Performing practical investigations and writing clear and concise reports are essential skills in chemistry. In this chapter, you will find guidelines for carrying out practical tasks safely and preparing thorough reports using appropriate scientific conventions.

All truths are easy to understand once they are discovered; the point is to discover them.

Galileo Galilei
Research investigations

A research investigation is an exploration of a scientific question or questions and presentation of findings. In outcome 3 you have the opportunity to find out more about an aspect of the chemistry of materials that you have studied in Unit 1. This will involve researching for information, evaluating it, interpreting it and presenting it in a cohesive, accurate and detailed report.

Planning

1. Decide whether you are going to record your information electronically or in a notebook.
2. This is a great opportunity to investigate a topic that interests you. You can also select from the suggested questions provided in each of the options. Alternatively, after a discussion with your teacher, you may prefer to respond to questions of your own choosing or have a combination of both. Typical questions could begin with how, why, what, when, who or where. Record the questions that you are going to investigate. These questions may change as you start researching.
3. Once the key questions have been decided, it is time to commence the research using the abundance of available sources. Switching on the computer and looking on the internet is one way of doing research; other sources include books, newspapers, scientific magazines, podcasts, videos, people with expertise in the relevant field and the many organisations that can provide valuable material. It is wise to use a variety of resources so that the information is not biased or limited by a narrow perspective. Your teacher and librarians at school and public libraries can point you in the right direction.
4. When doing web searches, use key words. Make use of an advanced search to find a key phrase, recent document or a particular file type such as ppt or doc. Assess websites carefully and identify the point of origin. Government websites and those from educational institutions and established organisations are usually reliable; when using other websites, it is a good idea to look for authors and dates to see if the information is verifiable and current. Evaluate your information by comparing it with other websites or other sources.
5. Record your information in an organised way. Prepare a separate page for each question and set up a table with headings such as:
   - Date accessed
   - Information (to be written in your own words). Dot points are adequate at this stage.
   - Reference: List all of the sources of your information; use correct bibliographical procedure and record this as you are writing down information.
   - Comment: For example, useful/not useful, detailed/little information.
   Once you have recorded information from a few sources, read your notes carefully and write it as if you were explaining it to another person, using your own words and sentence structure.
6. Analyse and interpret your information. Remember to note any gaps in the information or the presence of competing opinions, which is also useful. You can organise the information using highlighters to collate different groups of ideas or sections. Write a rough plan showing the flow of the report.
7. Decide how you will present your report. Do not plagiarise the material; this means that it is not acceptable to just change a few words or reorganise the sentence. If you are quoting another person, make this clear by using quotation marks, and remember to cite the author.
Presentation of findings

There are various ways of presenting a report, including written format, poster, slideshow, video, animation and oral presentation. Remember to include your name on the front page on a written report. Your report needs a title that is not too general but gives a good idea of what it is about. For example, 'The relationship between structure and properties of metals' is preferable to 'Metals.' The title and introductory paragraph can be written at the end of the drafting process because the final content will be established at this point. The introduction describes the focus of your investigations, the structure of the report and possibly the reasons for your explorations. Some definitions and the scope of the research may be useful early in your report.

Tables and images can provide added interest; however, they need to be relevant and referenced. Some images are copyright; a search through Creative Commons or using ‘usage rights’ in an advanced Google search engine will help you access copyright-free images.

Use correct and relevant terminology and explain all scientific terms; look up definitions while you are taking notes.

Divide the report into paragraphs and, where necessary, use subheadings to separate ideas. Take care with punctuation, spelling and grammar.

Finally, the conclusion should summarise and tie together the findings of the report and reflect back on the introductory paragraph. It might provide the opportunity to suggest areas for further investigation, but it should not include any new information. A bibliography, written in the correct format, is the way to end the report. There are many helpful online sites for writing a bibliography correctly.

Final checklist

Have you:
• understood your topic sufficiently
• used your own words
• included an introduction with an outline of what the topic is about
• communicated the information clearly, logically and accurately
• used correct chemical units and terminology
• explained important scientific terms
• referred to relevant chemical theories or models
• checked whether your information is reliable and trustworthy
• considered related ethical, environmental and social impacts where necessary
• referenced all diagrams and tables
• presented the report in an appropriate and succinct form that would be understood by a fellow student at this level
• written a concluding paragraph that relates back to the introduction
• provided a detailed bibliography?

Practical investigations

In Unit 2, outcome 3 you can use your developing experimental skills to investigate a question related to water quality. You will be doing a practical investigation that uses laboratory or fieldwork to respond to a question. A practical investigation involves considerable planning, expertise in working scientifically to design a method, record results, analyse findings and communicate conclusions. You will be familiar with the usual format of a practical report (see table 10.1).
TABLE 10.1 Format of a practical report

<table>
<thead>
<tr>
<th>Title</th>
<th>short heading related to the investigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aim</td>
<td>what you are investigating and why</td>
</tr>
<tr>
<td>Hypothesis</td>
<td>what you think will happen; often an ‘if/then’ statement is used</td>
</tr>
<tr>
<td>Method</td>
<td>outline of the steps in your procedure</td>
</tr>
<tr>
<td>Materials</td>
<td>list of chemicals and equipment used</td>
</tr>
<tr>
<td>Results</td>
<td>includes the data collected, usually in a table</td>
</tr>
<tr>
<td>Discussion</td>
<td>describes whether your data supports the hypothesis</td>
</tr>
<tr>
<td>Conclusion</td>
<td>relates to the aim and summarises the findings of the investigation</td>
</tr>
</tbody>
</table>

Procedure

1. Start a logbook; scraps of paper can be easily lost. This could be an electronic logbook. Record everything in your logbook, including dates, questions, changes in method, observations and results.
2. In consultation with your teacher, decide on a question to investigate.
3. Consider ethical and environmental implications of your question.
4. Write a short and relevant title. This may change as the investigation progresses.
5. Record your hypothesis, which is an educated guess about what you think will happen.
6. Review the theory related to your topic.
7. Plan your method. Which variables will you keep constant? What quantity will you be measuring? Will it be a fair test? Can you complete it in the time given? Are the chemicals and materials accessible?
8. List the steps in the method. These need to be explicit enough so that someone else could repeat your experiment.
9. Consider safety implications. Refer to the section on safety on the next page.
10. Prepare a materials list. Be specific about quantities and equipment required, including size of beakers, measuring cylinders etc.
11. Do an initial rough trial, and modify the method if necessary.
12. Prepare a results table with appropriate headings and units.
13. Do your experiment, and repeat it if possible to reduce random errors.
14. Record detailed observations and results as accurately as possible. Photos can be useful here.
15. Complete calculations to the correct number of significant figures. Use scientific notation as required.

Writing your report

1. Choose how you will present your report, as this will affect which of the following points are relevant.
2. Include your name.
3. Check with your teacher whether you need an abstract, which is a brief summary of the question examined, method, general results and findings.
4. Record your final title, hypothesis, materials, method and safety assessment.
5. Include your table of results, photos or diagrams. Include fully labelled graphs where applicable.
6. The discussion is particularly important. You do not need to repeat your results. Identify any trends and relate them to the theory. Comment on any unexpected results. Suggest any sources of error and possible modifications to the experiment. Discuss difficulties and suggest future investigations. Check that you have used correct scientific terminology and conventions.
7. In the conclusion, state whether the hypothesis is supported. The conclusion should relate to the aim and include no new information.
8. Check punctuation, spelling and grammar.
9. Include any references used and acknowledge assistance received from external sources.
10. Refer to the criteria sheet to ensure that you have addressed every point thoroughly.

**General safety rules**

Some general safety precautions will help to ensure that you and others will not be injured in the laboratory.

- Wear protective clothing. This might include laboratory coat, safety glasses and gloves.
- Be aware of the position of safety equipment such as fire blanket, fire extinguisher and safety shower.
- Ask if you are unsure of 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.
- Read instructions carefully before commencing an experiment.
- Prepare a risk assessment for required chemicals and equipment.

**Risk assessments**

Risk assessment is a procedure for identifying hazardous chemicals, what the risks are and how to work safely with them. Table 10.2 lists the usual requirements for a written risk assessment.

**TABLE 10.2 Requirements for a written risk assessment**

<table>
<thead>
<tr>
<th>Summary of method</th>
<th>brief list of steps indicating how the chemicals and equipment will be used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemicals used</td>
<td>list of chemicals used and their concentrations</td>
</tr>
<tr>
<td>Chemical hazards</td>
<td>details of the hazards caused by the chemicals. These can be found by looking at the SDS (safety data sheets), which can be accessed online.</td>
</tr>
<tr>
<td>Risk control methods</td>
<td>precautions taken to limit risks. This will depend on the chemicals involved.</td>
</tr>
<tr>
<td>Equipment</td>
<td>list of materials used in the experiment</td>
</tr>
<tr>
<td>Equipment risk</td>
<td>list of hazards associated with the equipment</td>
</tr>
<tr>
<td>Risk control measures</td>
<td>how the risks associated with the equipment will be minimised</td>
</tr>
</tbody>
</table>

**TABLE 10.3 Sample risk assessment**

<table>
<thead>
<tr>
<th>Assessor (name)</th>
<th>Bonny Bunsen</th>
<th>Date of activity</th>
<th>10/02/2016</th>
<th>Class/Year level</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title and outline of experiment</td>
<td>Flame test</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A wire inoculating loop is placed in HCl, and then dipped into the chemical to be tested. The loop is then held in the Bunsen flame.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Amount and concentration</th>
<th>Hazards — risk phrases</th>
<th>Controls — safety phrases</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCl, hydrochloric acid</td>
<td>20 mL, 2M</td>
<td>Harmful if swallowed</td>
<td>Do not breathe gas/fumes/vapour. Avoid contact with eyes.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Toxic by inhalation</td>
<td>Wear suitable protective clothing.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Causes severe burns</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Risk of serious damage to eyes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Skin contact may produce health damage.</td>
<td></td>
</tr>
</tbody>
</table>

(continued)
### Chemicals and Hazards

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Amount and concentration</th>
<th>Hazards — risk phrases</th>
<th>Controls — safety phrases</th>
</tr>
</thead>
</table>
| SrNO₃, strontium nitrate | solid                   | Risk of explosion by shock, friction, fire or other sources of ignition  
Contact with combustible material may cause fire.  
Irritating to skin and eyes  
Moderately toxic | Keep away from combustible material.  
Do not breathe dust.  
Avoid contact with skin.  
Wear eye/face protection.  
Wear gloves. |
| CuCl₂, copper chloride | solid                   | Toxic if swallowed  
Skin and eye irritant  
Risk of serious damage to eyes | Do not breathe dust.  
Avoid contact with eyes.  
Wear suitable protective clothing.  
Wear gloves. |
| BaCl₂, barium chloride | solid                   | Harmful by inhalation  
Toxic if swallowed | Do not breathe dust.  
Wear suitable protective clothing.  
In case of insufficient ventilation, wear suitable respiratory equipment. |
| NaCl, sodium chloride | solid                   | Not hazardous | |

**Risk control for all chemical experiments**
- Small quantities used
- Safety goggles, gloves, wash hands after use, laboratory coats and closed shoes
- Chemical labels, instructions for mixing and disposing of chemicals must be followed.
- Obey Science Safety Rules.

**Disposal**
- Very little waste produced
- Contaminated acid can be disposed of via sink with plenty of water.

**Other risk controls**

**Assessor (signed)**: Bonnie Bansen  
**Date of record**: 10/2/2016

### Revision questions

1. **Draw a plan of your laboratory and label the positions of safety equipment.**
2. **Describe the equipment hazards involved in heating a beaker of water.**
3. **(a) Identify and record the hazards involved when using 2.0M sodium hydroxide solution.**
   (b) **Suggest appropriate safety precautions.**

### Working with figures

**Scientific notation**

When working with the sizes of atoms, we are dealing with very, very small numbers and yet, when working with numbers of atoms, we need to use very, very large numbers. For example, depending on how it is calculated, there are 33 500 000 000 000 000 000 water molecules in a drop of water. It is really not convenient to write these figures with large numbers of zeroes before or after the decimal point. Using scientific notation this number is written as $3.35 \times 10^{19}$ water molecules.

There are two parts to scientific notation; the first part is the first digit of the number, and the second part is a decimal point followed by the remaining digits. This is multiplied by 10 raised to the power that returns the number to its original value.
Sample problem 10.1

Write 37 769 using scientific notation.

Solution:

\[ 37\ 769 = 3.7769 \times 10^4 \]

Remember that the power of 10 is positive if the number is greater than 1 and negative if the number is less than 1. On a calculator, the \(^{\wedge}\) key is used to raise 10 to a particular power. Scientific notation is also called standard form.

Revision questions

4. Express the following measurements using scientific notation:
   (a) A red blood cell is about 0.000 008 m across.
   (b) A flea is about 0.0013 m long.
   (c) The moon is 384 400 000 metres from the Earth.

5. Convert each of the following numbers to scientific notation.
   (a) 6942
   (b) 248
   (c) 0.000 49
   (d) 3.17
   (e) 0.0082
   (f) 64 500

6. Convert each of the following numbers from scientific notation to an ordinary number.
   (a) \(7.21 \times 10^{-4}\)
   (b) \(5.739 \times 10^5\)
   (c) \(1.552 \times 10^1\)
   (d) \(7.112 \times 10^0\)
   (e) \(4.71 \times 10^2\)
   (f) \(2.577 \times 10^{-6}\)
   (g) \(9.179 \times 10^{-5}\)

Significant figures

Every measurement that you make has an inherent level of uncertainty. This is due in part to the limitations of the measuring equipment itself and in part to user interpretation. Significant figures are one means of recognising these limitations. We say that significant figures indicate the level of precision in a measurement. When reading a scale, read it to \(\frac{1}{10}\) of the smallest division in the scale.

Sample problem 10.2

What is the reading on this burette?

Solution:

The reading at the bottom of the meniscus is 29.65 mL.

Revision questions

7. Record the reading on the burette in this diagram.
8. Explain why a student reading this burette as 8.67 mL is incorrect.

How do we count significant figures?

When calculations are to be made from different measurements, it is important that we are able to assess the number of significant figures in each measurement. We can then quote the answer to an appropriate level of precision.

In assessing the number of significant figures in a measurement, we use two rules:

- All non-zero digits are counted.
- Zeros are counted if they come after a non-zero digit.

Examples

- A burette reading of 21.37 mL has 4 significant figures.
- A pipette reading of 20.00 mL has 4 significant figures.
- A measurement of 100 mL from a gas syringe has 3 significant figures.
- A mass of 1.003 g has 4 significant figures.
- A mass of 0.003 g has 1 significant figure.
- A mass of 0.300 g has 3 significant figures.

*Note: Significant figures are not the same as decimal places. If a measurement is expressed in standard form, significant figures are counted from the decimal part only. For example, the Avogadro constant, when expressed as 6.02 × 10²³, contains 3 significant figures. The digits in the index are not counted.*

Significant figures and calculations

The number of significant figures allowed in any calculated answer is governed by the number of significant figures in the least precise value from which that answer is calculated.

If a calculation involves defined conversion constants, these are not counted. Remember that it is only the measurements that are considered.

Working with 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.

Sample problem 10.3

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 precision.
Solution: \[ \text{density} = \frac{\text{mass}}{\text{volume}} \]

\[
\begin{align*}
7.2136 & \quad (5 \text{ significant figures}) \\
8.3 & \quad (2 \text{ significant figures}) \\
\end{align*}
\]

\[
\frac{7.2136}{8.3} = 0.8691 \quad (\text{This needs to be rounded to } 2 \text{ significant figures.})
\]

\[= 0.87 \text{ g mL}^{-1} \]

Revision questions

9. How many significant figures are there in each of the following measurements?
   (a) 256 litres
   (b) 43 001 grams
   (c) 0.230 °C
   (d) 21.0 mL

10. Calculate the following to the correct number of significant figures.
   (a) 4.25 + 9
   (b) 0.04 + 3.7
   (c) 5.640 + 70.435
   (d) 0.80 − 0.3
   (e) 840 − 627.03
   (f) 12.01 + 6.7

11. Solve the following problems using the correct number of significant figures in the answers.
   (a) density = 27.8 grams/1.2 mL =
   (b) mass = 23.45 grams + 5.332 grams =
   (c) moles = 1.221 M × 2.6 L =
   (d) \( m(Cu) \) = 0.45 mol × 63.5 g mol\(^{-1} \) =

Errors and uncertainties

The ideas of errors and uncertainties are related to the topic of significant figures.

Errors cause the value of a measurement to change. The errors associated with taking a measurement cause its value to be different from the true value. Errors (no matter how small) are present in every measurement we make. There are two types of errors:

- Random errors cause measurements to be sometimes higher than their true values and sometimes lower. The effect of random errors can therefore be minimised by doing a large number of measurements and averaging them.
- Systematic errors are always biased the same way. In other words, they cause values to be always too high or always too low. The effect of systematic errors cannot be minimised by multiple observations and averaging.

Uncertainty is an extension of significant figures. A plus/minus notation is used to indicate the possible range of values for the last significant figure. For example, when using an electronic balance, a student might record the result as:

\[ 35.964 \pm 0.002 \text{ g} \]

As discussed above, the use of 35.964 indicates that the ‘4’ is the digit that we are least certain of. The ‘4’ is our ‘best estimate.’ The uncertainty of \( \pm 0.002 \) indicates how uncertain we are. In effect, we are stating that the measured mass could reasonably be expected to lie between 35.962 g and 35.966 g.
Effective study techniques to improve your results

Setting up a study routine
- Find a quiet place to study, whether it is at home or at a library.
- Prepare a realistic study timetable that takes into account sporting, work and other commitments.
- Study for about an hour and then take a short break. Use a timer on your computer to assist you.
- Limit your time spent on individual subjects; you will get more done if you realise that time is short.
- Put away all sources of distraction, including your mobile phone, and do not access any social networking sites.
- Reward yourself for persisting with your timetable.

Study skills
- Review each lesson as soon as practical after the class, highlighting/noting main points and learning terminology.
- Complete homework on time.
- Read the textbook regularly.
- Study the concepts and practise calculations. If you have any questions, put a sticky note on the page. Ask a friend first; if you are unable to get a satisfactory answer, ask your teacher.
- Make sure that the information is actively processed; reading is not an adequate study technique. Methods for processing information include using concept maps, preparing flash cards, writing a summary, telling a story, drawing a labelled diagram, making a video, creating a slide show, writing a song, creating a mnemonic, using a Venn diagram, recording a podcast or brainstorming using a large sheet of paper. Don’t fall into the trap of spending so long preparing these materials that you don’t have time to study them.
- A very effective way of learning is to teach someone else.
- Studying with a friend or small group can be very useful.
- Retaining information will be maximised with regular review and repetition.
- There are numerous excellent websites and YouTube videos that explain various concepts.
- Do past exams, preferably to time; analyse your mistakes and relearn the concept, rather than just writing the correct answers. Ask yourself if the mistakes are due to mathematical errors, not reading the question properly, lack of knowledge or lack of understanding. Learn from your mistakes.

Revision questions
12. In your opinion, what are the five most important study hints?
13. Record four strategies used by other students in the class to review concepts.
Exam preparation
- Eat healthily.
- Exercise regularly.
- Learn to relax; practising meditation could be beneficial.
- Have a good night’s sleep before the actual exam.
- Organise the necessary materials the night before.
- Arrive in good time.
- Be positive.

The exam

Using reading time effectively
- Read the whole paper, particularly the last pages.
- Decide which questions you will do first: that is, the ones that you think you can do easily. You will gain confidence and have more time for the other questions.
- Consider the units given in a question and the units required in the answer.
- Check multiple choice questions for qualifying words such as not, always and all.
- Plan time for each section and stick to it.

Getting the best results in writing time
- Read questions carefully and highlight relevant data.
- Remember that multiple choice questions are worth only 1 mark so move on if you are unable to answer a question. Answer all multiple choice questions, eliminate incorrect alternatives and guess if you have to.
- Use a diagram for analysis questions.
- Balance chemical equations and include states.
- Think about the terminology required in a question and use it appropriately.
- Try to answer all questions. It is easier to get half of the whole exam correct than all of half the exam correct!
- Be aware of the difference between a and the; for example, ‘write a structure (equation) for . . .’ versus ‘write the structure (equation) for . . .’
- When drawing structures, make sure that each atom has the correct number of bonds.
- If you find a question particularly difficult, read it carefully, highlight relevant information and come back to it later.
- If you are feeling stressed, take a minute to have a few deep breaths and relax.

Calculations
- Set work out clearly and show all working. Make your answer obvious.
- Give full information; for example, use ‘n(NaCl) =’ not just ‘n =’.
- Check formulas and molar masses.
- Make sure you use the correct number of significant figures throughout the whole question.
- Consequential marks apply in chemistry so, even if you know you have an incorrect answer but do not know why, continue with the calculations.