molecules that is capable of recovering its original shape after being stretched.

electrochemical cell A device that converts chemical energy into electrical energy (galvanic cells), or vice versa (electrolytic cells).

electrochemical series A list of half-equations, written as reduction reactions, arranged in order of reduction potentials, so that the strongest oxidising agents are on the top left side of the list.

electrode A solid conductor in a half-cell at which oxidation or reduction reactions occur.

electrolysis A process that causes a non-spontaneous redox reaction to occur by the passage of electrical energy from a power supply through a conducting liquid.

electrolyte A chemical substance that conducts an electric current as a result of dissociation into positively and negatively charged ions. In electrochemical cells, these ions migrate toward the negative and positive electrodes.

electrolytic cell A cell in which electrolysis can occur.

electromotive force The 'electrical pressure' between two points in a circuit, such as the electrodes of an electrochemical cell; defined as the energy given to electrons in a circuit. Measured in volts.

electronegative A measure of the ability of an atom of an element to attract electrons from within a covalent bond.

electroplating A process that uses electrolysis to deposit a layer of metal on the surface of another material.

elemental analysis A process that determines the mass of each element in a sample of a compound.

empirical formula A formula that shows the simplest whole number ratio of the elements in a compound, e.g. CH_2 is the empirical formula of propene (C_3H_6).

end point A point in a titration at which the indicator changes colour, usually marking the completion of the reaction.

endothermic A reaction that absorbs energy from the surroundings; ΔH is positive.

energy profile diagram A diagram that shows the energy changes during the course of a reaction.

enhanced greenhouse effect An increase in the temperature of Earth's surface due to an increased concentration of greenhouse gases, as a result of human activities.

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enzyme A protein molecule that functions as a catalyst of a specific biochemical reaction. A catalyst increases the rate of a reaction.

enzyme activity The amount of substrate converted to products per unit time by an enzyme. It represents the ability of the enzyme molecules to catalyse the reaction.

enzyme–substrate complex The intermediate molecule that forms when a substrate molecule interacts with the active site of an enzyme, during the catalysis of a chemical reaction.

equilibrium When a chemical reaction reaches equilibrium, the quantities of reactants and products in the reaction remain unchanged. The rates of the forward and reverse reactions are equal.

equilibrium constant The value of the concentration fraction when equilibrium is reached; symbol K_c. The equilibrium constant for the chemical equation:

$$aW + bX \rightleftharpoons cY + dZ$$

is given by the expression:

$$K_c = \frac{[Y]^c[Z]^d}{[W]^a[X]^b}$$

equilibrium law The equilibrium law for the chemical equation:

$$aW + bX \rightleftharpoons cY + dZ$$

is given by the expression:

$$K_c = \frac{[Y]^c[Z]^d}{[W]^a[X]^b}$$

where K_c is a constant at a particular temperature.

equilibrium yield The amount of product obtained when a chemical reaction reaches equilibrium.

equivalence point The point during a titration when the reactants in solution are present in stoichiometric proportions, i.e. in the mole ratio shown by the reaction equation.

essential amino acid An amino acid that must be included in the diet as it cannot be synthesised in the human body.

ester The name of the homologous series of molecules that contain the ester (–COO–) functional group.

ester functional group The functional group that is the result of the reaction between an alcohol and a carboxylic acid. It consists of a carbonyl group bonded to an oxygen atom bonded to another carbon atom, –COO–.

ester link Another name for the ester functional group, often used in the context of the polyesters, a type of condensation polymer.

esterification reaction The chemical reaction between an alcohol and a carboxylic acid to form an ester as the organic product.

exothermic An exothermic reaction releases energy to the surroundings; ΔH is negative.

extent of reaction The relative amounts of products compared with reactants. The extent of a reaction is indicated by the value of the equilibrium constant.

external circuit The section of an electrochemical cell in which electrons move. This section of the circuit will include the wires attached to the electrodes.

F

fatty acid A carboxylic acid that has a relatively long hydrocarbon chain.

fatty acid ester A carboxylic acid with a long hydrocarbon tail, usually containing 12–20 carbon atoms, derived from the reaction of an alcohol with a triglyceride.

fermentation The breakdown of sugar solutions, by the action of enzymes in yeasts, into ethanol and carbon dioxide. The chemical equation for the fermentation of glucose is:

$$C_6H_{12}O_2(aq) \rightarrow 2CH_3CH_2OH(aq) + 2CO_2(g)$$

fossil fuel A fuel that that has been produced over a long time by the breakdown of organic material. This process can take many thousands of years. Examples are coal, crude oil and natural gas.

fractional distillation The separation of the components in a mixture on the basis of their boiling temperatures.

fuel cell A type of electrochemical cell in which the reactants are supplied continuously, allowing continuous production of electrical energy.

functional group An atom or group of atoms in an organic molecule that largely determines the molecule's properties and reactions.

G

galvanic cell A type of electrochemical cell also known as a voltaic cell; a device that converts chemical energy into electrical energy.

galvanometer An instrument for detecting electric current.

geometric isomer A type of stereoisomer that can occur when there is restricted rotation in a molecule. Restricted rotation can occur about a carbon–carbon double bond or a ring. Stereoisomers of alkenes can be distinguished using the labels *cis*- and *trans*-.

global warming A gradual increase in the overall temperature of the Earth's atmosphere generally attributed to the greenhouse effect caused by increased levels of carbon dioxide, chlorofluorocarbons, and other pollutants.

green chemistry The design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances.

greenhouse effect The process by which heat radiation from Earth's surface is absorbed and re-radiated by gases in the atmosphere. The greenhouse effect maintains the temperature of Earth at conditions suitable for life.

greenhouse gas A gas that is able to absorb and re-radiate heat radiation. These gases contribute to the greenhouse effect. Examples are carbon dioxide, methane and water vapour.

H

Haber process The process for the industrial production of ammonia gas.

half-cell Half an electrochemical cell, which contains the oxidant and conjugate reductant. When two half-cells are combined, a galvanic cell is formed.

half-equation A balanced chemical equation which shows the loss or gain of electrons by a species during oxidation or reduction. For example, the oxidation of magnesium is written as the half-equation $Mg(s) \rightarrow Mg^{2+} + 2e^-$.

halogen displacement reaction A redox reaction where an elemental halogen is reduced to its ions by a reaction with ions of another halogen.

hard water Water that requires a lot of soap to obtain a lather or froth.

heterogeneous reaction A chemical reaction in which at least two of the species are in different state or phase.

high density polyethene (HDPE) A form of the polymer polyethene that is formed from polymer chains with very few, short branches. This means the polymer chains are packed together closely, making the polymer dense. HDPE can have a percentage crystallinity as high as 95% and has excellent mechanical properties. HDPE is used to make pipes, buckets and food containers, such as milk bottles.

homogeneous reaction A chemical reaction in which all the species are in the same state or phase.

homologous series A series of organic compounds in which each member of the group differs from the previous member by a $-CH_2$ unit. Examples are alkanes, alkenes and alcohols.

hydration reaction A reaction that involves water as a reactant.

hydrocarbon A compound that contains carbon and hydrogen only. Examples include alkanes and alkenes.

hydrogen economy A proposed system of delivering energy for society using hydrogen as the source of energy.

hydrogen halide Diatomic molecules consisting of a hydrogen atom and a halogen atom joined by a covalent bond. HF, HCl, HBr and HI are hydrogen halides.

hydrogenation reaction The reaction of an organic compound with hydrogen so that it becomes more saturated.

hydrolysis A reaction involving the breaking of a bond in a molecule using water as a reactant. Two smaller molecules are usually formed.

hydrolysis reaction A reaction that occurs when a molecule or ion in aqueous solution reacts with water either accepting or donating a proton.

hydrolytic reaction A reaction involving the breaking of a bond in a molecule using water as a reactant. Two smaller molecules are usually formed.

hydronium ion The $H_3O^+(aq)$ ion.

hydrophilic Describes molecules, or parts of a molecules, that form relatively strong intermolecular attractions with water molecules.

hydrophobic Describes molecules, or parts of a molecules, that tend to repel water. Hydrophobic substances are usually non-polar.

hydroxyl functional group A functional group that consists of an oxygen atom covalently bonded to a hydrogen atom, –OH. This functional group is present in alcohols.

I

immiscible Describes a liquid that will not mix with or dissolve in another liquid; for example, oil in water.

indicator A chemical that has a different colour in acidic and basic solutions and is used to distinguish between acids and bases. Indicators are also used to determine the pH of a solution.

indicator range The range of pH values over which an indicator changes colour.

induced fit model A mechanism of the action of an enzyme where the active site on the enzyme to changes shape in response to the presence of the (reacting) substrate molecule.

inert A substance that is unreactive, such as platinum or graphite used in electrodes.

inert electrode An electrode that is not consumed in the reaction that occurs at the electrode. The electrode serves only as a conductor of electrons. Precious metals and carbon (in the form of graphite) are typically used as inert electrodes.

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inorganic Of a compound that consists of elements other than carbon. Although certain compounds of carbon, such as carbon dioxide and carbonates, are also classified as inorganic.

internal circuit The part of an electrochemical cell in which ions move, e.g. solutions and salt bridge.

ion–dipole force The intermolecular attraction between a polar molecule (or polar section of a molecuke) and a positive or negative ion.

ionic product of water See *ionisation constant of water*.

ionisation either (i) The removal of one or more electrons from an atom or ion;
or (ii) the reaction of a molecular substance with a solvent to form ions in solution.

ionisation constant of water The equilibrium constant K_w, where $K_w = [H_3O^+][OH^-]$. At 25°C, $K_w = 1.00 \times 10^{-14}$.

ionise The reaction of a molecular substance with a solvent to form ions in solution. When some polar molecules dissolve in water they ionise to form a hydronium ion, e.g.
$HCl(g) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$.

irreversible reaction A reaction in which significant reaction can occur in one direction only.

isomers Molecules that have the same molecular formula but a different arrangement of atoms.

IUPAC nomenclature A set of rules for naming organic molecules. It is usually systematic and gives the number of carbon atoms and the location and type of functional groups present. (IUPAC = International Union of Pure and Applied Chemists)

K

ketone A homologous series of organic molecules that contains the carbonyl functional group (C=O) within the carbon chain.

kinetic energy The energy that a particle or body has due to its motion $\left(KE = \frac{1}{2}mv^2\right)$

kinetic energy distribution diagram A graph of kinetic energy against number of particles that shows the range of energies in a sample of a gas or a liquid at a given temperature. Also known as a Maxwell–Boltzmann distribution curve.

L

Le Châtelier's principle If an equilibrium system is subjected to a change, the system will adjust itself to partially oppose the effect of the change.

lead–acid battery A secondary cell or accumulator used to start most cars.

limiting reagent A reagent that is completely consumed in a reaction and which determines the amount of product.

lipid A class of organic compounds that includes fats, oils, waxes and steroids. They are insoluble in water but soluble in non-polar solvents.

lithium-ion cell A galvanic cell that generates electricity from the oxidation of lithium embedded in the lattice structure of a graphite rod and the reduction of a metal oxide. The reduction product combines with the lithium ions.

lock-and-key model A mechanism for the action of enzmes where Only molecules with the correct shape and size can 'fit' into the enzyme.

low density polyethene (LDPE) A form of the polymer polyethene which has a high degree of short and long chain branching. This means the polymer chains do not pack together closely in the crystal structure. It has therefore weaker intermolecular forces resulting in a lower tensile strength and increased ductility.

M

macroscopic property A property that can be seen by the naked eye. A property such as concentration, pressure, temperature and pH.

main group metal A metal in groups 1–3 such as lithium, sodium, potassium, magnesium, calcium, barium and aluminium.

Maxwell–Boltzmann distribution curve A graph of kinetic energy against number of particles that shows the range of energies in a sample of a gas or a liquid at a given temperature. Also known as a kinetic energy distribution diagram.

metal displacement reaction A reaction in which a metal causes the ions of another metal in solution to gain electrons and so precipitate out as the solid metal. The metal to be displaced must be less reactive (higher on the electrochemical series) than the metal that is added, e.g. Zn metal will displace Cu from a solution of Cu^{2+} ions.

methyl orange A synthetic indicator often used in the analysis of weak bases. It is also used as a textile dye.

micelle A group of molecules e.g lipids, in an aqueous solution, that arrange into clusters with the hydrophobic chains on the inside and the hydrophilic (polar) sections on the outside.

miscible Describes a liquid that will mix with or dissolve in another liquid; for example, ethanol and water.

molar concentration The concentration of a solution expressed as moles of solute per litre of solultion (mol L^{-1})

molecular formula A formula that gives the actual number and type of atoms present in a molecule.

monomer A small molecule that is able to react to form long chains of repeating units, called polymers.

monoprotic acid An acid that can donate only one hydrogen ion.

monounsaturated fatty acid A fatty acid that contains one carbon-carbon double bond.

N

N-terminal The end of a protein or polypeptide with a free amine group ($-NH_2$).

neutral salt A salt that dissociates in aqueous solution and its ions are neither proton donors or proton acceptors.

nickel–metal hydride cell A rechargeable cell that generates an electric current by the oxidation of nickel metal hydride and the reduction of NiOOH.

non-rechargeable cell A primary galvanic cell.

non-renewable Non-renewable energy resources are those that are being used at a faster rate than they can be replaced.

non-spontaneous reaction A reaction that would not normally occur without the application of electrical energy. They are the reverse of spontaneous reactions, which produce energy.

O

ocean acidity The reduction in the pH of the ocean caused mainly by absorption of atmospheric carbon dioxide.

open system A system that allows matter and energy to be exchanged with the surroundings.

optimum pH The pH at which enzyme activity is greatest.

optimum temperature The temperature at which enzyme activity is greatest.

organic molecule An molecule that is based on a hydrocarbon skeleton. Organic molecules also commonly contain other non-metal elements, such as oxygen, nitrogen, sulfur and chlorine.

oxidant A chemical species (element, compound or ion) that accepts one or more electrons in an oxidation–reduction reaction. An oxidant causes another substance to be oxidised, and in the process the oxidant is reduced. An oxidant is also called an oxidising agent.

oxidation The process by which a chemical species, such as a metal atom or a non-metal ion, loses electrons. An oxidation half-equation will show the electrons as products (on the right-hand side of the arrow). Oxidation is said to have occurred when there is an increase in an element's oxidation number during the reaction.

oxidation number A number assigned to an atom in a compound or as the free element, which represents the charge that atom would have if it was an ion. A series of oxidation number rules are used to determine the oxidation number of an element in a compound. Oxidation numbers are used to identify redox reactions.

oxidised The loss of electrons or an increase in oxidation number. When a substance is oxidised, the electrons are written on the right-hand side of the arrow in the half-equation.

oxidising agent A reactant that causes another reactant to lose electrons during a redox reaction. This reactant is, itself, reduced and gains electrons. The oxidation number of the oxidising agent decreases during the reaction. For example, in the reaction between magnesium and oxygen, the oxygen is the oxidising agent, as it causes magnesium to lose electrons and form Mg^{2+}.

P

parallax error The perceived shift in an object's position as it is viewed from different angles.

partial pressure The pressure exerted by one component of a mixture of gases. The total pressure of a mixture of gases is equal to the sum of the individual partial pressures of each component in the mixture.

peptide bond The bond between the carbon and nitrogen atoms in the amide group along a protein chain. This bond joins the amino acids in a polypeptide chain.

peptide link or peptide group The –CONH– functional group between amino acid units in a polypeptide chain; also called amide link.

percentage composition The proportion by mass of the different elements in a compound. % by mass of an element in a compound
$= \frac{\text{mass of the element present}}{\text{total mass of the compound}} \times 100$

percentage yield A measure of the quantity of a product obtained from a chemical process compared to the maximum amount possible if the reaction were complete, expressed as a percentage:

$$\text{percentage yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times \frac{100}{1}$$

petrodiesel The most common form of diesel fuel. It is produced from crude oil by fractional distillation. The composition of petrodiesel varies, but is generally around 75% alkanes and 25% aromatic hydrocarbons. The alkanes range from $C_{10}H_{22}$ to $C_{15}H_{32}$.

pH curve A plot showing change in pH when an acid is titrated against a base. See also titration curve.

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pH scale A measure of acidity and the concentration of hydronium ions, in solution. Acidic solutions have a pH value less than 7 at 25°C and bases have a pH value greater than 7 (at 25°C). Mathematically, pH is defined as $pH = -\log_{10}[H_3O^+]$.

phenolphthalein A synthetic indicator used in the analysis of weak acids.

photosynthesis The chemical process by which oxygen and glucose are produced in plant cells in the presence of light. It can be represented by the equation:

$6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_2(aq) + 6O_2(g)$

pipette Glassware used for volumetric analysis to transfer a fixed volume of solution accurately.

plastic A property of a material that can be reshaped by application of heat and pressure. In society, polymers are often referred to as plastics.

plasticiser Small molecules that soften a plastic by weakening intermolecular attractions between polymer chains.

polar Bonds or molecules with a permanent dipole. They have an uneven distribution of charge.

polyamide A condensation polymer consisting of monomers joined by amide linkages.

polyester A condensation polymer consisting of monomers joined by ester linkages.

polymer A natural or synthetic compound of high molar mass consisting of up to millions of repeated linked units known as monomers. There are many different types of polymers.

polymerisation The process of synthesising a polymer.

polypeptide An organic polymer molecule made from a condensation reaction between amino acids.

polyprotic acid An acid that can donate more than one hydrogen ion per molecule.

polyunsaturated fatty acid A fatty acid that contains more than one carbon–carbon double bond.

position of equilibrium The relative amounts of reactants and products at equilibrium. The position of equilibrium varies depending on the extent of the reaction.

positional isomers Isomers that arise from a functional group being in different locations on the carbon chain.

potential difference The electromotive force (measured as a voltage) between two points in a circuit, such as the electrodes of an electrochemical cell.

precise When repeated measurements of the same quantity give values that are in close agreement.

pressure The force exerted per unit area of a surface.

primary alcohol An alcohol in which the carbon that is bonded to the –OH group is only attached to one alkyl group.

primary amine An amine in which the nitrogen atom is bonded to one carbon and two hydrogen atoms.

primary cell A galvanic cell that is non-rechargeable because the products of the reaction migrate away from the electrodes.

primary standard A substance used to make a standard solution. It is so pure that its amount, in moles, can be accurately determined from its mass.

primary structure The sequence (number, order and type) of amino acids in a polypeptide chain.

protein An organic polymer molecule made from amino acids by condensation polymerisation. Proteins typically contain 50 or more amino acid units.

Protein Data Bank An online database containing structural information about proteins.

Q

quantitative analysis The determination of the quantities of particular components present in a substance.

quaternary structure The highest level of organisation in protein structure. Proteins have a quaternary structure if they are composed of two or more polypeptide chains.

R

random error An error that follows no regular pattern where measured results can be above or below the actual value . (The effects of random errors can be reduced by taking the average of many observations.)

rate of reaction The change in concentration of a reactant or product over a period of time (usually one second):

$$\text{rate of reaction} = \frac{\text{change in concentration}}{\text{time}}$$

reaction pathway A series of chemical reactions that converts a starting material into A product in a number of steps.

reaction quotient Another name for the concentration fraction. It is the ratio of concentrations of products to reactants in a reversible reaction, as expressed in the equilibrium law.

reactive electrode An electrode that is consumed in an electrochemical cell reaction.

reactivity series A ranking of metals in increasing order of their reactivity (ability to be oxidised) with the half-equations written as reduction equations of the corresponding ion. Least reactive metals are at the top and most reactive metals are at the bottom.

rechargeable cell A type of cell in which the chemical energy can be replenished repeatedly through application of electrical energy.

redox reaction A reaction in which electron transfer occurs from the reducing agent to the oxidising agent. In a redox reaction, the oxidation number of one element will increase (be oxidised) and the oxidation number of another element will decrease (be reduced).

reduced The gain of electrons or a decrease in oxidation number. When a substance is reduced, the electrons are written on the left-hand side of the arrow (as reactants) in the half-equation.

reducing agent A reactant that causes another reactant to gain electrons during a redox reaction. This reactant is, itself, oxidised and loses electrons. For example, in the reaction between magnesium and oxygen, the magnesium is the reducing agent, as it causes oxygen to gain electrons and form O^{2-} ions:

$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$

reductant A substance that causes another substance to be reduced; in the process the reductant is oxidised. A reductant is also called a reducing agent.

reduction The process by which a chemical species gains electrons or its oxidation number decreases. A reduction half-equation will show the electrons on the reactant side (left-hand side) of the equation.

renewable Resources are considered to be renewable if they are not finite (e.g. wind power) or can be replenished (e.g. biochemical fuels) within a relatively short time span.

respiration A process in living things in which complex organic molecules are oxidised by oxygen with the release of carbon dioxide, water and energy, by which life is sustained.

reverse reaction The reaction that occurs in the opposite direction to the staed reaction.

reversible reaction A reaction in which significant reaction can occur in the reverse direction because the products are present and can react with each other under suitable conditions.

S

sacrificial anode A highly reactive metal used to prevent a less reactive material surface from corroding.

sacrificial protection Protecting a metal from corrosion by coating it with a more reactive metal that will be preferentially oxidised.

salt A substance formed from a metal or ammonium cation and an anion. Salts are the products of reactions between acids and bases, metal oxides, carbonates and reactive metals.

salt bridge An electrical connection between the two half-cells in a galvanic cell; it is usually made from a material saturated in electrolyte solution.

saponification The process in which soap is produced by heating a fat or vegetable oil with alkali.

saturated Describes hydrocarbons composed of molecules with only carbon–carbon single bonds.

saturated ester An ester in which the hydrocarbon tail contains only carbon–carbon single bonds.

saturated fatty acid A fatty acid that contains carbon–carbon single bonds.

saturated molecule An organic compound in which all the atoms are joined by single bonds.

saturated solution A solution that cannot dissolve any more solute at the given temperature.

secondary alcohol An alcohol in which the carbon bonded to the –OH group is also bonded to two alkyl groups. The alkyl groups may be the same or different.

secondary cell An accumulator or rechargeable cell. Recharging can occur because the products formed in the cell during discharge remain in contact with the electrodes in a convertible form.

secondary structure Initial level of spatial arrangement of a polypeptide chain. There are two forms of secondary structure: α-helices and β-pleated sheets.

self-ionisation An ionisation reaction of pure water in which water behaves as both an acid and a base.

semistructural formula A condensed formula that summarises the structural formula of a compound in a single line of text.

side chain The R group in an amino acid molecule; there are 20 different side chains on the a-amino acids used to make human proteins.

smelting The process where a metal ore is heated in order to separate the desirable components from the other parts of the ore.

Soap A compound, normally derived from a fatty acid (long chain carboxylic acid) that acts as a surfactant, which used for cleaning or washing.

solute A substance that dissolves in a solvent, e.g. sugar is the solute when it dissolves in water.

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solution A homogeneous mixture of a solute dissolved in a solvent.

spontaneous reaction A reaction that occurs naturally, either in electrochemical cells or when chemicals are mixed directly. The reaction does not need to be driven by an external source of energy.

standard conditions Established reference conditions to compare testing of experimental activities. Conditions at which gas pressure is 100 kPa, the concentrations of dissolved species are 1.0 mol L^{-1} and the temperature is 25°C (298 K).

standard electrode potential The electromotive force that is measured when a half-cell, at standard conditions (gas pressures 100 kPa, solution concentrations of 1.0 mol L^{-1} and temperature of 25°C), is connected to a standard hydrogen half-cell; symbol $E°$. Gives a numerical measure of the tendency of a half-cell reaction to occur as a reduction reaction.

standard hydrogen half-cell A $H^+(aq)/H_2(g)$ half-cell; made from a platinum electrode placed in acid solution with hydrogen gas bubbled over it. The pressure of the gas is 1 bar, the H^+ concentration is 1 mol L^{-1} and the temperature is 25°C.

standard reduction potential A numerical measure of the tendency of a half-cell reaction to occur as a reduction reaction. It is measured by connecting a half-cell, at standard conditions (gas pressures 1 bar, solution concentrations of 1.0 mol L^{-1} and temperature of 25°C), to a standard hydrogen half-cell.

standard solution A solution of accurately known concentration.

stem name The name of a molecule derived from the number of carbon atoms in the longest continuous carbon chain in a hydrocarbon and the highest priority functional group present. For example, the stem name of 2-chlorobutane is butane.

strong acid A acid that readily accepts a hydrogen ion (proton) from an acid. A strong acid will completely ionise in water to produce H_3O^+ ions.

strong base A base that readily accepts a hydrogen ion (proton) from an acid. If the base is soluble, it will completely dissociate in water to produce OH– ions.

structural formula A formula that represents the three-dimensional arrangement of atoms in a molecule.

structural isomers Isomers are molecules that have the same molecular formulas but their atoms are bonded together in different ways.

substitution reaction A reaction that involves the replacement of an atom or group of atoms with another atom or group of atoms.

substrate A reactant in a reaction that is catalysed by an enzyme.

super acid An acid that has acidity greater than the acidity of 100% sulfuric acid.

surface area The area of all surfaces of the substance that are exposed to the other reactants. This is proportional to the amount of particles available at the surface to react.

surfactant A substance that causes non-polar and polar substances to mix due to the presence of hydrophilic and hydrophobic sections on molecules of the substance.

surroundings The environmment around a particular chemical reaction. The chemical reaction is the system. Energy moves between the system and surroundings in exothermic and endothermic reactions.

sustainable Able to support energy and resources into the future without depletion.

synthesis A process that results in the making of a new substance.

system In chemistry, a system is a chemical reaction. A system operates within its surroundings. Energy can move between the two. You always consider energy as being absorbed or released from the perspective of the system. For example, energy is absorbed into the system from the surroundings, or energy is released by the system to the surroundings.

systematic error An error that produces a constant bias in measurement – results are either always above, or always below the actual value. (Systematic errors are eliminated or minimised through calibration of apparatus and the careful design of a procedure.)

T

temperature A measure of the average kinetic energy of the particles in a substance expressed in units (degrees) based on a standard scale.

tertiary alcohol An alcohol in which the carbon bonded to the –OH group is also bonded to three alkyl groups.

tertiary structure The overall three-dimensional shape of a polypeptide chain.

tetrahedral In the shape of a tetrahedron, where four points at equal distances are spread as far apart as possible in three dimensions.

theoretical yield The mass of product that would be formed if the limiting reagent reacted fully. The mass that is expected for a particular product in a chemical reaction, based on the mass of limiting reactant used.

thermoplastic A thermoplastic polymer will soften and melt when heated, allowing it to be remoulded or recycled. When heated sufficiently, the intermolecular bonds break, allowing the molecules to become free to move and be remoulded.

thermosetting When a thermosetting polymer is heated, it does not melt, but at high temperatures, covalent bonds are broken and it decomposes or burns. It cannot be moulded into a different shape.

titration The process used to determine the concentration of a reactant where one solution is added from a burette to a known volume of another solution.

titration curve A graph obtained from a titration of pH against volume of reactant added from a burette. See also pH curve.

titre A variable volume of liquid measured in a burette by subtracting the final burette reading of a titration from the initial burette reading.

***trans* isomer** An isomer in which the highest priority groups attached to the carbons of a double bond are on opposite sides of the double bond plane.

transesterification A process in which triglyceride reacts with an alcohol to form esters.

transition element An element, such as iron, copper, nickel or chromium, that is found in the middle block of the periodic table, in groups 3–12.

transition state An arrangement of atoms in a reaction that occurs when sufficient energy is absorbed for the activation energy to be reached. It represents the stage of maximum potential energy in the reaction. Bond breaking and bond forming are both occurring at this stage, and the arrangement of atoms is unstable.

triglyceride An ester derived from a glycerol molecule and three fatty acids.

tripeptide An organic molecule made from three amino acid units linked by peptide bonds.

triprotic acid An acid molecule that generates three hydronium ions when ionised in water.

U

uncertainty An error associated with measurements made during experimental work.

universal indicator A widely used indicator for estimating the pH of a solution. It is a mixture of several indicators and changes through a range of colours, from red through yellow, green and blue, to violet as the pH increases.

unsaturated Describes hydrocarbons composed of molecules containing one or more carbon–carbon double (or triple) bonds.

V

valence shell electron pair repulsion (VSEPR) theory A model in chemistry used to predict the shape of molecules based on electrostatic repulsion between electron pairs.

volt The unit of potential difference.

voltaic cell A type of electrochemical cell that is also known as a galvanic cell; a device that converts chemical energy into electrical energy.

voltmeter An instrument for measuring electrical potential difference between two points in a circuit.

volumetric analysis Quantitative analysis using measurement of solution volumes, usually involving titration.

volumetric flask A laboratory flask calibrated to contain a precise volume.

W

weak acid An acid that is partly ionised in water.

weak base A base that accepts hydrogen ions (protons) from acids to a limited extent.

wet corrosion The corrosion of iron in the presence of oxygen and water. It takes place in stages; the final product is hydrated iron(III) oxide ($Fe_2O_3.xH_2O$), known as rust.

Z

zwitterion A dipolar ion formed when the amino and carboxyl groups in an amino acid or polypeptide are both charged.

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