14 Practical investigation

14.1 Overview
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14.1.1 Introduction
Performing practical investigations and writing clear and concise reports are essential skills in Chemistry. As part of Unit 4 in VCE Chemistry, you will conduct a practical investigation related to energy and food. Energy is vital for life and the way in which this is gained from food is vital for our survival. Conducting investigations allows questions to be investigated and answered, and conclusions to be drawn and. In this topic, you will find guidelines for carrying out practical tasks safely and preparing thorough reports and scientific posters using appropriate scientific conventions. You will learn how to develop a question, plan a methodology and present, analyse and evaluate data obtained using appropriate chemical terminology.

14.1.2 What you will learn

**KEY KNOWLEDGE**
In this topic, you will investigate:
- independent, dependent and controlled variables
- chemical concepts specific to the investigation and their significance, including definitions of key terms, and chemical representations
- the characteristics of scientific research methodologies and techniques of primary qualitative and quantitative data collection relevant to the selected investigation: volumetric analysis, instrumental analysis, calorimetry and/or construction of electrochemical cells; precision, accuracy, reliability and validity of data; and minimisation of experimental bias
- ethics of and concerns with research including identification and application of relevant health and safety guidelines
14.2 Key science skills in chemistry

KEY SCIENCE SKILLS
- Develop aims and questions, formulate hypotheses and make predictions
- Plan and undertake investigations
- Conduct investigations to collect and record data

KEY CONCEPTS
- Independent, dependent and controlled variables
- Chemical concepts specific to the investigation and their significance

14.2.1 The scientific method — why do we conduct investigations?

In Unit 4, you will be required to conduct an investigation to explore the links between energy and food. This will require you to present methodologies, evaluate results and draw conclusions in your logbook and present this as a scientific poster. You will be conducting a practical investigation that uses laboratory or fieldwork to respond to a question. A practical investigation involves considerable planning, expertise in working scientifically and time to be appropriately conducted. Figure 14.2 summarises this process of practical investigations and scientific method.
This investigation will draw upon a number of the key skills and key knowledge that you gained in Units 1 and 2 and have been developing in Units 3 and 4. You will have the opportunity to show your skill and imagination in experimental design, commitment to a task and your communication ability in explaining your results. You will need to develop a question, plan actions to answer this question, undertake an investigation and interpret the data to form a conclusion.

This Unit 4 Outcome 3 task requires four to six hours of class time, allowing time to both conduct the investigation and communicate your findings. Table 14.1 will assist with your planning. The timeline may be different depending on your school. Your teacher may also have set checkpoints regarding when you are required to submit work and what specific components need to be included.

<table>
<thead>
<tr>
<th>TABLE 14.1 Investigation planning with sample schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Task</strong></td>
</tr>
<tr>
<td>Introduction of task and expectations by teacher</td>
</tr>
<tr>
<td>• Brainstorm topics around the idea of energy and food</td>
</tr>
<tr>
<td>• Construct a choice of topics of investigation for your teacher</td>
</tr>
<tr>
<td>• You return your list of possible topics for approval by your teacher, who then provides feedback, recommendations and final approval.</td>
</tr>
<tr>
<td>• Submission of your detailed research proposal for your approved topic</td>
</tr>
<tr>
<td>• Submit your completed and signed risk assessment (this also must be signed by your teacher)</td>
</tr>
<tr>
<td>• Your requested equipment is assembled by the teacher and lab technician.</td>
</tr>
<tr>
<td>Your investigation begins.</td>
</tr>
<tr>
<td>• Set up equipment</td>
</tr>
<tr>
<td>• Collect preliminary data</td>
</tr>
<tr>
<td>• Troubleshoot any issues with equipment</td>
</tr>
<tr>
<td>• Collect data and measurements, graph your results and evaluate trends</td>
</tr>
<tr>
<td>• Adjust and refine method</td>
</tr>
<tr>
<td>• Continue the cycle of measurements and data analysis, leading to a review of progress and further more detailed measurements.</td>
</tr>
<tr>
<td>• Finalise writing the sections of your report and paste them into a poster template. Submit your logbook and finished poster.</td>
</tr>
</tbody>
</table>
14.2.2 Using a logbook

As part of your scientific investigation (as well as all practical experiments throughout the year), it is a requirement to keep a logbook. Usually this logbook is a bound exercise book, but your teacher may request a digital logbook instead. It is vital to show all aspects of your practical investigation within your logbook using the scientific approach.

Your logbook will be assessed by your teacher. You must date all work that is completed in your logbook to show when it was completed and assist in validating your work.

**TABLE 14.2** Components of a logbook

<table>
<thead>
<tr>
<th>Component</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chosen question and title</td>
<td>Information about your topic and how you chose it, and the question you have selected from this</td>
</tr>
<tr>
<td>Introductory material</td>
<td>Background data on your topic, diagrams, notes and tables, information about key terms and past experiments that were similar to that which you are conducting</td>
</tr>
<tr>
<td>Hypothesis and aim</td>
<td>A clear hypothesis and aim should be recorded outlining what you are investigating and why, and what you believe will happen.</td>
</tr>
<tr>
<td>Planning a method</td>
<td>Show all equipment you plan to use and a clear method you plan to follow, with detailed steps that could be reproducible by someone else</td>
</tr>
<tr>
<td>Experimental results</td>
<td>Observe and record results in an appropriate form — tables are particularly useful for this</td>
</tr>
<tr>
<td>Discussing and analysing results</td>
<td>Refer to your results and carefully evaluate these, referring back to your hypothesis and questions. You may have set discussion questions to answer to help scaffold your thoughts and ideas.</td>
</tr>
<tr>
<td>Thoughts and questions</td>
<td>Note down any concerns or questions you have about your investigation and research the answer to this.</td>
</tr>
<tr>
<td>Conclusion</td>
<td>Relates to the aim and hypothesis, and summarises the findings of the investigation</td>
</tr>
</tbody>
</table>

**FIGURE 14.4** All observations should be recorded in a logbook.
14.2.3 Variables

Independent, dependent and controlled variables

In an experiment, a variable is any factor that the researcher can control or change or measure. Three kinds of variables are commonly recognised (see figure 14.10). For some variables you will set the value at the start of each experiment, others will be determined by your experiment, and sometimes there will be variables that you calculate using your measurements.

- An **independent variable** is a factor that is deliberately manipulated by the investigator and affects the dependent variable. For example, you may be comparing the different energy content of various brands of cereal. The independent variable is the type of cereal.

  When graphing results, the independent variable is always placed on the horizontal axis.

- A **dependent variable** is the factor that the investigator measures. The dependent variable is affected by the independent variable. In the cereal brand investigation, the dependent variable would be the energy content.

  The dependent variable is always placed on the vertical axis of a graph.

- **Controlled variables** are all the other factors that the investigator must maintain at constant values through the course of an experiment. If these factors are not kept constant, they can confound the experimental results because they can cause changes in the dependent variable. In the cereal brand investigation, controlled variables would include the amount of each cereal used, the storage of the cereal and the instrument used to record data. Controlled variables should also include environmental factors such as humidity and air temperature, but these are harder to control.

  In summary:
  - the independent variable is what an investigator changes
  - the dependent variable is what an investigator observes and measures
  - controlled variables are what the investigator keeps constant.

The following is an example for identifying variables.

Allira and Hunter are investigating the use of different combinations of metals for the anodes and cathodes in constructing galvanic cells. They plan to measure and record the cell voltage.

**FIGURE 14.6** A galvanic cell

![Galvanic cell diagram](image-url)
• **Independent variable:** The factor that is being manipulated is *the metals used in the galvanic cell*
• **Dependent variable:** The factor that is being measured is the *cell voltage*
• **Controlled variables:** The factors that are kept consistent are the same amount of solution in beakers, same type of salt bridge, same voltmeter used for all setups, same size beakers, and same laboratory conditions

Variables can also be classified as numerical (quantitative) or categorical (qualitative). Refer to section 14.4.2 for further detail on this.

### 14.2.4 Developing aims and questions

#### Coming up with a topic

Choosing a topic is not an immediate process — it takes time and careful consideration. It is important you don’t just pick a topic that sounds interesting, but that you pick one that is reasonable to complete in the provided time frame and using the available resources.

The topic of your investigation needs to be around food and energy, so review the work you completed in Units 3 and 4 to help brainstorm ideas.

You may wish to create a mind map or a diagram outlining the various types of food and different ways that you measure each of these. Research the time this will take and what other research you could conduct. Plan what types of food you might investigate — figure 14.7 might give you some ideas. This will help you get your head around the different topics and what requirements there would be.

Some examples of topics may be:
- Comparing the energy values between different types of oils
- Checking the accuracy of nutritional information on different brands of chips
- Exploring how differences in pH affect the enzymatic breakdown of starch by amylase

#### Creating a question

Turning the topic into a question focuses your mind on what you want to find out. The question needs to be:
- one that can be investigated through scientific method
- practicable, given your knowledge, time and the school resources
- asked in a way that indicates what you will do.

The following is an example of formulating a question from a topic:

**Topic:** Comparing the energy found in carbohydrates and fats.

**Question:** Do fruits high in fats and oils such as avocados have more energy than fruits high in carbohydrates such as oranges?

OR
**Question:** How does the energy content differ between fats and carbohydrates when examined using solution calorimeter?

There are many ways of formulating a question from a topic. Just make sure it is something that can be measured, explored and answered in the scope of your practical investigation.

**Developing an aim**

Often, developing an aim of an investigation is done at the same time as formulating a question from your topic. The aim outlines the purpose or the key objective of the investigation. It outlines what you are trying to achieve in order to answer your question and either support or not support your hypothesis.

There are two different ways that you can format your aim.

1. To [determine/investigate/compare] how the **dependent variable** is affected by the **independent variable**
2. To [determine/investigate/compare] how the **independent variable** affects the **dependent variable**

Your aim must:

- Be no more than two lines
- Be linked to your question
- Link the independent and dependent variables.

Examples of aims include:

- To use solution calorimetry to find the enthalpy change of different concentrations of sugar solutions.
- To investigate what variety of bread has the highest energy content per gram.
- To compare the energy content of peanuts and baked beans.
- To observe if changing the temperature of amylase affects the rate of starch breakdown.
- To explore if different types of oil have the same energy content.

**14.2.5 Formulating hypotheses and making predictions**

Formulating a **hypothesis** is an important step in the scientific method.

**FIGURE 14.8 A hypothesis is a testable explanation for a concept.**

A hypothesis is a tentative, testable and falsifiable statement for an observed phenomenon, which predicts the relationship between two variables or predicts the outcome of an investigation.

**Testable** means that a hypothesis can be easily tested by observations and/or experiments.

**Falsifiable** means that there has to be a way to be prove the hypothesis wrong.
A hypothesis usually predicts the relationship between two kinds of variables: an independent and a dependent variable.

To write a hypothesis, a good tip is to use the following format:

\[ \text{If [statement involving independent variable], then [prediction involving dependent variable].} \]

Typically, a scientific hypothesis starts with the tentative explanation and includes a prediction by which the hypothesis can be tested.

### TABLE 14.3 Example of a good working hypothesis

<table>
<thead>
<tr>
<th>IF</th>
<th>THEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>IF a straw is used to blow bubbles of carbon dioxide into a glass of water</td>
<td>THEN the pH will increase due to the production of carbonic acid.</td>
</tr>
<tr>
<td>IF the number of double bonds decreases the melting temperature of a molecule</td>
<td>THEN unsaturated fats such as linoleic acid will have a lower melting point than saturated fats such as palmitic acid.</td>
</tr>
</tbody>
</table>

Now consider the following statements and decide if each is an example of a well-formatted hypothesis:

- **Statement 1:** ‘Small ice cubes melt faster.’
  - No. This is simply a testable prediction. It does not include a tentative explanation.

- **Statement 2:** ‘If an ice cube has a smaller volume, then it will melt faster when left at room temperature.’
  - No. This does not identify a tentative explanation. The statement shows a method and a predicted outcome.

- **Statement 3:** ‘If an ice cube has a smaller volume, particles will gain energy at an increased rate, causing it to melt faster at room temperature compared to an ice cube with a larger volume.’
  - Yes. This identifies a tentative hypothesis (explanation) and a predicted outcome by which the hypothesis can be tested.

### Resources

- **Interactivity** Formatting a hypothesis (int-XXXX)
SAMPLE PROBLEM 1

Polly is putting the kettle on. Polly is very curious about science and wants to see how she can change the speed the water boils. She has heard rumours that salt causes water to boil faster. She has four different types of salts in her house—table salt, sea salt, Himalayan pink salt and chicken salt.

Write an appropriate research question, aim and hypothesis for the scenario listed above:

THINK

1. Determine the variables to help write an aim, hypothesis and research question
   - The factor that Polly is manipulating (the independent variable) is the type of salt.
   - The factor that Polly is measuring (the dependent variable) is the time it takes for the water to boil.

2. Create a research question based on Polly’s problem.
   - Make sure that the question is one that is testable and clear outlines what is occurring in the investigation.

3. Write an aim—clearly outlining the purpose of the investigation. Be sure to link the IV and DV.

4. Write a hypothesis in the “IF...THEN” format.
   - Remember, a hypothesis needs to link the IV and DV—your hypothesis may not be correct, but it must be testable (you may also specify which salt you think would do this best).

WRITE

The IV is the salt type
The DV is the time it takes for the water to boil

Does the type of salt added to water impact the time it takes for water to boil?

To determine if different types of salts impact the time it takes for water to boil.

If table salt, sea salt, Himalayan salt or chicken salt is added to water, then the time taken for the water to boil will decrease with pure table salt causing the largest decrease in time.

PRACTICE PROBLEM 1

Jack wants to know if changing the material of the clothing that Jill is wearing will impact the speed in which she rolls down the hill.

Write an appropriate research question, aim and hypothesis for the scenario listed above.

14.2.6 Planning and undertaking experiments

Planning experiments

Once your teacher has approved your topic, and you have written a question, aim and hypothesis, the real work begins. One way that planning may begin is through the use of a practical proposal. At the end of your planning, you should be able to produce three written documents. These should be in your logbook and include the following.

- A risk analysis based on the hazards that you have identified (refer to section 14.6.2 for detail on risk assessments).
- A detailed list of equipment required, along with quantities (refer to section 14.5.3 for detail about different equipment used in chemistry).
- An explicit, step-by-step method that takes all of your planning into consideration, including diagrams if relevant. Setting this up as a Practical Investigation proposal as seen in figure 14.11 may be useful.
**FIGURE 14.11** A practical investigation proposal

<table>
<thead>
<tr>
<th>Practical investigation proposal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name:</strong></td>
</tr>
<tr>
<td><strong>Partner’s name:</strong> (optional)</td>
</tr>
<tr>
<td><strong>Title of your investigation</strong></td>
</tr>
<tr>
<td><strong>Briefly describe its purpose:</strong> (A brief sentence, but needs to be precise)</td>
</tr>
</tbody>
</table>
| **Write down three starting questions you want to answer.** (These are to help focus your planning.) | 1. Is there an optimal temperature for copper sulfate solubility in water?  
2. Is copper sulfate soluble at all temperatures?  
3. What is the solubility of copper sulfate at room temperature? |
| **List your independent variable as well as dependent variables.** (Enables your teacher to see if you have thought of all the obvious variables.) | Independent: Temperature of the water  
Dependent: Solubility of copper sulfate, mass of copper sulfate able to dissolve, colour of solution |
| **List the Chemistry concepts and relationships that you expect to use in your investigation.** (To give your teacher an indication of the extent of your understanding of the topic) | Solubility is the extent to which a solute dissolves in a solvent. All sulfates are soluble in water except those formed with silver, lead, calcium, strontium and barium. In water, copper sulfate dissociates as follows: $\text{CuSO}_4 (s) \rightarrow \text{Cu}^{2+} (aq) + \text{SO}_4^{2-} (aq)$  
The solubility of copper sulfate is known to be 20.5 g per 100 g of water at 20 °C |
| **List the equipment and measuring instruments that you plan to use.** (For your teacher to see whether you have the right tools for the task.) | • Copper sulfate solid  
• Watch glass  
• Spatula and stirring rod  
• Scales  
• Bunsen burner, heatproof mat, gauze mat and tripod  
• Thermometer  
• 200 mL beaker  
• Deionised water |
| **Sketch your experimental set up.** (This will make your first day of investigating smoother, and your teacher may be able to suggest refinements.) | [Diagram of experimental setup] |
| **List the steps in your experimental design.** (This is an important stage in your planning and it will enable your teacher to see if there is anything you have forgotten.) | 1. Fill the beaker with 100 mL of water  
2. Place copper sulfate on a watch glass and weigh it  
3. Record the temperature of the room  
4. Slowly add copper sulfate into the water, mixing with a stirring rod  
5. Determine when no more copper sulfate can be dissolved and record the mass  
6. Fill another beaker with 100 mL of water and heat to 40 °C and repeat step 4 and 5.  
7. Repeat step 8 at 80 °C, 80 °C and 100 °C |
| **Any special requests** (E.g. equipment may need to be left set up between classes, or access at lunchtime or after school may be needed.) | Will need a container to dispose copper sulfate solution |
Conducting investigations

When conducting investigations, it is vital to:

- Follow all health and safety protocols
- Make sure you know how to use any chosen equipment correctly to minimise errors.
- Carefully follow your methods — if any changes are required, note these down in your logbook.
- Make sure are controlling variables outside your independent variable to keep your results accurate and precise.
- Clearly record any results obtained, along with the date. This includes any results that did not go according to plan and any results for both control and experimental groups.
- Make sure that you are carefully packing up equipment after use. If equipment is required to be set up for a few days, make sure it will be in a location where it cannot be impacted by other individuals or environmental factors.
- If time allows, repeat your experiment to improve accuracy and reliability.

14.2 EXERCISE

To answer questions online and to receive immediate feedback and sample responses for every question go to your learnON title at www.jacplus.com.au

1. Using the following topics, create a testable question that could be used for a practical investigation.
   (a) Comparing the electrolysis of different electrodes in potassium nitrate solution.
   (b) Exploring the boiling point of different hydrocarbons.
   (c) Using the specific heat capacity of water to determine the heat energy released by different fuels.

2. What is the purpose of a logbook in practical investigations?

3. Describe the difference between a dependent and an independent variable.

4. Why is it important to control variables in an investigation?

5. A student conducted an experiment to measure the effect of changing temperature on the rate of the combustion of a certain type of fuel.
   Test 1: 0.01 mol at 10 °C
   Test 2: 0.02 mol at 20 °C
   Test 3: 0.03 mol at 30 °C
   The results from each trial were then analysed to produce an overall conclusion.
   (a) State the independent and the dependent variables in this experiment.
   (b) What were the controlled variables in this experiment?
   (c) Describe any improvements you would make to the experimental method.

6. The following is an excerpt from a report describing the method for an experiment on determining the temperature change of water when burning different brands of bread.
   Five brands of bread were chosen to be examined. Three slices of bread were selected from each packet of bread and broken down into pieces that were the same size and mass. All bread was baked on the same day and kept in the same conditions before the investigation was conducted. The pieces of bread were then burnt underneath a test tube of water and the change in temperature was recorded.
   (a) What is the independent variable in this experiment?
   (b) What is the dependent variable?
   (c) State as many controlled variables as you can think of for this experiment.

7. MC Select which of the following is an acceptable hypothesis.
   A. Does cordial have a higher pH than water?
   B. If the amount of hydrogen ions is higher in cordial compared to water, then the cordial is more acidic and will be recorded at a lower pH.
   C. If cordial is more acidic, it will have a lower pH recorded.

8. Testing a scientific question by experiment involves a number of stages. These are shown by the statements below. Use the letters to put these stages into their correct order.
   A. Formulate the hypothesis.
   B. Decide on the question.
   C. Analyse the results.
   D. Communicate the results.
   E. Plan the experiment.
   F. Carry out the experiment.
9. After some preliminary reading, a student has become intrigued by the possibility that hydrocarbons with double bonds (alkenes) have lower boiling points than those with single bonds (alkanes). Therefore, she proposes the questions: Do alkanes and alkenes have different boiling points?
(a) Write a reasonable hypothesis that she could test experimentally based on this question.
(b) MC Which of the following is a characteristic of a good hypothesis?
   A. It must be proven true.
   B. It must be testable by observation or an experiment.
   C. It must be based on experiments done by other scientists.

Fully worked solutions and sample responses are available in your digital formats.

14.3 Concepts specific to investigations

KEY CONCEPT
• Apply the chemical concepts specific to the investigation and their significance, including definitions of key terms, and chemical representations

14.3.1 Concepts specific to investigations
As part of an investigation, it is vital to link key chemistry concepts that are relevant and clearly explain their significance. This shows a clear link of your understanding for an investigation, and allows others to see the connection between theory and practical applications.

Background knowledge
Concepts should be researched prior to commencing your investigation, recorded in your logbook and referenced. This background information also will form part of your introduction in your poster.

Concepts that are relevant to your investigation include:
• explanations of key formulae
• definitions of key terms
• detail about the theories being examined
• information about other practical investigations exploring similar concepts.

An example of this may be investigating the heat energy released in the combustion of a fuel. In your background information, it would be important to:
• describe the fuels you are looking at in the investigation and their chemical formulas
• discuss previous investigations and experiments conducted, by yourself and by other researchers
• describe key theoretical ideas to provide the reader with knowledge to understand the key concepts (e.g. linking to thermochemical factors)
• defining key terminology relating to the investigation
• explaining key formula (such as $\Delta H = \frac{q}{n}$), including identifying the symbols used.

14.3.2 Key terms
It is vital in practical investigations to define any key terminology. This can be done in two ways:
• within the report itself
• as part of an appendix or glossary at the end of the report.
The following excerpt shows an introduction from a scientific report written by a student. This investigation was conducted to explore different types of hydrocarbons.

*Hydrocarbons are organic compounds that are composed solely of carbon and hydrogen, used in a variety of different roles, including as fuels. Two types of hydrocarbons are being explored in this investigation: alkanes, which only contain single carbon bonds and are saturated, and alkenes, which contain one or more double bonds between carbon atoms.*

This student has clearly defined key terms as part of their introduction within their report itself. What terms have they defined?

Read the following excerpt of an introduction from a scientific report written by a different student, investigating the same practical.

*In this investigation, different types of hydrocarbons are being compared, with a particular focus on their use as fuels. Two groups of hydrocarbons are being investigated: alkanes and alkenes.*

In this situation, the student has not defined the terms in their introduction itself, but has bolded key words that later appeared in their glossary as shown below:

**Glossary of key terms:**
- **Hydrocarbons:** organic compounds that are composed solely of carbon and hydrogen
- **Alkanes:** hydrocarbons that contain only single bonds between carbon atoms
- **Alkenes:** hydrocarbons that contain one double bond between carbon atoms

Both of these formats are valid methods to define key terms. The method used depends on the format of the report or personal preference. Be sure to check which method is most suitable for the practical investigation you are conducting with your teacher.

### 14.3.3 Chemical representations

A variety of representations are used in Chemistry. They include the use of models, sketches, graphs, equations, formulae, symbols and diagrams. As well as this, there are many vital conventions into the use of numerical data, including significant figures and scientific notation. Perhaps the most common chemical representation is the use of chemical formulas. Care should be taken with capital letters and subscripts and superscripts when representing atoms and ions. For example, CO is carbon monoxide, while Co is the metal cobalt.

**Formulas that demonstrate structure**

Structures are often drawn in a skeletal form in chemistry, particularly in organic chemistry. Lines between atoms represent the number of bonds present. Sometimes we can shorten these representations even further, as shown in the benzene ring and dodecane in figure 14.15.

![Figure 14.12](image_url)

**Figure 14.12** Representations form a vital part of chemistry reporting

![Figure 14.13](image_url)

**Figure 14.13** Different representations of methane: (a) Ball-and-stick model, (b) diagram showing bond angles, (c) valence structure and (d) shape diagram
FIGURE 14.14 Some common skeletal representing various molecules

- Ethane: \(\text{H} - \text{C} - \text{C} - \text{H}\)
- Ethene: \(\text{H} - \text{C} = \text{C} - \text{H}\)
- Ethyne: \(\text{H} - \text{C} = \text{C} = \text{H}\)
- Benzene: \(\text{C} = \text{C}\) (in the center of the ring)

FIGURE 14.15 Simplified representation of different molecules. Note that the specific atoms are not shown, nor are the bonds attaching the hydrogen atoms.

(a) Benzene \(\text{C}_6\text{H}_6\)
(b) Dodecane \(\text{C}_{12}\text{H}_{26}\)

Scientific notation

Very large and very small quantities can be more conveniently expressed in scientific notation. In scientific notation, a quantity is expressed as a number between one and ten multiplied by a power of ten. In chemistry, scientific notation is generally used for numbers less than 0.01 and greater than 1000.

To write in scientific notation, follow the form \(N \times 10^a\), where \(n\) is a number between one and ten and ‘\(a\)’ is an integer (positive or negative).

When converting numbers into scientific notation the following steps should be followed:
1. Determine where the decimal point needs to go so that \(N\) is between 1 and 10.
2. Count the number of places the decimal point is moved to determine \(a\) (the power of 10 or the exponent). If the decimal point was moved to the left, \(a\) will be positive, if it was moved to the right, \(a\) will be negative.
3. Write the number in scientific notation.

The power of ten can also be used to refer to measurements. For example, the average distance between the Earth and the moon is 380,000,000 m. This is more conveniently expressed as \(3.8 \times 10^8\) m in which the decimal point was moved 8 places to the left. The radius of a lead atom in metres is 0.000000000175. This is more conveniently expressed as \(1.75 \times 10^{-10}\) m, in which the decimal point was moved 10 places to the right.

As you can see, very large numbers will have a positive exponent (\(a\)), whereas very small numbers will have a negative exponent. \(5 \times 10^{-3}\) for example, can be written out as 0.005, whereas \(5 \times 10^3\) is written out as 5000.

Quantities in scientific notation can be entered into your calculator using the EXP button or \(^\times\) button.

SAMPLE PROBLEM 2

a. The average distance between Earth and Sun is 149 600 000 kilometres. Write this in scientific notation.

b. The mass of a proton is 0.000 000 000 000 000 000 000 001 67 g. Write this in scientific notation

[Teacher-led video: SP2 (tlvd-0103)]
### THINK

**a. 1.** Determine the point a decimal needs to go in order for the number to be between 1 and 10 and remove any 0s that are not between non zero digits.

The decimal place would need to go between 1 and 4 to form 1.496

**WRITE**

$149600000$  

$10^8$

**2.** Determine the exponent by establishing the number of times the decimal place was moved

If the decimal was moved to the left to convert to scientific notation, the exponent should be positive, if the number was moved to the right, the exponent should be negative.

The decimal was moved 8 spots to the left so the exponent is 8.

**3.** Place the number in scientific notation and remove

$a. 1.$ Determine the point a decimal needs to go in order for the number to be between 1 and 10 and remove any 0s that are not between non zero digits.

The decimal place would need to go between 1 and 6 to form 1.67.

**WRITE**

$1.496 \times 10^8 \text{ km}$

$1.67$

$10^{-24}$

$1.67 \times 10^{-24} \text{ g}$

### PRACTICE PROBLEM 2

Express the following quantities in scientific notation.

**a.** The distance from the Earth to the Sun is 149 600 000 km.

**b.** The radius of a potassium atom is 0.000000028 m.

**c.** There are an estimated 900 000 000 dogs in the world.

### 14.3 EXERCISE

To answer questions online and to receive immediate feedback and sample responses for every question go to your learnON title at www.jacplus.com.au

1. Show two ways that key terms can be defined in your report, by writing a short paragraph defining the terms ‘aim’ and ‘hypothesis’.

2. Why are representations useful in scientific reporting?

3. Express the following quantities in scientific notation.

   (a) The mass of a grain of sand that is 0.000667 g.

   (b) The diameter of the nucleus of uranium is 0.000000000000015 m

   (c) The approximate number of new skin cells produced in a month is 900 000.
4. Convert each of the following numbers from scientific notation to an ordinary number (the full number).

(a) $6.524 \times 10^{-4}$
(b) $5.1234 \times 10^{2}$
(c) $1.54 \times 10^{1}$
(d) $12.01 \times 10^{-3}$
(e) $4.5 \times 10^{2}$
(f) $2.457 \times 10^{-6}$
(g) $9.024 \times 10^{-5}$

Fully worked solutions and sample responses are available in your digital formats.

14.4 Scientific research methodologies and techniques

**KEY CONCEPT**

- The characteristics of laboratory techniques of primary qualitative and quantitative data collection relevant to the investigation: volumetric analysis, instrumental analysis, calorimetry and/or construction of electrochemical cells; precision, accuracy, reliability and validity of data; and minimisation of experimental bias
- Sources of error and uncertainty

14.4.1 Characteristics of scientific research methodologies

Carefully following scientific research methodology when conducting practical investigations is important to ensure that your results are as precise, accurate, reliable and valid. This includes minimising errors and uncertainties in data in order to draw conclusions in relation to your question.

Each type of research method has its specific purposes, procedures, advantages and limitations. The researcher’s choice depends on which method is most appropriate for the specific topic of research interest and hypothesis being tested.

There are different types of scientific inquiry and research methods that can be used. These are shown in table 14.4.

<table>
<thead>
<tr>
<th>Method</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controlled experiment</td>
<td>Determining the relationship between an independent and dependent variable. All other variables are controlled. For example, testing the melting temperatures of different metals.</td>
</tr>
<tr>
<td>Single variable investigation</td>
<td>Exploring how a variable can change over time and understanding causes of the observations and how other factors impact it. For example, investigating how an element decays over time.</td>
</tr>
<tr>
<td>Identification</td>
<td>Investigating if objects or events belong to specific sets or are part of new sets. For example, understanding if a new element is a metal or non-metal.</td>
</tr>
<tr>
<td>Designing</td>
<td>Designing a device using scientific knowledge. For example, designing, constructing, testing and evaluating a device that can be used to treat and purify water.</td>
</tr>
<tr>
<td>Investigating models</td>
<td>Exploring everyday phenomena and collecting evidence to test the model. For example, devising an investigation to test the law of conservation of mass.</td>
</tr>
</tbody>
</table>
In all scientific inquiries, various processes are followed. These include:
- formulating a question and hypothesis to be tested
- controlling variables
- completing a logbook outlining the introduction, methodology, results, discussion and conclusion of an investigation
- ensuring that methods are being taken to allow for validity, accuracy, precision and reliability
- ensuring that methods are being used that reduce uncertainties and errors
- collecting data accurately in an appropriate form that best suits the question being investigated
- where possible, having a control group (not exposed to an independent variable to act as a baseline) and numerous experimental groups (exposed to the independent variable).

Control groups

Usually, if the identification of controlled variables is complex, or many are present, it can be simpler to include a control group. A scientific control is an experiment or observation that involves all variables except the independent variable. For example, a scientist may be trying to measure the absorbance of light by various concentrations of cobalt chloride solutions. The independent variable in such an investigation would be the concentration of cobalt chloride, and the dependent variable would be the absorbance reading obtained. However, there are a number of other variables that may affect the result. These include the nature of the solvent, the type of glass that the containers holding the solutions are made from, the distance the light has to travel (especially through the solution) before it is measured, the temperature of the solution and so on. A convenient way to control all these variables, and maybe even some that you aren’t aware of, is to use a control. Everything about the control, from the way it is prepared to how it is manipulated and measured in the experiment, is the same as for the test solutions containing cobalt chloride. The only difference is that there is no cobalt chloride (the controlled variable) in the control. This allows the scientist to isolate the amount of absorption in each reading that is due to the cobalt chloride alone because it is the only variable left that is responsible for any differences in absorbance readings.

Another example of control and experimental groups being used may occur in a practical investigation exploring the conductivity of different concentrations of sodium chloride (NaCl) solution.

The experimental groups would be the different concentrations of sodium chloride being tested.

The control group would be testing with pure water (0% sodium chloride), to examine the conductivity when there is no NaCl present.

14.4.2 Techniques of primary qualitative and quantitative data collection

Data is a set of facts that are collected, observed or generated. Data that you gather may come from primary sources or from secondary sources. Typically, data that you collect is raw data that must later be analysed and interpreted to produce useful information.

Primary sources of data provide direct or firsthand evidence about some phenomenon, such as a research investigation. Your completed logbook will be a primary source of data about pursuing an investigation into your research question.
Secondary sources of data are comments on, or summaries and interpretations of, primary data. Sources of secondary data include review articles in newspapers and popular science magazines in which other individuals summarise and comment on the research of others.

Qualitative and quantitative data

Qualitative data (or categorical data) is expressed in words. It is descriptive and not numerical and can be easily observed but not measured. Bar graphs or pie graphs are often used to display the frequencies of categorical variables.

There are two types of categorical data.
1. **Ordinal data** can be ordered or ranked such as ionisation energies (1\textsuperscript{st}, 2\textsuperscript{nd}, 3\textsuperscript{rd}) or opinion polls (strongly agree, agree, disagree, strongly disagree)
2. **Nominal data** cannot be organised in a logical sequence such as the types of sub-atomic particles (proton, neutron or electron) and the colour litmus paper turns when exposed to an acid or base.

Quantitative data (or numerical data) can be precisely measured and have values that are expressed in numbers. Line graphs or scatterplots are often used to display the frequencies of numerical variables.

There are two types of numerical data.
1. **Continuous data** can take any numerical value, such as the temperature of a substance or the concentration of a solution.
2. **Discrete data** can only take on set values that can be counted, such as the number of protons in an atom or the number of electron shells.

Table 14.5 shows examples of how some attributes can be expressed both qualitatively and quantitatively.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Qualitative</th>
<th>Quantitative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of pendulum</td>
<td>Long</td>
<td>52 cm</td>
</tr>
<tr>
<td>Colour</td>
<td>Green</td>
<td>520 nm</td>
</tr>
<tr>
<td>Sound</td>
<td>Loud</td>
<td>85 decibels</td>
</tr>
<tr>
<td>Speed</td>
<td>Fast</td>
<td>120 kph</td>
</tr>
<tr>
<td>Temperature</td>
<td>Hot</td>
<td>100 °C</td>
</tr>
<tr>
<td>Gravitational force</td>
<td>Strong</td>
<td>9.807 m/s\textsuperscript{2}</td>
</tr>
</tbody>
</table>

When collecting data, it is vital to consider what is most appropriate for your investigation. Normally, the best evidence is primary quantitative data, and for a majority of your investigations this is what should be collected and recorded. However, while preferred, it is sometimes not always possible to collect quantitative data. In this case qualitative data can be collected instead. Qualitative data can be quite subjective or open to interpretation (one student may say dark, another may say dark blue and a third student may say black), so it is important to make sure that the data you collect and record is clear and as detailed as possible.

In terms of primary data collection, it is important that results are carefully checked to make sure that recorded data is correct. Many people interpret measurements slightly differently, or use the wrong units, so make sure you are double checking data. All your collected data should be recorded in your logbook — note down all observations (usually in a table). You may find noting down both the qualitative and quantitative data gives the clearest detail for your investigation.
14.4.3 Choosing techniques relevant to an investigation

It is important to select techniques that will best suit your investigation. You should consider the techniques used in experiments investigating topics similar to your own, and the construction and evaluation of devices used in these experiments.

When selecting appropriate techniques, it is important to ensure the following:

- the technique can be performed in an appropriate time frame
- the technique is appropriate to your investigation and serves a purpose to answering the question and supporting or rejected your hypothesis
- the data is easily recorded, measured and interpreted, with a particular emphasis on quantitative data
- the technique can be safely performed. This is particularly important in a school where health and safety restrictions are closely regulated.
- the equipment used in the technique is available and cost effective — if it is not available in a school, can it be used with permission at other locations?
- the technique allows for the control of other variables — if there are too many factors that cannot be controlled, the technique is not a good choice for an investigation.

Selecting your measuring instruments

You should consider the most appropriate equipment to use for the purposes of your investigation. For example, if a liquid volume of 25 mL is required, what would be the most appropriate piece of equipment to measure it? If a high-precision measurement is required (i.e. a lower uncertainty), a 25.00 mL pipette would probably be used. However, if this level is not required, a measuring cylinder or even a 100 mL beaker might be more appropriate.

Your school will have a range of measuring instruments, which will vary in precision and ease of use. You won’t always need to use the most accurate instrument. A simple instrument that allows for quick measurements will be enough more often than not. Sometimes a simple stopwatch is just as good as an electronic timer, or a voltmeter may compare well to a more accurate multimeter.

Some instruments that you might consider are as follows, listed based on what they measure.

Mass

- *Beam balance*: accurate with a large range of values; can be time-consuming to measure several masses
- **Spring balance:** quick to use; covers a large range of masses; not very accurate

![Spring balance](image1.png)

- **Top-loading balance:** very accurate; very good for small masses; simple to use. With equipment set up above the balance, it can be used to measure small variations in attractive and repulsive forces such as magnetic force, electric force and surface tension. If the balance sits on a laboratory jack, force against distance can be easily measured.

![Top-loading balance](image2.png)

### pH and concentrations
- **Titrations:** determine the concentration of a solution, particularly through acid-base titrations

![Equipment used in titrations](image3.png)

- **pH meter:** Measures pH accurately, but can easily break if not maintained or stored correctly.
- **Litmus paper:** Allows for a quick visual to determine if a solution is acidic or alkaline
- **Universal indicator:** Allows for an easy visual representation to determine the approximate pH of a solution.
Time
- **Stopwatch**: simple to use; accurate down to your response time; not reliable for short time intervals
- **Electronic timer**: requires some instruction; very accurate; best suited for short time intervals; can be used with electrical contacts and photogates

Electrical
- **Meters**: includes voltmeters, ammeters, galvanometers, etc; easy to set up, but care is needed to ensure the meter is wired into the circuit correctly, otherwise the meter can be damaged; large range of values; usually analogue displays

Specialised equipment
You may also have access to some specialised equipment, which you may use in your practical investigation. These are unlikely to be available in a general school laboratory, but it is important to note that the following equipment is all highly accurate and precise. Discuss with your teacher if any of these are available for use at your school or nearby. Alternatively, you may wish to explore these as a point of discussion when discussing uncertainties and possible errors in the data and results you obtained.
- **Gas chromatograph**: a sample is injected and it measures the content of various components in a sample

- **Mass spectrometer**: an analytical instrument that determines the relative isotopic masses of the different isotopes of an element and abundance
- **Solution calorimeter**: used to find energy change occurring in aqueous solutions

- **Bomb calorimeter**: used to determine the energy change for reactions involving gases
- **Atomic absorption spectrometer**: absorption of light to measure concentrations of metal ions.
• **HPLC (high-pressure liquid chromatography):** used to measure the concentration of organic substances.

![FIGURE 14.27](image)

### 14.4.4 Precision, accuracy, reliability and validity

For your investigation, it is important to carefully consider the data you obtain and the confidence you can have in the conclusions drawn. Understanding the precision and accuracy of your data is important to ensure your findings are both reliable and valid.

#### Precision

**Precision** refers to how close multiple measurements of the same investigation are to each other. Results that are precise may not be accurate. It is often difficult to have completely precise results due to random error.

**TABLE 14.6** Two investigations by different students measuring the point in which water boils. Which student’s investigation shows more precise results?

<table>
<thead>
<tr>
<th>Investigation by student 1</th>
<th>Investigation by student 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td>Temperature (°C)</td>
</tr>
<tr>
<td>Trial 1</td>
<td>Trial 1</td>
</tr>
<tr>
<td>98.5</td>
<td>100</td>
</tr>
<tr>
<td>Trial 2</td>
<td>Trial 2</td>
</tr>
<tr>
<td>98.6</td>
<td>102</td>
</tr>
<tr>
<td>Trial 3</td>
<td>Trial 3</td>
</tr>
<tr>
<td>99</td>
<td>95</td>
</tr>
<tr>
<td>Trial 4</td>
<td>Trial 4</td>
</tr>
<tr>
<td>98</td>
<td>99</td>
</tr>
<tr>
<td>Trial 5</td>
<td>Trial 5</td>
</tr>
<tr>
<td>99.2</td>
<td>106</td>
</tr>
</tbody>
</table>

It is clear that student 1 has more precise results, as the range of their measurements is much smaller when compared to student 2.

#### Accuracy

**Accuracy** refers to how close an experimental measurement is to a known value. If an archer is accurate, their arrows hit close to the target. Consider an experimental calculation of the boiling point of water, which is known to be 100 °C. A student who obtained a experimental value of 99 °C is more accurate than a student who obtains a value of 105 °C.
In Table 14.7, student 1 has the most accurate result. However, Student 2 has the most precise results. In order to obtain the best experimental data, we want results that are both accurate and precise.

**FIGURE 14.29** Comparing precision and accuracy

![Picture of precision and accuracy comparison]

- **NOT ACCURATE, NOT PRECISE**
- **ACCURATE, NOT PRECISE**
- **NOT ACCURATE, PRECISE**
- **ACCURATE, PRECISE**
SAMPLE PROBLEM 3

Students conducted an experiment to determine the temperature of a substance as it changed from a solid to a liquid. They repeated the experiment 4 times and achieved the following results:

- Student 1: 56.5 °C; 58.0 °C; 60.0 °C; 55.0 °C
- Student 2: 60.5 °C; 61.0 °C; 60.5 °C; 62.0 °C
- Student 3: 56.5 °C; 58.5 °C; 57.0 °C; 56.0 °C

Students were then provided with the exact value of the melting temperature of the substance, which was found to be 56.48 °C.

a. Which student had the least accurate data?

b. Which student had the least precise data?

c. Was the student with the most precise data also the student with the most accurate data? Explain your answer.

THINK

a. 1. Review what accuracy means. Accuracy refers to how close a measurement is to a known value.

2. Explore the data of the three students.

   - Student 1 had data 1.48 °C lower and 3.52 °C higher than the actual data
   - Student 2 had data that was up to 5.52 °C higher
   - Student 3 had data that was 0.48 °C lower and data that was 2.02 °C higher

3. Determine which student had the least accurate data

b. 1. Review what precision means. Precision refers to how close multiple measurements of the same investigation are to each other.

2. Explore the data of the three students.

   - Student 1 had a data range of 5.0 °C
   - Student 2 had a data range of 1.5 °C
   - Student 3 had a data range of 2.5 °C

3. Determine which student had the least precise data

   - Student 1 had the least precise data

c. 1. Identify the students with the most accurate and most precise data

2. Respond to the question and explain your answer

   - Using the results from a. and b. it can be seen that Student 3 had the most accurate data and Student 2 had the most precise data

   - The student who had the most precise data was not the same student who had the most accurate data. Students may have measurements very close together (precise), but it may not be accurate. This may be due to errors in their measuring device or their interpretation of the melting point (when the solid is a liquid). Data may also be accurate without being precise - you can be close to the target, but the readings are inconsistent. For reliable and valid results, data should be both accurate and precise.
PRACTICE PROBLEM 3

Students conducted an experiment to determine the temperature of a substance as it changed from a liquid to a gas. They repeated the experiment 4 times and achieved the following results:

- Student 1: 85.4 °C; 92.0 °C; 82.0 °C; 75.5 °C
- Student 2: 83.5 °C; 85.0 °C; 85.5 °C; 86.5 °C
- Student 3: 85.5 °C; 90.0 °C; 89.50 °C; 81.0 °C

Students were then provided with the exact value of the boiling temperature of the substance, which was found to be 85.4 °C.

a. Which student had the least accurate data?
b. Which student had the least precise data?
c. Was the student with the most precise data also the student with the most accurate data? Explain your answer.

Reliability

Reliability refers to whether or not another researcher could repeat your investigation by following your method and obtain similar results. As well as this, the more times an experiment is replicated, the more reliable the results are considered to be.

Experiments that are reliable shouldn’t just be able to be carried out by the investigator, but also by a third party. If a test is reliable, it usually has both accuracy and precision, because errors are reduced through repetition.

Validity

Validity refers to the credibility of the research results from experiments or from observations. Validity factors in both experimental design and implementation. Experiments that are valid are usually using the results from one manipulated variable, where other variables are controlled. It is also impacted by factors such as experimental bias.

Validity applies more to biology and psychology, where precise measurement is more difficult (and the misinterpretation of data is higher) and there is the risk of bias on the part of the researcher. In physics and chemistry, the variables are quantifiable and physically measurable.

If your experimental method clearly relates to the purpose of the investigation and you take care to be precise in your measurements and thorough in your analysis, your results should be valid and meaningful. Measurements that are valid must also be reliable, and therefore must have accuracy and precision.

Validity can be:

- **Internal** focuses on if the results can be believed and haven’t been impacted by other variables (as they were properly controlled). Did the experiment measure the variable that was being examined in the experimental question and outlined in the hypothesis?
- **External** is not often applicable chemistry, but is the idea that results obtained when using a sample should be indicative of the results expected for the entire population. This is often more prevalent in drug trials and making sure that a varied and large sample size is used.

14.4.5 Minimisation of experimental bias

Bias is an intentional or unintentional influence on a research investigation as a result of systematic errors introduced by the researcher into the sampling or the testing procedures of an experiment. These biases will prejudice the research findings and raise questions about their validity and reliability.
There are numerous types of bias in experiments, some of which apply more to chemistry compared to others. These include:

- **Measurement bias** occurs when experimenters manipulate results in order to get a desirable outcome. Sometimes this can be unintentional (if an experimenter consistently records the boiling point earlier than they should, leading to a lower recorded temperature), but often it is through the deliberate actions of an individual.

- **Selection bias** can arise when test subjects are not randomly assigned to the experimental and control groups.

  An example of selection bias is in clinical trials of a new synthetic drug a doctor may choose their family members they don’t know receive a placebo. Selection bias can be minimised by randomly and equally allocating subjects to each group.

- **Sampling bias** can arise if the subjects chosen for the study are not representative of the target population. If this occurs, the research results cannot be generalised to that population.

  For example, the average height of students at a school is calculated, but due to time constraints only 50 out of the 600 students are measured. If only Year 7 students were measured, the results will not be representative of the target population and is an example of sampling bias. Sampling bias can be minimised by ensuring that the participants in the study are a reasonable representation of the target population.

- **Response bias** arises when only certain members of the target population respond to an invitation to participate in the clinical trial, resulting in an unrepresentative sample of the larger population.

  Similarly to sampling bias, response bias can be minimised by ensuring that the subjects in the study are a reasonable representation of the target population.

### 14.4 EXERCISE

To answer questions online and to receive immediate feedback and sample responses for every question go to your learnON title at www.jacplus.com.au

1. Distinguish between validity and reliability.
2. Is it essential that the results of an experiment can be replicated in order for the experiment to be considered reliable? Explain your answer.
3. Give an example of when results would not be considered reliable.
4. Under what circumstances can it be said that the conclusions or findings of research are valid?
5. List two procedures that could adversely impact on the internal validity of an experiment.
6. Explain, how an experiment can be reliable but not valid, and why an experiment that is valid must also be reliable.
7. Explain, with examples, the difference between precision and accuracy.
8. Give an example of a strength and a weakness of quantitative and qualitative data.

Fully worked solutions and sample responses are available in your digital formats.

14.5 Ethics, and health and safety guidelines

**KEY CONCEPT**
- Ethics and concerns with research, including identification and application of relevant health and safety guidelines

14.5.1 Ethics

*Ethics* determine acceptable and moral conduct. They do not just apply to scientific investigations, but also to many aspects of life, guiding us between what ‘right’ and what is ‘wrong’.

Science interacts with ethics in several ways, including:
- The way an experiment is conducted
- Confidentiality and conduct with research
- Conflicts with religious and personal beliefs.

Ethical standards and considerations also apply to any type of research or data collection method involving people or animals. They are particularly obvious in drug trials, using both animal testing and human trials. It is important that individuals involved in drug trials give permission and know of all possible side effects and risks associated with treatments. The confidentiality of participant answers must also be ensured when individuals are taking part in a survey.

It is important to be mindful of individuals in regards to personal beliefs. While drug trials have minimum ethical standards for the use of animals in trials, for some individuals, differing personal beliefs may impact experimentation and interpretation of data. This is an ethical consideration that needs to be evaluated and understood when teaching and reporting on these topics.

14.5.2 Health and safety guidelines

Part of the enjoyment of a practical investigation is that the topic may be unconventional or use an innovative method. However, such situations can present some risk, so special care needs to be taken to ensure the safety of yourself and others.

**General safety rules**

Some general safety precautions will help to ensure that you and others are not injured in the laboratory.
- Wear protective clothing. This might include a laboratory coat, safety glasses and gloves.
- Be aware of the position of safety equipment such as the fire blanket, fire extinguisher, safety shower and eye wash.
- Ask your teacher if you are unsure how to operate equipment or how to use apparatus.
- Read labels carefully to confirm contents and concentration of chemicals.
• Clean and return all equipment to the correct places ensuring lids are placed back on containers when not in use.
• Check for the correct disposal of equipment and chemicals, including damaged equipment (i.e. broken glassware).
• Read instructions carefully before commencing an experiment.
• Prepare a risk assessment for required chemicals and equipment.
• Do the investigation as outlined in your approved plan. Don’t vary your plan without approval from your teacher.
• Don’t do experimental work unsupervised unless you have prior approval from your teacher.
• When first setting up electrical experiments, ask your teacher to check the circuit.
• Don’t interfere with the equipment set-up of others.

It is important to address health and safety concerns through the use of a risk assessment. This is a procedure for identifying hazardous chemicals, what the risks are and how to work safely with them. It also assesses potential hazards with equipment being used and standard handling procedures to ensure health and safety of individuals and the environment.

Risk assessments should also take into consideration the correct disposal of equipment and chemicals to adhere to safety and bioethical guidelines. Many chemicals are harmful to the environment, so correct disposal is paramount. Table 14.8 lists the usual requirements for a written risk assessment.

<table>
<thead>
<tr>
<th>TABLE 14.8 Requirements for a written risk assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Section</strong></td>
</tr>
<tr>
<td>Outline of investigation</td>
</tr>
<tr>
<td>Summary of method</td>
</tr>
<tr>
<td>Equipment/chemicals used</td>
</tr>
<tr>
<td>Equipment/chemical risk and hazards</td>
</tr>
<tr>
<td>Risk control measures</td>
</tr>
</tbody>
</table>

An example of a risk assessment is shown in figure 14.34.
FIGURE 14.34 (a) Risk assessment (b) GHS pictograms that can be found through risk assessments to visually show any possible hazards

(a) Cross-linking an addition polymer to make slime

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>SUMMARY OF EXPERIMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AIM</strong></td>
<td>To investigate how the properties of a linear polymer may be altered by the introduction of weak cross-linking between its chains.</td>
</tr>
</tbody>
</table>
| **METHOD** | 1. Pour the polyvinyl alcohol into the beaker and add a few drops of the food dye (optional).  
2. Add the borax solution and stir with the paddle pop stick. It will take a few minutes for the slime to appear.  
3. Perform tests on the product that will enable you to describe its properties and how these are different to the original polymer. |

<table>
<thead>
<tr>
<th>PROTECTIVE MEASURES</th>
<th>GLASSES</th>
<th>GLOVES</th>
<th>DUST MASK</th>
<th>LAB COAT</th>
<th>FUME HOOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>GLASSES</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GLOVES</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DUST MASK</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAB COAT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FUME HOOD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SAFETY INFORMATION</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>REACTANT</th>
<th>Polyvinyl alcohol</th>
</tr>
</thead>
</table>
| **Hazards** | • Flammable  
• Irritating to the eyes |
| **Safety precautions** | • Wear gloves, safety glasses and a lab coat  
• Keep away from sources of ignition  
• Use in well-ventilated areas |

<table>
<thead>
<tr>
<th>FIRST AID</th>
</tr>
</thead>
</table>

| SWALLOWED | Rinse mouth out with water immediately and repeat until all traces are removed. Seek medical attention. |
| EYE       | Flush out with water. Seek medical attention if pain or irritation persists |
| SKIN      | Wash with soap and water |
| INHALED   | Move into fresh air, give oxygen if required. Seek medical attention if breathing is difficult |

<table>
<thead>
<tr>
<th>REACTANT</th>
<th>Borax (sodium tetraborate, solution, 4%)</th>
</tr>
</thead>
</table>
| **Hazards** | • Not classified as hazardous substance at the concentration used  
• However, at concentrations above 4.5%, may damage fertility and unborn child |
| **Safety precautions** | • Wear gloves, safety glasses and a lab coat  
• Should not be handled by pregnant women. Those of reproductive age should also avoid the chemical.  
• Wash hands after use, even if gloves were worn |

<table>
<thead>
<tr>
<th>FIRST AID</th>
</tr>
</thead>
</table>

| SWALLOWED | Rinse mouth out with water immediately and repeat until all traces are removed. Seek medical attention. |
| EYE       | Flush out with water. Seek medical attention if pain or irritation persists |
| SKIN      | Wash with soap and water. Seek medical attention if pain or irritation persists |
| INHALED   | Move into fresh air, give oxygen if required. Seek medical attention if breathing is difficult |

<table>
<thead>
<tr>
<th>EQUIPMENT</th>
<th>Beaker</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hazards</strong></td>
<td>• Glass may break leading to cuts and damage to eyes and skin</td>
</tr>
</tbody>
</table>
| **Safety precautions** | • Do not use damaged or cracked equipment  
• Sweep up any broken glass, being aware of any chemical residue |

<table>
<thead>
<tr>
<th>CONCLUSION</th>
</tr>
</thead>
</table>

- Wear glasses, gloves and a lab coat for the duration of this experiment  
- Ensure all equipment has been maintained and checked for damage before use  
- Make sure that the area is well-ventilated

Signed: ______________________________                     Date: _______________________
14.5 EXERCISE
To answer questions online and to receive immediate feedback and sample responses for every question go to your learnON title at www.jacplus.com.au

1. Research and identify possible hazards and suggest safety precautions for the following equipment and chemicals.
   (a) 0.5 mol L\(^{-1}\) of sodium hydroxide
   (b) Beaker
   (c) Methane
   (d) Bunsen burner

2. Provide two examples of when ethics may be important in a Chemistry investigation.

3. List three purposes of a risk assessment.

4. What other things do you think should be added to a risk assessment?

5. Look around your laboratory and note its safety features and equipment.
   (a) Draw a plan of your laboratory and label the positions of safety equipment.
   (b) Does it have any foam fire extinguishers? How are these identified? On what types of fire can these be used and on what types of fire should they not be used?
   (c) Does it have any dry chemical or dry powder extinguishers? How are these identified? On what types of fire can these be used and on what types of fire should they not be used?
   (d) Are there any other fire extinguishers you can see? What are they used for?
   (e) Where is/are the fire blanket(s) located? Describe a scenario in which a fire blanket would be used and how you would use it.
   (f) Where are the master (emergency) shut-offs for gas and electricity located?

6. The Safety Data Sheet (SDS) for a chemical to be used in an experiment contains the following risk phrases.
   - Irritating to eyes/skin
   - Flammable
   - Vapours may cause dizziness
   Suggest appropriate methods to reduce these risks.

Fully worked solutions and sample responses are available in your digital formats.
14.6 Methods of organising, analysing and evaluating primary data

KEY CONCEPT
Methods of organising, analysing and evaluating primary data to identify patterns and relationships including identification of sources of error and uncertainty, and of limitations of data and methodologies

14.6.1 Organising primary data

Scientists gather raw data or plain facts from their observations, and this data must be recorded at the time in a suitable form (e.g. text entries, sketches, tables and diagrams in logbooks or in field notebooks). These may be supplemented by audio and video recordings.

Using a table

Tables should be used when you initially record data to help separate and organise your information. All tables should:
- have a heading
- display the data clearly, with the independent variable in the first column and the dependent variable in later columns.
- include units in the column headings and not with every data point
- be designed to be easy to read. If a table becomes too complicated, it is better to break it down into a number of smaller tables.

Using logbooks is an easy way to organise data

FIGURE 14.35

Using a table

Tables should be used when you initially record data to help separate and organise your information. All tables should:
- have a heading
- display the data clearly, with the independent variable in the first column and the dependent variable in later columns.
- include units in the column headings and not with every data point
- be designed to be easy to read. If a table becomes too complicated, it is better to break it down into a number of smaller tables.

FIGURE 14.36

Format on a scientific table

Always include a title for your table.

Include the measurement units in the headings.

The column headings show clearly what has been measured.

Use a ruler to draw lines for rows, columns and borders.

Enter the data in the body of the table. Do not include units in this part of the table.

Temperature of the Earth at different depths

<table>
<thead>
<tr>
<th>Depth (km)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>1</td>
<td>44</td>
</tr>
<tr>
<td>2</td>
<td>73</td>
</tr>
<tr>
<td>3</td>
<td>102</td>
</tr>
<tr>
<td>4</td>
<td>130</td>
</tr>
<tr>
<td>5</td>
<td>158</td>
</tr>
<tr>
<td>6</td>
<td>187</td>
</tr>
<tr>
<td>7</td>
<td>215</td>
</tr>
<tr>
<td>8</td>
<td>242</td>
</tr>
</tbody>
</table>
Using a graph
Presenting results as a graph makes it easier to see patterns and trends in your data, allowing more accurate result analysis. While you will usually use a table to record results in your logbook, displaying your data as a graph is preferred on your scientific poster.

When drawing graphs:
• decide on the type of graph to be used. Different types of information are better suited to different types of graphs. If both the dependent and independent variables are quantitative, a line graph or scatterplot is preferred. Bar graphs are used when one piece of data is qualitative and the other is quantitative. Histograms are used when intervals and frequency are being explored.
• include a title — this should link the dependent and independent variables that are shown in the graph.
• in most graph types (excluding pie graphs), the independent variable should be on the horizontal (x) axis, and the dependent variable on the vertical (y) axis.
• axes should be ruled and clearly labelled. Those displaying numerical variables should have a clearly marked scale and units.
• make sure your scale is suitable and the numbers are evenly distributed.
• use a line (or curve) of best fit as required. This is a smooth curve or line that passes as close as possible to all the plotted points.
• include the origin, the zero value for the variables, on both axes. If required, you can use a zigzagged lined to show that data has been condensed in an area, as seen in figure 14.37a.

The most common graphs you will use in chemistry include:
- scatterplots
- bar/column graphs
- line graphs
- histograms.

Scatterplots
Scatterplots require both sets of data to be numerical. Each dot represents one observation, recorded in regards to the independent and dependent variable. A scatterplot can easily show trends between data sets, and correlations can be seen.

**FIGURE 14.37** (a) Example of a scatterplot and (b) a scatterplot with a line of best fit

**DRAWING A LINE OF BEST FIT**
A line of best fit can be used to show the general trend of data and provides a quick summary. Figure 14.37b shows that line A, although not passing through any points, is a better fit than line B.

The line of best fit doesn't need to pass through each data point. Although you should try to draw the line through each error bar if possible, you may not be able to go through all of them. As a general rule, try to have as many data points above your line as you have below. Don’t assume your line must pass through the origin. For some data, a curve of best fit may be more appropriate.
Bar graphs

Bar (or column) graphs are often used when one piece of data is qualitative and the other is quantitative. The bars are separated from each other. The horizontal axis has no scale because it simply shows categories. The vertical axis has a scale showing the units of measurements. Bar graphs can also be used to compare two sets of data by using side-by-side bars, as shown in figure 14.38b.

Histograms

Histograms are a special kind of bar graph that show continuous categories, and are often used when examining frequency. The bars are not separated.

In figure 14.39, the exact values cannot be determined, because data is displayed in intervals. It can be seen that there were 30 samples that had a pH between 8 and 10 but we do not know what specific values these are.

Line graphs

Line graphs involve a series of dots that represent the values of a variable. The dots are usually joined using a straight line (this is different to a line of best fit, in which the line is straight and does not have to go through each point), but sometimes the line is curved.
Line graphs are often used to show changes over a continuous period of time, or over space. In particular, line graphs can identify patterns, trends and turning points in a dataset.

**FIGURE 14.40 Setting up a line graph**

3. **Setting up and labelling the axes**

Graphs represent a relationship between two variables. When choosing which variable to put on each axis, remember that there is usually an independent variable (which the investigator chooses) and a dependent variable. For example, if students wish to find how solubility of sugar changes with temperature, they may choose to measure the solubility (in g/100g) every 20°C. The temperature of each measurement was chosen by the students and is the independent variable. The solubility measured is therefore the dependent variable. Usually the independent variable is plotted on the x-axis and the dependent variable on the vertical y-axis.

After deciding on the variable for each axis, you must clearly label the axes with the variable and its units. The unit is written in brackets after the name of the variable.

4. **Setting up the scales**

Each axis should be marked into units that cover the entire range of the measurement. For example, if the solubility ranges from 0 to 415 g/100 g then 0 and 420 g/100 g could be the lowest and highest values on the vertical scale. If measurements start above zero, as per the solubility measurements on the vertical axis, an axis-break symbol can be used. The distance between the top and bottom values is then broken up into equal divisions and marked. The horizontal axis must also have its own range of values and uniform scale (which does not have to be the same scale as the vertical axis). The most important points about the scales are:

- They must show the entire range of measurements (have an axis-break symbol if required).
- They must be uniform, that is, show equal divisions for equal increases in value.

5. **Putting in the values**

A point is made for each pair of values (the meeting point of two imaginary lines from each axis). The points should be clearly visible. Include a point for (0, 0) only if you have the data for this point.

6. **Drawing the line**

A line is then drawn through the points. A line that follows the general direction of the points is called a ‘line of best fit’ because it best fits the data. It should be on or as close to as many points as possible. Some points follow the shape of a curve, rather than a straight line. A curved line that either touches all the points or conforms to a best fit can then be used.

The type of data you graph may lead you to expect either a straight line or a curve. For example, you might expect the increase in temperature of water being boiled to be a straight line because the temperature increases at a steady rate. In this example, the solubility of a sugar with increasing temperature is a curve. Inspecting the data will help you decide whether your line should be straight or smooth and curved.
Using Microsoft Excel

While you may very carefully hand-draw your graph, being able to create digital graphs is important, especially for neat presentation on your poster. Excel is extremely helpful for this. It can:

- calculate any derived physical quantities, such as speed and acceleration of a parachute or the percentage of energy lost by a bouncing ball. The ‘Fill down’ command is a timesaver.
- be a powerful graphing tool, but must be controlled by the user. You will have to select the type of graph, what aspects of your graph you want to show and the scale on the axis. You will also have to decide what label you want on your axis and whether you want the data displayed on the graphed points.
- generate a line of best fit. If you right-click on any data point, a window pops up with the option ‘Add Trendline’. This is the Excel command to create a line of best fit. Once selected, you have several choices. If your graph looks like a straight line, choose ‘Linear’.
- create error bars (in Excel all error bars are usually the same for each data point, rather than calculated separately which is the usual protocol).

Resources

Interactivity Selecting a graph  

14.6.2 Analysing primary data

When analysing primary data, it is important to explore trends and patterns that can be seen. This may involve asking questions such as:

- Is there a clear positive or negative correlation in data? (One variable increasing in response to another increasing shows positive correlation, whereas one variable decreasing in response to another increasing is negative correlation).
- Are there any outliers (unusual data)?
- What results would you expect for specific data that you didn’t observe experimentally?
- Can you calculate the average for your data?

Analysis of your data often depends on the type of graph selected, because it alters the way trends and patterns are seen. The graphs in figure 14.42 show the same data presented in three ways.
Each of the graphs in figure 14.42 will be analysed in slightly different ways. From these graphs, you might draw the following information:

- **Graph (a):** There is a clear downwards trend (negative correlation) in data, as temperature decreases over time. However, at 25 minutes, the temperature is slightly higher than expected based on the line of best fit, and at 30 minutes, the temperature is slightly lower than expected.

- **Graph (b):** There is a clear downwards trend in data (negative correlation), as temperature decreases over time. The rate of temperature drop slows after 15 minutes, before the rate increases again between 25 and 30 minutes.

- **Graph (c):** There is a clear downwards trend in data (negative correlation), as temperature decreases over time. The temperature is lowest at 30 minutes, where it is half the temperature seen at 15 minutes. The right graph is fundamental for data analysis. In this case, the representation of the data in Graphs a and b is far more powerful than that obtained from Graph c. Regardless, it is important to note down any clear trends and patterns seen in the data, and note down any outliers that can be seen.

Graph analysis can also be used to predict and make assumptions about data that was not gathered experimentally, but through interpolation (predicting data points within the data set that were not measured) or extrapolation (predicting data points outside data set based on predicted relationship). Based on the graphs you might estimate:

- The temperature at 35 minutes
- The temperature at 13 minutes
- The time that the temperature was 45 °C.
The estimation you make can vary greatly between all the graphs, so it is important to carefully consider which graph you use.

**TABLE 14.9** Analysing data from different graph types

<table>
<thead>
<tr>
<th></th>
<th>Graph (a)</th>
<th>Graph (b)</th>
<th>Graph (c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature at 35 min (°C)</td>
<td>25</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Temperature at 13 min (°C)</td>
<td>65</td>
<td>62</td>
<td>66</td>
</tr>
<tr>
<td>Time the temperature was 45 °C (mins)</td>
<td>24</td>
<td>27</td>
<td>26</td>
</tr>
</tbody>
</table>

**Outliers**

Outliers are results that are a long way from other results and seen as unusual. They should be accounted for and analysed, but are often not included when calculating averages.

**FIGURE 14.43** Outliers in data are unusual results.

14.6.3 Evaluating primary data

When you evaluate data, it is important to link back to the initial question of your investigation. It is important that you can explain and justify your data evaluation in relation to your question.

- Does the data provide an answer to the question?
- Does the data support or refute your hypothesis?
- If there are any outliers, errors or uncertainty in your data, why may these have occurred?
- Does your data link to correctly supported models and theories?
- Are there further improvements that you could make to improve your data in future investigations that may reduce errors or limitations?

The following are two examples of data evaluation by two different students, based on figure 14.42.

**Student 1:** The results show that temperature decreased.

**Student 2:** Table 2 shows a clear decrease in temperature over time, dropping from an initial temperature of 90 °C to a final recorded temperature of 30 °C. While there is a clear trend in temperature decreasing over time, the rate of decrease was inconsistent, particularly between 25 and 30 minutes. This may be due to a decrease in external air temperature, causing the rate of heat loss through convection to change.

It is clear that student 2 had a better grasp on evaluating the data and was able to describe trends and a link to theory. What else should they add?
14.6.4 Sources of uncertainty and error

Understanding sources of uncertainty and error is vital in scientific reporting, accounting for the fact that the conclusions are being drawn from data that is not perfectly accurate or precise. Uncertainty and errors can appear in any experiment. Uncertainty is acknowledging that no matter how precise an instrument might be, there is a limit to that precision. The uncertainty is a range within which a measurement lies. An error bar is a way of representing that uncertainty graphically.

Errors, on the other hand, are differences between a measurement taken and the true value that is expected; errors lead to a reduction in the accuracy of the investigation.

Every instrument has a limit to how precisely it measures. The scale or digital display imposes a constraint on how many digits you can record, and also reveals the tolerance of the measurement. For example, there are both errors and uncertainties associated with using thermometers. Two individuals might look at it and not get the exact same result as they might have been standing at different angles or interpret the reading slightly differently. Or results might not be identical between two different thermometers. The thermometer only gives measurements to the accuracy of 1 °C and not decimal values. However, through careful observation, 0.5 °C can usually be observed by looking at the gaps between markings.

Sources of error

Sources of error are the causes of errors found in experiments. Some of these are listed below.

- **Systematic errors** affect the accuracy of a measurement that cannot be improved by repeating an experiment. They are usually due to equipment or system errors and produce measurements that are consistently too high or too low. They include:
  - instrumental errors that arise because an instrument, such as a weighing balance, is uncalibrated and incorrectly set to zero
  - environmental errors that arise because of malfunctions, such as a power outage, that affect the conditions under which an experiment is being conducted.

- **Random errors**: Random errors are chance variations in measurements that affect the precision of measurements and are always present in measurements of continuous data. An example of a random error is an error of judgement when reading the smallest division on the scale of a measuring instrument, such as a ruler. Unlike systematic errors, this can usually be resolved with repetition of measurements.

  It should be noted that so-called ‘human errors’ are not errors but mistakes that result from carelessness. Examples include gross misreading of an instrument, and writing the wrong result in your logbook, such as 40 instead of 4.0.

Measuring errors

It is important to consider the instrument you are using when you consider uncertainties and errors.

**Reading Measuring Cylinders**

When measuring liquids, it is important to record from the bottom of the dip (the meniscus). What is the measurement in figure 14.45? Would every single individual correctly record this data?
Reading rulers

Measuring Errors

A metre ruler has lines to mark each millimetre, but there is space between these lines. You could measure a length to the nearest millimetre, but because of the space between the lines, if you look carefully, you can measure to a higher precision — to the nearest 0.5 mm.

The best estimate for the length of the red line in figure 14.46 is 2.35 cm. The actual length is closer to 2.35 cm than it is to either 2.30 cm or 2.40 cm. The measurement of 2.35 cm says the actual length is somewhere between 2.325 cm and 2.375 cm. The way to write this is:

The length of the red line = 2.35 ± 0.025 cm

The 0.025 represents the tolerance or uncertainty in the measurement (half of the precision that can be recorded).

Reading top-loading balances

If the reading on a digital scale is 8.94 g the mass is not 8.93 g nor 8.95 g. The actual mass is somewhere between 8.935 and 8.945 grams. In this example, the smallest unit of measurement is 0.01 g. Therefore the tolerance is half of this (0.005 g), as the measurement can be 0.005 g below or above the recorded measurement. The way to write this is:

Mass = 8.94 ± 0.005 g
SAMPLE PROBLEM 4

a. Record the reading on the scales shown in Figure 20.47a including the tolerance.
b. Record the reading on the thermometer shown in Figure 20.47b including the tolerance

THINK

a. 1. Determine the reading on the scale
   2. Determine the range of the measurement
   3. Determine the tolerance.
      One way to calculate this is half of the smallest unit that can be measured
   4. Record the reading including the tolerance

WRITE

128.93
The measurement can be between 128.925 and 128.935
0.01 g is smallest measurement possible
\[
\frac{0.01 g}{2} = 0.005 
\]
128.93 ± 0.005 g

47 °C
The measurement can be between 46.75 and 47.25
\[
\frac{0.5 ^\circ C}{2} = 0.25 ^\circ C 
\]

PRACTICE PROBLEM 4

a. Record the reading on scales that show a reading of 0.12 g, including the tolerance.
b. Record the reading on scales that show a reading of 0.195 g, including the tolerance.

Repeated measurements

Measurements of independent variables are usually precise and careful, so one measurement should be enough. However, measurements of the dependent variables are often prone to some variation.

Whether the variation is caused by the human reaction time when using a stopwatch, judging the rebound height of a basketball or, in the case of a parachute, the unpredictable way the canopy will open each time, each reading may be different. Therefore, it is sensible to take several readings to obtain an average. Three to five measurements would be needed, but more than five is generally unnecessary.

If your partner dropped a basketball from a height of 80.0 cm, and you judged the rebound height of the ball for five trials as 68 cm, 69.5 cm, 68.5 cm, 68.5 cm and 69.5 cm, the average is 68.8 cm. You would round this to the nearest 0.5 cm because of the difficulty of judging a moving ball and achieve an average of 69 cm. This set of measurements would then be written as 69 ± 1 cm (the 1 cm is the furthest the measurement is from the average).
Graphing error bars
You can show variations in measurement on graphs using errors bars. These are lines above and below the graphed point so show the average variation — that is, the margin for error.

For the basketball experiment previously discussed, you will plot 69 cm on your graph. To represent the ‘± 1 cm’ variation, you can draw a line through the point, up 1 cm and down 1 cm, with a short line across the top and bottom of the line to make the ends evident.

Calculating error bars
Rather than graphing rebound height against drop height, it is more revealing of the physics of the situation to calculate and graph the ratio of the rebound height to drop height against drop height. The ratio is a measure of how much of the original gravitational potential energy is restored.

In this case, the ratio would be \( \frac{69}{80.0} = 0.8625 \), but how many digits are we entitled to use and how big should the error bar be? The first question is reasonably straightforward. The number of digits in your answer should equal the smallest number of digits in the data you used in the calculation. In this instance, the average height has two digits, so the answer would be written as 0.86. You are not justified in including more digits because you don’t know the original data accurately enough.

Working out the size of an error bar takes more effort. If the two pieces of data are 69 ± 1 cm and 80.0 ± 0.3 cm, we can just add the uncertainties to get ± 1.3 cm, but that doesn’t make sense when the calculated value is 0.86. Dividing the uncertainties would produce another unusual result.

The method used is to first express the uncertainty for each data value as a percentage. For example:

Percentage error of 69 ± 1 cm = \( \left( \frac{1}{69} \right) \times 100 = 1.4\% \)

Percentage error of 80.0 ± 0.3 cm = \( \left( \frac{0.3}{80} \right) \times 100 = 0.4\% \)

Now add the two percentage errors together.

Total percentage error = 1.4% + 0.4% = 1.8%

Use this total percentage error to find the error in the calculated answer.

Error = 0.86 × 1.8% = 0.016

This would be rounded to one digit as 0.02. Therefore, the full calculated answer would be 0.86 ± 0.02.

Resources

Video eLesson Calculating error (eles-2560)
14.6.5 Limitations of data and methodology

The data that is gathered from the experimental results will have limitations. Limitations arise from several sources that can affect the quality of the data.

- Experiments create artificial situations that do not necessarily represent real-life situations.
- While every effort may be made to identify controlled variables and keep them constant throughout the course of an experiment, it is not always possible to identify and control every one of this type of variable.
- The degree on which results obtained in the laboratory can be generalised to other situations and applied in the real world is limited.

It is important to consider limitations when analysing and drawing conclusions from data. Limitations should be factors that are out of your control, but need to be discussed in regards to how they might impact your results. As part of your practical investigation, you need to clearly outline limitations and possible suggestions on improvements to the method or data collection to avoid these.

14.6 EXERCISE

To answer questions online and to receive immediate feedback and sample responses for every question go to your learnON title at www.jacplus.com.au

1. Describe the difference between a random and systematic error and provide two examples of each.
2. List two ways that you can minimise uncertainty in an investigation.
3. Identify which graph type would be most appropriate for the following investigations. Justify your choice:
   (a) Comparing the pH of different household liquids
   (b) Showing how pH changes with temperature
   (c) Measuring the temperature inside a car every 5 minutes for an hour
   (d) Showing the frequencies of different test mark intervals for 400 students
4. Using the provided data, construct an appropriate graph.

<table>
<thead>
<tr>
<th>Time (mins)</th>
<th>Volume of ice cube (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>10</td>
<td>21</td>
</tr>
<tr>
<td>15</td>
<td>18</td>
</tr>
<tr>
<td>20</td>
<td>14</td>
</tr>
<tr>
<td>25</td>
<td>10</td>
</tr>
</tbody>
</table>

Once you construct the graph, analyse and evaluate the data shown.

5. Describe how an outlier should be treated when analysing and evaluating data.
6. Record the reading on the burette in this diagram (remember the measurements on a burette go downwards, unlike in a measuring cylinder).
7. Explain why a student reading this burette as 8.67 mL is incorrect.

8. Determine the length of each line in the following diagram, showing the tolerance in each case.

(a) 

(b) 

(c) 

9. A student is designing an experiment that involves measuring liquid volumes at various stages. A number of glassware items are available for this purpose, as shown in the following table.

<table>
<thead>
<tr>
<th>Item</th>
<th>Uncertainty (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Volumetric flask (250 mL)</td>
<td>±0.1</td>
</tr>
<tr>
<td>B Beaker (100 mL)</td>
<td>±10</td>
</tr>
<tr>
<td>C Measuring cylinder (100 mL)</td>
<td>±0.1</td>
</tr>
<tr>
<td>D Burette (50 mL)</td>
<td>±0.02</td>
</tr>
<tr>
<td>E Conical flask (250 mL)</td>
<td>±25</td>
</tr>
</tbody>
</table>

Which item(s) would be most appropriate for:
(a) rinsing a burette with 10 mL of water
(b) producing 250 mL of a solution of accurately known concentration
(c) producing 250 mL of a solution of approximately known concentration.

Fully worked solutions and sample responses are available in your digital formats.

14.7 Models and theories to understand observed phenomena

KEY CONCEPT
- Models and theories and their use in organising and understanding observed phenomena and chemical concepts including their limitations
Limitations exist in the models and theories that we use in chemistry. It is important to be able to use models and theories to allow us to understand a variety of observed phenomena, but to also understand the limitations in models and theories and that they may change over time.

14.7.1 Models

Models are representations of ideas, phenomena or scientific processes. They can be physical models, mathematical models or conceptual models. Models can provide a framework that explains observed phenomena and helps with the understanding of abstract concept. In chemistry, many concepts are hard to visualise, so models help contextualise the idea on a smaller and simpler scale.

While they are very useful, models have their limitations. These include:

- Models cannot include all the details of the processes or the things that they represent because of the complexity of the processes
- Models are only approximations of the real world. For example, we can use ideal gas laws to make predictions about the behavior of gases, but this model is constrained by certain conditions, such as specific pressure and temperature. The model's predictions would not always match what happens in real-world situations. We can also model various lattices (as seen in figure 14.51) or bonding, but we often assume ideal conditions around temperature and pressure, which is not realistic about what happens in the real world.
- Models have some limits in their accuracy and are often simplified and stylised. For example, a ball and stick model of methane (see figure 14.50) is useful, but it is a very highly simplified and stylised representation that reduces covalent bonds to sticks and atoms to solid balls.
- Models are based off current observations and knowledge at the time. This means that they aren’t definite and can change as observations allow for different ideas to come to light. New observations and experiments often lead to the development and changing of previously supported models. In the future, more discoveries could come to light that change models that we currently believe to be accurate.
14.7.2 Theories

A theory is a well-supported explanation of a phenomena. It is based on the interpretation of facts that have been obtained through investigations, research and observations.

There are limitations that can exist with theories. These include:

- A reliance on theories rather than observations made during practical investigations. Often, individuals manipulate results to match a theory, rather than realise that observations are more powerful. Often, theories are treated as perfect, when in fact, they are able to be disproven as new observations and evidence come to light.
- Theories often rely on a specific set of conditions to be met. For example, the Law of Conservation of Mass cannot be used in systems that are open systems (not isolated) or systems that involve very large amounts of energy.
- Often, a phenomenon needs to be described using multiple theories. Sometimes, aspects of theories contradict each other.

Theories can change seemingly overnight or can take a very long time to change. Theories that were once popular and widely accepted can be discarded when too much evidence builds up against them. They are replaced by a theory that better fits the observations.

Some examples of theories that have been superseded by other theories are:

- Miasma theory of disease — the idea that diseases were caused by bad air
- The Sun and planets orbit around the Earth (geocentrism)
- The flat Earth theory

How do refinements of existing theory come about?

Refinements of existing theory come about in a number of ways. These include:

- carefully planned laboratory-based or field-based experiments designed to support or refute a particular hypothesis
- critical reinterpretation of previously accepted facts, producing a new framework
- collection and analysis of new data
- identification and exploration of patterns or anomalies
- new technologies that allow for changes to understanding and more depth of knowledge.

14.7 EXERCISE

To answer questions online and to receive immediate feedback and sample responses for every question go to your learnON title at www.jacplus.com.au

1. Describe three ways in which models can be useful.
2. Describe three limitations of models.
3. What is the difference between a model and a theory?
4. How can theories help us understand phenomena?

Fully worked solutions and sample responses are available in your digital formats.
14.8 Nature of evidence and key findings of investigations

**KEY CONCEPTS**
- The nature of evidence that supports or refutes a hypothesis, model or theory
- The key findings of the selected investigation and their relationship to thermochemical, equilibrium and/or organic structure and bonding concepts

14.8.1 Nature of evidence — supporting or refuting a hypothesis, model or theory

Evaluating a hypothesis, model or theory uses the evidence from the results obtained in an investigation. In your investigation, it is important to understand how to best use evidence in order to correctly support or refute your hypothesis.

Evidence can be strong or weak, as summarised in table 14.10. It is vital that the evidence you choose allows the provision of strong and clear conclusions.

Strong evidence should:
- be based on facts derived from studies with high validity and minimal bias
- use data to support conclusions
- clearly link to the aim and hypothesis of an experiment
- be obtained from an investigation that has a reproducible and reliable method.

If the prediction from your hypothesis was validated by your experimental results, you should evaluate your hypothesis as ‘supported’; if your hypothesis was not supported by results, it is ‘rejected’ or ‘not supported’.

Scientific hypothesis can be rejected (or not supported), but it can never be proven true — it can only be supported. This is because the nature of evidence is that as new technologies and information become available, evidence can change and be interpreted in different ways. This may than disprove a previously made hypothesis.

<table>
<thead>
<tr>
<th>Observation</th>
<th>Hypothesis</th>
<th>Test of hypothesis</th>
<th>Result</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>The toaster has stopped working</td>
<td>The power point is faulty</td>
<td>Use a different power point</td>
<td>The toaster works in the different power point</td>
<td>Hypothesis supported</td>
</tr>
<tr>
<td>The car won’t turn on</td>
<td>The battery is empty</td>
<td>Replace the battery</td>
<td>The car still won’t turn on</td>
<td>Hypothesis not supported</td>
</tr>
<tr>
<td>The measurement on the scales is too high</td>
<td>The scales weren’t set to zero before use</td>
<td>Set the scales back to zero</td>
<td>The reading is more accurate</td>
<td>Hypothesis supported</td>
</tr>
</tbody>
</table>

14.8.2 The key findings of investigations

For your investigation, you wrote a question and a hypothesis, created a clear reproducible methodology, conducted an experiment, and collected and analysed data. Once these steps are complete it is important to determine the key findings of your investigation.
Your key findings should include:
- information about the data obtained in the practical investigation and any patterns and trends
- the relationship of your findings to chemical concepts including thermochemical, equilibrium and/or organic structure and bonding concepts
- an answer to the question of your investigation.

For example, you might be investigating the question: How does the molar mass affect the heat of combustion of alcohols? You have produced figure 14.53 and you would link this to thermochemical ideas.

Many alcohols are commonly used as fuels due to their high heat of combustion, which measures the heat energy released when the fuel burns completely in oxygen.

Five main alcohols were examined in this investigation, and the heat of combustion was recorded. The chosen alcohols were methanol, ethanol, propanol, butanol and pentanol. These were graphed in accordance with their molar mass, in order to allow for quantitative data to be examined.

From the graph shown, it can be observed that as the molar mass of an alcohol increases, the heat of combustion also increases. This is because the heat energy released would be higher. Because there are more bonds in the larger molecules, there is more energy already present, and therefore more energy is released in the process of combustion.

There appears to be a positive correlation between molar mass and heat of combustion, and generally a linear trend with some minor deviations. Therefore, it is clear that the size and number of atoms and, in turn, the molar mass impact the heat of combustion, supporting the hypothesis of the investigation.

14.8 EXERCISE
To answer questions online and to receive immediate feedback and sample responses for every question go to your learnON title at www.jacplus.com.au

1. Why do we say that we ‘support’ a hypothesis rather than ‘prove’ it?
2. Provide three examples of strong evidence.
3. Describe what key findings you should communicate in a discussion.
4. Why is it important to show the relationship of your results to concepts such as solubility and concentration?

Fully worked solutions and sample responses are available in your digital formats.

14.9 Conventions of scientific report writing and scientific poster presentation

KEY CONCEPT
- The conventions of scientific report writing including chemical terminology and representations, symbols, chemical equations, formulas, units of measurement, significant figures, standard abbreviations and acknowledgement of references.
14.9.1 Conventions of report writing
It is vital to follow the set structure in scientific report writing and scientific poster presentation to follow the protocols of scientific written communication.

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title</td>
<td>A precise and complete description of what you investigated</td>
</tr>
<tr>
<td>Abstract</td>
<td>An optional section to outline the key findings and information.</td>
</tr>
<tr>
<td>Introduction</td>
<td>A paragraph explaining the relevant chemical and background concepts and how they apply to this investigation. It should explore any prior investigations conducted on this topic. This should also include a clear aim and hypothesis.</td>
</tr>
<tr>
<td>Methodology</td>
<td>A detailed section that describes your selection of equipment and measuring instruments, and your step-by-step method. This may include diagrams and photos. Refer to how you controlled variables, achieved the desired accuracy, and overcame, avoided or anticipated difficulties. It should be clear enough for someone else (at your level) to repeat your experiment. Do not forget to highlight how the relevant ethical and safety concerns have been addressed.</td>
</tr>
<tr>
<td>Results</td>
<td>A clear representation of your results, including your data and graphs. If there is too much data, refer to your logbook for the full set. Make sure you present your results in an organised and clear manner, following accepted conventions (such as numbering sequentially). Make sure you include the appropriate units and use the correct number of significant figures. Try to organise this in such a way that any patterns or relationships start to become obvious, thus making it easier to analyse in the next section. Show sample calculations if required.</td>
</tr>
<tr>
<td>Discussion</td>
<td>A detailed analysis and evaluation of your results. How does your data support your initial intentions and link to relevant chemistry concepts? What trends and relationships are apparent as a result of your investigation? How much of your analysis is limited by uncertainties? Were there any outliers in your investigation and how were they treated? What limitations and sources of error were present in your investigations and how would you improve this in future repetitions? What would be your next steps in the investigation if you had more time?</td>
</tr>
<tr>
<td>Conclusion</td>
<td>This should relate to the aim and must be based entirely on the evidence obtained in the experiment. It should state whether the hypothesis is supported, and summarise the meaning of your results in response to your question. No new information should be included.</td>
</tr>
<tr>
<td>References and acknowledgements</td>
<td>You should quote the sources of any content that you include that is not your own original work. Unaltered tables, diagrams and graphs are examples that fit this description, as are direct quotes. In your introduction, you may have mentioned previous work that your investigation is based on. This also needs to be acknowledged, along with any sources that inform your discussion of concepts and theory in a more general sense. This section is not counted in your final word count.</td>
</tr>
</tbody>
</table>

It is important to remember that your assessed practical investigation is based on both your scientific poster and your logbook. The information you will be marked on may be in either your poster or your logbook, or it may appear in both. It is important that all information is presented.
There are some other important points to remember when writing your scientific report or poster. These include:
- try to avoid subjective language — where possible, use third-person (he, she, they, etc)
- don’t just record the data you believe supports your hypothesis — you should also include any errors, uncertainties and outliers
- if you used any calculations, show your working out
- use subheadings throughout your report to make it clear to read
- provide headings for all graphs, tables and figures, and label them sequentially (graph 1, graph 2, etc).

14.9.2 Terminology and representations
Throughout your report, it is important to use clear and concise terminology relevant to the related chemistry concept. The use of key terms was covered in section 14.3.2.

Furthermore, chemical representations are required to be accurate and use common conventions. These representations were discussed in section 14.3.3. There may be other representations used that are appropriate to your specific investigation. These should be used consistently in both your logbook and your poster.

14.9.3 Symbols
Symbols are commonly used in chemistry to represent specific variables, different elements and measurements, among other things. There are many also many symbols that are specific to drawing the skeletal structure of molecules. Symbols are often letters but, due to the sheer quantity of variables we have to represent, it is important to note that the capital and lowercase letter usually represent different things. As well as that, sometimes the same symbol is used to represent different variables.

\( \mu \) can be used to represent:
- the statistical mean
- micro in measurement.

C can be used to represent:
- carbon (C)
- concentration (c).

It is important to know various symbols, including those used in equations, and to use them correctly and carefully in your report to minimise confusion. Table 14.12 shows some commonly used symbols in chemistry.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>∆</td>
<td>Change in variable</td>
</tr>
<tr>
<td>⇌</td>
<td>Equilibrium arrow</td>
</tr>
<tr>
<td>( N_A )</td>
<td>Avogadro’s Constant</td>
</tr>
<tr>
<td>( N )</td>
<td>Number of particles</td>
</tr>
<tr>
<td>( n )</td>
<td>Amount in mole</td>
</tr>
<tr>
<td>( M )</td>
<td>Molar mass</td>
</tr>
<tr>
<td>( m )</td>
<td>Mass</td>
</tr>
</tbody>
</table>
### 14.9.4 Equations and formulas

During your exam you will be provided with a data book, which will contain physical constants, formulas and data that will help you answer many questions. When using equations and formulas in your scientific investigation, it is important to:

- define all variables
- provide any figures for constants (e.g. Avogadro’s number).

Some key formulas in chemistry are included here, and many of which can be found in your VCE Chemistry Data Book. You should become very familiar with this data book prior to your exam as it contains a huge amount of useful information which you do not need to memorise.

#### Determining the number of moles \((n)\)

- \(n = \frac{\text{mass}}{\text{molar mass}} = \frac{m}{M}\)
- \(n = \frac{\text{number of particles}}{6.02 \times 10^{23}} = \frac{N}{N_A}\)
- \(n = \text{concentration} \times \text{volume} = cV\)
- \(n = \frac{\text{volume}}{\text{molar volume}} = \frac{V}{V_m}\)

#### Chemical relationships

- Universal gas equation: \(pV = nRT\)
- Heat energy released from combustion: \(q = mc\Delta T\)
- Enthalpy of combustion: \(\Delta H = \frac{q}{n}\)
- Calibration factor for bomb calorimetry: \(\text{CF} = \frac{VIt}{\Delta T}\)
- Number of moles of electrons: \(n(e^-) = \frac{Q}{F}\)
- % yield: \(\frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%\)
- % atom economy: \(\frac{\text{molar mass of desired products}}{\text{molar mass of all reactants}} \times 100\%\)
- Electric charge: \(Q = It\)
14.9.5 Units of measurement

In chemistry, it is vital to use the correct unit of measurement for accurate and clear scientific communication.

Prefixes

Prefixes are used at the start of measurements to denote how large or small a value is. These values are from a base unit. Examples of base units include meter, seconds or games. These base units have the value of $10^0$ (or 1). All other prefixes are compared to this base unit.

<table>
<thead>
<tr>
<th>Prefixes</th>
<th>Symbols</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pico</td>
<td>p</td>
</tr>
<tr>
<td>Nano</td>
<td>n</td>
</tr>
<tr>
<td>Micro</td>
<td>$\mu$</td>
</tr>
<tr>
<td>Milli</td>
<td>m</td>
</tr>
<tr>
<td>Centi</td>
<td>c</td>
</tr>
<tr>
<td>Deci</td>
<td>d</td>
</tr>
<tr>
<td>Kilo</td>
<td>k</td>
</tr>
<tr>
<td>Mega</td>
<td>M</td>
</tr>
<tr>
<td>Giga</td>
<td>G</td>
</tr>
</tbody>
</table>

Understanding the different prefixes allows the correct units to be used in practical investigations, and also allows for easy conversion between different units.

\[
\text{initial unit (}10^a\text{)} \times \frac{10^b}{\text{changed unit (}10^c\text{)}} \times \text{value}
\]

**SAMPLE PROBLEM 5**

Convert:
- a. 12.412 millilitres to microlitres
- b. 26 153 milligram to decigram
- c. 8.7 metres to nanometres

**THINK**

a. 1. Determine the conversion between the units (millilitres / microlitres)
   2. Multiply this by the value to be converted
   3. Add the new unit

b. 1. Determine the conversion between the units (milligram / decigram)
   2. Multiply this by the value to be converted
   3. Add the new unit

c. 1. Determine the conversion between the units (metre / nanometre)
   2. We use $10^0$ for metres as it is our standard unit, so is equal to 1
   3. Multiply this by the value to be converted
   4. Add the new unit (round if required)

**WRITE**

- a. $10^-3 \times 12.412 \text{ mL} = 12412 \mu\text{L}$
- b. $10^-3 \times 26153 \text{ mg} = 261.53 \text{ dg}$
- c. $10^9 \times 8.7 \text{ m} = 870000000 \text{ nm}$
PRACTICE PROBLEM 5
Convert:

a. 738.3 micromole into nanomole
b. 8233 centimetres into kilometres.

SI units of measurement
SI units (or Système Internationale) are our metric system of measurements. It is an internationally standardised system.

<table>
<thead>
<tr>
<th>TABLE 14.14</th>
<th>Common SI units used in chemistry</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Quantity</strong></td>
<td><strong>Unit</strong></td>
</tr>
<tr>
<td>Length</td>
<td>Metre</td>
</tr>
<tr>
<td>Mass</td>
<td>Kilogram</td>
</tr>
<tr>
<td>Time</td>
<td>Second</td>
</tr>
<tr>
<td>Temperature</td>
<td>Kelvin</td>
</tr>
<tr>
<td>Electric current</td>
<td>Ampere</td>
</tr>
<tr>
<td>Amount of substance</td>
<td>Mole</td>
</tr>
<tr>
<td>Energy</td>
<td>Electron volt</td>
</tr>
</tbody>
</table>

Derived units

Derived units are units of measurements derived from the SI units.

Speed is an example of a quantity that is measured in derived SI units. The unit of enthalpy change is kilojoule per mole, derived from the SI unit of energy (joule) and SI unit mole which measures the number of particles in a given substance. Enthalpy is written as kJ/mol, or with a negative index, as kJ mol$^{-1}$.

<table>
<thead>
<tr>
<th>TABLE 14.15</th>
<th>Commonly used derived units used in chemistry</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Quantity</strong></td>
<td><strong>Unit</strong></td>
</tr>
<tr>
<td>Molar mass</td>
<td>Amu</td>
</tr>
<tr>
<td>Enthalpy change</td>
<td>Δ$H$</td>
</tr>
<tr>
<td>Energy and work</td>
<td>Joule</td>
</tr>
<tr>
<td>Pressure</td>
<td>Pascal</td>
</tr>
<tr>
<td>Temperature</td>
<td>Degrees Celsius</td>
</tr>
<tr>
<td>Density</td>
<td>d</td>
</tr>
<tr>
<td>Radiation dose</td>
<td>Sievert</td>
</tr>
</tbody>
</table>

14.9.6 Significant figures

There is a degree of uncertainty in any physical measurement. The uncertainty can be due to an error or to the limitations of the measuring instrument.

In most physical measurements, the last significant figure shows a small degree of uncertainty. For example, the length of an Olympic competition swimming pool is correctly expressed as 50.00 m. The last zero has a small degree of uncertainty.
Complicated by zeros

Two simple rules can be used to help you decide if zeros are significant.

- Zeros before the decimal point are significant if they are between non-zero digits. For example, all of the zeros in the numbers 4506, 27 034 and 602 007 are significant. Therefore, the numbers have four, five and six significant figures respectively. The zero in the number 0.56 is not significant.

- Zeros after the decimal point are significant if they follow a non-zero digit. For example, in the number 28.00, the two zeros are significant. The number has four significant figures. However, in the number 0.0028, the zeros are not significant (the one before the decimal point and the two after the decimal point). They do not follow a non-zero digit and are present only to indicate the position of the decimal point. Therefore, this number has only two significant figures. The number 0.002 80 has three significant figures.

**FIGURE 14.54** Examples of significant figures: (a) has three significant figures and (b) has five significant figures

Calculating significant figures

When multiplying or dividing, the answer is written to the least number of significant digits. When adding or subtracting, the answer is written to the least number of decimal places.

For example, if you knew a substance had a mass of 7.6 g and a molar mass of 18.5 g mol\(^{-1}\), the amount in mol would be given by:

\[
\text{mol} = \frac{\text{mass}}{\text{molar mass}} = \frac{7.6}{18.5} = 0.4108108 \text{ mol} = 0.41 \text{ mol}
\]

The result should be rounded off to two significant figures as this is the least number of significant figures we can be confident on.

When quantities are added or subtracted, the result should be expressed to the minimum number of decimal places used in the data. For example, if you measured three consecutive volumes of 23.4 mL, 24.63 mL and 20.123 mL, the total volume measured would be given by:

\[
23.4 + 24.63 + 20.123 = 68.153 \\
= 68.2
\]

The result should be rounded off to one decimal place because this was the minimum number of decimal places used in the data.
SAMPLE PROBLEM 6

In determining the density of a particular liquid, a student measured the volume of a sample as 8.3 mL. She then weighed the same sample and obtained a mass of 7.2136 g. Calculate the density to the correct level of significant figures.

THINK

a. 1. Determine the number of significant figures you have been provided.
   2. Determine the least number of significant figures—this is what your answer will be in
   3. Calculate the density
   4. Round down to the appropriate number of significant figures

WRITE

7.2136 = 5 significant figures
8.3 = 2 significant figures
2 significant figures

Density = \( \frac{7.2136}{8.3} = 0.8691 \)

Round 0.8691 to 2 significant figures

= 0.87 g mL\(^{-1}\)

PRACTICE PROBLEM 6

Sodium has a molar mass of 22.989 g mol\(^{-1}\). A sample was found to have a mass of 6.65381 g. What is the amount in mole of sodium?

14.9.7 Standard abbreviations

Writing out terms in each instance can make a scientific report bulky and hard to follow. Therefore, it is often appropriate to abbreviate frequently repeated terms.

In chemistry, we often shorten formulas instead of writing them out in full. This is particularly true with molecules such as water, for which the abbreviation H\(_2\)O is universally known.

Some common abbreviations used in chemistry are:

- IUPAC: International Union of Pure and Applied Chemistry
- pH: Potential of hydrogen
- UV: Ultraviolet
- AAS: Atomic absorption spectroscopy
- HPLC: High performance liquid chromatography
- ppm: Parts per million
- ppb: Parts per billion
- CF: Calibration factor
- IR: Infrared spectroscopy
- MS: Mass spectrometry
- NMR: Nuclear magnetic resonance
- SLC: Standard laboratory conditions
When using an abbreviation, write the word out in full on the first appearance followed by its abbreviation in brackets and then the abbreviation can be used in subsequent appearances.

For example:

Atomic absorption spectroscopy (AAS) was developed in Australia. In AAS, the concentrations of metal ions are detected.

14.9.8 Acknowledgement of references

An in-depth scientific report requires a depth of research for concepts relating to the investigation. This could include:

- using other sources for definitions and background material
- finding examples of similar investigations
- research on the obtained results to link to scientific understanding.

If you use any material that is the work of another person, you must acknowledge its source. Do not claim it as your own work. Acknowledgments come in two formats: a short version when it occurs in the body of your report or poster, and a longer version when it occurs in the Reference and Acknowledgments section at the end of your poster or scientific investigation.

There are many ways to make such acknowledgments, and various institutions and publications use different systems. Details of these systems can be found online and can be quite complicated. You should check with your teacher about which system they want you to use. Remember, you cannot mix systems so all your references, both in-text and in the References and Acknowledgments, must follow the same style.

Acknowledging sources within your report: In-text referencing

An in-text reference is an abbreviated form of a reference and should be used in the body of your report in the location the sourced information is referred to. It is used not just for direct quotes, but also for tables, images and any information that has been paraphrased.

There are numerous ways to use in-text references and these depends on what style you are using.

Author-date system

The author-date style of in-text referencing is the most commonly used, particularly in the APA and Harvard systems of referencing. As well as the shortened in-text referencing, a full reference is included in the reference list.

Text that has been sourced has the in-text reference at the end of the information being used. For example:

... over the past 10 years, the number of eligible children has increased (Kringle, 2008) and a need has therefore developed for sleighs to travel faster to meet the required delivery schedule. More efficient fuels are required for this purpose.

Tables, diagrams and graphs that are being inserted without being substantially altered can often be acknowledged by stating the details directly underneath them. Table 14.16 shows an example.

<table>
<thead>
<tr>
<th>TABLE 14.16 Energy content of commonly available sleigh fuels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>Rudolphene</td>
</tr>
<tr>
<td>Polar plus</td>
</tr>
<tr>
<td>Super sleigh</td>
</tr>
</tbody>
</table>

(Claus, 2016, p. 45)
There are some points to remember about in-text referencing using the author-date system. These include:

- if the online article is undated, put (n. d.) in place of the date
- if there is no author, use the title in place of the author’s name
- if there are up to three authors, list them all
- if there are more than three authors, only use the name of the first author and follow it with the phrase ‘et al’, which means ‘and others’
- if you quote directly from an author or cite a specific idea or piece of information from the source, you need to include the page number of the quote in your in-text reference.

**Footnotes system**

The footnotes system of in-text referencing is usually used in the Chicago and Vancouver systems. In this style, the citation is denoted by a superscript number showing the point in which a reference have been used. For example:

> ... over the past 10 years, the number of eligible children has increased⁵ and a need has therefore developed for sleighs to travel faster to meet the required delivery schedule. More efficient fuels are required for this purpose.

In the footnotes section of the page (depending on the format of the report) the work is referenced with the corresponding number, and is then included again in the reference list.


**Acknowledging sources at the end of your report: Reference list**

At the end of a scientific report or poster, a reference list is included. If you are using the author-date systems, your references should be listed alphabetically. If you are using the footnotes system, references should be listed in order of footnote number.

Following are examples showing references using the Harvard (author–date) system.

**Book**

*Author surname(s), initial(s) (Year published). Title. Edition (if applicable). Place of publication: publisher.*

*Example:*


Do not use et al. in your reference list. This is only appropriate in your in-text referencing.

**Journal**

*Author surname(s), initial(s) (Year published). Title of article. Title of Journal. Volume number. Page numbers.*

*Example:*


If available, you may also include the DOI (digital object identifier) after the page numbers. A DOI is a permanent identifier for a journal article and is often used in place of a URL.

**TV programs**

*Title of program (date), (TV program) Channel identification.*

*Example:*

Gene editing made simple (2016), (TV program), ABC Sydney.

**Websites**

Any websites you use in your report should be written for an academic target audience.

*Author surname(s), initial(s) (Year published). Title of page. Name of website, date and website of retrieval.*

*Example:*

14.9.9 Presenting a scientific poster

You will be assessed on two items: your logbook and your scientific poster. A sample format of the poster is shown in figure 14.55.

![Format of scientific poster](image)

### FIGURE 14.55 Format of scientific poster

<table>
<thead>
<tr>
<th>SCHOOL LOGO/OTHER IMAGE</th>
<th>TITLE</th>
<th>NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The question under investigation with a clear link to the independent and dependent variables</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INTRODUCTION</th>
<th>RESULTS</th>
<th>CONCLUSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Aim</td>
<td>• Presentation of collected data/evidence in an appropriate form to illustrate trends, patterns and/or relationships</td>
<td>• Provides a response to the question, referring to the aim and hypothesis</td>
</tr>
<tr>
<td>• Hypothesis</td>
<td>• May include graphs, images and tables with clear headings</td>
<td></td>
</tr>
<tr>
<td>• Purpose of the investigation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Background information</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>METHODOLOGY</th>
<th>DISCUSSION</th>
<th>REFERENCES/ACKNOWLEDGEMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Summary of the materials and method used that can be authenticated by logbook entries</td>
<td>• Analysis and evaluation of primary data: does it support your initial intentions and relevant theory?</td>
<td>• Referencing and acknowledgement of all quotations and sourced content</td>
</tr>
<tr>
<td>• Information about the choice of equipment and how variables were controlled</td>
<td>• Identification of outliers and their subsequent treatment</td>
<td></td>
</tr>
<tr>
<td>• Identification and management of relevant risks, including health, safety and ethics</td>
<td>• Discussion of sources of error</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Identification of limitations in data and methods, and suggested improvements</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Linking of results to relevant Chemistry concepts</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Outlining of possible next steps in the investigation</td>
<td></td>
</tr>
</tbody>
</table>

14.9.10 Practical investigation checklist

Before you submit your report, use the following checklist to make sure you have included everything you need to.

- Your name, the title and the aim/hypothesis are listed.
- An introduction describes the purpose and outlines the investigation in a logical and concise manner. Key terms are defined and variables are stated clearly. Relevant theory is addressed.
- The method is outlined clearly in step form and includes a consideration of ethics, health and safety. A risk assessment is provided.
- Your logbook contains dates, headings and complete records.
- Any abbreviations are explained.
- Results are presented in an organised way, in a table if possible. All relevant measurements are recorded with appropriate accuracy and units.
- Observations are clear and concise, as are all diagrams, graphs and tables.
- Any calculations are shown.
- There is a concise summary and interpretation of key findings, including trends and any unexpected results with connection to theory.
- The experimental design is evaluated and possible improvements are included.
- There are suggestions for future investigations.
- The conclusion concisely summarises how your results support or contradict your original hypothesis.
- All sources are acknowledged and references correctly cited.
- The use of key terms, symbols and equations is appropriate.
A poster or other form of scientific report should address the sections outlined in table 14.11 without going into too much detail. For example, you would display only a subset of the data to convey your findings and accuracy. Similarly, not all your graphs need appear.

14.9 EXERCISE
To answer questions online and to receive immediate feedback and sample responses for every question go to your learnON title at www.jacplus.com.au

1. Convert the following units to the SI base unit shown.
   (a) 142 mL (to L)
   (b) 0.67 kg (to g)
   (c) 762 184 µm (to m)

2. Convert the following to the unit shown.
   (a) 1.67 kg (to mg)
   (b) 198 µmol (to mmol)

3. Describe the following aspects of a scientific report.
   (a) Introduction
   (b) Discussion
   (c) Conclusion

4. Write a reference in Harvard style for this textbook. Show both the in-text referencing and the full reference for the reference list.

5. How many significant figures are in the following?
   (a) 760.4
   (b) 0.0109
   (c) 1.200
   (d) 4.08

6. Calculate the following and express your answer in the appropriate number of significant figures.
   (a) 4 + 9
   (b) 0.002 + 3.7
   (c) 5.9 + 70.4134
   (d) 0.80 − 0.2
   (e) 840 − 612.03
   (f) 62.098 + 6.72

7. Solve the following problems using the correct number of significant figures.
   (a) density = 63.45 g / 1.2 mL
   (b) mass = 23.713 g + 11.2 g
   (c) moles = 1.4 mol L⁻¹ × 2.05 L
   (d) m(Cu) = 1.8 mol × 63.5 g mol⁻¹

Fully worked solutions and sample responses are available in your digital formats.

14.10 Review
14.10.1 Summary
Key science skills in chemistry
- It is important to choose a topic that allows for the development of a question and observations to be made.
- Variables are factors that an investigator can control, change or measure.
- An independent variable is manipulated by the investigator (e.g. the type of metal examined).
- A dependent variable is measured by the investigator and is influenced by the independent variable (e.g. the melting temperature of a metal).
- A controlled variable is one that is kept the same in an investigation — there are usually numerous controlled variables in an experiment (e.g. the device used to record temperature, environmental factors such as air temperature and humidity, and the mass of the metal being investigated).
It is important to control variables in order to examine one independent variable at a time to better understand its relationship to the dependent variable.

An aim is a one to two sentence outline of the purpose the investigation, linking the dependent and independent variables.

A hypothesis is a tentative, testable and falsifiable statement for an observed phenomenon and acts as a prediction for the investigation.

Part of scientific method or process is designing an experiment, conducting the experiment and analysing the results.

Concepts specific to investigation

- Key terms can be defined as part of a scientific report or in a glossary.
- Key terms that are selected should be those that are vital to understand the investigation.
- There are various representations used in chemistry, including symbols, models, equations and formulas.
- Understanding various representations helps make communication easier and clearer.

Scientific research methodologies and techniques

- Primary sources of data are direct or firsthand evidence, often gained through practical investigations.
- Data can be quantitative (numerical) or qualitative.
- It is vital to carefully choose the best techniques and equipment for an investigation. These should be precise, accurate and easy to conduct within a school environment.
- In an investigation, it is vital to consider accuracy, precision, reliability and validity.
- Accuracy is how close a measurement is to a known value (like hitting the target on a bullseye).
- Precision is how close multiple measures are to each other (like hitting a six on a target three times in a row).
- Reliability shows that if an experiment is replicated (by oneself or another researcher), the results should be similar.
- Validity is how much credibility can be given to the results — do the results measure what they intended to and back up their claims?
- The best designed experiments are accurate, precise, reliable and valid, while minimising errors and uncertainties.

Ethics, and health and safety guidelines

- In an investigation, care must be taken to follow ethical, and health and safety guidelines.
- Ethics are involved in moral conduct, particularly when humans and animals are involved as test subjects — this does not tend to be an issue is chemistry compared with biology and psychology.
- Health and safety is often evaluated using a risk assessment, where different hazards are analysed and safety requirements are explained.

Methods of organising, analysing and evaluating primary data

- Data can be organised in a variety of ways, including through the use of tables and graphs.
- Scatterplots and line graphs are used when both variables are quantitative.
- Bar graphs are used when one piece of data is qualitative and the other is quantitative.
- Histograms are used when intervals and frequency are being explored.
- It is important to choose an appropriate method of organising data in order to effectively analyse trends, patterns and relationships.
- Graphs can be used to predict data outside of the investigated set.
- When evaluating data, it is important to link to scientific concepts, models and theories, link back to your aim and hypothesis, describe trends and patterns, and identify any outliers or limitations.
- Both errors and uncertainty can affect the results gained.
  - Errors are a measurement of the difference between a measured value and the true value (the accuracy).
  - Uncertainty is the limit to precision and the range of values that can be measured.
Model and theories to understand observed phenomena

- Models represent ideas, phenomena or scientific processes. They can be physical models, mathematical models or conceptual models.
- Limitations of models include an oversimplification of concepts, an inability to be completely accurate and being specific to a set of conditions, which may or may not reflect the real world.
- Theories are well-supported explanations of phenomena.
- Similar to models, theories are often oversimplifications of concepts, specific to a set of conditions and subject to change as new information becomes available.

Nature of evidence and the key findings of investigations

- Evidence can be used to support or reject a hypothesis. A hypothesis is not stated to be confirmed or proven true because new evidence can come to light, which later leads to its rejection.
- When reporting key findings, it is important to provide information about the data obtained in the practical investigation and any patterns and trends, show the relationship of your findings to chemistry concepts and provide an answer to the question of your investigation.

Conventions of scientific report writing and scientific poster presentation

- Both your logbook and scientific poster are forms of scientific reporting and combine for your mark for Unit 4 AOS 3.
- Components required in a scientific report are a title, date, name, introduction, aim, hypothesis, methodology (method and materials), results, discussion, conclusion and references.
- A variety of key symbols, formulas, equations, terminology, representations and abbreviations are used in chemistry and are required for effective communication.
- All sourced information must be correctly and clearly referenced using a style such as Harvard or APA.
- Your poster will not have every piece of information that your logbook will, but it will show the important and key points that will allow for a clear understanding of your investigation.

Resources

- Digital document  Topic summary – Topic 14 (doc-31428)

14.10.2 Key terms

- **accuracy** how close an experimental measurement is to a known value
- **aim** a statement outlining the purpose of an investigation, linking the dependent and independent variables
- **bar graphs** graphs in which data is represented by a series of bars. They are usually used when one variable is quantitative and the other is qualitative.
- **bias** the intentional or unintentional influence on a research investigation
- **categorical data** also known as qualitative data, this is when data has labels or names rather than a range of numerical quantities
- **column graphs** see **bar graphs**
- **conclusion** a section at the end of a report that relates back to the question, sums up key findings and states whether the hypothesis was supported or rejected
- **control group** a group that is not affected by the independent variables, and is used as a baseline for comparison
- **controlled variables** variables that are kept constant across different experimental groups
- **dependent variable** the variable that is influenced by the independent variable. It is the variable that is measured.
- **discussion** a detailed area of a report in which results are discussed, analysed and evaluated, relationships to concepts are made, errors, limitations and uncertainties are assessed, and suggestions for future improvements are made
error differences between a measurement taken and the true value that is expected; they lead to a reduction in the accuracy of the investigation
ethics acceptable and moral conduct determining what ‘right’ and what is ‘wrong’
experimental group test groups that are exposed to the independent variable
falsifiable there has to be a way to prove the hypothesis wrong
histograms a graph in which data is sorted in intervals and frequency is examined. This is used when both pieces of data are quantitative. Columns are not separated in a histogram.
hypothesis a tentative, testable and falsifiable statement for an observed phenomenon that acts as a prediction for the investigation
independent variable the variable that is changed or manipulated by an investigator
limitations factors that have impacted the interpretation and/or collection of findings in a practical investigation
line graphs graphs in which points of data are joined by a connecting line. These are used when both pieces of data are quantitative (numerical).
line of best fit a trend line that is added to a scatterplot to best express the data shown. These are straight lines, and are not required to pass through all points.
models representations of ideas, phenomena or scientific processes; they can be physical models, mathematical models or conceptual models
numerical data also known as quantitative data, this is when data involves numbers and can be measured or counted
outlier results that are a long way from other results and seen as unusual
precision how close multiple measurements of the same investigation are to each other
primary source direct or firsthand evidence about some phenomenon
qualitative data categorical data that examines the quality of something (i.e. colour, gender), rather than numerical values
quantitative data numerical data that examines the quantity of something (i.e. length, time).
random errors chance variations in measurements
reliability whether or not another researcher could repeat your investigation by following your method and obtain similar results
results a section in a report in which all data obtained is recorded, usually in the form of tables and graphs
risk assessment a document that examines the different hazards in an investigation and suggests safety precautions
scatterplots graphs in which two quantitative variables are plotted as a series of dots
scientific method sometimes referred to as scientific process, this is the procedure that must be followed in scientific investigations that consists of questioning, researching, predicting, observing, experimenting and analysing
scientific research methodology the principles of research based on the scientific method
secondary source comments on or summaries and interpretations of primary data
systematic errors errors that affect the accuracy of a measurement, that cannot be improved by repeating an experiment. They are usually due to equipment or system errors.
testable a hypothesis can be easily tested by observations and/or experiments
theory a well-supported explanation of a phenomena, based on facts that have been obtained through investigations, research and observations
validity credibility of the research results from experiments or from observations. Validity shows how much results measure what they intend to and how well they show the claims they make.

14.10 Exercises
To answer questions online and to receive immediate feedback and sample responses for every question go to your learnON title at www.jacplus.com.au
14.10 Exercise 1: Multiple choice questions

1. Belinda conducted an experiment to test the combustion of different types of fuel. In this experiment, type of fuel being tested is:
   A. the dependent variable
   B. the independent variable
   C. the controlled variable
   D. the control group.

2. Ben conducted an investigation to experimentally determine if the specific heat capacity of water is actually 4.18 J g\(^{-1}\) K\(^{-1}\). His experimental results are shown:

   \[
   \begin{align*}
   &6.28 \text{ J g}^{-1} \text{ K}^{-1} \\
   &6.24 \text{ J g}^{-1} \text{ K}^{-1} \\
   &6.47 \text{ J g}^{-1} \text{ K}^{-1}
   \end{align*}
   \]

   Which of the following statements is correct about his results?
   A. It was neither precise nor accurate.
   B. It was precise but not accurate.
   C. It was accurate but not precise.
   D. It was accurate and valid.

3. Paul was investigating how temperature impacted the rate of a reaction for the combustion of a fuel. He calculated this by determining the volume of carbon dioxide produced in the process. The results of his investigation are shown below.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Rate of reaction (mL of CO(_2) per minute)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.4</td>
</tr>
<tr>
<td>10</td>
<td>5.6</td>
</tr>
<tr>
<td>20</td>
<td>12.8</td>
</tr>
<tr>
<td>30</td>
<td>8.2</td>
</tr>
<tr>
<td>40</td>
<td>8.4</td>
</tr>
</tbody>
</table>

The most appropriate graph to use to show and analyse trends in this data is:
4. In the formula \( q = mc\Delta T \), \( \Delta T \) represents:
   A. the change in temperature
   B. the change in time
   C. the initial temperature
   D. the final temperature.

5. A ruler is shown below. The measure of uncertainty would be:
   A. 0.5 cm
   B. 0.1 cm
   C. 0.05 cm
   D. 0.025 cm.

6. One way to reduce systematic errors is to:
   A. repeat an experiment with the same piece of equipment
   B. make sure all equipment has been correctly calibrated
   C. make sure that the correct units are being recorded in results
   D. carefully follow practical instructions.

7. The difference between an aim and a hypothesis is:
   A. the aim of an experiment is a statement, but the hypothesis is a question
   B. the aim includes the dependent and independent variables, but the hypothesis doesn’t
   C. the aim explains the expected data, but the hypothesis explains how you will get the data
   D. the aim outlines the purpose of the investigation, but the hypothesis is a testable prediction.

8. Vic and Dan both competed to see who could do 100 push-ups the fastest. In a very close finish, it was found that Dan was 4.50 seconds faster than Vic. Which of the following correct about this result?
   A. It is equal to 4500 milliseconds.
   B. It contains 2 significant figures.
   C. It can be written as \( 450 \times 10^2 \) seconds.
   D. It is equal to 450 000 microseconds.

9. Theories are:
   A. concepts that were once accurate, but have now been rejected
   B. diagrammatic representations of abstract concepts
   C. ideas that are unable to be rejected due to the amount of evidence they have
   D. well-supported ideas where evidence has been gained from investigations, research and observations.
10. The conclusion section of a report should:
   A. include new information that has not been covered in other sections of the report
   B. include graphs that best outline the data
   C. link the findings of the investigation back to the hypothesis and question of the investigation
   D. describe any outliers and errors that occurred in the data.

14.10 Exercise 2: Short answer questions

1. An investigation was conducted to observe the differences in the energy content of carbohydrates, proteins and fats.
   a. Identify two pieces of quantitative data that you could record and measure.
   b. What instruments, if any, would you need to make these observations?
   c. Identify two pieces of qualitative data that you could observe.
   d. What instruments, if any, would you need to make these observations?

2. Identify a key difference between the members of the following pairs.
   a. Independent and dependent variables
   b. Models and theories
   c. Systematic and random errors
   d. Primary and secondary sources of data
   e. Uncertainty and error

3. In an investigation conducted in class, Jayde recorded a temperature of 812.010 °C.
   a. How many significant figures does this recorded temperature have?
   b. Write this temperature in scientific notation.

4. Chris used gas chromatography (GC) to measure the ethanol content of some alcoholic beverages. GC works on a similar principle to high-performance liquid chromatography (HPLC). In both instruments, it is necessary to produce a calibration curve in addition to obtaining readings for the test samples. One such calibration curve is shown below.

   ![Calibration Curve](image)

   a. Sample A produced a reading of 36000 from the GC. Estimate the level of ethanol in this sample.
   b. Sample B produced a reading of 50500. Estimate the level of ethanol in this sample and comment on your answer.
   c. Sample C produced a reading of 95000. Is it possible to estimate the ethanol level in this sample? Explain why or why not.
   d. Write a conclusion for this investigation.
5. The following is an extract from a student’s logbook where the temperature was recorded at regular intervals during an experiment.

Initial temperature = 15.0 °C

Temperature every 30 seconds after initial recording in °C: 16.5, 18.1, 19.5, 20.8, 22.4, 23.7, 24.0, 23.9, 23.5, 23.2

a. Using graph paper, plot the data in the most appropriate table, including a scale and labels.
b. Describe the trends and patterns in this graph.
c. What conclusions would you make from this investigation?

6. An investigation was being conducted to examine how changing the pressure affects the volume of a gas.

a. Write a suitable aim for this investigation.
b. Write a suitable hypothesis.
c. Design an investigation that could be used to test this.

14.10 Exercise 3: Exam practice questions

Question 1 (10 marks)
Vicki decided to investigate how the rate of reaction is affected by the concentration of acid. She weighed out 3.00 g of calcium carbonate powder and put it in a balloon. She put on some safety gloves and added 50 mL of 1.0 M hydrochloric acid to a flask. She then weighed the balloon and the flask and recorded her results. Vicki then stretched the balloon over the opening of the flask before mixing the two chemicals. When the bubbling stopped, she weighed the balloon and flask again. She repeated the experiment again using 3.00 g of calcium carbonate powder but used 50 mL of 2.0 M hydrochloric acid. She found that changing the concentration had little effect on the rate of reaction because there was hardly any change in mass.

a. Comment on the safety precautions taken. Do you think they were sufficient? 2 marks
b. Identify the dependent variable in this investigation. 1 mark
c. List two variables that need to be controlled in this investigation? 1 mark
d. Describe what measuring equipment should be used in this investigation and identify one factor that could affect the accuracy of this piece of equipment 2 marks
e. Vicki’s method is flawed as it does not allow for the rate of the reaction to be measured as mass should be conserved (due to the conservation of mass). Write a clear experimental method for Vicki that shows how she can investigate how the concentration of hydrochloric acid affects the rate of a reaction. You may need to add to her method to make sure that more data is being collected and to ensure it is reproducible 4 marks

Question 2 (10 marks)
An investigation was being conducted to examine how changing the pressure affects the volume of a gas.

a. Write a suitable aim for this investigation. 1 mark
b. Identify the hypothesis for this investigation. 1 mark
c. Describe one piece of qualitative data and one piece of quantitative data that may be collected in this investigation 2 marks
d. Explain two factors that may lead to differences in results between different students 2 marks
e. Design an investigation that could be used to test this 4 marks

Question 3 (8 marks)
A student conducted an experiment, examining the rate of production of hydrogen gas and magnesium oxide from hydrochloric acid and magnesium. The student used the same amount of magnesium in all experiments, but altered the concentration of the pH.
The student recorded how long it took for hydrogen bubbles to first appear. The results from this investigation are shown below:

<table>
<thead>
<tr>
<th>Concentration of HCl (mol L(^{-1}))</th>
<th>Time for hydrogen bubbles to appear (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>10.2</td>
</tr>
<tr>
<td>1</td>
<td>8.2</td>
</tr>
<tr>
<td>2</td>
<td>5.3</td>
</tr>
<tr>
<td>3</td>
<td>3.0</td>
</tr>
<tr>
<td>4</td>
<td>1.5</td>
</tr>
<tr>
<td>5</td>
<td>0.8</td>
</tr>
</tbody>
</table>

a. On the axes provided below:
- Plot the graph showing the data provided, ensuring that the time is shown on the vertical axis (this is different compared to other line graphs you may have drawn)
- Label the graph and axes as appropriate
- Draw a straight line of best fit in one colour
- Draw a smooth line joining the points in another colour

b. Describe the trends seen in your data

c. Explain the differences between your line of best fit and your line joining the points. Which is better for this data?

Question 4 (8 marks)
Two students, Joe and Robert wanted to explore if the energy content of carbohydrates was 16.7 kilojoules per gram. They used a pack of corn chips to investigate this, each testing five corn chips. Their results are shown in the table below:

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Joe Energy content (kJ g(^{-1}))</th>
<th>Robert Energy content (kJ g(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14.2</td>
<td>10.1</td>
</tr>
<tr>
<td>2</td>
<td>12.9</td>
<td>10.5</td>
</tr>
<tr>
<td>3</td>
<td>16.2</td>
<td>9.90</td>
</tr>
<tr>
<td>4</td>
<td>11.1</td>
<td>11.1</td>
</tr>
<tr>
<td>5</td>
<td>15.6</td>
<td>12.0</td>
</tr>
</tbody>
</table>
a. Describe one error that may have occurred which reduced the accuracy of the data for both Joe and Robert and identify how this error may be avoided? 2 marks

b. Calculate the average energy content recorded by Robert, using correct significant figures based on the data provided (2 marks)

c. Describe, with reference to the known value of the energy content of carbohydrates, why the results obtained by Joe are more accurate than those obtained by Robert. 2 marks

d. It was found that the average energy content recorded by Joe was 14.0 kJ g$^{-1}$. Convert this to J g$^{-1}$. 

Question 5 (12 marks)

A student conducted an investigation to explore the different boiling points of organic molecules containing 3 carbons.

The student’s report is shown below:

Introduction: In this experiment, various 3-carbon organic compounds were investigated. The substances being explored were propanoic acid, propan-1-ol, propan-2-ol, propanone and propanal. This investigation was conducted in the laboratory and all substances were slowly heated to a maximum temperature of 100 °C and the boiling point was recorded. Propane was not included in this investigation as it was already a gas at room temperature.

Aim: To examine if different carbon containing compounds have different boiling points.

Hypothesis: If various three-carbon containing organic molecules are heated, then propanoic acid will have the highest boiling point.

Method:

1. Set up 5 beakers. Label each with the organic compound.
2. Pour the organic compound in the appropriate beaker.
3. Place a thermometer in the liquid- record the initial temperature.
4. Place the first beaker above the bunsen burner, using a tripod and gauze mat.
5. Heat the liquid to 100 °C, recording the temperature of boiling.
6. Repeat with the next liquid.

<table>
<thead>
<tr>
<th></th>
<th>Initial temperature</th>
<th>Boiling point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propanoic acid</td>
<td>20.0 °C</td>
<td>&gt;100 °C</td>
</tr>
<tr>
<td>Propan-1-ol</td>
<td>25.0 °C</td>
<td>95.0 °C</td>
</tr>
<tr>
<td>Propan-2-ol</td>
<td>24.0 °C</td>
<td>83.5 °C</td>
</tr>
<tr>
<td>Propanone</td>
<td>23.5 °C</td>
<td>59.0 °C</td>
</tr>
<tr>
<td>Propanal</td>
<td>23.5 °C</td>
<td>49.5 °C</td>
</tr>
</tbody>
</table>

a. Describe an issue with the hypothesis written by the student. How would you adjust this to make it testable? 2 marks

b. In the experiment, the substances were only heated to a maximum of 100 °C. Explain why this may lead to errors in the data obtained. 2 marks

c. Students were only able to use a thermometer in which temperature could only be measured to the nearest 0.5 °C. Identify the tolerance of this device and describe the uncertainty expected in the data. 2 marks

d. Outline two limitations in the experimental method or data collection process that would affect the conclusions drawn? 2 marks

e. Describe the most appropriate graph that the student should use to represent their data. Justify your choice. 2 marks

f. Based on the student’s results, write a conclusion for this investigation, linking back to the hypothesis. 2 marks