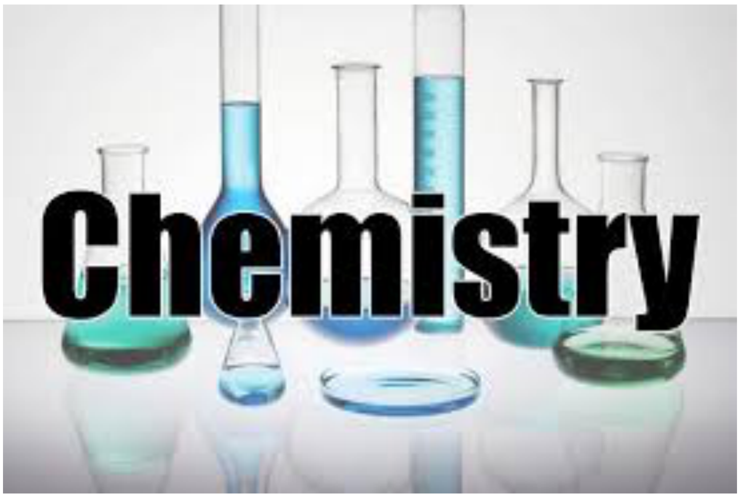
SWINBURNE
SENIOR SECONDARY COLLEGE



Summer Holiday Homework 2020-2021

Name: ____

Teacher:
DrT
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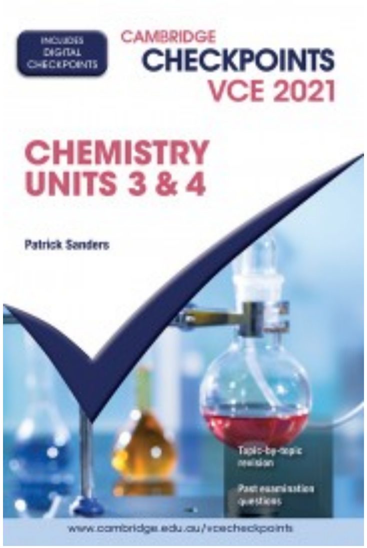
Textbook & Other resources:

Chemistry 2, Heinemann 5th edition (units 3 & 4), Pearson

CheckPoints Chemistry 2021, Cambridge Press



Edrolo Chemistry (via School website)

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Edrolo

Scope of study

Chemistry explores and explains the composition and behaviour of matter and the chemical processes that occur on Earth and beyond. Chemical models and theories are used to describe and explain known chemical reactions and processes. Chemistry underpins the production and development of energy, the maintenance of clean air and water, the production of food, medicines and new materials, and the treatment of wastes.

VCE Chemistry enables students to explore key processes related to matter and its behaviour. Students consider the relationship between materials and energy through four themes: the design and composition of useful materials, the reactions and analysis of chemicals in water, the efficient production and use of energy and materials, and the investigation of carbon-based compounds as important components of body tissues and materials used in society. Students examine classical and contemporary research, models and theories to understand how knowledge in chemistry has evolved and continues to evolve in response to new evidence and discoveries. An understanding of the complexities and diversity of chemistry leads students to appreciate the interconnectedness of the content areas both within chemistry, and across chemistry and the other sciences.

An important feature of undertaking a VCE science study is the opportunity for students to engage in a range of inquiry tasks that may be self-designed, develop key science skills and interrogate the links between theory, knowledge and practice. In VCE Chemistry inquiry methodologies can include laboratory experimentation, modelling, site tours, fieldwork, local and remote data-logging, simulations, animations, literature reviews and the use of global databases. Students work collaboratively as well as independently on a range of tasks. They pose questions, formulate hypotheses and collect, analyse and critically interpret qualitative and quantitative data. Students analyse the limitations of data, evaluate methodologies and results, justify conclusions, make recommendations and communicate their findings. They investigate and evaluate issues, changes and alternative proposals by considering both shorter and longer term consequences for the individual, environment and society. Knowledge of the safety considerations, including use of safety data sheets, and ethical standards associated with chemical investigations is integral to the study of VCE Chemistry.

As well as an increased understanding of scientific processes, students develop capacities that enable them to critically assess the strengths and limitations of science, respect evidence-based conclusions and gain an awareness of the ethical, social and political contexts of scientific endeavours.

Aims

This study enables students to:

• apply models, theories and concepts to describe, explain, analyse and make predictions about chemical phenomena, systems, structures and properties, and the factors that can affect them

• understand and use the language and methodologies of chemistry to solve qualitative and quantitative problems in familiar and unfamiliar contexts and more broadly to:

• understand the cooperative, cumulative, evolutionary and interdisciplinary nature of science as a human endeavour, including its possibilities, limitations and political and sociocultural influences

• develop a range of individual and collaborative science investigation skills through experimental and inquiry tasks in the field and in the laboratory

• develop an informed perspective on contemporary science-based issues of local and global significance

• apply their scientific understanding to familiar and unfamiliar situations including personal, social, environmental and technological contexts

• develop attitudes that include curiosity, open-mindedness, creativity, flexibility, integrity, attention to detail and respect for evidence-based conclusions

• understand and apply the research, ethical and safety principles that govern the study and practice of the discipline in the collection, analysis, critical evaluation and reporting of data

• communicate clearly and accurately an understanding of the discipline using appropriate terminology, conventions and formats.

Contribution to final assessment (VCAA points towards ATAR)

Unit 3

Outcomes	Marks allocated*	Assessment tasks
Outcome 1 Compare fuels quantitatively with reference to combustion products and energy outputs, apply knowledge of the electrochemical series to design, construct and test galvanic cells, and evaluate energy resources based on energy efficiency, renewability and environmental impact.	50	Analysis and evaluation of stimulus material. OR A report on a laboratory investigation. OR A comparison of two electricity-generating cells. OR A reflective learning journal/blog related to selected activities or in response to an issue. (approximately 50 minutes or not exceeding 1000 words)
Outcome 2 Apply rate and equilibrium principles to predict how the rate and extent of reactions can be optimised, and explain how electrolysis is involved in the production of chemicals and in the recharging of batteries.	50	At least one task selected from: • annotations of at least two practical activities from a practical logbook • a report of a student investigation • an evaluation of research • analysis of data including generalisations and conclusions • media analysis/response • a graphic organiser illustrating a chemical process • an analysis of an unfamiliar chemical manufacturing process or electrolytic cell • a response to a set of structured questions. (approximately 50 minutes or not exceeding 1000 words for each task)
Total marks	**100**	

*School-assessed Coursework for Unit 3 contributes 16 per cent.

Unit 4

Outcome 1 Compare the general structures and reactions of the major organic families of compounds, deduce structures of organic compounds using instrumental analysis data, and design reaction pathways for the synthesis of organic molecules.	30	At least one task selected from: • annotations of at least two practical activities from a practical logbook • a report of a student investigation • analysis of data including generalisations and conclusions • media analysis/response • a response to a set of structured questions • a reflective learning journal/blog related to comparison of organic structures or pathways. (approximately 50 minutes or not exceeding 1000 words for each task)
Outcome 2 Distinguish between the chemical structures of key food molecules, analyse the chemical reactions involved in the metabolism of the major components of food including the role of enzymes, and calculate the energy content of food using calorimetry.	30	Response to stimulus material. OR A report of a laboratory investigation. OR A comparison of food molecules OR A reflective learning journal/blog related to selected activities or in response to an issue. (approximately 50 minutes or not exceeding 1000 words)
Outcome 3 Design and undertake a practical investigation related to energy and/or food, and present methodologies, findings and conclusions in a scientific poster.	30	A structured scientific poster according to the VCAA standard template. (not exceeding 1000 words)
Total marks	**90**	

*School-assessed Coursework for Unit 4 contributes 24 per cent.

End-of-year examination

Description

The examination will be set by a panel appointed by the VCAA. All the key knowledge that underpins the outcomes in Units 3 and 4 and the cross-study key science skills are examinable.

Conditions

The examination will be completed under the following conditions:

- Duration: 2.5 hours.
- Date: end-of-year, on a date to be published annually by the VCAA.
- VCAA examination rules will apply. Details of these rules are published annually in the *VCE and VCAL Administrative Handbook*.
- The examination will be marked by assessors appointed by the VCAA.

Unit 3

Area of Study 1

<u>What are the options for energy production?</u>

In this area of study students focus on analysing and comparing a range of energy resources and technologies, including fossil fuels, biofuels, galvanic cells and fuel cells, with reference to the energy transformations and chemical reactions involved, energy efficiencies, environmental impacts and potential applications. Students use the speci c heat capacity of water and thermochemical equations to determine the enthalpy changes and quantities of reactants and products involved in the combustion reactions of a range of renewable and non-renewable fuels.

Students conduct practical investigations involving redox reactions, including the design, construction and testing of galvanic cells, and account for differences between experimental findings and predictions made by using the electrochemical series. They compare the design features, operating principles and uses of galvanic cells and fuel cells, and summarise cell processes by writing balanced equations for half and overall cell processes.

Area of Study 2

How can the yield of a chemical product be optimised?

In this area of study students explore the factors that increase the efficiency and percentage yield of a chemical manufacturing process while reducing the energy demand and associated costs.

Students investigate how the rate of a reaction can be controlled so that it occurs at the optimum rate while avoiding unwanted side reactions and by-products. They explain reactions with reference to the collision theory including reference to Maxwell-Boltzmann distribution curves. The progression of exothermic and endothermic reactions, including the use of a catalyst, is represented using energy pro le diagrams.

Students explore homogeneous equilibrium systems and apply the equilibrium law to calculate equilibrium constants and concentrations of reactants and products. They investigate Le Chatelier's principle and the effect of different changes on an equilibrium system and make predictions about the optimum conditions for the production of chemicals, taking into account rate and yield considerations. Students represent the establishment of equilibrium and the effect of changes to an equilibrium system using concentration-time graphs.

Students investigate a range of electrolytic cells with reference to their basic design features and purpose, their operating principles and the energy transformations that occur. They examine the discharging and recharging processes in rechargeable cells, and apply Faraday's laws to calculate quantities in electrochemistry and to determine cell efficiencies.

Unit 4

Area of Study 1

How can the diversity of carbon compounds be explained and categorised?

In this area of study students explore why such a vast range of carbon compounds is possible. They examine the structural features of members of several homologous series of compounds, including some of the simpler structural isomers, and learn how they are represented and named.

Students investigate trends in the physical and chemical properties of various organic families of compounds. They study typical reactions of organic families and some of their reaction pathways, and write balanced chemical equations for organic syntheses.

Students learn to deduce or confirm the structure and identity of organic compounds by interpreting data from mass spectrometry, infrared spectroscopy and proton and carbon-13 nuclear magnetic resonance spectroscopy.

Area of Study 2

What is the chemistry of food?

Food contains various organic compounds that are the source of both the energy and the raw materials that the human body needs for growth and repair. In this area of study students explore the importance of food from a chemical perspective.

Students study the major components of food with reference to their structures, properties and functions. They examine the hydrolysis reactions in which foods are broken down, the condensation reactions in which new biomolecules are formed and the role of enzymes, assisted by coenzymes, in the metabolism of food.

Students study the role of glucose in cellular respiration and investigate the principles of calorimetry and its application in determining enthalpy changes for reactions in solution. They explore applications of food chemistry by considering the differences in structures of natural and artificial sweeteners, the chemical significance of the glycaemic index of foods, the rancidity of fats and oils, and the use of the term 'essential' to describe some amino acids and fatty acids in the diet.

Area of Study 3

Practical investigation

A student-designed or adapted practical investigation related to energy and/or food is undertaken in either Unit 3 or Unit 4, or across both Units 3 and 4. The investigation relates to knowledge and skills developed across Unit 3 and/or Unit 4. The investigation requires the student to identify an aim, develop a question, formulate a hypothesis and plan a course of action to answer the question and that complies with safety and ethical requirements. The student then undertakes an experiment that involves the collection of primary qualitative and/or quantitative data, analyses and evaluates the data, identi es limitations of data and methods, links experimental results to science ideas, reaches a conclusion in response to the question and suggests further investigations which may be undertaken. Findings are communicated in a scienti c poster format according to the template on page 11. A practical logbook must be maintained by the student for record, authentication and assessment purposes.

Holiday Homework
first section

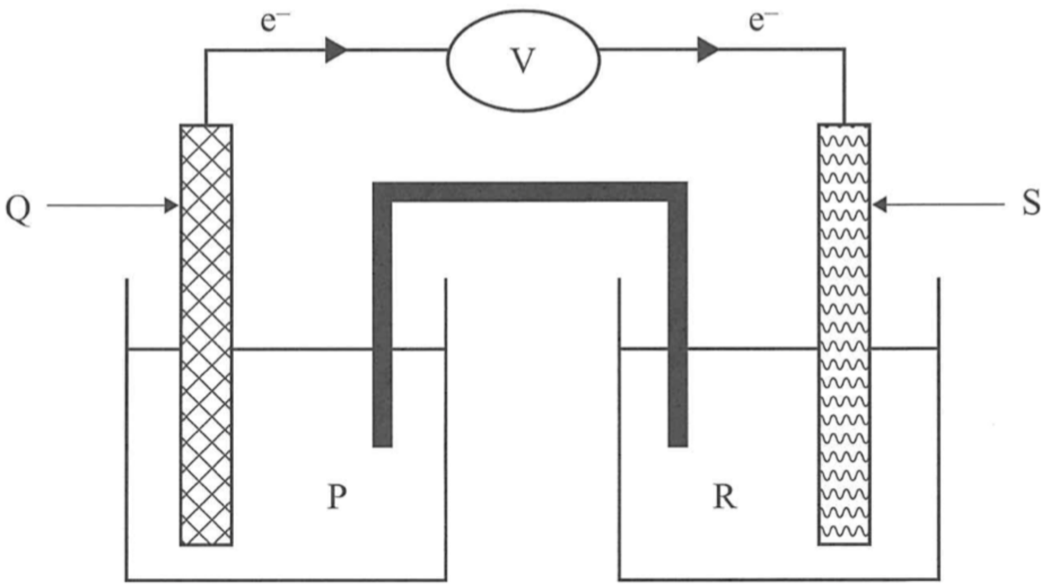
This course material will be covered as part of the standard Chemistry course, however, enthusiastic students can attempt some 'flipped-learning' before this – have fun!

Main areas of study in *first section* are (i) Redox, (ii) Galvanic Cells and (iii) Electrolytic Cells

B.O.B. (Suggested solutions) to first section

1. C	11. A	21. C	31. B
2. B	12. D	22. C	32. D
3. C	13. D	23. D	33. D
4. B	14. C	24. B	34. D
5. D	15. A	25. A	35. D
6. A	16. C	26. D	
7. B	17. A	27. A	
8. C	18. C	28. A	
9. D	19. A	29. B	
10. C	20. D	30. A	

1.
A diagram of an electrochemical cell is shown below.



Which of the following gives the correct combination of
(i) the electrode in the oxidation half-cell
and
(ii) the electrolyte in the reduction half-cell?

	Electrode (oxidation half-cell)	Electrolyte (reduction half-cell)
A.	S	P
B.	S	R
C.	Q	R
D.	Q	P

2.
A zinc-carbon dry cell battery has a potential of +1.50 V measured at standard conditions. The two half-reactions that occur in this battery are shown in the following equations.

Equation 1 $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^{-}$
Equation 2 $MnO_2(s) + H_2O(l) + e^{-} \rightarrow MnO(OH)(s) + OH^{-}(aq)$

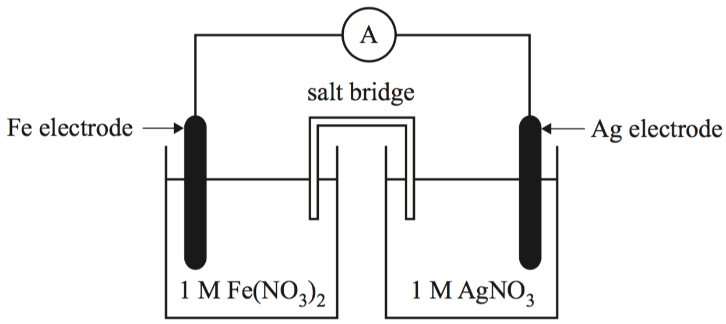
Assuming standard conditions, the electrode potential of Equation 2 is

A. + 2.26 V
B. + 0.74 V
C. - 0.74 V
D. - 2.26 V

3.
A galvanic cell consists of two connected half-cells that can produce an electron flow.
Which combination of standard half-cell pairs would be expected to result in a cell potential of 1.41 V?

A.	Al electrode with $Al(NO_3)_3$	Ag electrode with $AgNO_3$
B.	Zn electrode with $Zn(NO_3)_2$	Ni electrode with $Ni(NO_3)_2$
C.	Ni electrode with $Ni(NO_3)_2$	Al electrode with $Al(NO_3)_3$
D.	Ag electrode with $AgNO_3$	Zn electrode with $Zn(NO_3)_2$

4.
A galvanic cell is set up as shown in the diagram below.



When this cell is operating

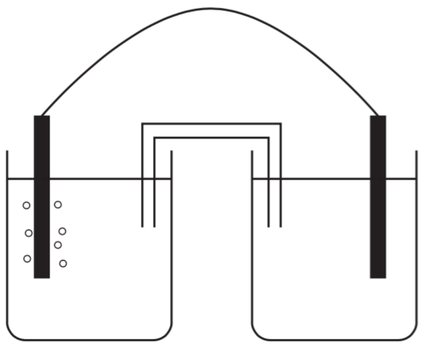
A. a gas forms at the Ag electrode.

B. the mass of the Ag electrode increases.

C. Ag^{+} ions move towards the Fe electrode.

D. electrons move from the Ag electrode to the Fe electrode.

5.

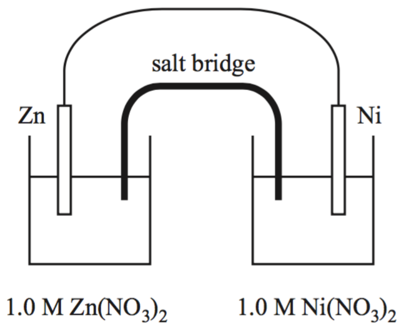


A galvanic cell is set up as shown in the diagram above. Bubbling is observed at one of the electrodes. From this evidence it can be stated that

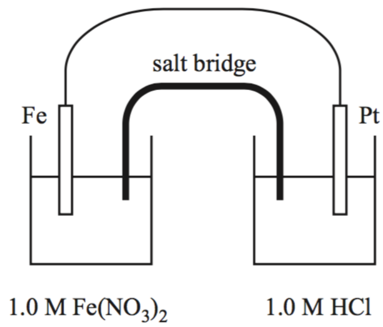
A. the bubbles observed must be hydrogen, H_2.
B. electrons must be flowing across the salt bridge.
C. the two electrodes cannot be made of the same material.
D. there is not enough information to form a valid conclusion.

6.
Which one of the following galvanic cells will produce the largest cell voltage under standard laboratory conditions (SLC)?

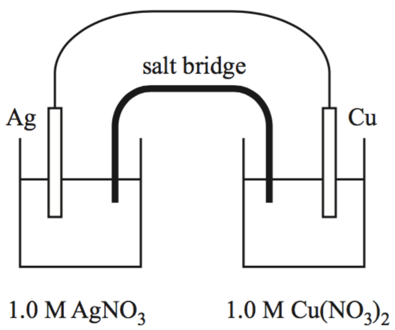
A.



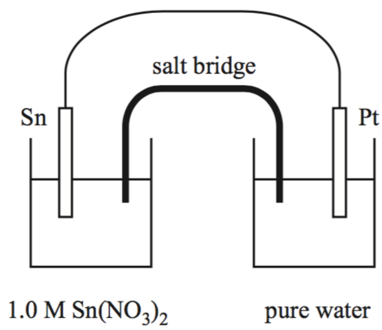
B.



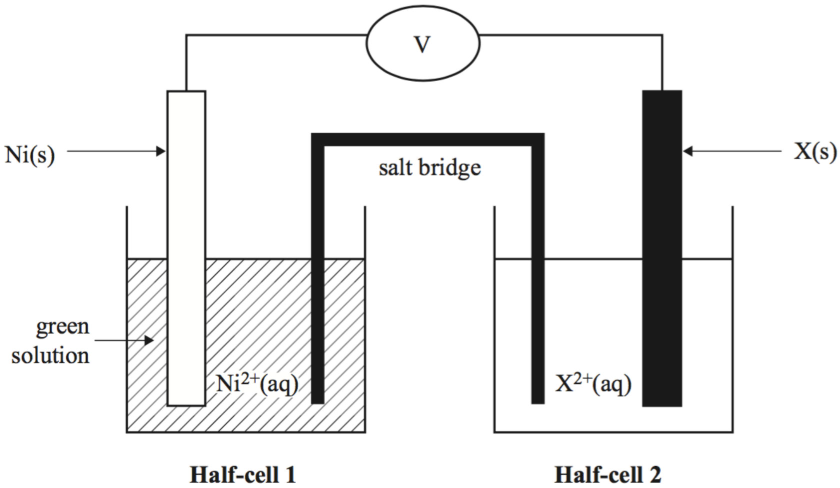
C.



D.



7.
At the start of the day, a student set up a galvanic cell using two electrodes: nickel, Ni, and metal X. This set-up is shown in the diagram below.



Consider the following alternative metals that could be used to replace metal X :

1. zinc, Zn 2. lead, Pb 3. cadnium, Cd 4. copper, Cu

At the end of the day, the student checked the colour of the solution in **Half-cell 1** and observed that the solution was a darker green colour.

Which of the alternative metals could cause the colour of **Half-cell 1** to become a darker green?

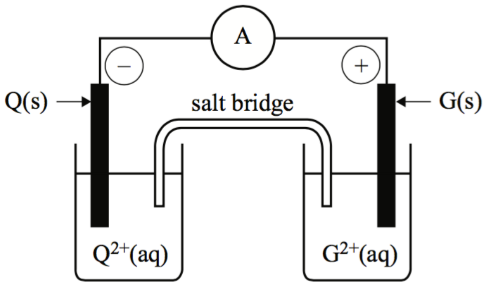
A. metals 1 and 3
B. metals 2 and 4
C. metals 1, 2 and 3
D. metals 3 and 4

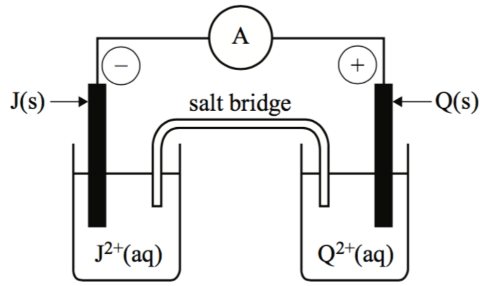
8.
The following digrams represent combinations of four galvanic half-cells (G/G^{2+}, J/J^{2+}, Q/Q^{2+} and R/R^{2+}) that were investigated under standard conditions.

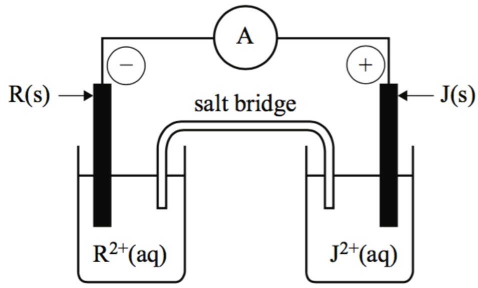
Each half-cell consisted of a metal electrode placed in a 1.0 $\frac{mol}{L}$ nitrate solution of the respective metal ion.

The diagram shows the polarity of the electrodes in each half-cell, as determined using an ammeter.

The results were then used to determine the order of the E^o value of the half-reactions.







Which of the following indicates the order of the half-cell reactions, from the lowest E^o value to the highest?

A. $J/J^{2+}, R/R^{2+}, G/G^{2+}, Q/Q^{2+}$
B. $Q/Q^{2+}, G/G^{2+}, R/R^{2+}, J/J^{2+}$
C. $R/R^{2+}, J/J^{2+}, Q/Q^{2+}, G/G^{2+}$
D. $G/G^{2+}, Q/Q^{2+}, J/J^{2+}, R/R^{2+}$

9.

Some strips of the metals, iron (Fe), zinc (Zn), and silver (Ag), were placed in separate beakers, each containing 1.0 $\frac{mol}{L}$ nickel (II) sulfate solution ($NiSO_4$(aq)) in water at $25°C$.

What is expected to occur over time?

A. Ni will be deposited in all of the beakers.
B. Ni will not be deposited in any of the beakers.
C. A reaction will occur only in the beaker containing Ag.
D. A reaction will occur only in the beakers containing Fe and Zn.

10.
An aqueous solution of ethanol, CH_3CH_2OH, left exposed to the air, will undergo a redox reaction with oxygen, O_2, to form ethanoic acid, CH_3COOH.

The half-equation for the oxidation reaction is

A. $O_2(g) + 4H^+(aq) + 4e^- \rightarrow H_2O(l)$

B. $O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$

C. $CH_3CH_2OH(aq) + H_2O(l) \rightarrow CH_3COOH(aq) + 4H^+(aq) + 4e^-$

D. $CH_3CH_2OH(aq) + \frac{1}{2}O_2(g) \rightarrow CH_3COOH(aq) + 2H^+(aq) + 2e^-$

11.
Some scientists are exploring batteries that utilise the metals potassium (K) or calcium (Ca) as anode components.

If all other aspects of the cell are the same, a cell using Ca would produce more current because

A. Ca produces more electrons per mole than K.

B. K produces more electrons per mole than Ca.

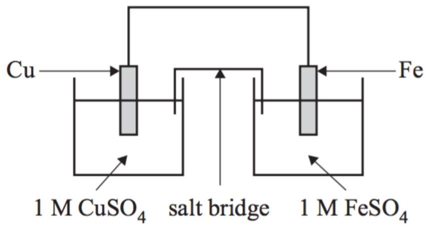
C. K produces a higher voltage than Ca.

D. Ca has a higher molar mass than K.

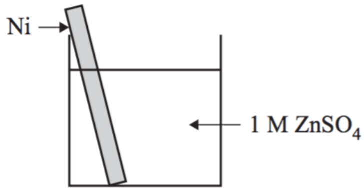
12.

Which one of the following produces heat energy as its main energy output?

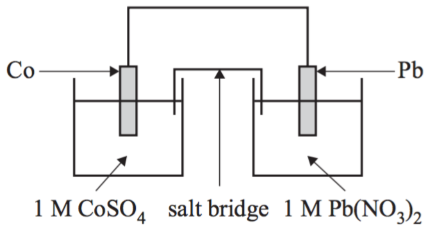
A.



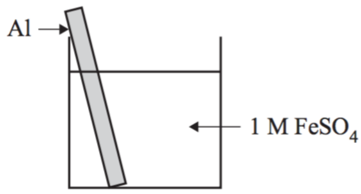
B.



C.



D.



13.
The following reactions occur in a primary cell battery.

$$Zn + 2OH^- \rightarrow ZnO + H_2O + 2e^-$$
$$2MnO_2 + 2e^- + H_2O \rightarrow Mn_2O_3 + 2OH^-$$

Which one of the following statements about the battery is correct?

A. The reaction produces heat and Zn reacts directly with MnO_2.
B. The reaction produces heat and Zn does not react directly with MnO_2.
C. The reaction does not produce heat and Zn reacts directly with MnO_2.
D. The reaction does not produce heat and Zn does not react directly with MnO_2.

14.
Consider the following half-equation.

$$ClO_2(g) + e^- \rightleftharpoons ClO_2^-(aq)$$

It is also know that:
* $ClO_2(g)$ will oxidise $HI(aq)$, but not $HCl(aq)$
* $Fe^{3+}(aq)$ will oxidise $HI(aq)$, but not $NaClO_2(aq)$

Based on this information, $Fe^{2+}(aq)$ can be oxidised by

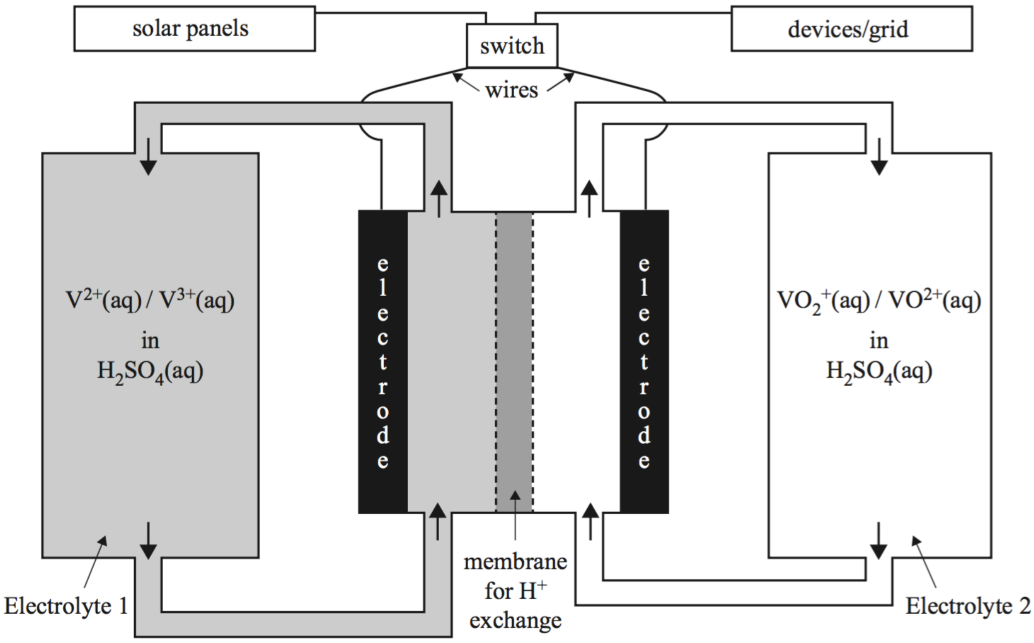
A. $Cl_2(g)$ and $I_2(aq)$
B. $Cl_2(g)$, but not $ClO_2(g)$
C. $ClO_2(g)$ and $Cl_2(g)$, but not $I_2(aq)$
D. $ClO_2(g)$, $Cl_2(g)$ and $I_2(aq)$

15.

part 1

An increasingly popular battery for storing energy from solar panels is the vanadium redox battery. The battery takes advantage of the four oxidation states of vanadium that are stable in aqueous acidic solutions in the absence of oxygen.

A schematic diagram of a vanadium redox battery is shown below.



The two relevant half-equations for the battery are as follows.

$$VO_2^+(aq) + 2H^+(aq) + e^- \rightarrow VO^{2+}(aq) + H_2O(l) \qquad E^o = +1.00\ V$$

$$V^{3+}(aq) + e^- \rightarrow V^{2+}(aq) \qquad E^o = -0.26\ V$$

The overall reaction that occurs when the battery is discharging is

A. $VO_2^+(aq) + 2H^+(aq) + V^{2+}(aq) \rightarrow VO^{2+}(aq) + V^{3+}(aq) + H_2O(l)$

B. $VO^{2+}(aq) + H_2O(l) + V^{3+}(aq) \rightarrow VO_2^+(aq) + V^{2+}(aq) + 2H^+(aq)$

C. $VO^{2+}(aq) + V^{2+}(aq) + 2H^+(aq) \rightarrow 2V^{3+}(aq) + H_2O(l)$

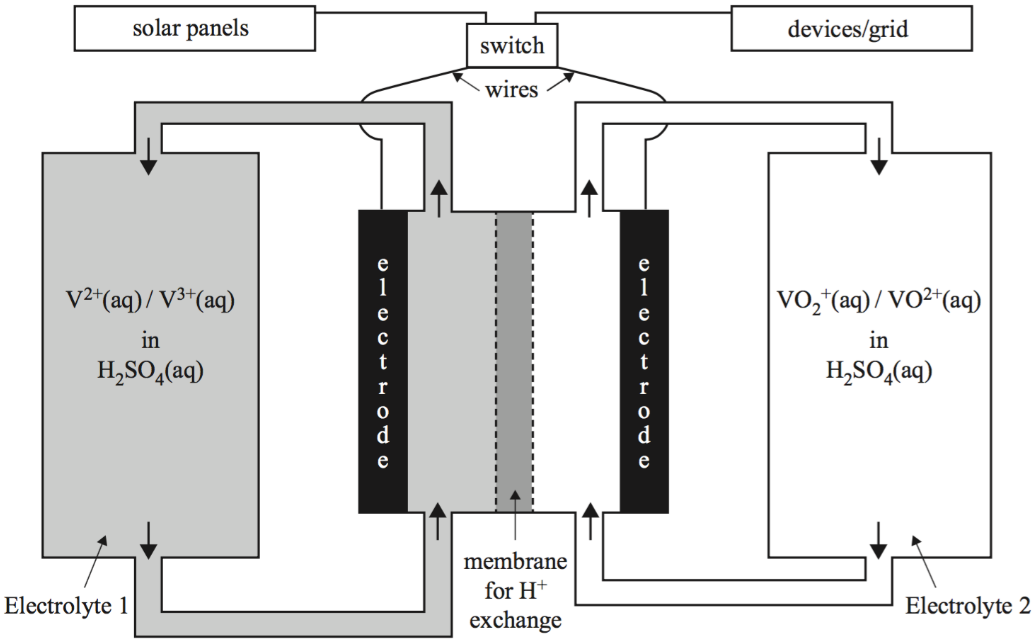
D. $VO_2^+(aq) + V^{3+}(aq) \rightarrow 2VO^{2+}(aq)$

16.

part 2

An increasingly popular battery for storing energy from solar panels is the vanadium redox battery. The battery takes advantage of the four oxidation states of vanadium that are stable in aqueous acidic solutions in the absence of oxygen.

A schematic diagram of a vanadium redox battery is shown below.



The two relevant half-equations for the battery are as follows.

$$VO_2^+(aq) + 2H^+(aq) + e^- \rightarrow VO^{2+}(aq) + H_2O(l) \qquad E^o = +1.00\ V$$
$$V^{3+}(aq) + e^- \rightarrow V^{2+}(a\square) \qquad E^o = -0.26\ V$$

If air is present, the following half-equations are also relevant.

$$O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O(l) \qquad E^o = +1.23\ V$$
$$VO^{2+}(aq) + 2H^+(aq) + e^- \rightarrow V^{3+}(aq) + H_2O(l) \qquad E^o = +0.34\ V$$

If air is present, the

A. $VO^{2+}(aq)$ ion is oxidised to the $V^{2+}(aq)$ ion.

B. $VO^{2+}(aq)$ ion is reduced to the $V^{3+}(aq)$ ion.

C. $V^{2+}(aq)$ ion is oxidised to the $VO^{2+}(aq)$ ion.

D. $VO_2^+(aq)$ ion is reduced to the $VO^{2+}(aq)$ ion.

17.

When molten sodium chloride ($NaCl$) is electrolysed, the product formed at the cathode is

A. sodium liquid, Na.
B. hydrogen gas, H_2.
C. chlorine gas, Cl_2.
D. oxygen gas, O_2.

18.
A molten mixture of equal parts aluminium fluoride (AlF_3) and sodium chloride ($NaCl$) undergoes electrolysis. Which one of the following statements about this reaction is correct?

A. Sodium metal will be produced at the cathode and fluorine gas will be produced at the anode.

B. Sodium metal will be produced at the anode and chlorine gas will be produced at the cathode.

C. Aluminium metal will be produced at the cathode and chloride gas will be produced at the anode.

D. Aluminium metal will be produced at the anode and fluorine gas will be produced at the cathode.

19.
Which one of the following statements is the **most** accurate?

A. All fuel cells are galvanic cells.
B. All galvanic cells are primary cells.
C. All secondary cells have porous electrodes.
D. All fuel cells are more efficient than all secondary cells.

20.
All fuels cells

A. are rechargeable and have electrodes that are separated.

B. are galvanic cells and the required reactants are stored in the cells.

C. are rechargeable and the reactants are stored externally and continuously supplied.

D. convert chemical energy into electrical energy and the reactants are continuously supplied.

21.
The overall reaction for an acidic fuel cell is shown below.

$$2H_2 + O_2 \rightarrow 2H_2O$$

Porous electrodes are often used in acidic fuel cells because they

A. are highly reactive.
B. are cheap to produce and readily available.
C. are more efficient than solid electrodes at moving charges and reactants.
D. provide a surface for the hydrogen and oxygen to directly react together.

22.
The overall equation for a particular methanol fuel cell is shown below.

$$2CH_3OH(g) + 3O_2(g) \rightarrow 2CO_2(g) + 4H_2O(l)$$

The equation for the reaction that occurs at the cathode in this fuel cell is

A. $CO_2(g) + 5H_2O(l) + 6e^- \rightarrow CH_3OH(g) + 6OH^-(aq)$

B. $CH_3OH(g) + 6OH^-(aq) \rightarrow CO_2(g) + 5H_2O(l) + 6e^-$

C. $O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$

D. $4OH^-(aq) \rightarrow O_2(g) + 2H_2O(\square) + 4e^-$

23.
The cathode reaction for a particular alkaline fuel cell is given below.

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$

The only product of the overall fuel cell reaction is water, H_2O.

The half-equation that represents the anode reaction is

A. $H_2 \rightarrow 2H^+ + 2e^-$
B. $H_2 + O^{2-} \rightarrow H_2O + 2e^-$
C. $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$
D. $H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$

24.
Consider the following statement about galvanic cells and fuel cells.

Statement number	**Statement**
1	The overall reaction is exothermic.
2	Electrons are consumed at the negative electrode.
3	Both the reducing agent and the oxidising agent are stored in each half-cell.
4	The electrodes are in contact with the reactants and the electrolyte.
5	The production of electricity requires the electrodes to be replaced regularly.

Which one of the following sets of statements is correct for **both** galvanic cells and fuel cells?

A. statement numbers 2 and 3
B. statement numbers 1 and 4
C. statement numbers 2, 4 and 5
D. statement numbers 1, 3 and 5

25.
Which one of the following pairs of statements is correct for both electrolysis cells and galvanic cells?

	Electrolysis cell	**Galvanic cell**
A.	Both electrodes are always inert.	Both electrodes are always made of metal.
B.	Electrical energy is converted to chemical energy.	The voltage of the cell is independent of the electrolyte concentration.
C.	Chemical energy is converted to electrical energy.	The products are dependent on the half-cell components.
D.	The products are dependent on the half-cell components.	Chemical energy is converted to electrical energy.

26.
Which one of the following is the most correct statement about fuel cells and secondary cells?

A. Fuel cells can be recharged like secondary cells.

B. Fuels cells produce thermal energy, whereas secondary cells do not produce thermal energy.

C. The anode in a fuel cell is positive, whereas the anode in a secondary cell is negative.

D. Fuel cells deliver a constant voltage during their operation, whereas secondary cells reduce in voltage as they discharge.

27.
The silver oxide-zinc battery is rechargeable and utilises sodium hydroxide, $NaOH$, solution as the electrolyte. The battery is used as a backup in spacecraft, if the primary energy supply fails.

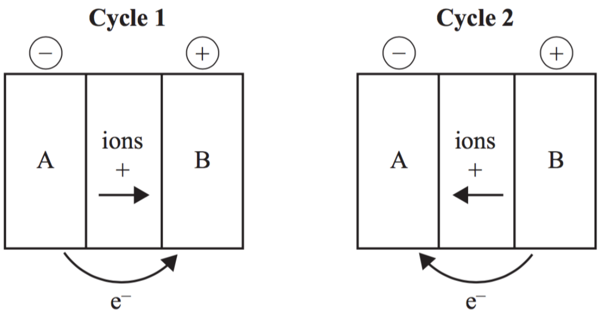
The overall reaction during discharge is

$$Zn + Ag_2O \rightarrow ZnO + 2Ag$$

When the silver oxide-zinc battery is being **recharged**, the reaction at the anode is

A. $2Ag + 2OH^- \rightarrow Ag_2O + H_2O + 2e^-$
B. $Ag_2O + H_2O + 2e^- \rightarrow 2Ag + 2OH^-$
C. $ZnO + H_2O + 2e^- \rightarrow Zn + 2OH^-$
D. $Zn + 2OH^- \rightarrow ZnO + H_2O + 2e^-$

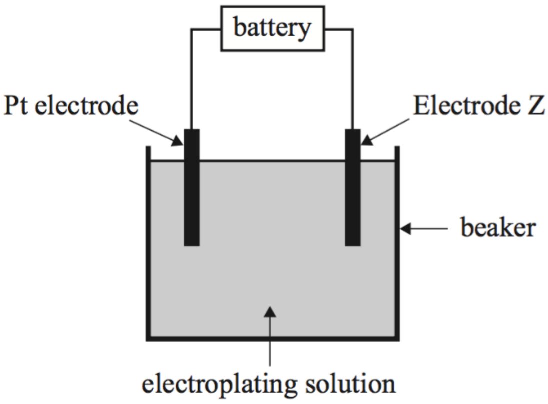
28.
The following diagrams represent the operation of a secondary cell during recharge and discharge, in no particular order. The diagrams of the circuits are not complete.



Which of the options below correctly describes the cell and it's operation?

	Cycle 1	Cycle 2
A.	energy produced	anode is positive
B.	spontaneous reaction	energy produced
C.	anode is positive	energy required
D.	spontaneous reaction	cathode is positive

29.
The diagram below shows the basic set-up of an electroplating cell.



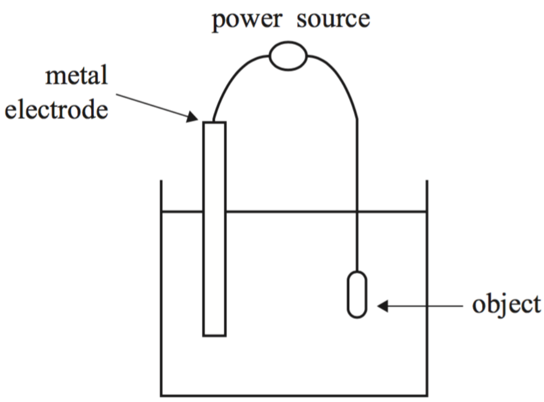
Initially the cell is set up with a lead, Pb, electrode as Electrode Z and 1.0 $\frac{mol}{L}$ lead nitrate, $Pb(NO_3)_2$, as the electroplating solution. The cell runs for a set time and current, with 1.0 g of Pb deposited onto Electrode Z.

Four subsequent electroplating cells are set up, each containing a platinum, Pt, electrode, a different Electrode Z and an appropriate 1.0 $\frac{mol}{L}$ electroplating solution. These four electroplating cells are operated for the same time and at the same current as the original Pb electroplating cell.

Which combination of Electrode Z and electroplating solution would be expected to deposit **more** metal by mass onto Electrode Z than the original Pb electroplating cell?

	Electrode Z	Electroplating solution
A.	chromium, Cr	1.0 M $Cr(NO_3)_3$
B.	silver, Ag	1.0 M $AgNO_3$
C.	gold, Au	1.0 M $AuCl_3$
D.	tin, Sn	1.0 M $SnSO_4$

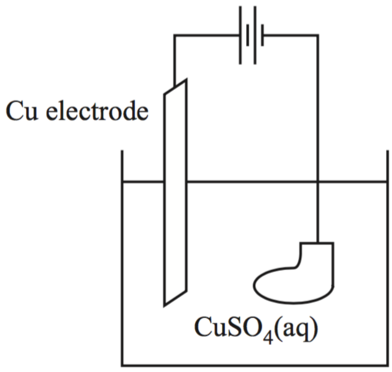
30.
The diagram below shows an electroplating cell.



The cell contains 1.0 L of an electroplating solution. The electroplating cell is run for one hour at 3.0 A. Which one of the following electroplating solutions will deposit the largest mass of metal onto the object?

A. 1 M $AgNO_3$
B. 1 M $Cd(NO_3)_2$
C. 1 M $Pb(NO_3)_2$
D. 1 M $Al(NO_3)_3$

31.
The tradition of bronzing baby shoes dates back for generations. Before electroplating, the shoe is painted with a conductive material. The copper, Cu, electrode and copper sulfate, $CuSO_4$, solution cell used for electroplating a shoe is shown below.



During the electroplating process

A. the copper electrode is oxidised and its mass is unchanged.
B. the shoe is coated with copper metal at the cathode.
C. the copper electrode is the oxidising agent.
D. oxygen is produced at the cathode.

32.
An electroplating cell containing two platinum electrodes and an electroplating solution is operated at 5.0 A for 600 s. After the cell is turned off, 0.54 g of metal is found to have been deposited on the cathode.

Which electroplating solution was used in this process?

A. 1 M $AgNO_3$
B. 1 M $Ni(NO_3)_2$
C. 1 M $Pb(NO_3)_2$
D. 1 M $Cr(NO_3)_3$

33.
An electrolysis cell is made up of a 500 mL solution of a metal salt with two inert electrodes. A current of 3.0 A is applied for one hour and 1.9 g of metal is deposited on the cathode.

The 500 mL solution used in this electrolysis cell is

A. 1.0 M $CuSO_4$
B. 0.3 M $CuSO_4$
C. 0.8 M Ag_2SO_4
D. 0.5 M $Cr_2(SO_4)_3$

34.
Hydrogen, H_2, fuel cells and H_2-powered combustion engines can both be used to power cars. Three statements about H_2 fuel cells and H_2-powered combustion engine are given below:

I Neither H_2 fuel cells nor H_2-powered combustion engines produce greenhouse gases.

II Less H_2 is required per kilometre travelled when using an H_2-powered combustion engine than when using H_2 fuel cells.

III More heat per kilogram of H_2 is generated in an H_2-powered combustion engine than in H_2 fuel cells.

Which of the statements above are correct?

A. II only
B. I and II only
C. III only
D. I and III only

35.
The reaction below represents the discharge cycle of a standard lead-acid rechargeable car battery.

$$Pb(s) + PbO_2(s) + 4H^+(aq) + 2SO_4^{2-}(aq) \rightarrow 2PbSO_4(s) + H_2O(l)$$

During the recharging cycle, the pH

A. increases and solid Pb is a reactant.
B. increases and solid PbO_2 is produced.
C. decreases and chemical energy is converted to electrical energy.
D. decreases and electrical energy is converted to chemical energy.

Holiday Homework

second section

B.O.B. (Suggested solutions) to Chapter 21 questions

Chapter 21 Practical investigation

21.1 Designing and planning investigations

1 a Electrical conductivity b Concentration of lead
c Electrical conductivity d pH

2 A hypothesis is a suggested outcome, based on evidence and prior knowledge, to answer the research question.

3 a pH of the water b Mussel shells dissolving
c Difference in mass of the mussel shells before and after the experiment
d Temperature of the water, the mass of mussel shells, the length of time the mussel shells are left in the water

21.2 Conducting investigations and recording and presenting data

1 17.34 mL, 17.38 mL, 17.44 mL

2 B

3 a Systematic error b Mistake c Random error

4 C

5 The mean

21.3 Discussing investigations and drawing evidence-based conclusions

2 Inverse, non-linear relationship

3 a Reliability b Validity
c Accuracy d Precision

4 It is not directly related to the hypothesis—it should have referred to the temperature of the water and its electrical conductivity.

Chapter 21 review

1 Independent variable: C; dependent variable: A; controlled variable: B

2 Independent variable = source of the water, dependent variable = phosphate concentration, controlled variables = temperature, time of testing, method of testing

3 Accuracy refers to the ability of the method to obtain the correct measurement close to a true or accepted value. Validity refers to whether an experiment or investigation is in fact testing the set hypothesis and aims

4 a It can dissolve or eat away at substances including tissues such as your skin or lungs.
b It Is toxic (poisonous) if inhaled.
c It is a highly combustible liquid that could catch on fire.

5 a Mistake b Random error c Systematic error

6 a Bar graph b Line graph
c Scatter graph (with line of best fit) d Pie chart

7 b Data point 4
c An outlier is a point in the data that does not fit the trend.

8 Temperature

9 Add a title, label the *x*- and *y*-axes, add units to the *x*-axis variable, exclude the obvious outliers from line of best fit.

10 Evaluate the method; identify issues that could affect validity, accuracy, precision and reliability of data; state systematic sources of error and uncertainty; and recommend improvements to the investigation if it is to be repeated

11 A pattern or relationship between the dependent and independent variables; may be linear, positive non-linear, linear or non-linear inverse

12 To avoid plagiarism and ensure creators and sources are properly credited for their work.

13 a Aim: To determine the effect of increasing water temperature on the electrical conductivity of water.
b Independent variable: water temperature; dependent variable: electrical conductivity of water; controlled variables: pH, water source, sampling container
c Conductivity, using a probe; quantitative.
d 10 mL measuring cylinder ±0.1 mL, pH probe ±0.02, alcohol-filled glass thermometer ±0.1°C, electrical conductivity probe ±2
e Raw data is data collected in the field and recorded as measurements are taken. Processed data is data that has been manipulated in some way (e.g. calculated, tabulated).

Common Chemistry Symbols, units & constants

Symbols, units and fundamental constants

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

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

TABLE 2 SI prefixes, their symbols and values

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

TABLE 3 Some physical constants

Description	Symbol	Valuev
Avogadro's constant	N_A	$6.02 \times 10^{23}\ mol^{-1}$
Charge of an electron	e	-1.60×10^{-19} C
Mass of electron	m_e	9.109×10^{-31} kg
Mass of proton	m_p	1.673×10^{-27} kg
Mass of neutron	m_n	1.675×10^{-27} kg
Gas constant	R	$8.31\ J\ K^{-1}\ mol^{-1}$
Ionic product for water	K_w	$1.00 \times 10^{-14}\ mol^2\ L^{-2}$ at 298 K
Molar volume of an ideal gas	V_m	
at 273 K, 100 kPa		$22.7\ L\ mol^{-1}$
at 298 K, 100 kPa		$24.8\ L\ mol^{-1}$
Specific heat capacity of water	c	$4.18\ J^{-1}\ g^{-1}\ K^{-1}$
Density of water	d	$1.00\ g\ mL^{-1}$ at 298 K

Significant Figures
&
Standard form for number
(scientific notation)

Significant figures and standard form

SIGNIFICANT FIGURES

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

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

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

Which figures are significant?

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

In the data above:

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

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

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

Using significant figures

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

Addition and subtraction

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

Example

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

12.78 mL + 10.0 mL = 22.78 = 22.8 mL

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

Multiplication and division

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

Example

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

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

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

Rounding off

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

STANDARD FORM

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

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

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

Sources of bias,

Evaluating Evidence

Avoiding Plagiarism

Sources of potential bias

Information can be obtained from a wide variety of sources, and you should be aware of the origin of the information to understand whether or not the source is likely to be expressing a particular **bias** or **agenda**.

Individuals or organisations with a **vested interest** (such as a financial interest) in the results of research may not present all of the information. When data or evidence is not presented objectively, it is said to be biased. For example, a food manufacturer may want to highlight the nutritional benefits of a product without giving equal prominence to less favourable aspects of an analysis.

Reputable scientists clearly state their affiliations and potential **conflict of interest** in articles submitted to peer-reviewed journals. Commonly, research projects are funded by government and non-government **grants**. Any funding associated with a research project should be clearly stated in connection with the author details in a peer-reviewed journal article. This provides **transparency** and enables the reader to judge whether the research may or may not be biased.

Scientific verses non-scientific ideas

Science is a way of explaining things. It is based on the systematic collection and analysis of data and evidence to answer questions.

Reputable scientists publish their research findings in peer-reviewed journals. Peer-reviewed journals are those that have qualified scientists in a particular field review any research before it is published in the journal to ensure that its methods are scientifically sound and the conclusions are supported by evidence.

In general, the peer-review system works well. However, occasionally, bad research is published after going through peer-review. In these cases, the scientific community writes to the journal stating their concerns and the articles are **retracted**. For example, an article published in the reputable medical journal *The Lancet* suggesting a link between autism and the measles, mumps and rubella vaccine was subsequently discredited and retracted.

Beware of publications or information that is presented as science but is not scientifically valid. Non-scientific ideas and writing can be identified by:

- a lack of data or evidence
- bias—only part of the data or evidence is considered (usually the data supporting the claim)
- poorly collected data or evidence; for example, basing data or evidence on a **sample group** that is too small or not representative of the whole
- invalid conclusions (that is, not supported by evidence)
- lack of objectivity—appealing to emotion rather than presenting facts and evidence impartially.

EVALUATING EVIDENCE

Strong evidence is credible, transparent, valid and reliable.

Validity

Validity refers to whether the evidence is in fact supporting the argument. Evidence should be relevant to the question and should support the conclusion. To learn more about validity in the context of an investigation, refer to Chapter 21.

Reliability

Reliability refers to the notion that the experiment or data collection can be repeated many times and will obtain consistent results. Reliability depends on:

- establishing a control to ensure that the results are due to changes in the independent variable
- replicating the experiment or data collection to account for errors.

Errors and limitations

Reputable sources will clearly state the limitations and errors of the reported research. There are two types of errors:

- **systematic errors**
- **random errors**.

Systematic errors

A systematic error is an error that is consistent and will occur again if the investigation is repeated in the same way. Systematic errors are usually a result of instruments that are not calibrated correctly or methods that are flawed. For example, if a weighing balance is not regularly calibrated, then it may consistently read higher or lower than the true value, producing a systematic error.

Random errors

Random errors occur by chance. For example, they may occur because the researcher does not have the skills or knowledge required to use a piece of equipment. Random errors can be reduced by repeating the experiment several times and calculating an average value.

AVOIDING PLAGIARISM

Plagiarism is using other people's work without acknowledging them as the author or creator. To avoid plagiarism, include a reference every time you report the work of others; for example, at the end of a sentence or following a diagram. If you use a direct quotation from a source, enclose it in quotation marks. This will ensure you give credit to the original author and it will enable the reader to find the original source.

References and bibliography

A **bibliography** is a list of resources referred to in your research. It includes details about each resource. In order to avoid plagiarising the work of others, it is very important that you acknowledge where you have found information. All sources must be listed at the end of the report in alphabetical order (by author last name or organisation name). The referencing needs to give the reader the opportunity of easily locating the source.

As you gather resources, you should also begin compiling your references in a separate document. This will prevent you from wasting time later trying to relocate your sources, and will be the basis of your bibliography.

APA (American Psychological Association) style is the most commonly used referencing style. Table 11.1.3 gives examples of how to write citations and references of different types of sources using APA academic referencing style.

In-text citations

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

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

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

Or

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

The bibliographic details of the example above would be:

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

TABLE 11.1.3 APA academic referencing style

Resource type	Information required	Example
Print book	• Author's surname and initials • Date of publication • Title • Edition number • Publisher's name • Place of publication	Rickard G., Phillips G., Monckton S., Roberson P., Hamer J., Whalley K. (2005), *Science Dimensions 1*, Pearson Education, Melbourne
Digital book	• Author's surname and initials • Date of publication • Title • Edition number • Publisher's name • Date website was accessed • Website address	Commons C., Commons P., Hogendoorn B., Clarke W., Derry L., Huddart E., O'Shea P., Porter M., Quinton G., Ross B., Sanders P., Sanders R., Spence R. (2015), *Pearson Lightbook Chemistry Western Australia 11*, Pearson Education, accessed 29 June 2015, from http://staging.lightbook.pearsonplaces.com.au/CH11_WA/unit/CH11_WA-U01
Article	• Author's surname and initials • Date of publication • Title • Journal/magazine title • Volume • Page numbers	Chiappini, C., De Rosa, E., Martinez, J.O., Liu, X., Steele, J., Stevens, M.M., & Tasciotti, E. (2015). Biodegradable silicon nanoneedles delivering nucleic acids intracellularly induce localized in vivo neovascularization. *Nature Materials, 14*(5), 532–539
Internet	• Author's surname and initials, or name of organisation or title • Year website was written or last revised • Date website was accessed • Website address	National Geographic (2015), 'Killer fungus that's devastating bats may have met its match', accessed 29 May 2015, from http://news.nationalgeographic.com/2015/05/150527-bats-white-nose-syndrome-treatment-conservation-animals-science

Keeping track of sources

Categorising the information and evidence you find while you are researching will make it easier to locate information later and to write your final investigation. Categories you might use while researching could include:

- research methods
- key findings
- evidence
- research relevance
- use
- **stakeholders** and impacts
- future concerns.

Record information from resources in a clear way so you can retrieve it and use it. An example of a useful method of doing this is in a table like Table 11.1.4.

TABLE 11.1.4 Recording information from different resources

Bibliographic information	
Summary of content	
Relevant findings and evidence	
Limitations, bias or flaws within the article	
Useful quotations	
Additional notes	

Uncertainties

Precision & Accuracy

Types of Errors (Mistakes, Systematic errors, Random errors)

Uncertainties

The accuracy with which the volumes of the aliquot and titre are measured in volumetric analysis depends on the calibration of the pieces of equipment used. There are always errors associated with measurements of quantities such as mass and volume made during experimental work. These are some typical **uncertainties** associated with volumetric analysis:

- 20 mL pipette: ±0.03 mL
- 50 mL burette: ±0.02 mL for each reading
- 250 mL volumetric flask: ±0.3 mL
- 100 g capacity top loading balance: ±0.001 g
- 60 g capacity analytical balance: ±0.0001 g.

Other graduated laboratory glassware provides less precise measures:

- 50 mL measuring cylinder: ±0.3 mL
- 50 mL graduated beaker: ±5 mL.

Precision and accuracy

Every measurement in a **quantitative analysis** is subject to some form of error. Therefore, a calculation that makes use of these measurements will produce a result in which the errors have accumulated.

If repeated measurements of the same quantity yield values that are in close agreement, then the measurement is said to be **precise**. For example, a titration is generally repeated until at least three titres are obtained that are within narrowly specified limits. These are called concordant titres. Repeated measurement of the titres increases the precision of the result and minimises errors that may have affected one titre more than others.

If the average of a set of measurements of a quantity is very close to the true or accepted value of the quantity, then the measurement is said to be **accurate**. Figure 20.5.3 compares accuracy and precision.

FIGURE 20.5.3 The holes in the targets illustrate the difference between accuracy and precision. Target (a) shows good accuracy and good precision. Target (b) illustrates poor accuracy but good precision, and target (c) shows both poor accuracy and poor precision. Analytical chemists aim to produce results that are both precise and accurate.

You can see that it is possible for a result to be precise but inaccurate.

Methods used for accurate quantitative analysis should be designed to minimise errors. Where errors cannot be avoided, any discussion of results should refer to the level of inaccuracy that may have accumulated. This requires an understanding of the different types of errors.

Types of errors

Mistakes

Mistakes are avoidable errors. Mistakes made during acid–base titrations could include:

- misreading the numbers on a scale
- mistakenly using a pipette of incorrect volume
- spilling a portion of a sample.

The effects of incorrectly rinsing volumetric glassware are detailed in Table 20.5.3.

TABLE 20.5.3 Rinsing glassware for volumetric analysis

	Correct	Incorrect
Burette Pipette	The final rinse should be with the acid or base they are to be filled with.	Rinsing with water only would dilute the acid or base solution.
Volumetric flask Titration flask (conical flask)	Should only be rinsed with deionised water.	Rinsing with acidic or basic solutions will introduce unmeasured amounts of acids or bases into the flask that can react and affect the results.

A measurement that involves a mistake must be rejected and not included in any calculations or averaged with other measurements of the same quantity. Mistakes are not generally referred to as errors.

Systematic errors

A **systematic error** produces a constant bias in a measurement that cannot be eliminated by repeating the measurement. Systematic errors that affect an acid–base titration could include:

- a faulty balance
- a 20.0 mL pipette that delivers 20.2 mL
- an unsuitable indicator being used
- a person reading the scale on a burette with a constant parallax error.

Whatever the cause, the resulting error is in the same direction for every measurement and the average will be either higher or lower than the true value.

Systematic errors are eliminated or minimised through calibration of apparatus and the careful design of a procedure. If the error cannot be eliminated an effort should be made to determine its size so that the error can be taken into account in calculations.

Random errors

Random errors follow no regular pattern. The measurement is sometimes too large and sometimes too small. Random errors in volumetric analysis could include:

- inherent uncertainty in the last value after the decimal place in the measurement of the mass of a primary standard on an analytical balance
- difficulty in judging where the meniscus sits on the line when measuring a volume using a pipette
- difficulty in judging the fraction between two 0.1 mL scale markings on a burette.

The effects of random errors can be reduced by taking multiple measurements of the same quantity, then calculating an average. In volumetric analysis, the average of three concordant titres is used to reduce random error.

CHEMISTRY

SUMMER
HOLIDAY
HOMEWORK
QUESTIONS

CHAPTER 21

Practical investigation

Science is a practical subject. Most of what is known about how the world works is the result of practical investigations and from testing out ideas. In this chapter, you will learn how to design, plan and conduct investigations, including how to write a hypothesis and identify variables. You will also assess the validity, reliability and accuracy of results and research.

Finally, you will learn how to discuss your investigation and draw evidence-based conclusions in relation to your hypothesis and research question.

Key knowledge

- the chemical concepts specific to the investigation and their significance, including definitions of key terms, and chemical representations
- the characteristics of laboratory techniques of primary qualitative and quantitative data collection relevant to the investigation: sampling protocols; gravimetric analysis, acid-base titrations and/or pH measurement; 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
- 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
- observations and experiments that are consistent with, or challenge, current chemical models or theories
- the nature of evidence that supports or refutes a hypothesis, model or theory
- options, strategies or solutions to issues related to water quality
- the key findings of the selected investigation and their relationship to solubility, concentration, acid/base and/or redox concepts
- the conventions of scientific report writing including chemical terminology and representations, symbols, chemical equations, formulas, units of measurement, significant figures and standard abbreviations

Key science skills

Develop aims and questions, formulate hypotheses and make predictions

- Determine aims, hypotheses, questions and predictions that can be tested
- Identify independent, dependent and controlled variables

Plan and undertake investigations

- Determine appropriate type of investigation: experiments (including use of controls and calibration curves); solving a scientific or technological problem; simulations; access to secondary data, including data sourced through the internet that would otherwise be difficult to source as raw or primary data through a laboratory or a classroom
- Select and use equipment, materials and procedures appropriate to the investigation, taking into account potential sources of error and uncertainty

Comply with safety and ethical guidelines

- Apply ethical principles when undertaking and reporting investigations
- Apply relevant occupational health and safety guidelines while undertaking

practical investigations, including following recommended protocols from safety data sheets

Conduct investigations to collect and record data

- Work independently and collaboratively as appropriate and within identified research constraints
- Systematically generate, collect, record and summarise both qualitative and quantitative data

Analyse and evaluate data, methods and scientific models

- Process quantitative data using appropriate mathematical relationships, units and number of significant figures
- Organise, present and interpret data using schematic diagrams and flow charts, balanced chemical equations, tables, graphs, percentages and calculations of mean
- Take a qualitative approach when identifying and analysing experimental data with reference to accuracy, precision, reliability, validity, uncertainty and errors (random and systematic)
- Explain the merit of replicating procedures and the effects of sample sizes in obtaining reliable data
- Evaluate investigative procedures and possible sources of bias, and suggest improvements
- Explain how models are used to organise and understand observed phenomena and concepts related to chemistry, identifying limitations of the models

Draw evidence-based conclusions

- Determine to what extent evidence from an investigation supports the purpose of the investigation, and make recommendations, as appropriate, for modifying or extending the investigation
- Draw conclusions consistent with evidence and relevant to the question under investigation
- Identify, describe and explain the limitations of conclusions, including identification of further evidence required
- Critically evaluate various types of information related to chemistry from journal articles, mass media and opinions presented in the public domain
- Discuss the implications of research findings and proposals

Communicate and explain scientific ideas

- Use appropriate chemical terminology, representations and conventions, including standard abbreviations, graphing conventions and units of measurement
- Discuss relevant chemical information, ideas, concepts, theories and models and the connections between them
- Identify and explain formal chemical terminology about investigations and concepts
- Use clear, coherent and concise expression
- Acknowledge sources of information and use standard scientific referencing conventions

21.1 Designing and planning investigations

Taking the time to carefully plan and design a practical investigation before you begin will help you to maintain a clear and concise focus throughout. Preparation is essential.

It is important to have both a solid understanding of the theory behind your investigation and a detailed plan for the practical components of your investigation. In this section, you will learn about the key steps you should take when planning and designing a practical investigation.

DEVELOPING AIMS, HYPOTHESES AND PREDICTIONS

The research question, aim and hypothesis are interlinked. It is important to note that each of these can be refined as the planning of the investigation continues.

Research questions, aims and hypotheses

A **research question** is a sentence that seeks information. A question must end with a question mark ('?'). For example: 'What is the effect of increasing acid temperature on the rate of reaction between 1 g of magnesium and 10 mL of 0.1 M hydrochloric acid?'

An **aim** is a sentence summarising what will be investigated. For example: 'To determine the effect of acid temperature on the rate of reaction between 1 g of magnesium and 10 mL of 0.1 M hydrochloric acid'.

A **hypothesis** is a possible outcome of the experiment. It is based on previous knowledge on which you can make a prediction for the results of the experiment. For example: 'If the temperature of the acid increases, the rate of reaction will also increase.'

Formulating a question

Before you are able to formulate a hypothesis, you will need to formulate a question that you want to answer. This question will lead you to a hypothesis when you:

- are able to reduce the question to measurable **variables**
- can suggest a possible outcome of the experiment.

The question for your investigation must be related to an aspect of water quality. Some examples of questions you might study include the following.

- Is the **biological oxygen demand (BOD)** of water sampled from the Yarra River within acceptable limits?
- Is there a difference between the electrical **conductivity** of drinking water and the electrical conductivity of ground water at a specified location?
- What is the **pH** of commercially available mineral waters?

Knowing what resources you have available will also help you formulate a question. Available equipment may include thermometers, pH paper, pH meters, burettes, pipettes, volumetric flasks, conductivity meters, weighing balances and other common laboratory equipment.

Hypothesis

A hypothesis is a prediction, based on evidence and prior knowledge. It takes the form of a cause and effect.

Examples:

- An increase in water temperature will lead to a decrease in the pH of water.
- The electrical conductivity of ground water will be greater than that of drinking water.
- If water is filtered through a domestic water purifier, then its electrical conductivity will decrease.

- Sparkling mineral water will have a lower pH at room temperature than non-sparkling mineral water.

It is sometimes easier to write a hypothesis in which the prediction serves to disprove a question.

Examples:

- Increasing the water temperature will not have an effect on measured pH.
- The electrical conductivity of ground water and drinking water will be the same.
- Filtering water through a domestic water purifier will not affect its electrical conductivity.
- The pH of sparkling and non-sparkling mineral water will be the same at a given temperature.

Variables

A good scientific hypothesis can be tested through investigation.

There are three categories of variables.

- The **independent variable** is the variable that is changed by the researcher.
- The **dependent variable** is the variable that may change in response to a change in the independent variable. This is the variable that you will measure or observe.
- **Controlled variables** are all the variables that must be kept constant during the investigation. You should only test one variable at a time; otherwise, you cannot be sure that the changes in the dependent variable are the result of changes in the independent variable.

Completing a table like Table 21.1.1 will assist in evaluating your question, or questions.

TABLE 21.1.1 An example of the relationship between the investigation question, the variables and the hypothesis

Research question	Independent variable	Dependent variable	Controlled variables	Potential hypothesis
Does the use of a domestic water purifier cause a decrease in electrical conductivity of water?	Type of water purifier	Electrical conductivity of water	Water source, type of sampling container, temperature, humidity	If water is filtered through a domestic water purifier, then its electrical conductivity will decrease.

Qualitative and quantitative variables

Variables are either **qualitative** or **quantitative**, depending on whether or not they can be measured. Figure 21.1.1 shows examples of variables belonging to both types.

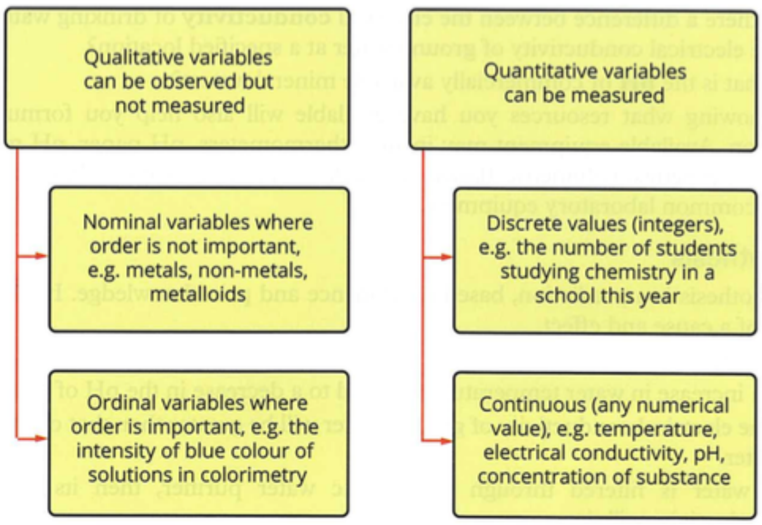


FIGURE 21.1.1 A description of qualitative and quantitative variables can be broken down further.

(a) (b)

FIGURE 21.1.2 Determining whether a solution is acidic or basic can be qualitative or quantitative. (a) Litmus paper gives a qualitative observation indicating the nature of the solution. (If the paper turns purple, the solution is basic; if the paper turns pink, the solution is acidic.) (b) A calibrated pH meter gives a quantitative measurement indicating the nature of the solution (pH < 7, the solution is acidic; pH > 7, the solution is basic.)

Defining the aim of the investigation

The aim is the key step required to test your hypothesis. The aim should relate directly to the variables in the hypothesis, describing how each will be measured. The aim does not need to include the details of the method. Table 21.1.2 provides an example of a hypothesis, the variables to be measured and the aim of an investigation into the electrical conductivity of water.

TABLE 21.1.2 The relationship between hypothesis, variables and aim

Hypothesis	Variables	Aim
If water is filtered through a domestic water purifier, then its electrical conductivity will decrease.	Independent variable: type of water purifier Dependent variable: electrical conductivity	To measure and compare the electrical conductivity of water samples before and after filtering through different domestic water purifiers

Writing the methodology

The methodology of your investigation is a step-by-step procedure that a reader can follow. As outlined below, a successful method is valid, reliable and accurate.

Validity

Validity refers to whether an experiment or investigation is testing the set hypothesis and aims.

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

To ensure validity, carefully determine the:

- independent variable (the variable that you will change) and how you will change it
- dependent variable (the variable that you will measure)
- controlled variables (the variables that must remain constant) and how you will maintain them.

Reliability

Reliability refers to the consistency of the results when the experiment is repeated many times. Maintain your investigation's reliability by:

- defining the control
- ensuring there is sufficient replication of the experiment.

Control

The **control** is an identical experiment carried out at the same time but the independent variable is not changed. The control is a basis for comparison with the experiment and helps to support a hypothesis.

Replication

It is also important to determine how many times the experiment needs to be replicated.

Repeat each reading at least three times. Record each measurement and then average the three measurements.

Accuracy and precision

If repeated measurements of the same quantity give values that are in close agreement, the measurement is said to be **precise**.

If the average of a set of measurements of a quantity is very close to the true or accepted value of the quantity, then the measurement is said to be **accurate**.

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

- unit in which you will measure the independent and dependent variables
- instrument that you will use to measure the independent and dependent variables.

The precision of glassware used used in chemistry experiments varies. Table 21.1.3 shows some typical uncertainties of laboratory glassware.

TABLE 21.1.3 Typical uncertainties of laboratory glassware

Type of laboratory glassware	Typical uncertainty
10 mL measuring cylinder	10.0±0.1 mL
20 mL pipette	20.00±0.03 mL
50 mL burette	50.00±0.02 mL
250 mL volumetric (standard) flask	250.0±0.3 mL

Data analysis

Before you begin your experiment you should consider the data that you will collect.

Table 21.1.4 provides an example of the data to be collected and analysed in an experiment, and the things you should consider.

A table of results for the experiment measuring the pH of commercially available mineral waters is shown in Table 21.1.5.

Sometimes methods need to be changed. If so:

- record everything
- be prepared to make changes to your approach
- note any difficulties you encounter and the ways you overcame them. What were the failures and successes? List these as you work, including all tests performed, to ensure you have a well-written report.

TABLE 21.1.4 Types of variables and the ways in which they could be measured and used within an example research investigation

Research question: What is the pH of commercially available mineral waters?	
List the independent variable (the variable that you will change in the experiment). Is the variable quantitative or qualitative?	The independent variable is the name and brand of commercially available mineral water (qualitative).
List the dependent variable. This is the variable that you will measure. What equipment will you use to measure it?	A calibrated pH meter connected to a computer will be used to measure pH. The pH meter has an uncertainty of ±0.1 pH units.
List the variables that you will control. What will you do to control these variables?	All mineral waters will be stored in a temperature-controlled environment where the air temperature will be maintained at 20°C. The temperature of each will be measured with an ethanol-filled glass thermometer. The uncertainty of the thermometer is ±0.1°C.

TABLE 21.1.5 Results table indicating the pH of three different mineral waters (X, Y and Z)

Brand and volume of commercial mineral water	Date	pH	Temperature (°C)
X 1 L		6.7	22.3
Y 1 L		6.4	22.3
Z 1 L		6.4	22.3
Uncertainty of equipment		±0.1	±0.1

COMPLYING WITH ETHICAL AND SAFETY GUIDELINES

Everything we do involves some risk. A **risk assessment** is performed to identify, assess and control hazards. Always identify the risks and control them to keep everyone safe.

To identify risks, think about the:

- activity that you will be carrying out
- equipment or chemicals that you will be using.

Figure 21.1.3 shows a flow chart of how to consider and assess the risks involved in a research investigation.

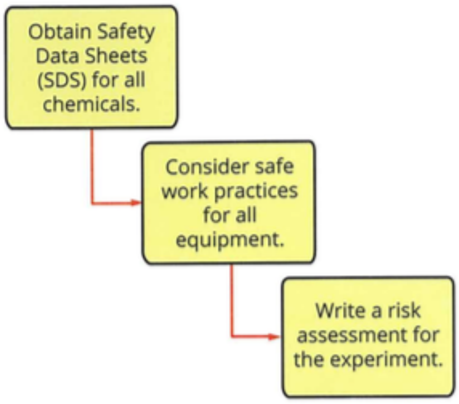


FIGURE 21.1.3 Steps involved in identifying risks.

Chemical codes

The chemicals at school or at the hardware shop have a warning symbol on the label. These are **chemical** (HAZCHEM) **codes**. Some common codes and their meanings are shown in Figure 21.1.4. Trucks that carry chemicals display hazard symbols, as shown in Figure 21.1.5.

Safety Data Sheets

HAZCHEM INTERPRETATION

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

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

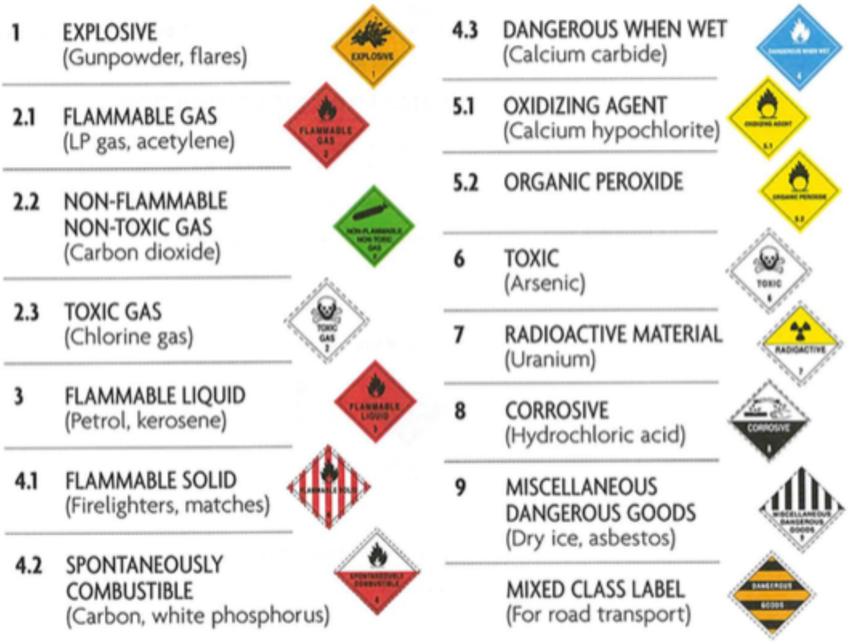


FIGURE 21.1.4 HAZCHEM signs.

FIGURE 21.1.5 Trucks transporting hazardous substances such as flammable liquids have hazard symbols attached.

Each chemical substance has an accompanying document called a **Safety Data Sheet (SDS)** (Figure 21.1.6), previously a Material Safety Data Sheet (MSDS). An SDS contains important safety and first aid information about each chemical you commonly use in the laboratory. If the products of a reaction are toxic to the environment, you must pour your waste into a special container (not down the sink).

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

1. IDENTIFICATION OF THE MATERIAL AND SUPPLIER

Product Name:	**HYDROCHLORIC ACID - 20% OR GREATER**
Recommended use of the chemical and restrictions on use:	Precursor for generation of chlorine dioxide gas used in water treatment.
Supplier:	Ixom Operations Pty Ltd
ABN:	51 600 546 512
Street Address:	Level 8, 1 Nicholson Street Melbourne 3000 Australia
Telephone Number:	+61 3 9665 7111
Facsimile:	+61 3 9665 7937
Emergency Telephone:	**1 800 033 111 (ALL HOURS)**

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

2. HAZARDS IDENTIFICATION

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

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

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

SIGNAL WORD: DANGER

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

Precautionary Statement(s):

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

FIGURE 21.1.6 Extracts of a Safety Data Sheet (SDS) for concentrated hydrochloric acid. The SDS alerts the reader to any potential hazards when using a substance, including appropriate measures to reduce risk of harm.

Protective equipment

Everyone who works in a laboratory should wear items that help keep them safe. This is called personal protective equipment (PPE) (Figure 21.1.7) and includes:

- safety glasses
- closed-toe shoes
- disposable gloves when handling chemicals
- a disposable apron or a lab coat if there is risk of damage to clothes
- ear protection if there is risk to hearing.

A fume cupboard should be used when toxic or corrosive gases are being handled or produced.

FIGURE 21.1.7 It is important to wear appropriate personal protective equipment as identified in a risk assessment.

21.1 Review

SUMMARY

- A research question is a statement defining what is being investigated.
- An aim is a statement describing in detail what will be investigated.
- A hypothesis:
  - is a prediction of the outcome of an experiment, based on previous knowledge
  - often takes the form of a proposed connection between two or more variables in a cause-and-effect relationship.
- A practical investigation determines the relationship between variables, measuring the results.
- The three types of variables are:
  - independent—the variable that is controlled by the researcher (the one that is selected and changed)
  - dependent—the variable that may change in response to a change in the independent variable, and is measured or observed
  - controlled variables—all the variables that must be kept constant during the investigation.
- Quantitative variables are measured; qualitative variables are observed but cannot be measured.
- An investigation or experiment should be valid, reliable and accurate.
  - Validity refers to whether an experiment or investigation is in fact testing the set hypothesis and aims.
  - Reliability refers to the consistency of the results when the experiment is repeated many times.
  - Accuracy refers to the ability to obtain the correct measurement using the correct instrument.
- Ethical and safety considerations must be of the highest priority at all times during a practical investigation.
  - Safety Data Sheets need to be obtained for all chemicals used.
  - Safe work procedures outline how to use equipment safely.
  - A risk assessment should be conducted prior to commencing the investigation.
  - Appropriate protective equipment including personal protective equipment should be used according to the risk assessment.

KEY QUESTIONS

1 For each of the following hypotheses, select the dependent variable.
  - a If water is filtered through a domestic water purifier, then its electrical conductivity will decrease.
  - b The concentration of lead in water will be higher in storm water close to an industrial site than in drinking water.
  - c The electrical conductivity of water from the Gippsland Lakes in Victoria will be greatest where ocean water can mix with lake water.
  - d The pH of commercially available sparkling mineral water will be lower than commercially available non-sparkling mineral water.

2 Give the meaning of the term 'hypothesis', using the terms 'variables' and 'evidence'.

3 A student wanted to find out at what pH mussel shells begin to dissolve.
  - a What would be the independent variable for the experiment?
  - b What would be the dependent variable?
  - c What would be an appropriate way of measuring quantitatively the dissolution of mussel shells?
  - d What variables would need to be controlled in the student's experiment?

21.2 Conducting investigations and recording and presenting data

Once you have planned your practical investigation, the next step is to undertake the experimental part. As with the planning stages, there are key steps to keep in mind to maintain high standards and minimise errors while carrying out your investigation.

This section will focus on the best methods of conducting a practical investigation using an analysis of water quality as an example. You will look at how to generate, record and process data. Finally, you will look at how you will present it to your audience.

CONDUCTING INVESTIGATIONS TO COLLECT AND RECORD DATA

For an investigation to be scientific, you must be objective and systematic. Ensuring that you are familiar with your method before you begin will help you to do so.

As you work, keep asking yourself questions. Is there any **bias** in the work in any way? If changes are made, how will it affect the study? Will your investigation still be valid for your aim and hypothesis?

It is essential that during your investigation, you record the following in your logbook:

- dates of all entries
- all quantitative and qualitative data collected
- the methods used to collect the data
- any unexpected event that may have affected the quality or validity of your data.

Raw data is what you collect and record as you do the experiment. This will need to be processed in a manner that makes it easy to read in the presentation of your investigation.

> During experiments scientists constantly take notes and track any changes they make in an experimental method to ensure the method could be followed by somebody else and that the results are accurate.

IDENTIFYING ERRORS

Most practical investigations have errors associated with them. As shown in Figure 21.2.1, there are many different types of errors that can occur. You will also remember looking at these in Chapter 20.

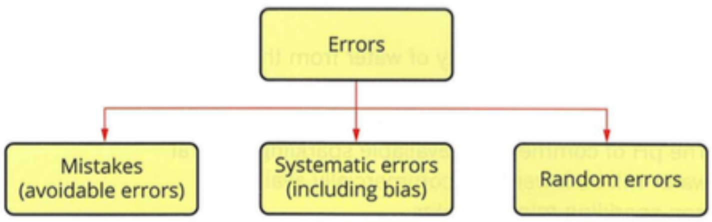


FIGURE 21.2.1 Types of errors that can be made in an experiment.

Mistakes

Mistakes are avoidable errors. Mistakes made during water quality analysis could include:

- misreading the numbers on a scale
- not labelling a sample adequately
- spilling a portion of a sample.

A measurement that involves a mistake must be rejected and not included in any calculations, or averaged with other measurements of the same quantity. Mistakes are not generally referred to as errors.

Systematic errors

A **systematic error** produces a constant bias in a measurement that cannot be eliminated by repeating the measurement. Systematic errors that affect water quality analysis could include:

- a balance used in gravimetric analysis that has not been **calibrated**, for example to weigh a precipitate
- a 20.0 mL pipette that delivers 20.2 mL **aliquots**
- an unsuitable indicator being used in a **titration**
- a person reading the scale on a burette with a constant **parallax error**.

Whatever the cause, the resulting error is in the same direction for every measurement and the average will be either too high or too low as a result. These lead to bias. Examples of bias are shown in Figure 21.2.2.

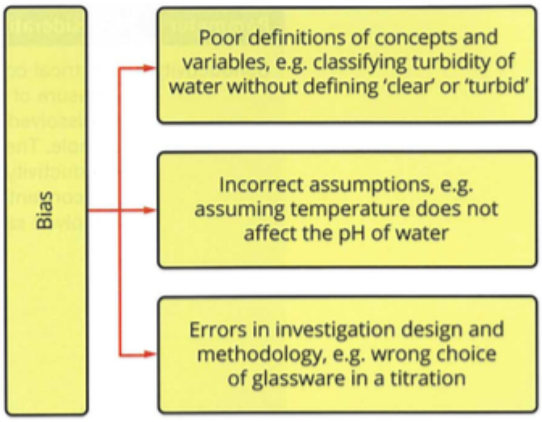


FIGURE 21.2.2 Types and examples of bias in an analysis of water quality.

Random errors

Random errors follow no regular pattern. The measurement is sometimes too large and sometimes too small. Random errors in water quality analysis could include:

- error in estimating the position of a needle between divisions on a scale
- temperature fluctuations during the measurement of pH or conductivity.

The effects of random errors can be reduced by taking multiple measurements of the same quantity, then calculating an average. For example, **concordant titres** are always obtained in a titration in an effort to reduce random errors.

TECHNIQUES FOR REDUCING ERROR

Designing the method carefully, including selection and use of equipment, will help reduce errors. Once you have chosen the appropriate equipment, it is necessary to calibrate the equipment to increase the accuracy of any measurements. To increase precision, include a larger sample size.

Equipment

To minimise errors, check the precision of the equipment that you intend to use. Pipettes, burettes and volumetric flasks have greater precision than using a beaker to measure volumes of liquids. However, you must still use all equipment correctly to reduce error.

For example, when using a pipette and/or volumetric flask, ensure that you look at the bottom of the meniscus on the calibration line. To avoid parallax error, ensure that you take measurements at eye level, as shown in Figure 21.2.3.

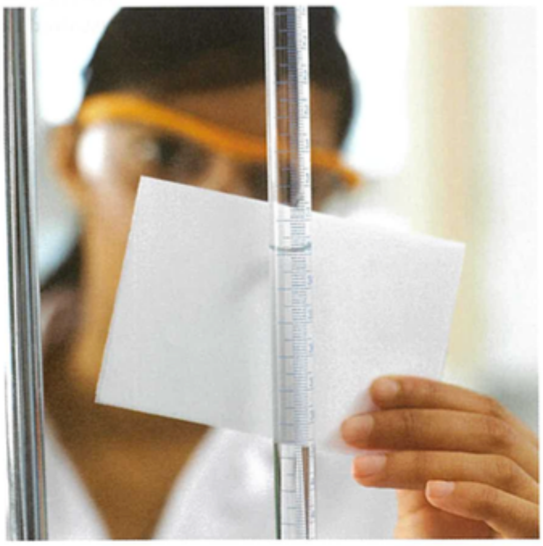
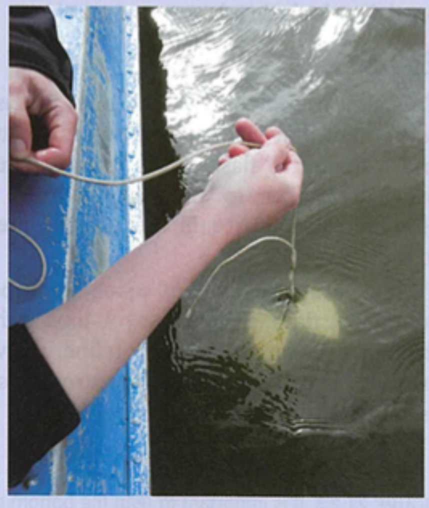


FIGURE 21.2.3 It is important to read the bottom of the meniscus at eye level in order to avoid parallax error. This student is showing how you can use a piece of white card (or a tile) to improve the contrast between the solution and the scale.

Other equipment used for water analysis

Table 21.2.1 lists the types of equipment used for water analysis.

TABLE 21.2.1 Types of equipment used for measuring water quality

Parameter	Considerations	Equipment
Conductivity	Electrical conductivity is a measure of the total level of dissolved salts in a water sample. The greater the conductivity, the greater the concentration of total dissolved salts.	Portable conductivity meters can be used qualitatively (indicates relative conductivity), or quantitatively using a data-logging conductivity probe attached to a computer, as shown in Figure 21.2.4.  FIGURE 21.2.4 Analysing a stream for electrical conductivity.
Turbidity	Turbidity is a measure of the clarity of water. Highly turbid water contains more suspended particles (such as clay, silt, plankton etc.) than clear water. Less light can penetrate turbid water, thereby reducing photosynthesis and concentration of **dissolved oxygen**.	Turbidity can be measured using a **Secchi disk.** (The depth at which the disk is no longer visible is taken as a measure of the transparency of the water, as seen in Figure 21.2.5.) Alternatively, a sample can be inserted into a turbidity meter connected via **data-logging equipment** to a computer.  FIGURE 21.2.5 A Secchi disk is lowered into water to measure the depth at which the disk is no longer visible. This is a measure of the relative turbidity of a sample.

Calibration

Some equipment, such as pH meters and weighing balances, need calibrating before use. By using calibrated equipment, you can be more certain that your measured values are accurate.

Sampling size

In general, the larger the sample of water that is taken for analysis, the more precise the measured values will be. However, you will be limited by the size of the container that you can transport back to school.

For example, if you need to measure 10 mL of a liquid, a measuring cylinder will afford more accurate and precise readings than a 100 mL measuring cylinder.

Record the precision of the equipment that you intend to use.

Table 21.2.2 lists typical precision for water-testing equipment.

Often glassware and equipment have information that indicates its precision. Figure 21.2.6 shows where this can be found on a pipette.

TABLE 21.2.2 Precision of water-testing equipment and glassware

Equipment	Typical precision
pH meter	±0.1
50 mL burette	±0.02
20 mL pipette	±0.03

FIGURE 21.2.6 Record the uncertainty for glassware and instruments in your logbook. This pipette can dispense an aliquot of 25.00 mL ± 0.03 mL.

RECORDING AND PRESENTING QUANTITATIVE DATA

Consider how you will present the data that you collect. Prepare a table in which to record your data.

Presenting raw data in tables

Table 21.2.3 shows an example of how to present raw data in a table.

TABLE 21.2.3 Analysis of Yarra River water and how it could be recorded

Title: Analysis of Yarra River water							
Location	Date and time	Temperature (°C) (±0.1)	pH (±0.1)	Conductivity (mS m^{-1}) (±1)	Turbidity (NTU) (±2)	Dissolved oxygen (DO) (mg L^{-1}) (±0.1)	Biological oxygen demand (BOD) (mg L^{-1}) (±0.1)
A		10.4	6.5	72	5	11.8	0.9
B		9.2	6.6	73	10	11.4	0.7
C		9.5	6.4	77	10	10.9	0.9
D		9.9	6.5	75	10	11.3	1.0

Table 21.2.3 includes:

- a descriptive title
- column headings (including the unit)
- aligned figures (align the decimal points)
- the independent variables (location and date/time) listed towards the left-hand side of the table
- the uncertainty of each measurement.

PROCESSING DATA

Calculating the mean

Table 21.2.4 shows an example of **mean** (average) values of water temperature with uncertainty.

TABLE 21.2.4 Mean water temperature of the Murray River in winter

Average water temperature of the Murray River at Yarrawonga, 2014	
Month	Mean water temperature (°C) (±2)
June	10
July	9
August	8

The mean value for June was calculated from raw data given by the results in Table 21.2.5.

TABLE 21.2.5 Water temperature readings from different dates in June

Date	Water temperature (°C) (±1)
19 June	9
20 June	8
21 June	9
22 June	10
23 June	11
24 June	12
25 June	11

The mean value is calculated by finding the sum of the daily values and dividing by the number of days, as shown below.

$$(9 + 8 + 9 + 10 + 11 + 12 + 11) \div 9 = 10°C$$

However, the mean on its own does not provide an accurate picture of the results.

Uncertainty

For your results to be presented in an accurate way, the mean must be accompanied by the uncertainty. In other words, the mean must be accompanied by a description of the **range** of data obtained.

Uncertainty is sometimes calculated by:

$$\text{uncertainty} = (\text{maximum value} - \text{minimum value}) \div 2$$

According to the data in Table 21.2.5, in June, the maximum water temperature was 12°C and the minimum water temperature was 8°C. The uncertainty can be calculated by:

$$(12 - 8) \div 2 = 2$$

Mode and median

Other statistical measures that can be used, depending on the data obtained, are:

- **mode**—the value that appears most often in a data set. This measure is useful to describe qualitative or **discrete** data (e.g. the mode of the values 0.01, 0.01, 0.02, 0.02, 0.02, 0.03 and 0.04 is 0.02).
- **median**—the median is the 'middle' value of an ordered list of values (e.g. the median of the values 5, 5, 8, 8, 9, 10 and 20 is 8). The median is used when the data is spread. Data can often become spread; for example, due to the presence of **outliers**, making the mean unreliable.

Graphs

It is easier to observe trends and patterns in data in graph form rather than in table form.

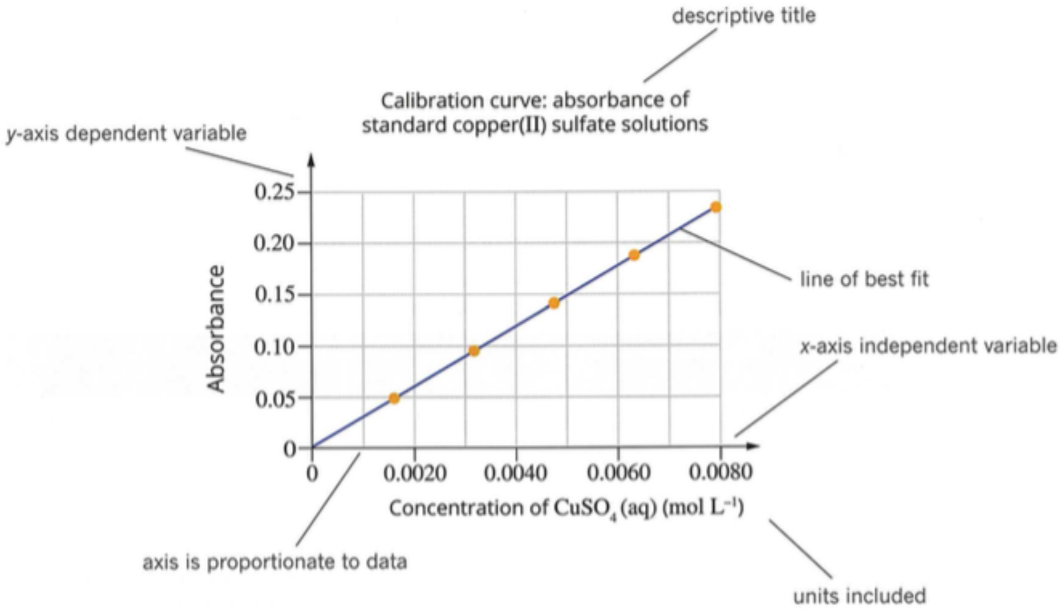


FIGURE 21.2.7 A graph is a better way to observe trends and patterns in data form.

A scatter graph, such as Figure 21.2.7, is used when two variables are being considered and one variable is dependent on the other. The independent variable is plotted along the *x*-axis and the dependent variable is plotted along the *y*-axis. When an appropriate line of best fit is fitted to the data points, the graph should show the relationship between the two variables.

Outliers

Sometimes when you collect data, there may be one point that does not fit the trend. An outlier is often caused by a mistake when measuring or recording data.

The graph shown in Figure 21.2.8 on page 566 is a **calibration curve** for determining the concentration of phosphate in a water sample. The data point that does not fit the trend of the other data points is an outlier. A mistake may have occurred when preparing that particular phosphate standard solution. In this case, show the data point, but do not use this point when drawing a line of best fit.

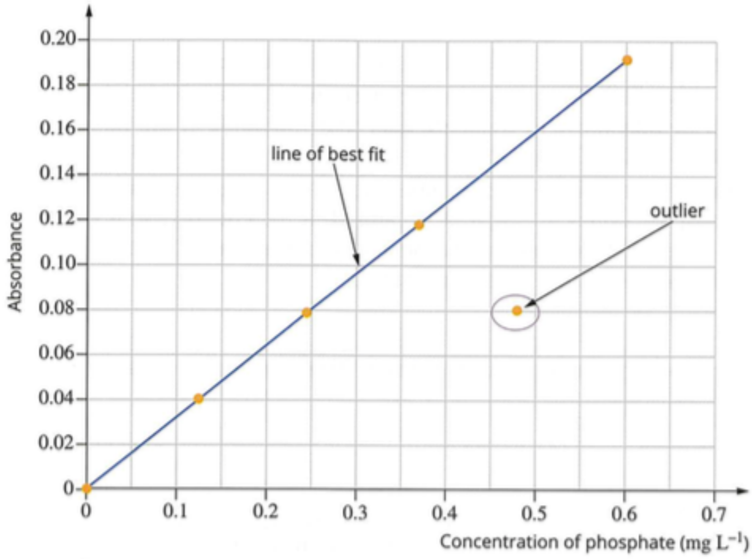


FIGURE 21.2.8 The graph is a calibration curve for determining the concentration of phosphate in a water sample.

Table 21.2.7 lists the types of graphs used for various examples.

TABLE 21.2.7 Examples of the types of graphs that could be used in your report

Type of graph	When to use	Example
Scatter graph	When showing quantitative data where one variable is dependent on another variable; draw a line of best fit to show the relationship between the two variables	Constructing a calibration curve in colorimetry
Line graph	With continuous quantitative data	Concentration of dissolved oxygen at a particular location of a creek over a period of time
Bar graphs	When comparing data in an investigation with a qualitative independent variable	Turbidity of water at various locations, as shown in Figure 21.2.9
Pie diagrams	When summarising qualitative data; to display proportions	Relative proportion of different pesticides in a sample of water

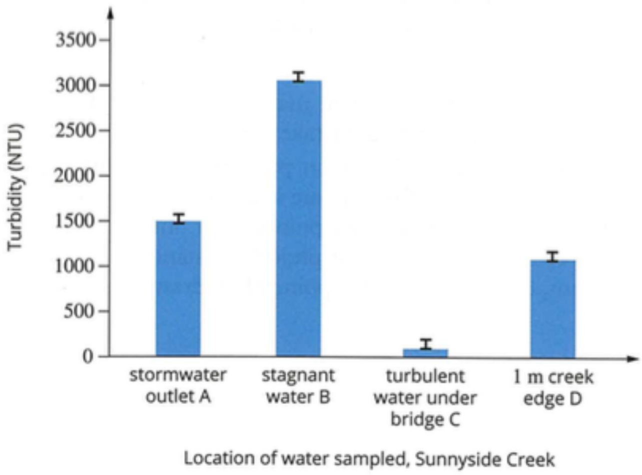


FIGURE 21.2.9 A bar graph can be used to compare data. This graph shows the measured turbidity of water samples taken from various locations along Sunnyside Creek.

21.2 Review

SUMMARY

- Record all information objectively in your logbook, including data and method during an investigation.
- Be aware of potential errors when conducting an investigation, including:
  - mistakes—are avoidable
  - systematic errors—errors that are consistent and will occur again if the investigation is repeated in the same way
  - random errors—errors that occur in an unpredictable manner and are generally small.
- Reduce errors by:
  - selecting appropriate equipment
  - properly calibrating equipment
  - using equipment correctly
  - using a larger sample.
- Tables are often an efficient way in which to record raw data.
- Processed data can be presented in tables, flow charts, diagrams or graphs.
- Tables allow the presentation of more detail, while graphs allow trends to be shown more clearly.
- To present data accurately, the mean and its uncertainty should be included.
- Scatter graphs are useful when showing quantitative data where one variable is dependent on another variable.
- Line graphs are useful for presenting continuous quantitative data.
- Bar graphs are useful for comparing data.
- Pie diagrams are useful for showing proportional data.

KEY QUESTIONS

1 A titration was carried out by a student during a research investigation. These titres were recorded: 18.34 mL, 17.34 mL, 17.38 mL, 17.84 mL and 17.44 mL. Which three are concordant titres?

2 Which of the following would not cause an error in measuring the turbidity of a sample?

A The presence of air bubbles in the water sample
B Using a control with distilled water
C Dirty fingermarks on the sample container inserted into the turbidity sensor
D Putting the water sample in an opaque container, then inserting this into the turbidity sensor

3 Identify whether each error is a mistake, a systematic error or a random error.

a A pipette that should have dispensed aliquots of 25.00 ± 0.03 mL actually dispensed aliquots of 25.87 ± 0.03 mL.
b A student misread the value of the burette for the second titration.
c A sample of sodium carbonate powder was weighed three times with the following results: 1.5791 g, 1.5792 g and 1.5790 g.

4 Which of the following methods is likely to be the most accurate, quantitative method for measuring the pH of water?

A Using pH paper (e.g. litmus paper)
B Using universal indicator and a colour chart
C Using a calibrated pH meter at a particular temperature
D Using a conductivity meter

5 What kind of statistical measurement is most affected by an outlier: mean, median or mode?

21.3 Discussing investigations and drawing evidence-based conclusions

The final part of your investigation involves summarising your findings in an objective, clear and concise manner for your audience.

In this section, you will learn how to discuss your investigation and draw evidence-based conclusions in relation to your hypothesis and research question.

EXPLAINING RESULTS IN THE DISCUSSION

The discussion is the part of your investigation in which you evaluate and explain your methods and results. You should finally interpret what your results mean.

The key sections of the discussion are:

- analysing and evaluating data
- evaluating the investigative method
- explaining the link between the investigation findings and relevant chemical concepts.

Consider the message you want to convey to the audience when writing your discussion. Statements need to be clear and concise. At the conclusion of your discussion, the audience must understand the context, results and implications of your investigation.

ANALYSING AND EVALUATING DATA

In the discussion, the findings of your investigation need to be analysed and interpreted. The following factors should be looked at and discussed.

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

Trends in line graphs

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

- Variables that change in linear or direct proportion to each other produce a straight trend line, as shown in Figure 21.3.1.

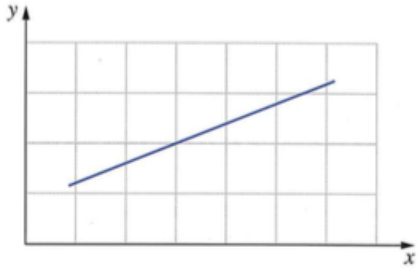


FIGURE 21.3.1 Trend line for variables that change in direct response to each other.

- Variables that change non-linearly in proportion to each other produce a curved trend line, as shown in Figure 21.3.2.

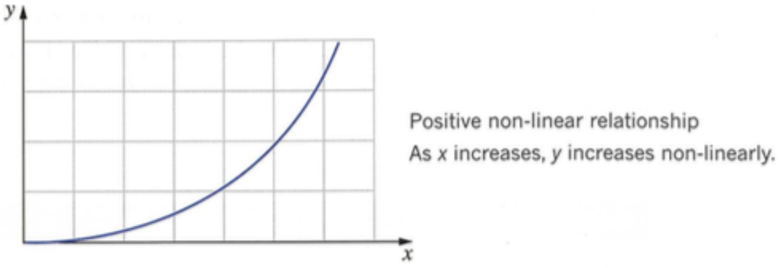


FIGURE 21.3.2 Variables that change in response to each other in a non-linear way.

- When there is an inverse relationship, one variable increases as the other variable decreases (see Figure 21.3.3).

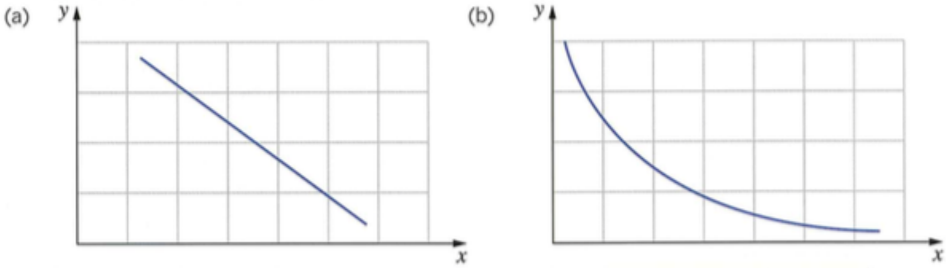


FIGURE 21.3.3 An inverse relationship in which one variable decreases in response to the other variable increasing. It may be (a) direct or (b) non-linear.

- When there is no relationship between two variables, one variable will not change even if the other changes. A graph in which there is no relationship can be seen in Figure 21.3.4.

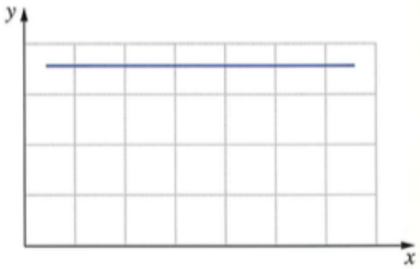


FIGURE 21.3.4 When two variables show no relationship, there is no trend in the graph.

Remember that your results may be unexpected. This does not make the investigation a failure. However, you must be able to relate your findings to the hypothesis, aims and method.

EVALUATING THE METHOD

It is important to discuss the limitations of your method. You can do this by:

- evaluating the method
- identifying issues that could affect validity, accuracy, precision and reliability of data
- state sources of systematic and random errors
- recommend improvements to the investigation if it is to be repeated.

The more times an experiment is repeated, the more reliable the results are. Limited time and resources to repeat your experiment may make your results less reliable. Your control group is important to the reliability of your experiment. This will help you work out if you have overlooked a variable and may explain unexpected results.

DISCUSSING RELEVANT CHEMICAL CONCEPTS

You need to be able to explain your results in relation to chemical ideas, concepts and theories. Doing this will allow you to explain your hypothesis.

For example, if you were studying the impact of dissolved carbon dioxide on the pH of sparkling mineral water, you could include the information in Table 21.3.1 in your discussion.

TABLE 21.3.1 Examples of how to include chemical concepts in your discussion

Key ideas	Example
Definitions of key terms	'pH', 'dissolved carbon dioxide' and 'sparkling' mineral water
The function of added carbon dioxide	In order to create 'sparkling' water
Relationship between variables	Dissolved carbon dioxide and pH of water, temperature was controlled in the experiment
Chemical principles	Dissolved carbon dioxide and formation of carbonic acid (H_2CO_3), including relevant equations
Sources of error	Reducing random error, by repeating measurements and calculating average

Relating your findings to your hypothesis

You now need to be able to discuss whether your data supports or refutes your hypothesis.

Ask yourself questions relating to your hypothesis and the literature regarding chemical concepts as shown in Figure 21.3.5.

Ensure you discuss the broader implications of your findings. Implications are the bigger picture. Outlining them for the audience is an important part of the investigation.

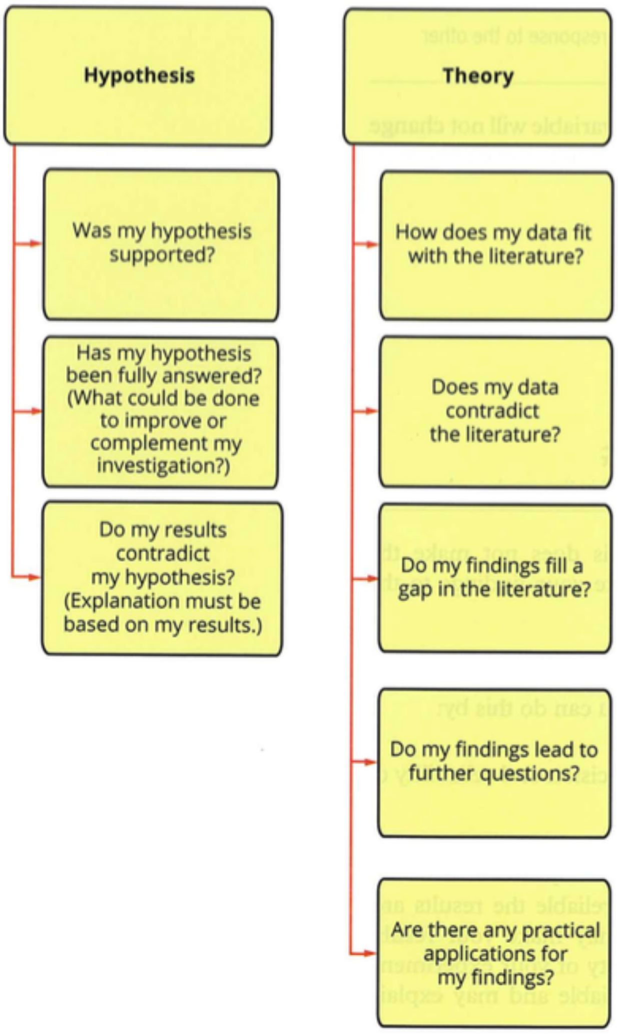


FIGURE 21.3.5 Use these questions to help relate your data to your hypothesis.

DRAWING EVIDENCE-BASED CONCLUSIONS

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

Read the examples of poor and better conclusions in Tables 21.3.2 and 21.3.3 for the hypothesis and research question shown.

TABLE 21.3.2 Examples of strong and weak conclusions to the hypothesis

Hypothesis: An increase in the temperature of pond water will result in a decrease in the measured pH of the water sample	
Strong conclusion	**Weak conclusion**
An increase in temperature from 5°C to 40°C resulted in a decrease in the pH of the water from 7.4 to 6.8.	The pH of water decreased as temperature increased.

TABLE 21.3.3 Examples of strong and weak conclusions in response to the research question

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

REFERENCES AND ACKNOWLEDGEMENTS

All the quotations, documents, publications and ideas used in your investigation need to be listed in the references and acknowledgments. In order to avoid plagiarism and to ensure creators are properly credited for their work, this must be completed accurately.

References and acknowledgements also give credibility to your study and allow the audience to locate information sources should they wish to study it further. For example: 'Melbourne Water reported similar turbidity levels in Yarra River water (Melbourne Water, 2015).'

In Chapter 11 on page 270 you will find a guide on how to write citations and references of different types of sources. The standard referencing style used is the American Psychological Society (APA) academic referencing style.

21.3 Review

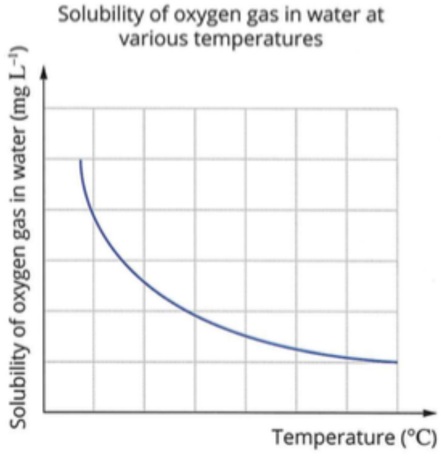
SUMMARY

- A discussion should:
  - analyse and evaluate data
  - identify patterns and limitations
  - identify issues that may have affected validity, accuracy and precision, reliability
  - make recommendations for improving the investigation method
  - explain the link between investigation findings and relevant chemical concepts
  - define concepts and investigation variables
  - discuss the investigation results in relation to the hypothesis
  - link the investigation's findings to existing knowledge and literature
  - discuss the implications and possible applications of the investigation's findings
  - suggest further investigations related to this question.
- A conclusion should:
  - link the evidence collected to the hypothesis and research question
  - indicate whether the hypothesis was supported or refuted.
- References and acknowledgements should be presented in the appropriate format.

KEY QUESTIONS

1 If you hypothesise that the solubility of potassium nitrate in water increases non-linearly with increasing temperature, what would you expect a graph of the data to look like?

2 Describe the trend in the following graph.



3 A scientist designed and completed an experiment to test the following hypothesis:
'Increasing the temperature of water would result in an increase in the measured electrical conductivity of water.'

The discussion section of the scientist's report included comments on the reliability, validity, accuracy and precision of the investigation.

Determine which of the following sentences comment on the reliability, validity, accuracy or precision.

a Three water samples from the same source were examined at each temperature. Each water sample was analysed and the measurements were recorded.

b The temperature and the electrical conductivity of the water samples were recorded using data-logging equipment. The temperature of some of the water samples was measured using a glass thermometer.

c The data logging equipment was calibrated for electrical conductivity against a known standard. The equipment was calibrated before measurements were taken.

d The temperature probe (data logger) measured temperature to the nearest 0.1°C. The glass thermometer measured temperature to the nearest 1°C.

4 The scientist testing the hypothesis from Question 3 concluded that there was no relationship between pH and electrical conductivity. Why is this conclusion invalid?

Chapter review

KEY TERMS

accurate
aim
aliquot
bias
biological oxygen demand (BOD)
calibrated
calibration curve
chemical code
concordant titre
conductivity
control
controlled variable
data-logging equipment
dependent variable
deviation
discrete
dissolved oxygen (DO)
hypothesis
independent variable
mean
median
mistake
mode
outlier
parallax error
pH
precise
qualitative
quantitative
random error
range
raw data
reliability
research question
risk assessment
Safety Data Sheet (SDS)
Secchi disk
systematic error
titration
trend
validity
variable

Designing and planning investigations

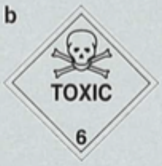
1 Consider the following research question:
'Is the concentration of lead in water sampled from along the Yarra River within acceptable limits?'
Which of the following is the independent, dependent and controlled variables?
A Concentration of lead
B Analytical technique, temperature of water sample, type of sampling container
C Source and location of water

2 Consider the following hypothesis:
'The phosphate concentration of laundry-waste water will be greater than that of drinking water.'
Name the independent, dependent and controlled variables for an experiment with this hypothesis.

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

4 What are the meanings of the following chemical codes?

a


b


c


Conducting investigations and recording and presenting data

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

6 Which graph from the following list would be best to use with each set of data listed here?
Graph types: pie diagram, scatter graph (with line of best fit), bar graph, line graph
a The levels of a pesticide detected in drinking water at various locations
b The temperature of water sampled at the same time of day over a period of a month
c A calibration curve showing absorbance of standard solutions of phosphate measured using UV–visible spectroscopy
d The proportion of specific contaminants detected in water

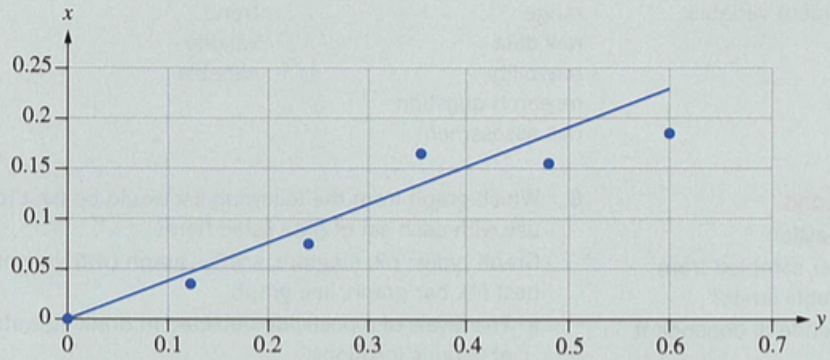
7 a Use the following values to plot a calibration curve to determine the concentration of phosphate in samples of water. The absorbance values were obtained during an experiment at 450 nm.

Standard phosphate concentration (mg L^{-1})	Absorbance
0.00	0.000
0.12	0.038
0.24	0.079
0.36	0.159
0.48	0.154
0.60	0.191

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

8 Biological oxygen demand (BOD) is a measure of the amount of decomposing organic material in a water sample. It can be determined by taking two water samples at a particular location and measuring the dissolved oxygen (DO) content in mg L^{-1} at the time of sampling and then 5 days later. What other measurements should be taken at the time of water sampling?

9 The following calibration curve was obtained by UV–visible spectroscopy at 450 nm. The curve plots the absorbance of phosphate solutions against their concentration.
Describe four changes that should be made to improve the calibration curve.



Discussing investigations and drawing evidence-based conclusions

10 What factors can you look at to ensure you discuss the limitations of your method?

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

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

Connecting the main ideas

13 A scientist designed and completed an experiment to test the following hypothesis:
'Increasing the temperature of water would result in an increase in the measured electrical conductivity of water.'
- a Write a possible aim for this scientist's experiment.
- b What would be the independent, dependent and controlled variables in this investigation?
- c What kind of data would be collected? Would it be qualitative or quantitative?
- d List the equipment that could be used and the type of precision expected for each item.
- e Explain the difference between raw data and processed data, using this as an example. What would you expect the graph of the results to look like if the scientist's hypothesis was correct?

The first two topics of semester 1 in 2021 are:
(i) Galvanic Cells as a source of energy

Chapter 4 & 5

(ii) Fuel cells as a source of energy

Chapter 6

Knowledge with 'VCAA' marks

(i) Galvanic Cells as a source of energy

(a) redox reactions with reference to electron transfer, reduction and oxidation reactions, reducing and oxidising agents, and use of oxidation numbers to identify conjugate reducing and oxidising agent

(b) the writing of balanced half-equations for oxidation and reduction reactions and balanced ionic equations, including states, for overall redox reactions

(c) galvanic cells as primary cells and as portable or fixed chemical energy storage devices that can produce electricity including common design features (anode, cathode, electrolyte, salt bridge and separation of half-cells) and chemical processes (electron-flow and ion-flow, half-equations and overall equations)

(d) the comparison of the energy transformations occurring in spontaneous exothermic redox reactions involving direct contact between reactants transforming chemical energy to heat energy, compared with those occurring when the reactants are separated in galvanic cells transforming chemical energy to electrical energy

(e) the use of the electrochemical series in designing and constructing galvanic cells and as a tool for predicting the products of redox reactions, deducing overall equations from redox half-equations and determining maximum cell voltage understand conditions.

(ii) Fuel Cells as a source of energy

(a) the common design features of fuel cells including use of porous electrodes for gaseous reactants to increase cell efficiency

(b) the comparison of the use of fuel cells and combustion of fuels to supply energy with reference to their energy efficiency (qualitative), safety, fuel supply including the storage of hydrogen, production of greenhouse gases and applications

(c) the comparison of fuel cells and galvanic cells with reference to their definitions, functions, design features, energy transformations, energy efficiencies (qualitative) and applications.