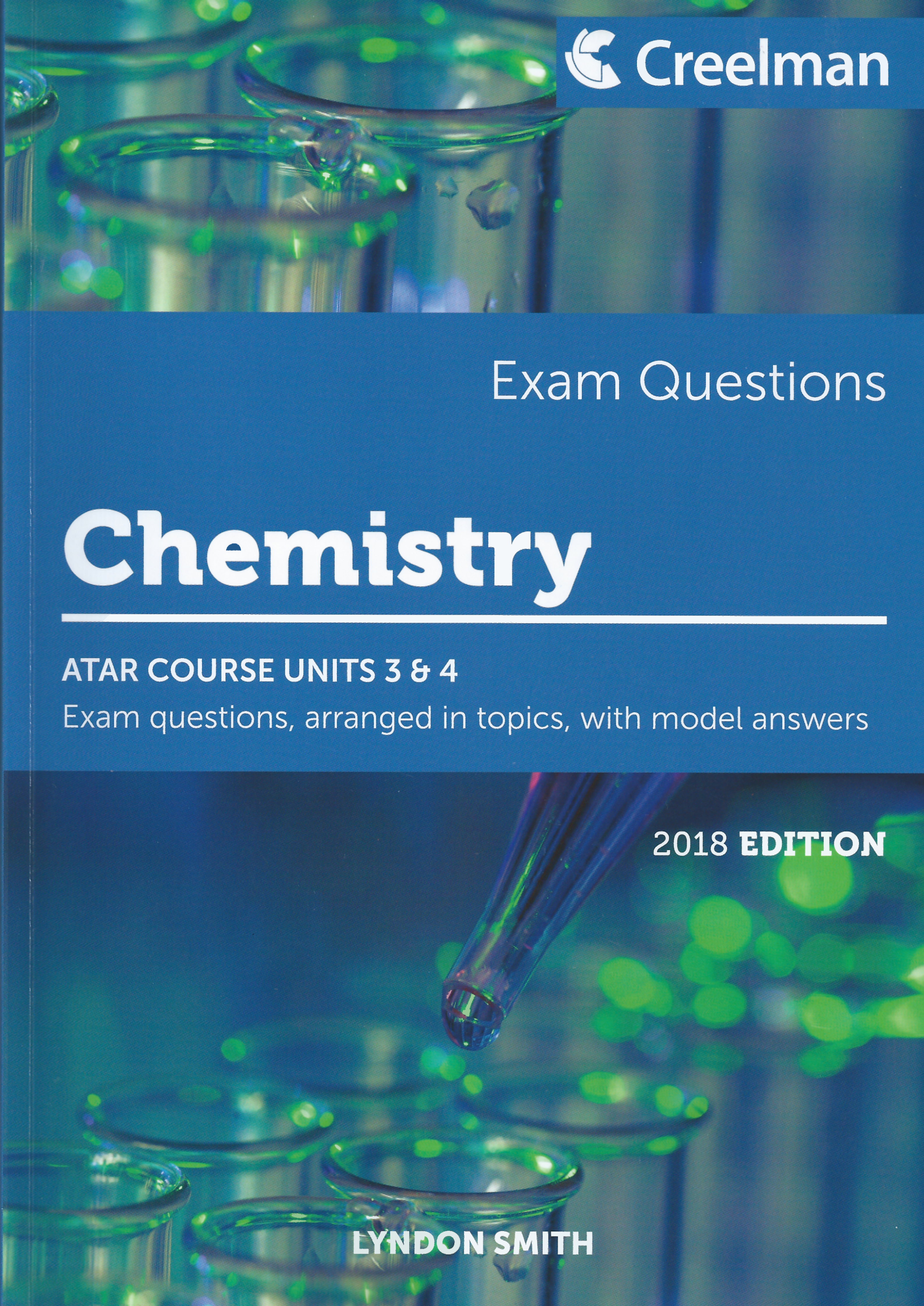

Creelman

Exam Questions

Chemistry

ATAR COURSE UNITS 3 & 4

Exam questions, arranged in topics, with model answers

2018 **EDITION**

LYNDON SMITH

ACADEMIC TASK FORCE

Creelman

Exam Questions

CHEMISTRY YEAR 12
ATAR COURSE UNITS 3 AND 4

2018 Edition

Lyndon Smith

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Preface

Help in Preparing for ATAR Exams

Academic Task Force's Creelman Exam Questions series aim is to help your exam preparation by providing a structured resource, using the actual WACE exam questions from previous years to help you prepare for your ATAR exams. This format ensures you become familiar with all parts of the ATAR syllabus, grouped into topics, to give you vital help by practicing real exam questions. Model answers and marks allocation help you monitor your progress. By following this revision pattern you will be able to face your exams with confidence.

The Creelman Exam Questions series follows the format developed by Andrew Creelman, a maths teacher. The format was based on his experience as a student and teacher. 'It was my practice in preparing for exams to go through the last few years of exams and group the questions into topics to gain an understanding of the type of questions asked, the frequency of questions in certain areas and to get an insight into what the examiners were looking for. This focussed my exam preparation and I went into exams well prepared.'

Teachers, by placing this book on your school booklist your students will have access to actual previous WACE exam questions, arranged in topics with model answers. Revision for ATAR topic tests or exams becomes easier - you can refer your students to the relevant chapter for class work or homework.

About the Consulting Editor

Lyndon Smith has taught senior chemistry for over four decades under seven different syllabus documents in both South Australia and Western Australia. He has edited 7 text books in chemistry education.

He has been a member of Curriculum Committees in both states in subject areas including Chemistry, Physics, Engineering and Integrated Science. He has served as both an Examiner and a Chief Examiner and he brings this experience to Chemistry 12 in WA.

His involvement with Science education has extended to working in Diploma of Education programmes in science with both SA and WA student teachers. He has also worked in the TAFE sector teaching hydraulics, pneumatics and PLC programming.

How to Use this Book

This book contains questions from previous Year 12 examinations that have been arranged topically and in chronological order. By completing these expertly written exam questions (write-on) in the book and then checking the solutions at the back, students are able to get immediate feedback on the key points of understanding required in each topic. Becoming familiar with the standard required through practise on the questions, chapter by chapter, will confidently prepare students for tests and exams throughout the year.

The Syllabus

Chemical equilibrium systems

1.0 Science as a Human Endeavour

Levels of carbon dioxide in the atmosphere are rising and have a significant impact on global systems, including surface temperatures. The increasing level of carbon dioxide in the atmosphere causes more carbon dioxide to dissolve in the ocean producing carbonic acid and leading to increased ocean acidity. This is predicted to have a range of negative consequences for marine ecosystems such as coral reefs. Calcification is the process which results in the formation of calcium carbonate structures in marine organisms. Acidification shifts the equilibrium of carbonate chemistry in seawater, decreasing the rate and amount of calcification among a wide range of marine organisms. The United Nations Kyoto Protocol and the Intergovernmental Panel on Climate Change aim to secure a global commitment to reducing greenhouse gas emissions over the next few decades.

Science Understanding

1.1 collision theory can be used to explain and predict the effects of concentration, temperature, pressure, the presence of catalysts and surface area of reactants on the rates of chemical reactions

1.2 chemical systems include physical changes and chemical reactions and may be open (which allow matter and energy to be exchanged with the surroundings) or closed (which allow energy, but not matter, to be exchanged with the surroundings)

1.3 observable changes in chemical reactions and physical changes can be described and explained at an atomic and molecular level

1.4 over time, in a closed system, reversible physical and chemical changes may reach a state of dynamic equilibrium, with the relative concentrations of products and reactants defining the position of equilibrium

1.5 the characteristics of a system in dynamic equilibrium can be described and explained in terms of reaction rates and macroscopic properties

1.6 the reversibility of chemical reactions can be explained in terms of the activation energies of the forward and reverse reactions

1.7 the effect of changes of temperature on chemical systems initially at equilibrium can be predicted by considering the enthalpy changes for the forward and reverse reactions; this can be represented on energy profile diagrams and explained by the changes in the rates of the forward and reverse reactions

1.8 the effects of changes in concentration of solutions and partial pressures of gases on chemical systems initially at equilibrium can be predicted and explained by applying collision theory to the forward and reverse reactions

1.9 the effects of changes in temperature, concentration of species in solution, partial pressures of gases, total volume and the addition of a catalyst on equilibrium systems can be predicted using Le Châtelier's Principle

1.10 equilibrium law expressions can be written for homogeneous and heterogeneous systems; the equilibrium constant (K), at any given temperature, indicates the relationship between product and reactant concentrations at equilibrium

1.11 the relative amounts of reactants and products (equilibrium position) can be predicted qualitatively using equilibrium constants (K_c)

Acids and bases

2.0 Science as a Human Endeavour

Models and theories are contested and refined or replaced when new evidence challenges them, or when a new model or theory has greater explanatory scope. Davy initially proposed that acids were substances that contained replaceable hydrogen (hydrogen that could be partly or totally replaced by metals) and bases were substances that reacted with acids to form salts and water. The Arrhenius model, which includes only soluble acids and bases, identified acids as substances which produce hydrogen ions in solution and bases as substances which produce hydroxide ions in solution. Subsequently, the Brønsted-Lowry model describes acid-base behaviour in terms of proton donors and proton acceptors. This approach includes a wider range of substances and can be more broadly applied.

Science Understanding

2.1 acids are substances that can act as proton (hydrogen ion) donors and can be classified as monoprotic or polyprotic, depending on the number of protons available for donation

2.2 the strength of acids is explained by the degree of ionisation at equilibrium in aqueous solution which can be represented by chemical equations and acidity constants (K_a)

2.3 the relationship between acids and bases in equilibrium systems can be explained using the Brønsted-Lowry model and represented using chemical equations that illustrate the transfer of protons between conjugate acid-base pairs

2.4 the hydrolysis of salts of weak acids and weak bases can be represented using equations; the Brønsted-Lowry model can be applied to explain the acidic, basic and neutral nature of salts derived from bases and monoprotic and polyprotic acids

2.5 buffer solutions are conjugate in nature and resist changes in pH when small amounts of strong acid or base are added to the solution; buffering capacity can be explained qualitatively; Le Châtelier's Principle can be applied to predict how buffers respond to the addition of hydrogen ions and hydroxide ions

2.6 water is a weak electrolyte; the self-ionisation of water is represented by $K_w = [H^+][OH^-]$ where $K_w = 1.0 \times 10^{-14}$ at 25°C

2.7 K_w can be used to calculate the concentration of hydrogen ions or hydroxide ions in solutions of strong acids or bases

2.8 the pH scale is a logarithmic scale and the pH of a solution can be calculated from the concentration of hydrogen ions using the relationship $pH = -\log_{10} [H^+]$

2.9 acid-base indicators are weak acids, or weak bases, in which the acidic form is a different colour from the basic form

2.10 volumetric analysis methods involving acid-base reactions rely on the identification of an equivalence point by measuring the associated change in pH, using appropriate acid-base indicators or pH meters, to reveal an observable end point

2.11 data obtained from acid-base titrations can be used to calculate the masses of substances and concentrations and volumes of solutions involved

Oxidation and reduction

3.0 Science as a Human Endeavour

Spontaneous redox reactions can be used as a source of electrical energy, including primary, secondary and fuel cells. Fuel cells are a potential lower-emission alternative to the internal combustion engine and are already being used to power various modes of transport. Organisations, including the International Partnership for Hydrogen and Fuel Cells in the Economy, have been created to foster global cooperation on research and development, common codes and standards, and information sharing on infrastructure development.

Science Understanding

3.1 oxidation-reduction (redox) reactions involve the transfer of one or more electrons from one species to another

3.2 oxidation involves the loss of electrons from a chemical species, and reduction involves the gain of electrons by a chemical species; these processes can be represented using half-equations and redox equations (acidic conditions only)

3.3 a range of reactions involve the oxidation of one species and reduction of another species, including metal and halogen displacement reactions, combustion and corrosion

3.4 the species being oxidised and reduced in a redox reaction can be identified using oxidation numbers

3.5 the relative strength of oxidising and reducing agents can be determined by comparing standard electrode potentials, and can be used to predict reaction tendency

3.6 electrochemical cells, including galvanic and electrolytic cells, consist of oxidation and reduction half-reactions connected via an external circuit through which electrons move from the anode (oxidation reaction) to the cathode (reduction reaction)

3.7 galvanic cells produce an electric current from a spontaneous redox reaction

3.8 the electric potential difference of a cell under standard conditions can be calculated from standard electrode potentials; these values can be used to compare the voltages generated by cells constructed from different materials

3.9 electrochemical cells can be described in terms of the reactions occurring at the anode and cathode, the role of the electrolyte, salt bridge (galvanic cell), ion migration, and electron flow in the external circuit

3.10 cell diagrams can be used to represent electrochemical cells

3.11 electrolytic cells use an external electrical potential difference to provide the energy to allow a non-spontaneous redox reaction to occur; electrolytic cells are used in a range of industrial situations, including metal plating and the purification of copper

Organic chemistry

4.0 Science as a Human Endeavour

Properties and structure of organic materials

The Protein Data Bank (PDB) houses an international repository of structural data of proteins. The information is accessed and contributed to by scientists worldwide. The function of a protein is closely linked to its structure.

Science Understanding

4.1 organic molecules have a hydrocarbon skeleton and can contain functional groups, including alkenes, alcohols, aldehydes, ketones, carboxylic acids, esters, amines and amides; functional groups are groups of atoms or bonds within molecules which are responsible for the molecule's characteristic chemical properties

4.2 structural formulae (condensed or showing bonds) can be used to show the arrangement of atoms and bonding in organic molecules that contain the following functional groups: alkenes, alcohols, aldehydes, ketones, carboxylic acids, esters, amines and amides

4.3 functional groups within organic compounds display characteristic chemical properties and undergo specific reactions; these reactions include addition reactions of alkenes, redox reactions of alcohols, and acid-base reactions of carboxylic acids; these reactions can be used to identify the functional group present within the organic compound

4.4 IUPAC nomenclature is used to name organic species, including those with a parent chain of up to 8 carbon atoms with simple branching and one of the following functional groups: alkenes, alcohols, aldehydes, ketones, carboxylic acids, esters, amines and amides

4.5 isomers are compounds with the same molecular formulae but different structures; different types of isomerism include chain and position structural isomerism and cis-trans isomerism

4.6 all alcohols can undergo complete combustion; with oxidising agents, including acidified MnO_4^- or $Cr_2O_7^{2-}$ oxidation of primary alcohols produces aldehydes and carboxylic acids, while the oxidation of secondary alcohols produce ketones; these reactions have characteristic observations and can be represented with equations

4.7 alcohols can react with carboxylic acids in a condensation reaction to produce esters and can be represented with equations

4.8 organic compounds display characteristic physical properties, including boiling point and solubility in water and organic solvents; these properties can be explained in terms of intermolecular forces (dispersion forces, dipole-dipole interactions and hydrogen bonds) which are influenced by the nature of the functional groups

4.9 empirical and molecular formulae can be determined by calculation and the structure of an organic compound established from the chemical reactions they undergo, and other analytical data

4.10 addition reactions can be used to produce polymers, including polyethene and polytetrafluoroethene

4.11 the structure of an addition polymer can be predicted from its monomer and the structure of an addition polymer can be used to predict the monomer from which it was derived

4.12 condensation reactions can be used to produce polymers, including polyamides and polyesters

4.13 the structure of a condensation polymer can be predicted and drawn from its monomer(s) and the structure of a condensation polymer can be used to predict the monomer(s) from which it was derived

4.14 α-amino acids can be represented using a generalised structure

4.15 the characteristic properties of α-amino acids include the formation of zwitterions and the ability to react to form amide (peptide) bonds through condensation reactions

4.16 α-amino acids undergo condensation reactions to form polypeptides (proteins) in which the α-amino acid monomers are joined by peptide bonds

4.17 the sequence of α-amino acids in a protein is called its primary structure

4.18 secondary structures of proteins, (α-helix and β-pleated sheets) result from hydrogen bonding between amide and carbonyl functional groups; hydrogen bonding between amide and carbonyl functional groups within a peptide chain leads to α-helix structures while hydrogen bonding between adjacent polypeptide chains leads to β-pleated sheets

4.19 the tertiary structure of a protein (the overall three-dimensional shape) is a result of folding due to interactions between the side chains of the α-amino acid in the polypeptide, including disulfide bridges, hydrogen bonding, dipole-dipole interactions, dispersion forces and ionic interactions

Chemical synthesis

5.0 Science as a Human Endeavour

Scientific knowledge can be used to design alternative chemical synthesis pathways, taking into account sustainability, local resources, economics and environmental impacts (green chemistry), including the production of ethanol and biodiesel.

Science Understanding

5.1 chemical synthesis to form products with specific properties may require the construction of reaction sequences with more than one chemical reaction and involves the selection of particular reagents and reaction conditions in order to optimise the rate and yield of the product

5.2 quantities of products in a chemical synthesis reaction can be calculated by comparing stoichiometric quantities with actual quantities and by determining the limiting reagent

5.3 the percentage yield of a chemical synthesis reaction can be calculated by comparing theoretical versus actual product quantities

5.4 reagents and reaction conditions are chosen to optimise yield and rate for chemical synthesis processes, including in the production of ammonia (Haber process), sulfuric acid (Contact process) and biodiesel (base-catalysed and lipase-catalysed methods)

5.5 enzymes are protein molecules which are biological catalysts and can be used on an industrial scale to produce chemicals that would otherwise require high pressure or temperature conditions to achieve an economically viable rate, including fermentation to produce ethanol versus hydrolysis of ethene

5.6 chemical synthesis processes may involve the construction of reaction sequences with more than one chemical reaction, including the hydration of ethene to form ethanol and the subsequent reaction of ethanol with acetic (ethanoic) acid to produce ethyl ethanoate

5.7 the base hydrolysis (saponification) of fats (triglycerides) produces glycerol and the salt of a long chain fatty acid (soap)

5.8 the structure of soaps contains a non-polar hydrocarbon chain and a carboxylate group; the structure of the anionic detergents derived from dodecylbenzene contains a non-polar hydrocarbon chain and a sulfonate group

5.9 the cleaning action of soaps and detergents can be explained in terms of their non-polar hydrocarbon chain and charged group; the properties of soaps and detergents in hard water can be explained in terms of the solubilities of their calcium salts

5.10 industry produces a vast range of plastics, including addition polymers (polyethene, polytetrafluoroethene) and condensation polymers (nylon and polyethylene terephthalate [PET]) which have different properties and uses

Science Enquiry Skills

6.1 identify, research, construct and refine questions for investigation; propose hypotheses; and predict possible outcomes

6.2 design investigations, including the procedure(s) to be followed, the materials required, and the type and amount of primary and/or secondary data to be collected; conduct risk assessments; and consider research ethics

6.3 conduct investigations safely, competently and methodically for the collection of valid and reliable data, including: acid-base properties, using acid-base volumetric analysis techniques, effects of changes to equilibrium systems, and constructing electrochemical cells

6.4 represent data in meaningful and useful ways, including using appropriate graphic representations and correct units and symbols; organise and process data to identify trends, patterns and relationships; identify and distinguish between random and systematic errors, and estimate their effect on measured results; discuss how the nature of the procedure and the sample size may influence uncertainty and limitations in data; and select, synthesise and use evidence to make and justify conclusions

6.5 interpret a range of scientific texts, and evaluate processes, claims and conclusions by considering the quality of available evidence, including confidence intervals in secondary data; and use reasoning to construct scientific arguments

6.6 communicate to specific audiences and for specific purposes using appropriate language, nomenclature and formats, including scientific reports

Appendix 2

Students should be able to recognise and write the formula of the following ions and molecules:

Ion name	Formula
ammonium	NH_4^+
caesium	Cs^+
hydrogen	H^+
lithium	Li^+
potassium	K^+
rubidium	Rb^+
silver	Ag^+
sodium	Na^+
barium	Ba^{2+}
calcium	Ca^{2+}
cobalt(II)	Co^{2+}
copper(II)	Cu^{2+}
iron(II)	Fe^{2+}
lead(II)	Pb^{2+}
magnesium	Mg^{2+}
manganese(II)	Mn^{2+}
nickel(II)	Ni^{2+}
strontium	Sr^{2+}
zinc	Zn^{2+}
aluminium	$A\ell^{3+}$
chromium(III)	Cr^{3+}
iron(III)	Fe^{3+}

Common molecules that have non-systemic names:

Molecule name	Formula
ammonia	NH_3
water	H_2O
hydrogen peroxide	H_2O_2
ethanoic acid	CH_3COOH
hydrochloric acid	$HC\ell$
nitric acid	HNO_3
carbonic acid	H_2CO_3
sulfuric acid	H_2SO_4
sulfurous acid	H_2SO_3
phosphoric acid	H_3PO_4

Ion name	Formula
bromide	Br^-
chloride	$C\ell^-$
cyanide	CN^-
dihydrogenphosphate	$H_2PO_4^-$
ethanoate (acetate)	CH_3COO^-
fluoride	F^-
hydrogencarbonate	HCO_3^-
hydrogensulfate	HSO_4^-
hydroxide	OH^-
iodide	I^-
nitrate	NO_3^-
nitrite	NO_2^-
permanganate	MnO_4^-
carbonate	CO_3^{2-}
chromate	CrO_4^{2-}
dichromate	$Cr_2O_7^{2-}$
hydrogenphosphate	HPO_4^{2-}
oxalate	$C_2O_4^{2-}$
oxide	O^{2-}
sulfate	SO_4^{2-}
sulfide	S^{2-}
sulfite	SO_3^{2-}
nitride	N^{3-}
phosphate	PO_4^{3-}

Chemical Equilibrium

Chapter 1

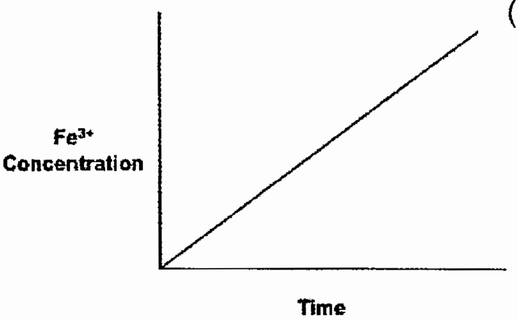
1. *1.4 (2010:18)*

When aqueous solutions of Ag^+ and Fe^{2+} are mixed, Ag and Fe^{3+} form according to the following equilibrium.

$$Ag^+(aq) + Fe^{2+}(aq) \rightleftharpoons Ag(s) + Fe^{3+}(aq)$$

Which one of the following concentration versus time graphs best represents the way in which the Fe^{3+} concentration varies as the reaction proceeds to equilibrium?

(a)



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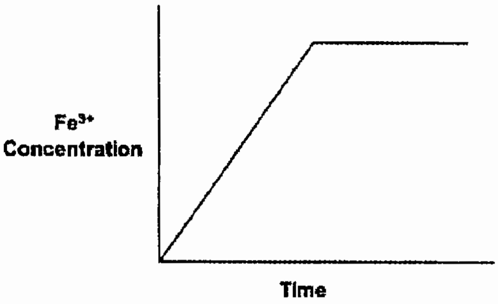

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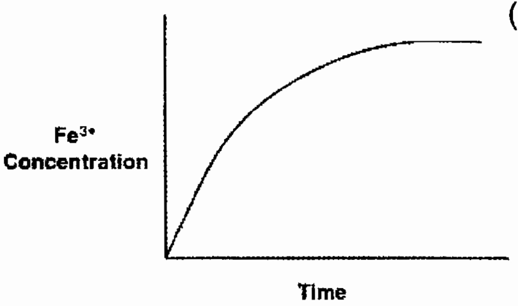

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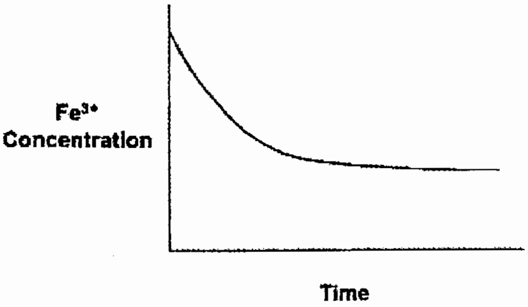


2. *1.1 (2011:10)*

An enzyme is a biological catalyst. Esters can be hydrolysed, as represented below by an esterase enzyme.

$$\text{ester} + \text{water} \xrightleftharpoons{\text{esterase}} \text{carboxylic acid} + \text{alcohol}$$

In the presence of esterase which one of the following statements is true for this process?

(a) The position of the equilibrium for this reaction is shifted to the right.

(b) The rate of forward reaction and rate of reverse reaction both increase equally.

(c) The rate of forward reaction increases more than the rate of reverse reaction.

(d) The rate of forward reaction increases and rate of reverse reaction decreases.

3. *1.9 (2011:11)*

Hydrogen can be produced by the reaction

$$CH_4(g) \quad + \quad H_2O(g) \rightleftharpoons CO(g) \quad + \quad 3\ H_2(g) \qquad \Delta H > 0$$

Which one of the following will increase the equilibrium yield of hydrogen?

(a) increasing the total pressure of the reaction system

(b) decreasing the partial pressure of the water vapour

(c) removing carbon monoxide from the system as it is produced

(d) decreasing the temperature of the system

4. *1.4 (2011:12)*

Which of the properties listed below are characteristic of a gaseous system in dynamic equilibrium?

(i) The concentrations of reactants are equal to the concentrations of products.

(ii) The concentrations of reactants and products are constant.

(iii) The rate of the forward reaction is equal to the rate of the reverse reaction.

(iv) The pressure of the system is constant.

(a) (i), (ii) and (iii)

(b) (i), (ii) and (iv)

(c) (ii), (iii) and (iv)

(d) (iii) only

5. *1.9 (2012:17)*

The reaction of iron(III) oxide with carbon monoxide gas is shown below:

$$Fe_2O_3(s) + 3\ CO(g) \rightleftharpoons 2\ Fe(\ell) + 3\ CO_2(g)$$

Which one of the following changes to the system will decrease the rate of the forward reaction?

(a) decreasing the volume of the reaction vessel

(b) decreasing the pressure of $CO(g)$ in the vessel

(c) decreasing the $Fe_2O_3(s)$ particle size

(d) decreasing the concentration of $CO_2(g)$ in the system

6. *1.6 (2012:18)*

Ammonium chloride ($NH_4C\ell$) dissolves readily in water at room temperature. If a sample of ammonium chloride is dissolved in a beaker of water, the beaker becomes cold to the touch. Which one of the following is the **best** explanation for this observation?

(a) The reaction is exothermic with a small activation energy.

(b) The reaction is exothermic with a large activation energy.

(c) The reaction is endothermic with a small activation energy.

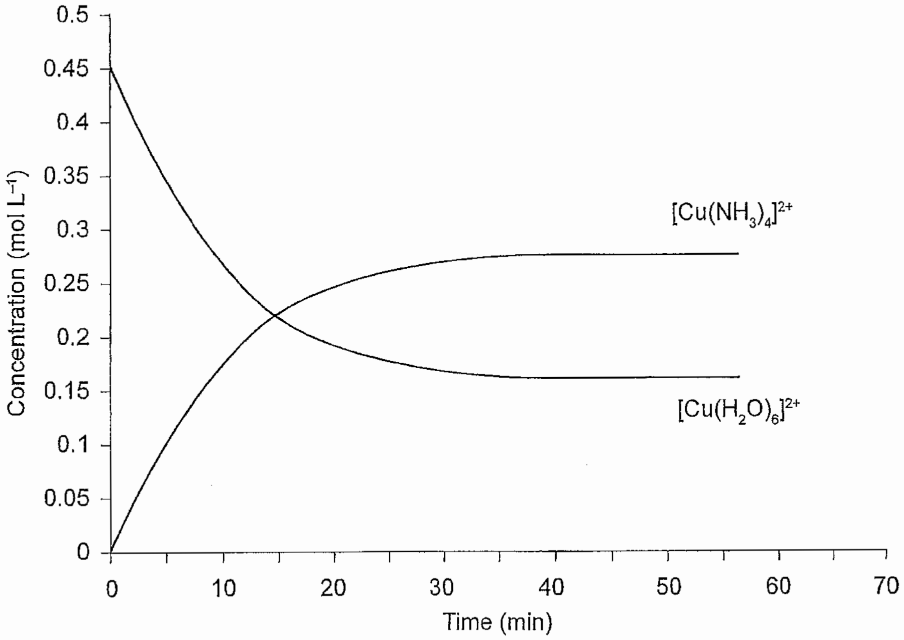
(d) The reaction is endothermic with a large activation energy.

Questions *(2013:12)* and *(2013:13)* refer to the information and graph below.

Aqueous solutions of copper(II) ions and ammonia form the equilibrium represented below.

$$\underset{\text{pale blue}}{[Cu(H_2O)_6]^{2+}(aq)} + 4\,NH_3(aq) \rightleftharpoons \underset{\text{deep royal blue}}{[Cu(NH_3)_4]^{2+}(aq)} + 6\,H_2O(\ell)$$

The following graph shows the changes in concentration with time for $[Cu(H_2O)_6]^{2+}$ and $[Cu(NH_3)_4]^{2+}$ ions when solutions of copper(II) nitrate and ammonia are mixed.



7. *1.4 (2013:12)*

Which one of the following statements is true for this equilibrium system?

(a) The system reaches equilibrium at approximately 35 minutes.

(b) At equilibrium, the concentration of NH_3 will always be four times greater than the concentration of $[Cu(NH_3)_4]^{2+}$.

(c) Adding ammonia to the system will decrease the equilibrium constant.

(d) At equilibrium, the rate of the forward reaction is less than the rate of the reverse reaction.

8. *1.9 (2013:13)*

Which one of the following would be observed if a small quantity of concentrated nitric acid was added to the system after it had reached equilibrium?

(a) The solution would be a deeper royal blue colour.

(b) The solution would be a paler blue colour.

(c) There would be no change in the colour of the system.

(d) Copper(II) nitrate crystals would precipitate from solution.

9. *1.1 (2013:14)*

Consider the following reaction.

$$2\,SO_2(g) + O_2(g) \rightleftharpoons 2\,SO_3(g) + 198\text{ kJ}$$

After equilibrium has been established, which one of the following would immediately increase the rate of the reverse reaction?

(a) adding a catalyst

(b) increasing the concentration of SO_2

(c) cooling the reaction vessel and its contents

(d) adding a small amount of neon gas

10. *1.10 (2014:10)*

Consider the following endothermic reaction

$$N_2O(g) + NO_2(g) \rightleftharpoons 3\,NO(g) \qquad \Delta H = +156\text{ kJ mol}^{-1}$$

Which one of the following changes to the system at equilibrium will increase the value of its equilibrium constant, K?

(a) increased pressure

(b) addition of a catalyst

(c) increased temperature

(d) decreased temperature

11. *1.11 (2014:11)*

Which one of the following is the equilibrium law expression for the equilibrium represented below?

$$2\,CrO_4^{2-}(aq) + 2\,H^+(aq) \rightleftharpoons Cr_2O_7^{2-}(aq) + H_2O(\ell)$$

(a) $\dfrac{[Cr_2O_7^{2-}]}{[CrO_4^{2-}]^2[H^+]^2}$

(b) $\dfrac{[CrO_4^{2-}]^2[H^+]^2}{[Cr_2O_7^{2-}]}$

(c) $\dfrac{[CrO_4^{2-}]^2[H^+]^2}{[Cr_2O_7^{2-}][H_2O]}$

(d) $\dfrac{[Cr_2O_7^{2-}][H_2O]}{[CrO_4^{2-}]^2[H^+]^2}$

12. *1.9 (2014:12)*

Aqueous solutions of iron(III) ions and thiocyanate ions form the equilibrium represented below.

$Fe^{3+}(aq)$	+	$SCN^-(aq)$	$\rightleftharpoons$	$[Fe(SCN)]^{2+}(aq)$
pale brown		colourless		deep red

The reaction is exothermic.

Which one of the following statements about changes to the system and the effect on the colour of the solution is true?

(a) Adding water will make it turn darker red.

(b) Cooling the solution will make it turn darker red.

(c) Adding a small volume of aqueous Na_2CO_3 solution will turn it darker red.

(d) Adding solid iron(III) chloride to the solution will make it lighter red.

13. *1.3 (2015:04)*

Consider the following equilibrium.

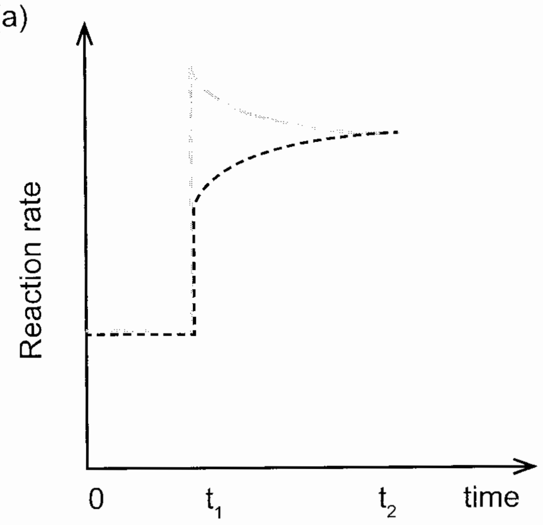
$$2\,C\ell F_3(g) \rightleftharpoons 3F_2(g) + C\ell_2(g) \qquad \Delta H = \text{negative}$$

The system is initially at equilibrium. At time t_1, the temperature of the system was increased. Which of the following **best** represents the changes in the forward and reverse reaction rates until equilibrium is re-established at time, t_2?

The forward reaction rate is represented by ……………

The reverse reaction rate is represented by ----------

(a)



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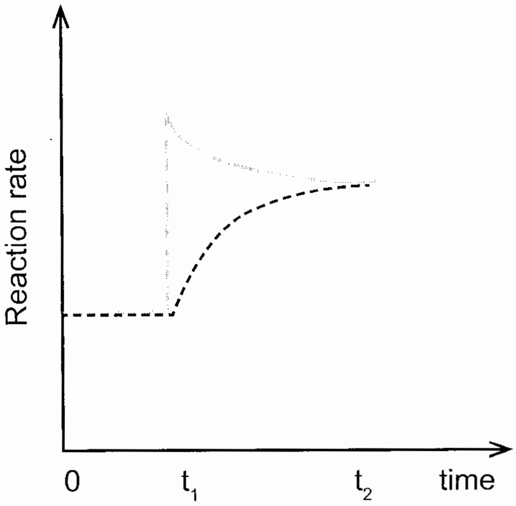

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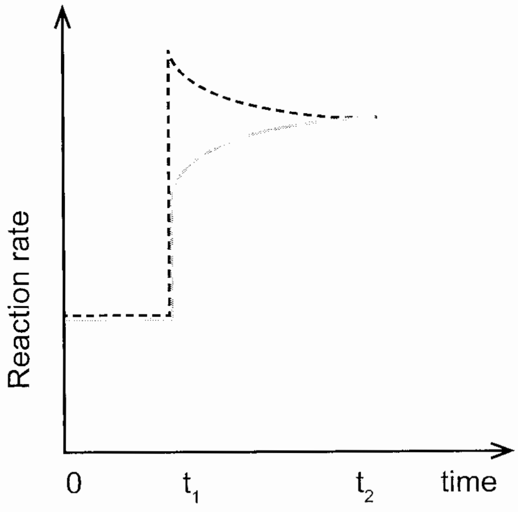

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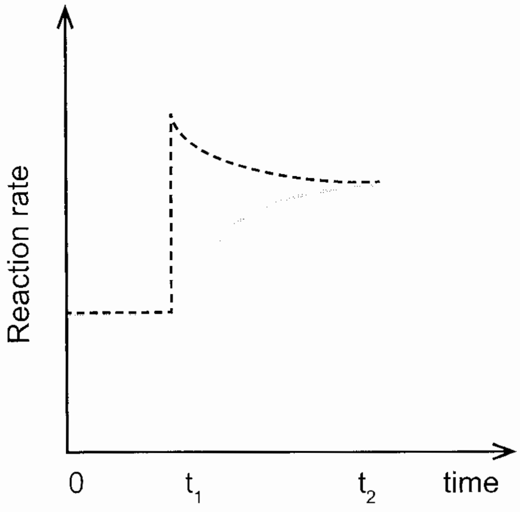


Questions *(2015:06)* and *(2015:07)* refer to the reaction represented by the equation shown below.

$$Pb(s) + PbO_2(s) + 4\,H^+(aq) + 2\,SO_4^{2-}(aq) \rightleftharpoons 2\,PbSO_4(s) + 2\,H_2O(\ell)$$

14. *1.10 (2015:06)*

Which one of the following is the equilibrium law expression for this reaction?

(a) $K = \dfrac{1}{[H^+]^4[SO_4^{2-}]^2}$

(b) $K = \dfrac{[H_2O]^2}{[H^+]^4[SO_4^{2-}]^2}$

(c) $K = \dfrac{[PbSO_4]^2}{[H^+]^4[SO_4^{2-}]^2}$

(d) $K = \dfrac{1}{[H^+]^2[SO_4^{2-}]}$

15. *1.10 (2015:07)*

Assuming equilibrium has been established, which one of the following will cause a decrease in pH?

(a) adding more solid lead

(b) adding solid sodium sulfate

(c) removing solid lead sulfate

(d) adding barium nitrate solution

16. *1.9 (2016:01)*

The decomposition of hydrogen peroxide in a closed system is represented by the equation below.

$$2\,H_2O_2(aq) \rightleftharpoons 2\,H_2O(\ell) + O_2(g) \qquad \Delta H < 0$$

Which one of the following will increase the equilibrium yield of oxygen?

(a) decreasing the concentration of hydrogen peroxide

(b) increasing the total pressure of the system

(c) decreasing the temperature of the system

(d) adding an inert gas to the system

17. *1.8 (2016:02)*

Sulfur can be obtained from hydrogen sulfide found in natural gas according to the equation below.

$$2\,H_2S(g) + SO_2(g) \rightarrow 2\,H_2O(g) + 3\,S(g) \qquad \Delta H > 0$$

Which one of the following changes will initially decrease the rate at which sulfur is produced?

(a) reduce the partial pressure of the hydrogen sulfide ($H_2S(g)$)

(b) increase the partial pressure of sulfur dioxide ($SO_2(g)$)

(c) add a metal catalyst to the reaction vessel

(d) heating the reaction vessel

18. *1.11 (2016:03)*

Consider the equilibrium system below.

$$N_2(g) + O_2(g) \rightleftharpoons 2\,NO(g)$$

If the equilibrium constant (K) for this reaction is 4.1×10^{-31}, which one of the following statements is **true** for the system where the initial partial pressures of nitrogen and oxygen were equal to each other?

(a) Once equilibrium is reached, the reverse reaction rate is much faster than the forward reaction rate.

(b) The partial pressure of $NO(g)$ is less than the partial pressure of $N_2(g)$.

(c) The actual ratio of gaseous N_2 particles to NO gaseous particles is 1:2.

(d) When nitrogen gas is injected into a vessel containing mostly oxygen gas, the partial pressure of oxygen decreases dramatically.

19. *1.9 (2016:04)*

A 500 mL solution of dichromate ions and chromate ions at equilibrium is described by the equation below.

$$\underset{\text{orange}}{Cr_2O_7^{2-}(aq)} + H_2O(\ell) \rightleftharpoons \underset{\text{yellow}}{2\,CrO_4^{2-}(aq)} + 2\,H^+(aq)$$

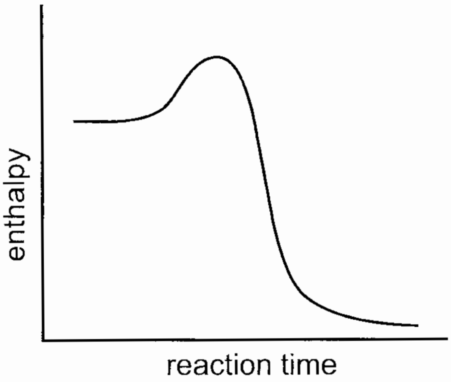
Which of the following **best** describes the effect of adding 10 mL of concentrated potassium hydroxide solution to the system once equilibrium has been re-established.

	Relative change in concentration of $Cr_2O_7^{2-}(aq)$	Relative change in concentration of $CrO_4^{2-}(aq)$	Relative change in concentration of $H^+(aq)$	Colour change of solution
(a)	increase	decrease	decrease	more orange
(b)	decrease	increase	decrease	more yellow
(c)	no change	no change	no change	no change
(d)	decrease	increase	increase	more yellow

20. *1.7 (2016:08)*

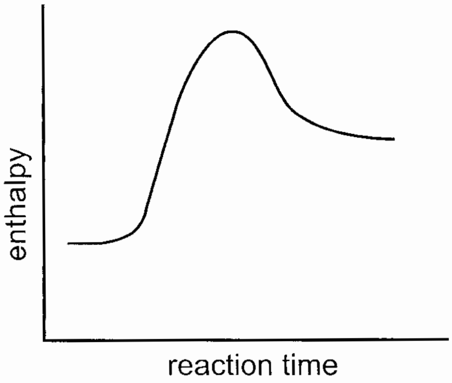
Which of the following energy profile diagrams **best** represents a spontaneous, exothermic reaction?

(a)

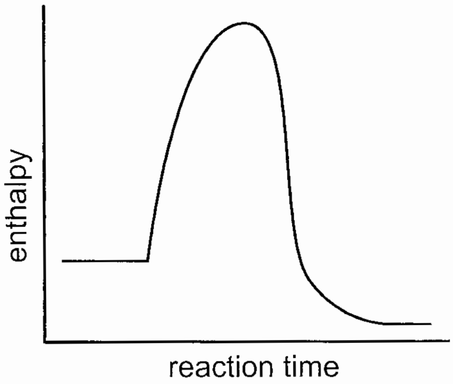


(b)

(c)

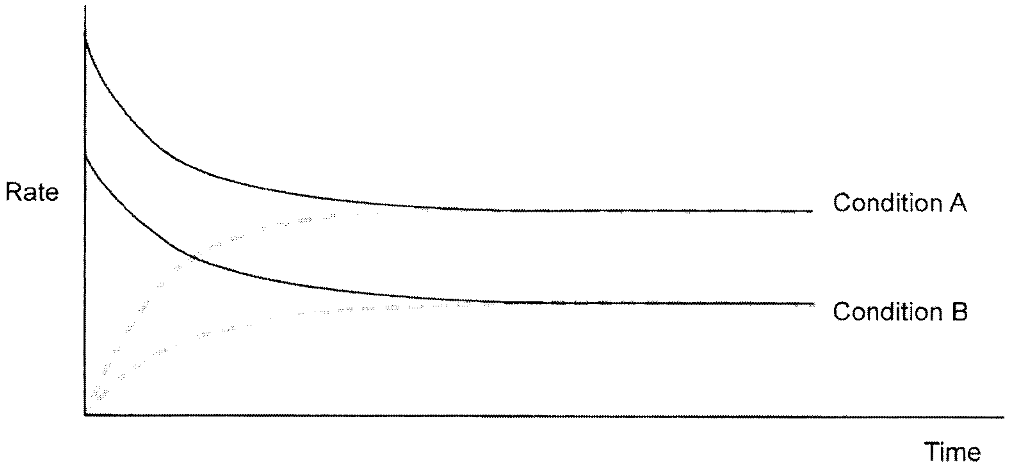


(d)



21. *1.5 (2017:05)*

The following graph shows both the forward (——) and reverse (-----) reaction rates for a reaction under two different sets of conditions (Condition A and Condition B).



What is different about these conditions that would account for the graphs as shown?

(a) Condition A is at a higher temperature.

(b) Condition B is at a higher temperature.

(c) Condition B had a catalyst added to it.

(d) Condition B was conducted at a higher temperature and pressure.

22. *1.8 (2017:06)*

The reaction of acetic (ethanoic) acid with propanol is slow at room temperature. If it is assumed that the reaction proceeds by a process involving the acid accepting a proton in the first step, then the rate at which equilibrium is reached could be increased by

(a) adding a strong acid to increase the proton concentration of the reactants.

(b) lowering the temperature to reduce the collision frequency of reactants.

(c) adding a base to lower the number of protons present in the reaction vessel.

(d) adding water to the system to alter the proton concentration.

23. *1.1 (2017:07)*

Consider the following statements about the effect of a catalyst being added to a reaction mixture.

(i) The formation of intermediate species not found in the uncatalysed reaction.

(ii) The availability of a new reaction path having a lower activation energy.

(iii) An increase in the percentage of collisions resulting in a reaction.

(iv) The equal increase of both forward and reverse reaction rates.

Which of these statements describe what will occur when a catalyst is added to a reaction mixture?

(a) i and ii only

(b) ii and iv only

(c) i, ii and iv only

(d) i, ii, iii and iv

24. *1.9 (2017:12)*

A sealed glass tube at room temperature contains nitrogen dioxide (a brown gas) and dinitrogen tetroxide (a colourless gas) in equilibrium, as represented by the following equation.

$$2\,NO_2\,(g) \rightleftarrows N_2O_4\,(g) \qquad \Delta H < 0$$

If the appearance of the gas mixture at room temperature is pale brown, which one of the following is true if the glass tube is placed in hot water?

(a) The gas mixture will not undergo any noticeable change in appearance.

(b) The gas mixture will become darker brown.

(c) The gas mixture will become even paler at first, but would then return to its original appearance of pale brown.

(d) The gas mixture will become colourless.

25. *1.0 (2017:18)*

The acidification of oceans due to their increased concentrations of carbon dioxide decreases the rate and amount of calcification in some marine organisms, e.g. shellfish and coral reefs. Which one of the following equations best represents the chemistry involved in decreasing the rate and amount of calcification?

(a) $2\,H^+ + CaCO_3 \rightarrow Ca^{2+} + H_2O + CO_2$

(b) $CO_2 + H_2O + CO_3^{2-} \rightarrow 2\,HCO_3^-$

(c) $4\,H^+ + 2\,CO_3^{2-} \rightarrow H_2CO_3 + H_2O + CO_2$

(d) $CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O$

Chapter 2

Acids and Bases

1. *2.3 (2012:06)*

Consider the following equation:

$$HS^-(aq) + CO_3^{2-}(aq) \rightleftharpoons S^{2-}(aq) + HCO_3^-(aq)$$

Which one of the following is **not** true of this equation?

(a) HCO_3^- is acting as a Brønsted-Lowry acid.

(b) CO_3^{2-} is acting as a conjugate base.

(c) HS^- is acting as a conjugate base.

(d) S^{2-} is acting as a Brønsted-Lowry base.

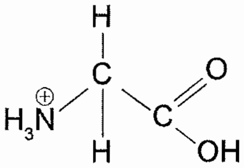
2. *2.5 (2012:07)*

Consider the list below.

(i) PO_4^{3-}

(ii) NaH_2PO_4

(iii)



(iv) $NH_2CH_2COO^-$

(v) Na_2HPO_4

(vi) $HC\ell$

Which two of the above species, when mixed together in water, form a buffer solution?

(a) (i) and (ii)

(b) (ii) and (v)

(c) (iii) and (iv)

(d) (i) and (vi)

3. *2.4 (2012:08)*

Consider the following list of compounds:

(i) KNO_3

(ii) Na_3PO_4

(iii) Fe_2O_3

(iv) Na_2S

(v) $Ba(OH)_2$

(vi) $A\ell C\ell_3$

(vii) $Ca(NO_3)_2$

Which of the above compounds will dissolve in water to give a basic solution?

(a) (i), (ii), (iii), (iv) and (v)

(b) (ii), (iii), (iv), (v), (vii)

(c) (ii), (iv), (v)

(d) (ii), (iv)

4. *2.4 (2013:15)*

Which one of the following substances can behave as a Brønsted-Lowry acid or base?

(a) H_2O_2

(b) NH_4^+

(c) CH_3NH_2

(d) $H_2PO_4^-$

5. *2.2 (2013:16)*

A solution of hydrochloric acid conducts an electric current more readily than an equimolar solution of acetic acid. Which one of the following **best** explains this observation?

(a) Hydrochloric acid is a smaller molecule than acetic acid.

(b) Hydrochloric acid is more soluble in water than acetic acid.

(c) The equilibrium constant for the ionisation of hydrochloric acid is greater than that for acetic acid.

(d) The pH of hydrochloric acid solution is always greater than that for acetic acid solution.

6. *2.4 (2013:17)*

Sodium hydrogensulfate was added to a swimming pool to reduce the pH of the water. Which one of the following equations **best** shows the reaction responsible for this?

(a) $Na+(aq) + H_2O(\ell) \rightarrow NaOH(aq) + H^+(aq)$

(b) $HSO_4^-(aq) + H_2O(\ell) \rightarrow H_3O^+(aq) + SO_4^{2-}(aq)$

(c) $2\ HSO_4^-(aq) + H_2O(\ell) \rightarrow H_3O^+(aq) + H_2SO_4(aq) + SO_4^{2-}(aq)$

(d) $HSO_4^-(aq) + H_2O(\ell) \rightarrow OH^-(aq) + H_2SO_4(aq)$

7. *2.5 (2013:18)*

A buffer solution is prepared by mixing equal moles of sodium acetate (ethanoate) and acetic acid in water. Which one of the following statements applies to the buffer?

(a) Addition of a few drops of concentrated nitric acid will produce more acetic acid molecules.

(b) The sodium ions play a significant role in the buffering action.

(c) Addition of water to the buffer will reduce its buffering capacity.

(d) Most of the hydrogen ions will be supplied by water.

8. *2.9 (2013:19)*

The pH ranges for the colour change of four indicators are given below.

Alizarin yellow	10.1–12.0
Crystal violet	6.4–8.2
Bromocresol green	3.8–5.4
Malachite green	0.2–1.8

Which one of the indicators in the table is **most** suitable for the titration of hydrochloric acid with potassium carbonate solution?

(a) alizarin yellow

(b) crystal violet

(c) bromocresol green

(d) malachite green

9. *2.2 (2014:13)*

Which of the following is the strongest acid?

	Acid	Acid dissociation (equilibrium) constant
(a)	CH_3COOH	1.8×10^{-5}
(b)	HCO_3^-	5.6×10^{-11}
(c)	HF	6.8×10^{-4}
(d)	$H_2C_2O_4$	5.4×10^{-2}

10. *2.4 (2014:14)*

Which of the following 0.1 mol L^{-1} aqueous solutions has the highest pH?

(a) ammonium sulfate

(b) hydrochloric acid

(c) potassium phosphate

(d) sodium nitrate

11. *2.3 (2014:15)*

Consider the following reaction.

$$OBr^-(aq) + H_2O(\ell) \rightleftharpoons HOBr(aq) + OH^-(aq)$$

Which one of the following represents an acid-base conjugate pair for this reaction?

(a) OBr^-/H_2O

(b) $HOBr/OH^-$

(c) OBr^-/OH^-

(d) H_2O/OH^-

12. *2.6 (2014:16)*

Consider the self-ionisation of water:

$$2\,H_2O(\ell) \rightleftharpoons H_3O^+(aq) + OH^-(aq) \qquad \Delta H > 0.$$

Which of the following statements about aqueous solutions is true?

I All aqueous solutions contain H_3O^+ and OH^- ions.
II In any neutral aqueous solution at any temperature, $[H_3O^+] = [OH^-]$
III In aqueous solutions with pH greater than 7, $[H_3O^+] > [OH^-]$
IV A neutral aqueous solution at 100°C has a pH < 7

(a) I only

(b) I and II only

(c) I, II and III only

(d) I, II and IV only

13. *2.5 (2014:19)*

A buffer solution is made by dissolving ammonium chloride in a dilute solution of ammonia. The following equilibrium exists in the prepared solution:

$$NH_3(aq) + H_2O(\ell) \rightleftharpoons NH_4^+(aq) + OH^-(aq).$$

A small amount of a strong acid is added to the buffer solution. Once the equilibrium has been re-established, the effect would be

(a) an overall decrease in the H^+ ion concentration.

(b) that the equilibrium has shifted to the left.

(c) an overall increase in the NH_4^+ ion concentration.

(d) an overall increase in the OH^- ion concentration.

14. *2.2 (2015:15)*

Which one of the following is the same for equal volumes of 0.100 mol L^{-1} solutions of ammonia and sodium hydroxide?

(a) pH of the solutions at 25.0°C

(b) mass of the solute used to form each solution

(c) conductivity of the solutions at 25.0°C and standard atmospheric pressure

(d) number of moles of hydrochloric acid needed for neutralisation

15. *2.8 (2015:16)*

An aqueous solution at 25.0°C with a pH less than zero

(a) contains neither $H^+(aq)$ or $OH^-(aq)$ ions.

(b) has a very high concentration of $H^+(aq)$ ions.

(c) contains no $OH^-(aq)$ ions.

(d) contains an equal concentration of $H^+(aq)$ and $OH^-(aq)$ ions.

16. *2.3 (2015:18)*

The reaction equilibrium between hydrogencarbonate ion and dihydrogen sulfide is represented by the equation shown below.

$$HCO_3^-(aq) + H_2S(aq) \rightleftharpoons H_2CO_3(aq) + HS^-(aq)$$

According to the Brønsted-Lowry theory of acids and bases, which one of the following shows the two species acting as bases in this equilibrium system?

(a) HCO_3^- and H_2CO_3

(b) H_2S and HS^-

(c) H_2S and H_2CO_3

(d) HCO_3^- and HS^-

17. *2.8 (2015:19)*

The following 1.00 mol L^{-1} solutions are diluted by the addition of water. In which solution will the pH **not** change but the electrical conductivity will decrease?

(a) sodium carbonate

(b) ammonium chloride

(c) sodium chloride

(d) ethanoic (acetic) acid

18. *2.11 (2015:21)*

Five trials resulting in the following titres were obtained using a burette in an acid-base titration.

Trial	1	2	3	4	5
Titre volume (mL)	37.82	36.98	36.95	38.76	37.03

Which of the trials should be used to calculate the average titre?

(a) 2, 3 only

(b) 2, 3, 4 only

(c) 2, 3, 5 only

(d) 1, 2, 3, 4, 5

19. *2.3 (2016 SP:04)*

Which one of the following reactions does **not** represent the Brønsted-Lowry model?

(a) $HSO_4^-(aq) + H_2O(\ell) \rightarrow SO_4^{2-}(aq) + H_3O^+(aq)$

(b) $CH_3COOH(aq) + NaOH(aq) \rightarrow NaCH_3COO(aq) + H_2O(\ell)$

(c) $HCO_3^-(aq) + H_2O(\ell) \rightarrow H_2CO_3(aq) + OH^-(aq)$

(d) $CaCO_3(s) + 2\,HC\ell(aq) \rightarrow Ca^{2+}(aq) + CO_2(g) + 2\,H_2O(\ell)$

20. *2.8 (2016 SP:10)*

Over the last 200 years, the pH of oceans has dropped from 8.2 to 8.1. A drop of 0.1 pH units represents an

(a) approximate 20% increase in the concentration of hydrogen ions.

(b) increase of the hydrogen ion concentration by a factor of 10.

(c) approximate 20% increase in pH.

(d) insignificant change in hydrogen ion concentration, due to the large volume of the ocean.

21. *2.11 (2016:07)*

In an acid-base titration, which of the following is **least** likely to cause an error in the calculated concentration?

(a) using a funnel in the burette and leaving it in the same place for each titration

(b) measuring the volume at the bottom of the meniscus

(c) each member of the experimental team taking turns to measure the burette

(d) rinsing the burette with distilled water before the titration

22. *2.1 (2016:09)*

How many moles of a diprotic acid would be required to neutralise 1 mole of sodium hydroxide?

(a) 0.5

(b) 1.0

(c) 1.5

(d) 2.0

23. *2.3 (2016:10)*

Which one of the following represents a conjugate acid-base pair?

(a) N^{3-}/CN^-

(b) NH_3/NH_2^-

(c) CH_3CH_2OH/CH_3CHO

(d) H_3PO_4/PO_4^{3-}

24. *2.3 (2016:11)*

Which of the following equations **best** represents the self-ionisation of water according to the Brønsted-Lowry model?

(a) $H_2O(\ell) \rightleftharpoons H^+(aq) + OH^-(aq)$

(b) $H_2O(\ell) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$

(c) $2\,H_2O(\ell) \rightleftharpoons H_3O^+(aq) + 2\,OH^-(aq)$

(d) $2\,H_2O(\ell) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$

25. *2.10 (2016:12)*

The **best** definition of the equivalence point in an acid-base titration is the point at which the

(a) indicator changes colour.

(b) volume of acid equals the volume of base.

(c) pH of the solution is 7.

(d) mole ratio of acid to base is equal to their stoichiometric ratio.

26. *2.2 (2017:01)*

Which one of the following pairs contains a strong acid and a weak acid?

(a) $HC\ell$ and NaOH

(b) $MgCO_3$ and CH_3COOH

(c) NH_3 and KOH

(d) HNO_3 and H_2CO_3

27. *2.9 (2017:08*

The indicator HIn is used in a titration between hydrochloric acid and magnesium hydroxide solutions. The following equation represents how the indicator works.

$$\underset{\text{green}}{HIn(aq)} \rightleftharpoons H^+(aq) + \underset{\text{purple}}{In^-(aq)}$$

The indicator is added to 20.0 mL of magnesium hydroxide solution in a conical flask and the hydrochloric acid is added via a burette until the end point is observed. The acidic and basic solutions are of similar concentrations and the flask is swirled continuously as the acid is added.

Which one of the following statements describes the expected observations for the colour of the solution in the conical flask?

(a) The solution starts green and turns purple after the addition of approximately 10 mL.

(b) The solution starts green and turns purple after the addition of approximately 40 mL.

(c) The solution starts purple and turns green after the addition of approximately 10 mL

(d) The solution starts purple and turns green after the addition of approximately 40 mL.

Chapter 3

Oxidation–Reduction

1. *3.5 (2011:24)*

Which one of the species below is **not** commonly used as a reducing agent?

(a) $C_2O_4^{2-}$

(b) H_2

(c) $C\ell_2$

(d) C

2. *3.3 (2011 S2:10)*

Copper(II) oxide undergoes a redox reaction with carbon to produce copper metal and carbon monoxide gas, as shown in the equation below.

$$CuO(s) + C(s) \rightarrow Cu(s) + CO(g)$$

Which one of the following is the reductant in this reaction?

(a) copper(II) oxide

(b) carbon

(c) copper

(d) carbon monoxide

3. *3.1 (2011 S2:11)*

Consider the following reaction between manganese and lead ions.

$$Mn(s) + Pb^{2+}(aq) \rightarrow Mn^{2+}(aq) + Pb(s)$$

Which one of the following statements is correct?

(a) The manganese metal has removed electrons from the lead ions.

(b) The lead ions have reduced the manganese metal.

(c) Electrons have been transferred from the manganese metal to the lead ions.

(d) The oxidation number of the lead ions has increased.

4. *3.4 (2011 S2:12)*

Which one of the four elements (S, C, Cℓ, Cr) shown in **bold** below has the **lowest** oxidation number?

(a) $KH\mathbf{S}O_4$

(b) $Na_2\mathbf{Cr}_2O_4$

(c) $HO\mathbf{C\ell}$

(d) $K_2\mathbf{Cr}_2O_7$

5. *3.2 (2012:09)*

Identify the oxidant in the following reaction:

$$2\,A\ell(s) + Cr_2O_3(s) \rightarrow A\ell_2O_3(s) + 2\,Cr(s)$$

(a) $A\ell$

(b) Cr_2O_3

(c) O

(d) Cr

6. *3.5 (2012:10)*

Which one of the following is commonly used as an oxidising agent?

(a) $PbSO_4(s)$

(b) $H_2O(\ell)$

(c) $MnO_4^-(aq)$

(d) $CO_2(g)$

7. *3.5 (2012:11)*

Which one of the reactions below is **most** likely to occur spontaneously?

(a) $H_2(g) + PbSO_4(s) \rightarrow 2\,H^+(aq) + Pb(s) + SO_4^{2-}(aq)$

(b) $Zn^{2+}(aq) + Fe(aq) \rightarrow Zn(s) + Fe^{2+}(aq)$

(c) $Cu^{2+}(aq) + Ni(s) \rightarrow Cu(s) + Ni^{2+}(aq)$

(d) $2\,Fe^{3+}(aq) + H_2O_2(aq) \rightarrow O_2(g) + 2\,Fe^{2+}(aq) + 2\,H^+(aq)$

8. *3.4 (2012 S2:09)*

The oxidation numbers of nitrogen in the series, N_2, N_2O, NO_3^- and NH_3 respectively are

(a) 0, 0, +5, –3.

(b) 0, –1, –1, +3.

(c) 0, +1, +5, –3.

(d) +2, +2, +1, +1.

9. *3.11 (2012 S2:14)*

Which combination of anode, cathode and electrolyte could be used to silver-plate a nickel knife?

	Anode	**Cathode**	**Electrolyte**
(a)	knife	$Ag(s)$	$AgNO_3(aq)$
(b)	knife	$Ag(s)$	$Ni(NO_3)_2(aq)$
(c)	$Ag(s)$	knife	$AgNO_3\,(aq)$
(d)	$Ag(s)$	knife	$Ni(NO_3)_2(aq)$

10. *3.4 (2013:09)*

Consider the following reaction.

$$2\,H^+(aq) + 2\,NO_3^-(aq) + H_2S(g) \rightarrow 2\,NO_2(aq) + S(s) + 2\,H_2O(\ell)$$

Which one of the following statements is true for this reaction?

(a) The H^+ is oxidised and the H_2O is reduced.

(b) The oxidation number of the nitrogen changes from +5 to +4 during the reaction.

(c) The sulfur is reduced in the reaction.

(d) This is an acid-base reaction, not a redox reaction.

Use the table of standard reduction potentials in the Chemistry Data Book to answer *(2013:10)* and *(2013:11)*.

11. *3.4 (2013:10)*

Predict in which of the following a reaction would occur. Assume all solutions are 1.0 mol L^{-1}.

I	Acidified potassium permanganate is mixed with potassium iodide solution.
II	Chlorine gas is bubbled through hydrogen sulfide solution.
III	Acidified potassium dichromate is mixed with potassium fluoride.
IV	An iron(II) sulfate solution is placed in a nickel container.
V	A piece of copper metal is placed in a hydrochloric acid solution.

(a) I and II only

(b) I, II and III only

(c) II and V only

(d) II, III and V only

Use the following additional table of standard reduction potentials to answer *(2013:11)*.

Half-Reaction	E° (V)
$2\,HC\ell O_2 + 6\,H^+ + 6\,e^- \rightarrow C\ell_2(g) + 4\,H_2O$	1.64
$2\,HOC\ell + 2\,H^+ + 2\,e^- \rightarrow C\ell_2(g) + 2\,H_2O$	1.63
$2\,C\ell O_3^- + 12\,H^+ + 10\,e^- \rightarrow C\ell_2(g) + 6\,H_2O$	1.47
$2\,C\ell O_4^- + 16\,H^+ + 14\,e^- \rightarrow C\ell_2(g) + 8\,H_2O$	1.42
$C\ell O^- + H_2O + 2\,e^- \rightarrow C\ell^- + 2\,OH^-$	0.89
$C\ell O_2^- + 2\,H_2O + 4\,e^- \rightarrow C\ell^- + 4\,OH^-$	0.78

12. *3.5 (2013:11)*

Which of the species below **cannot** react with hydrogen peroxide to produce oxygen gas?

(a) $C\ell O^-$, $C\ell O_2^-$, $C\ell O_3^-$ and $C\ell O_4^-$

(b) $HC\ell O_2$ and $HOC\ell$

(c) $HC\ell O_2$, $HOC\ell$, $C\ell O_3^-$ and $C\ell O_4^-$

(d) All can react with hydrogen peroxide to produce oxygen gas.

13. *3.9 (2013 S2:20)*

In an electrolytic cell, the electrons flow

(a) clockwise from the positive electrode to the negative electrode.

(b) from the anode to the cathode.

(c) through the solution to balance the charge build-up.

(d) from the oxidising agent to the reducing agent.

14. *3.2 (2014:17)*

The equation below shows the reaction when sulfur dioxide gas (SO_2) is bubbled through a solution containing hypochlorite ions ($C\ell O^-$).

$$C\ell O^-(aq) + SO_2(g) + H_2O(\ell) \rightarrow C\ell^-(aq) + SO_4^{2-}(aq) + 2\,H^+(aq)$$

Which of the following statements about this reaction is correct?

I The sulfur in sulfur dioxide is oxidised.
II The hydrogen in water is reduced.
III The hypochlorite ion is the reducing agent.
IV The water is the oxidising agent.

(a) I only

(b) II and III only

(c) III and IV only

(d) I and IV only

15. *3.5 (2014:18)*

Consider the following mixtures:

I solid I_2 is added to a solution of H_2S
II liquid Br_2 is added to a solution of Fe^{2+}
III freshly exposed $A\ell$ metal is added to a solution of $HC\ell$
IV a piece of cobalt metal is placed in an aqueous solution of Cr^{3+}.

Based on E° values, in which of the above mixtures will a chemical reaction occur?

(a) II only

(b) I and III only

(c) I, II and III only

(d) III and IV only

16. *3.11 (2014 S2:12)*

If molten sodium chloride ($NaC\ell$) is electrolysed using inert electrodes, which one of the following will occur?

(a) Sodium ions will move toward the anode through the molten electrolyte.

(b) Chloride ions will be oxidised at the anode to form chlorine gas.

(c) Electrons will combine with chloride ions.

(d) Electrons will travel through the electrolyte.

17. *3.4 (2014 S2:14)*

Which one of the following is the oxidation state of sulfur in H_2SO_4?

(a) –4

(b) –2

(c) +1

(d) +6

18. *3.4 (2015:01)*

In which of the following compounds is the oxidation number of manganese **lowest**?

(a) Mn_2O_3

(b) K_2MnO_4

(c) $NaMnO_4$

(d) MnO_2

19. *3.5 (2015:05)*

Which one of the following reactions can occur spontaneously at 25.0°C? (Assume the solutions have a concentration of 1.00 mol L^{-1}.)

(a) $C(s) + O_2(g) \rightarrow CO_2(g)$

(b) $2\ Fe^{2+}(aq) + C\ell_2(g) \rightarrow 2\ Fe^{3+}(aq) + 2\ C\ell^{-}(aq)$

(c) $Zn^{2+}(aq) + Cu(s) \rightarrow Zn(s) + Cu^{2+}(aq)$

(d) $Cu(s) + 2\ H^{+}(aq) \rightarrow Cu^{2+}(aq) + H_2(g)$

20. *3.5 (2015:08)*

In which one of the following situations will there be no visible reaction?

(a) Solutions of sodium fluoride and potassium chloride are mixed together.

(b) A clean strip of copper metal is placed into a silver nitrate solution.

(c) Bromine water and ethene are shaken together.

(d) Sodium metal is dropped into a beaker of distilled water.

21. *3.5 (2015:10)*

When a grey solid was added to a green solution, the **most** obvious observation was decolourising of the solution.

Which one of the following might have been the reactants?

	Solid	**Solution**
(a)	chromium	lead(II) nitrate
(b)	zinc	cobalt(II) nitrate
(c)	cadmium	nickel(II) nitrate
(d)	lead	chromium(III) nitrate

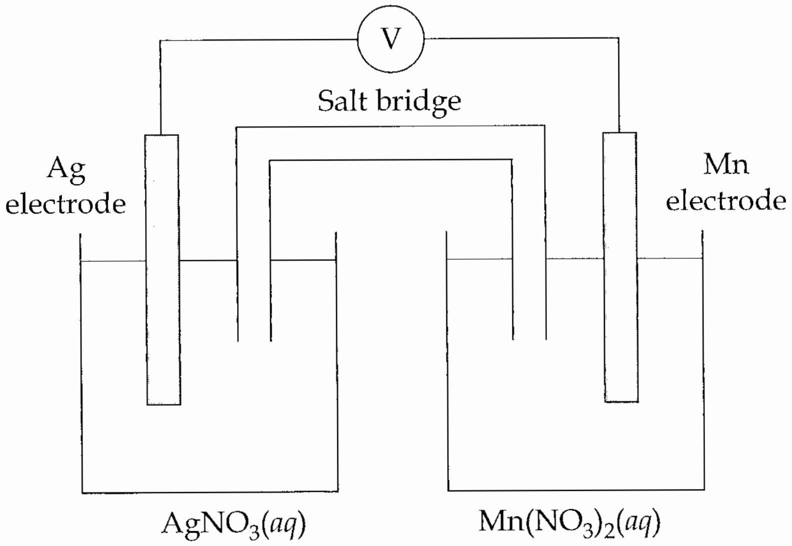
22. *3.8 (2015:17)*

A half-cell containing a metal electrode in a sodium nitrate solution is joined to another half-cell containing an inert electrode in a metal nitrate solution. Which one of the following combinations of electrode and metal nitrate solution will produce an electrochemical cell with the greatest electrical potential under standard conditions?

	Electrode	**Nitrate solution**
(a)	Ag	Sn^{2+}
(b)	$A\ell$	Cd^{2+}
(c)	Cr	Fe^{2+}
(d)	Cu	Fe^{3+}

23. *3.8 (2016 SP:15)*

A galvanic cell consisting of Ag//Ag^+ and Mn//Mn^{2+} couples is constructed as represented by the diagram below. All solutions are 1.0 mol L^{-1} and the temperature is 25 °C.



Which one of the following gives the predicted emf for this cell in volts?

(a) 0.42

(b) 0.80

(c) 1.98

(d) 2.78

24. *3.0 (2016 SP:16)*

Consider the following statements about fuel cells.

(i) A fuel cell is a device that converts chemical energy to electrical energy via a redox reaction.

(ii) Fuel cell technology involves the continuous supply of reactants to the cells and the continuous removal of the products.

(iii) A fuel cell can be recharged by reversing the direction of current flow through the cell.

(iv) Fuel cells are considered a low-emission technology.

Which of the above statements about fuel cells are true?

(a) i only

(b) i and ii

(c) i, iii and iv

(d) i, ii and iv

25. *3.4 (2016:13)*

Nitric acid can be manufactured from the element nitrogen using the steps below.

Step	**1**	**2**	**3**	**4**
	$N_2 \rightarrow NH_3$	$NH_3 \rightarrow NO$	$NO \rightarrow NO_2$	$NO_2 \rightarrow HNO_3$

The smallest change in the oxidation number of nitrogen is found in

(a) step 1.

(b) step 2.

(c) step 3.

(d) step 4.

26. *3.4 (2016:14)*

Which one of the following is **not** a redox reaction?

(a) $2\,CrO_4^{2-} + 2\,H^+ \rightarrow Cr_2O_7^{2-} + H_2O$

(b) $2\,Cr^{2+} + 2\,H^+ \rightarrow 2\,Cr^{3+} + H_2$

(c) $(NH_4)_2\,Cr_2O_7 \rightarrow N_2 + 4\,H_2O + Cr_2O_3$

(d) $Cr_2O_3 + 3\,C \rightarrow 2\,Cr + 3\,CO$

27. *3.5 (2016:15)*

Which one of the following shows the substances listed in order of increasing strength as reducing agents?

(a) F^-, $A\ell$, Zn, Cu, I^-

(b) I^-, F^-, Zn, $A\ell$, Cu

(c) F^-, I^-, Cu, Zn, $A\ell$

(d) Zn, $A\ell$, Cu, I^-, F^-

28. *3.7 (2016:16)*

Which one of the following reactions would **not** produce a current at 25.0°C, when set up as a galvanic cell?

(a) $MnO_4^-(aq) + 8\,H^+(aq) + 5\,Fe^{2+}(aq) \rightarrow Mn^{2+}(aq) + 4\,H_2O(\ell) + 5\,Fe^{3+}(aq)$

(b) $Fe(s) + Pb^{2+}(aq) \rightarrow Fe^{2+}(aq) + Pb(s)$

(c) $Br_2(\ell) + 2\,C\ell^-(aq) \rightarrow 2\,Br^-(aq) + C\ell_2(g)$

(d) $Fe(s) + Cu^{2+}(aq) \rightarrow Fe^{2+}(aq) + Cu(s)$

29. *3.5 (2016:17)*

Three metals, A, B and C, were tested to compare their reactivity. Samples of each metal were placed separately into test tubes each containing a nitrate solution of the other metal ions. The following results were obtained.

	A(*s*)	**B(*s*)**	**C(*s*)**
$A^{2+}(aq)$		No visible reaction	Solid A forms
$B^{2+}(aq)$	Solid B forms		Solid B forms
$C^{2+}(aq)$	No visible reaction	No visible reaction	

From these results, the metals arranged in order of decreasing strength as reducing agents can be concluded to be

(a) C > A > B.

(b) B > C > A.

(c) B > A > C.

(d) A > C > B.

30. *3.4 (2017:02)*

Copper reacts with nitric acid as shown in the redox equation below.

$$Cu(s) + 4\,H^+(aq) + 2\,NO_3^-(aq) \rightarrow Cu^{2+}(aq) + 2\,NO_2(g) + 2\,H_2O(\ell)$$

Which one of the following states the change in the oxidation number of nitrogen?

(a) 3+ to 0

(b) 5+ to 4+

(c) 3+ to 2+

(d) 5+ to 0

31. *3.6 (2017:03)*

In the electrolysis of molten calcium bromide, one mole of bromine molecules is formed for every one mole of calcium. This is because

(a) the formula of calcium bromide is Ca_2Br.

(b) the valency on a calcium ion is twice that on a bromide ion.

(c) bromine is more reactive than calcium.

(d) the atomic mass of bromine is twice that of calcium.

32. *3.6 (2017:04)*

Which of the following are common to both galvanic and electrolytic cells?

- (i) a salt bridge
- (ii) an external circuit
- (iii) the transfer of electrons and movement of ions
- (iv) at least two different reactions with distinct reduction potentials

(a) i and ii only

(b) i, ii and iv only

(c) ii, iii and iv only

(d) i, ii, iii and iv

33. *3.3 (2017:09)*

An example of an undesirable electrochemical process is the corrosion of metals. Which one of the following equations does **not** represent what might occur during corrosion?

(a) $4\ Fe(OH)_2(s) + 2\ H_2O(aq) + O_2(g) \rightarrow 4\ Fe(OH)_3(s)$

(b) $O_2(g) + 2\ H_2O(\ell) + 4\ e^- \rightarrow 4\ OH^-(aq)$

(c) $FeC\ell_3(s) \rightarrow Fe^{3+}(aq) + 3\ C\ell^-(aq)$

(d) $Pb^{2+}(aq) \rightarrow Pb^{4+}(aq) + 2\ e^-$

34. *3.0 (2017:10)*

Which one of the following reactions will be spontaneous under standard conditions?

(a) $Cr_2O_7^{2-}(aq) + 3\ H_2O_2(aq) + 8\ H^+(aq) \rightarrow 2\ Cr^{3+}(aq) + 7\ H_2O(\ell) + 3\ O_2(g)$

(b) $3\ O_2(g) + 4\ Au(s) + 12\ H^+(aq) \rightarrow 4\ Au^{3+}(aq) + 6\ H_2O(\ell)$

(c) $2\ Ag^+(aq) + 2\ Br^-(aq) \rightarrow 2\ Ag(s) + Br_2(\ell)$

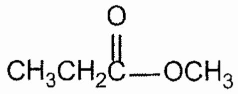
(d) $2\ C\ell^-(aq) + I_2(s) \rightarrow C\ell_2(g) + 2I^-(aq)$

Chapter

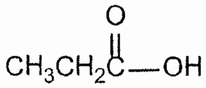
4

Organic Chemistry

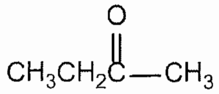
The following two questions refer to the compounds shown below.

I 

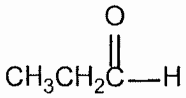
$CH_3CH_2\overset{O}{\overset{\|}{C}}-OCH_3$

II 

$CH_3CH_2\overset{O}{\overset{\|}{C}}-OH$

III 

$CH_3CH_2\overset{O}{\overset{\|}{C}}-CH_3$

IV 

$CH_3CH_2\overset{O}{\overset{\|}{C}}-H$

1. *4.2 (2011:08)*

Which one of the following lists places these compounds in their correct class?

	I	II	III	IV
(a)	Ester	Aldehyde	Ketone	Carboxylic acid
(b)	Carboxylic acid	Ketone	Aldehyde	Ester
(c)	Ketone	Carboxylic acid	Ester	Aldehyde
(d)	Ester	Carboxylic acid	Ketone	Aldehyde

2. *4.6 (2011:09)*

Which of these compounds can be prepared by oxidation of propan-1-ol, $CH_3CH_2CH_2OH$?

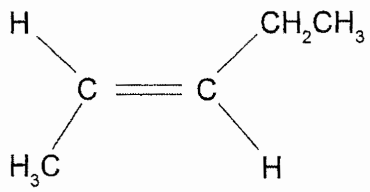
(a) I only

(b) I and II

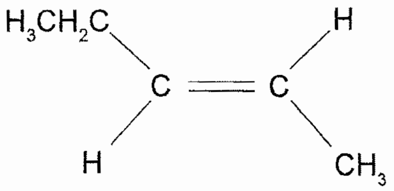
(c) II and III

(d) II and IV

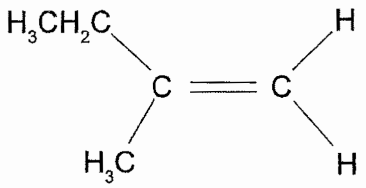
Examine the structures for compounds (i), (ii), (iii) and (iv) below to answer Questions *(2012:22)* and *(2012:24)*.



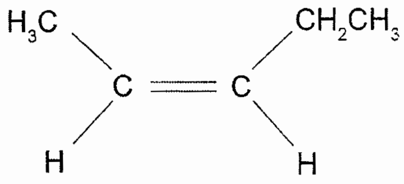
(i)



(ii)



(iii)



(iv)

3. *4.5 (2012:22*

Which of these compounds are cis-trans isomers?

(a) (i) and (ii)

(b) (i), (ii) and (iii)

(c) (i) and (iv)

(d) (iii) and (iv)

4. *4.3 (2012:24*

Which one of the following is the product from the reaction of bromine with compound (iii)?

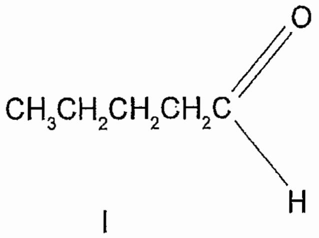
(a) $CH_3CH_2CBr(CH_3)CH_2Br$

(b) $CH_3CH_2BrCH(CH_3)CH_3$

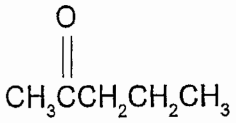
(c) $CH_3CH_2BrCH(CH_3)CH_2Br$

(d) $CH_3CH_2CH(CH_3)CH_2Br$

Questions *(2013:22)*, *(2013:23)* and *(2013:24)* refer to compounds I to IV below.

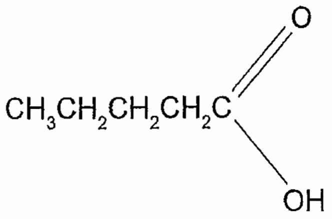


I

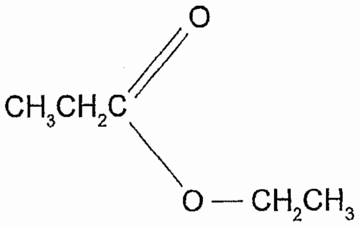


$CH_3C(=O)CH_2CH_2CH_3$

II



III



IV

5. *4.2 (2013:22)*

Which one of the following lists the functional groups for compounds I to IV correctly?

	I	**II**	**III**	**IV**
(a)	aldehyde	ketone	ester	carboxylic acid
(b)	carboxylic acid	aldehyde	ester	ketone
(c)	aldehyde	ketone	alcohol	carboxylic acid
(d)	aldehyde	ketone	carboxylic acid	ester

6. *4.6 (2013:23)*

Which one of the alcohols below can be oxidised to produce compound II?

(a) $CH_3CH_2CH_2CH_2CH_2OH$

(b) $CH_3CH_2CH_2CHOHCH_3$

(c) $CH_3CH_2CHOHCH_2CH_3$

(d) $CH_3C(OH)(CH_3)CH_2CH_3$

7. *4.7 (2013:24)*

Which one of compounds I to IV will react with an alcohol in the presence of an acid?

(a) I

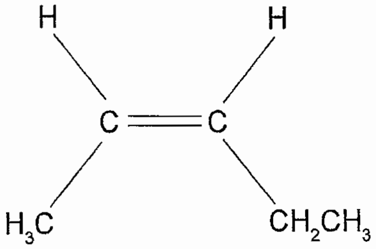
(b) II

(c) III

(d) IV

8. *4.3 (2013:25)*

Consider the following statements about the compound shown below.



I It will decolourise iodine water.
II If 1 mol of the compound is mixed with 2 mol of chlorine, all of the chlorine can react.
III Its systematic name is *cis*-pent-2-ene.
IV It is soluble in hexene.

Which of the statements are correct?

(a) I, and III only

(b) II, and IV only

(c) II, III, and IV only

(d) I, II, III, and IV

9. *4.5 (2014:21)*

How many isomers are there with the molecular formula $C_2H_2Br_2$?

(a) 2

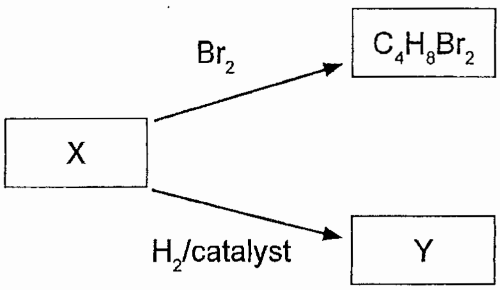
(b) 3

(c) 4

(d) 5

10. *4.3 (2014:23)*

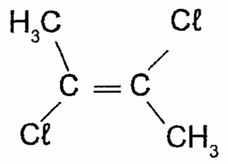
In the following diagram what are the molecular formulae of substances X and Y likely to be?



	X	Y
(a)	C_4H_8	C_4H_6
(b)	C_4H_8	C_4H_{10}
(c)	C_4H_{10}	C_4H_8
(d)	C_4H_6	C_4H_8

11. *4.5 (2014:24)*

Which one of the following is the IUPAC name for the compound below?



(a) 2,3-dichloro-*trans*-but-2-ene

(b) 2,3-dichloro-*cis*-but-2-ene

(c) 1,2-dichloro-*trans*-but-2-ene

(d) 1,2-dichloro-*cis*-but-2-ene

12. *4.8 (2015:14)*

Which one of the following lists the solubilities of butane (C_4H_{10}), butan-2-ol ($CH_3CH(OH)CH_2CH_3$) and butanone ($CH_3COCH_2CH_3$) in water, from **most** soluble to **least** soluble?

(a) butan-2-ol butanone butane

(b) butan-2-ol butane butanone

(c) butanone butan-2-ol butane

(d) butane butanone butan-2-ol

13. *4.8 (2015:22)*

Which one of the following lists the substances in order of **increasing** (from lowest to highest) boiling point?

(a) CH_3CH_3 CH_3CH_2OH CH_3CHO CH_3COOH

(b) CH_3CH_3 CH_3CHO CH_3CH_2OH CH_3COOH

(c) CH_3CH_2OH CH_3CH_3 CH_3COOH CH_3CHO

(d) CH_3COOH CH_3CHO CH_3CH_2OH CH_3CH_3

14. *4.10 (2015:23)*

Under the right conditions, a compound containing two double bonds, buta-1,3-diene ($H_2C{=}CH{-}HC{=}CH_2$), can react with itself to make Buna rubber. This process is **best** referred to as

(a) saponification.

(b) condensation polymerisation.

(c) esterification.

(d) addition polymerisation.

15. *4.3 (2015:24)*

What is the name of the organic compound produced when 2-fluoropent-1-ene reacts with fluorine gas?

(a) 2-fluoropentane

(b) 1,2-difluoropentane

(c) 1,1,2-trifluoropentane

(d) 1,2,2-trifluoropentane

16. *4.3 (2015:25)*

Between which of the following pairs of substances can hydrogen bonding occur?

I CH_3COCH_3 and CH_3NH_2
II CH_3CHO and HF
III C_2H_6 and CH_3OH
IV CH_3F and H_2O

(a) I, II and III only

(b) I, II only

(c) I, III and IV only

(d) II only

17. *4.6 (2016 SP:17)*

Which one of the following will react with acidified potassium dichromate solution to give a ketone?

(a) $CH_3CH_2CH_2OH$

(b) CH_3CH_2CHO

(c) $CH_3CH(OH)CH_3$

(d) $(CH_3)_3COH$

18. *4.8 (2016 SP:20)*

Consider the following substances.

(i) $BaSO_4$

(ii) $CH_3CH_2CH_2CH_2OH$

(iii) $CH_3CH_2COCH_3$

(iv) H_2NCH_2COOH

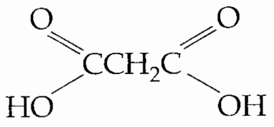
Which one of the following lists the substances in order of **decreasing** solubility in water?

(a)	i	iv	ii	iii
(b)	i	iii	ii	iv
(c)	iv	ii	iii	i
(d)	ii	iv	iii	i

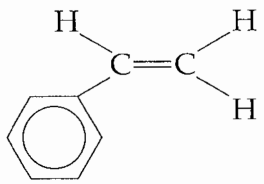
19. *4.13 (2016 SP:23)*

Which one of the following pairs represent monomers that could react together to form a polymer?

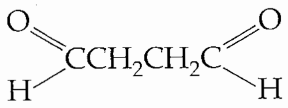
(i)



(ii)



(iii)



(iv)

HO—$CH_2CH_2CH_2CH_2$—OH

(a) i and iv

(b) i and iii

(c) ii and iii

(d) iii and iv

20. *4.0 (2016 SP:24)*

Proteins that show a high degree of similarity in their primary structure in the Protein Data Bank are most likely to have

(a) similar function.

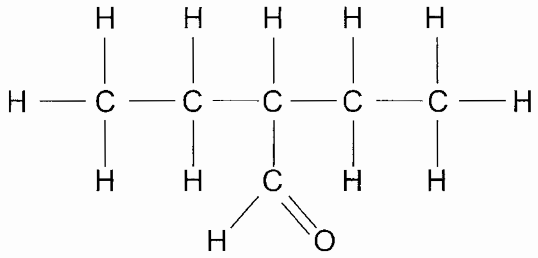
(b) identical tertiary structure.

(c) been isolated from the same species.

(d) the same amino acid composition.

21. *4.4 (2016:18)*

What is the IUPAC name of the following compound?



(a) 3-methylpentan-3-al

(b) 2-ethylbutanal

(c) 2,2-diethylethanal

(d) 2-methylbutanal

22. *4.6 (2016:19)*

Below is a table of reactions involving organic compounds.

Reaction	Product
ethene + hydrogen	1
ethanal + permanganate ion	2
ethanol + acetic (ethanoic) acid	3
acetic (ethanoic) acid + sodium carbonate	4

Which row of the table below identifies a product of each reaction correctly?

	Product 1	Product 2	Product 3	Product 4
(a)	an alkane	a carboxylic acid	an aldehyde	an ester
(b)	an alkene	a carboxylic acid	an ester	carbon dioxide
(c)	an alkane	carbon dioxide	an aldehyde	a carboxylic acid
(d)	an alkane	carbon dioxide	an ester	a carboxylic acid

23. *4.10 (2016:20)*

Which of the following compounds could be used to produce a polymer?

I CH_2CHCH_3
II $HOOCCH_2COOH$
III CH_2CHOH
IV $HOCH_2CH_3$
V $H_2NCH_2NH_2$

(a) I, II, V

(b) I, II, IV

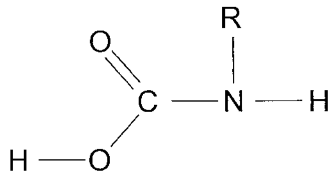
(c) I, II, III, V

(d) II, III, IV, V

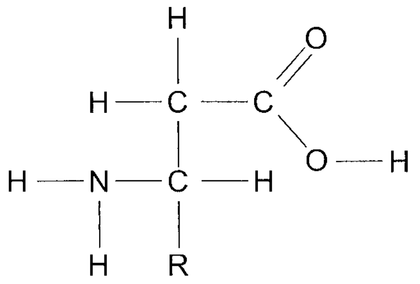
24. *4.14 (2016:21)*

Which of the following **best** represents the generalised structure of α-amino acids? (Note: R represents a side chain.)

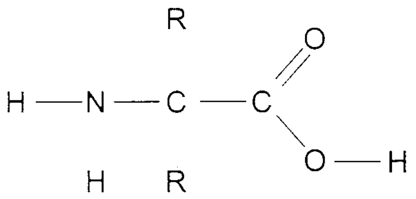
(a)



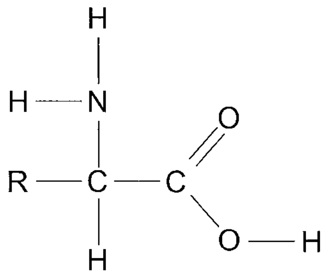
(b)



(c)



(d)



25. *4.5 (2017:14)*

Which of the following are isomers of $C_5H_8O_2$?

(i) $CH_3CH_2COCH_2CHO$

(ii) $CH_3CH_2CH_2CH_2COOH$

(iii) $CH_3COCH(CH_3)CHO$

(iv) $CH_2CHCH_2CH_2COOH$

(a) i and ii only

(b) i, ii and iv only

(c) i, iii and iv only

(d) ii, iii and iv only

26. *4.14 (2017:15)*

Which one of the following is the dominant form of glycine in basic solution?

(a) $NH_2\text{-}CH_2\text{-}COOH$

(b) $NH_2\text{-}CH_2\text{-}COO^-$

(c) $NH_3^+\text{-}CH_2\text{-}COO^-$

(d) $NH_3^+\text{-}CH_2\text{-}COOH$

27. *4.3 (2017:16)*

A chemist attempts to identify a pungent, colourless liquid by conducting several experiments. The results are shown in the table below:

Experiment	**Observations**
add acidified potassium dichromate solution	orange solution turns green
a lighted taper held above the liquid	flame and heat produced
add sodium metal	metal reacts and colourless, odourless gas evolved
add acidified, concentrated acetic (ethanoic) acid	fruity odour produced

Using this information, identify the functional group present in the liquid.

(a) ketone

(b) alcohol

(c) amine

(d) carboxylic acid

28. *4.17 (2017:17)*

The amino acid sequence of a protein is referred to as its

(a) primary structure.

(b) secondary structure.

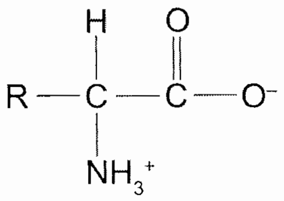
(c) tertiary structure.

(d) parent chain.

29. *4.15 (2017:19)*

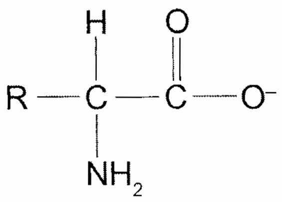
Which one of the following structures represents a zwitterion?

(a)



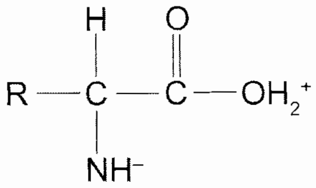
$R-CH(NH_3^+)-C(=O)-O^-$

(c)



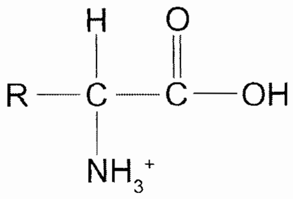
$R-CH(NH_2)-C(=O)-O^-$

(b)



$R-CH(NH^-)-C(=O)-OH_2^+$

(d)



$R-CH(NH_3^+)-C(=O)-OH$

30. *4.0 (2017:20)*

The function of a protein is linked closely to

(a) its method of production.

(b) the nature of its intermolecular forces.

(c) the number of atoms bonded to it.

(d) its structure.

Synthesis

Chapter

5

1. *5.1 (2016 SP:22)*

Ethene (CH_2CH_2) can be used to manufacture ethyl ethanoate, $CH_3COOCH_2CH_3$ in three steps, as indicated below:

$$\boxed{CH_2CH_2} \xrightarrow{\text{Step 1}} \boxed{A} \xrightarrow{\text{Step 2}} \boxed{B} \xrightarrow[\text{esterification}]{\text{Step 3}} \boxed{CH_3COOCH_2CH_3}$$

Which one of the following is the correct sequence of Steps 1 and 2?

	Step 1	**Step 2**
(a)	substitution with water	oxidation
(b)	addition of water	oxidation
(c)	oxidation	addition of water
(d)	oxidation	substitution with water

2. 5.4 (2016:15

Which one of the following substances completes the equation illustrating the process of transesterification to produce biodiesel?

$$\text{Triglyceride} + \boxed{\qquad\qquad\qquad\qquad} \rightarrow \text{ester (biodiesel)} + \text{glycerol}$$

(a) sodium hydroxide

(b) methanol

(c) sodium methoxide

(d) lipase

3. *5.9 (2016:22)*

A soap solution can be used to measure the hardness of a water sample. Four 100.0 mL water samples were tested. The table below shows the results of the tests on the four samples.

Sample	**Boiling point (°C) at atmospheric pressure**	**Volume (mL) of soap solution required to form a permanent lather**	**Mass (g) of precipitate formed when excess silver nitrate solution is added**
A	101.7	17.2	1.2
B	100.3	2.1	0.9
C	100.6	4.2	0.6
D	102.4	9.3	1.4

Which of the four samples contained water with the greatest hardness?

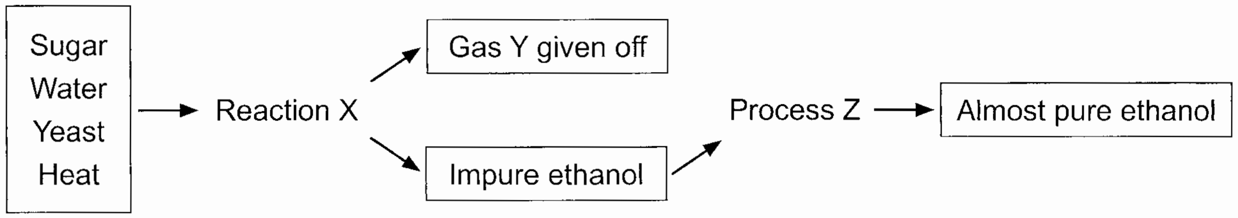
(a) Sample A

(b) Sample B

(c) Sample C

(d) Sample D

Questions *(2016:23)*, *(2016:24)* and *(2016:25)* relate to the flow diagram below showing a process for making ethanol.



4. *5.0 (2016:23)*

Reaction X is called

(a) neutralisation.

(b) fermentation.

(c) condensation.

(d) esterification.

5. *5.0 (2016:24)*

Gas Y is

(a) oxygen.

(b) hydrogen.

(c) carbon dioxide.

(d) carbon monoxide.

6. *5.0 (2016:25)*

Process Z is

(a) fractional distillation.

(b) condensation.

(c) filtration.

(d) precipitation.

7. *5.0 (2017:11)*

The purpose of 'green chemistry' is to

(a) utilise renewable energy sources (such as wind, solar or wave) at all times, even if they are more costly.

(b) design chemical products and processes that maximise profits and, if economical to do so, reduce harm to the environment.

(c) design chemical products and processes that work most efficiently.

(d) design safer chemical products and processes that reduce or eliminate the use and generation of hazardous substances.

8. *5.1 (2017:13)*

Consider the following reaction sequence.
Step 1: $H_2O_2(aq) + I^-(aq) \rightarrow H_2O(\ell) + IO^-(aq)$

Step 2: $H_2O_2(aq) + IO^-(aq) \rightarrow H_2O(\ell) + O_2(g) + I^-(aq)$

At the same temperature, Step 1 consumes $H_2O_2(aq)$ at a rate of 4.55×10^{22} molecules per second and Step 2 consumes $H_2O_2(aq)$ at a rate of 3.67×10^{24} molecules per second.

The only source of $IO^-(aq)$ for Step 2 comes from the reaction in Step 1.
Which one of the following statements identifies, with justification, the rate-determining step?

(a) Step 1, because it is the first step in the sequence.

(b) Step 2, because it is the last step in the sequence.

(c) Step 1, because it is the slower step in the sequence.

(d) Step 2, because it is the faster step in the sequence.

9. *5.8 (2017:21)*

The structure of detergent could be represented as R-X where R is dodecylbenzene and X is a sulfonate. X is represented by which one of the following?

(a) SO_4^{2-}

(b) SO_3^{2-}

(c) SO_3^{-}

(d) SO_2^{-}

Science Enquiry Skills

Chapter 6

1. *6.3 (2012:13)*

Concentrated sulfuric acid is spilt on a bench top in a laboratory. Which one of the following would be the **most** suitable substance to use in the first step in safely cleaning up the spilt acid?

(a) 1.0 mol L^{-1} NaOH solution

(b) water

(c) $NaHCO_3$ powder

(d) 1.0 mol L^{-1} Na_2CO_3 solution

2. *6.4 (2016 SP:11)*

20.0 mL of 0.10 mol L^{-1} hydrochloric acid is mixed with 20.0 mL of 0.10 mol L^{-1} sodium hydroxide in a glass beaker. The volumes are measured using a 50.0 mL measuring cylinder. The temperature rise that occurred is measured and used to calculate the enthalpy change for the reaction. Which one of the following statements is correct?

(a) Systematic error will be reduced by repeating the experiment several times and averaging the results.

(b) Random error will be reduced by using a 20.0 mL graduated pipette instead of the 50.0 mL measuring cylinder.

(c) Random error will be reduced by insulating the beaker.

(d) Systematic error will be increased by doubling the volume of solution.

3. *6.4 (2016:06)*

Which one of the following sets of titres indicates a systematic error if the actual volume being measured is 85.2 mL?

(a) 85.1 mL, 85.1 mL, 85.3 mL, 85.5 mL

(b) 65.2 mL, 75.2 mL, 85.2 mL, 95.2 mL

(c) 85.2 mL, 85.3 mL, 85.1 mL, 85.1 mL

(d) 87.3 mL, 86.9 mL, 89.1 mL, 88.2 mL

Questions *(2017:22)* to *(2017:25)* refer to the following information.

Some chemistry students were investigating the relationship between concentration and rate of reaction. In the investigation, different concentrations of hydrochloric acid were added to a sodium thiosulfate solution to produce solid sulfur. This reaction was represented by the following equation.

$$2\,H^+(aq) + S_2O_3^{2-}(aq) \rightarrow SO_2(g) + S(s) + H_2O(\ell)$$

A piece of paper with a cross drawn on it was placed under the reaction vessel. The time taken for the cross to disappear due to the formation of the precipitate was measured.

4. *6.3 (2017:22)*

The independent variable was the

(a) time taken for the cross to disappear.

(b) total volume of the mixture.

(c) rate of reaction.

(d) concentration of hydrochloric acid.

5. *6.3 (2017:23)*

The type of data collected and the source of data are best characterised as

(a) qualitative and primary.

(b) qualitative and secondary.

(c) quantitative and primary.

(d) quantitative and secondary.

6. *6.3 (2017:24)*

When a number of laboratory groups pooled their data, one group's results were consistently higher than those of the others. This is an example of

(a) a systematic error.

(b) not enough trials.

(c) a random error.

(d) uncertainty.

7. *6.3 (2017:25)*

One group chose to have its members take turns observing and timing the cross disappearing. This was poor methodology because

(a) it could make the data invalid.

(b) it introduced a possible systematic error.

(c) more trials would be needed to produce better results.

(d) the data would be less reliable.

Chapter

7

Chemical Equilibrium

1. [8 marks] *1.9 (2011:28)*

Chloromethane can be produced industrially by the reaction of methanol and hydrogen chloride at high temperature in the presence of a catalyst. The equation for this reaction is shown below.

$$CH_3OH + HC\ell \rightleftharpoons CH_3C\ell + H_2O$$

The boiling points and melting points for each of the species involved in the reaction are shown below.

Species	**Boiling point (°C)**	**Melting point (°C)**
CH_3OH	65	-98
$HC\ell$	-85	-114
$CH_3C\ell$	-24	-98
H_2O	100	0

Write the phase, i.e., solid (*s*), liquid (*ℓ*) or gas (*g*), of each species in this system at the temperatures shown in the table below, and predict the effect of an increase in total pressure on this equilibrium at each of the temperatures.

Temperature (°C)	**Phase (*s*, *ℓ* or *g*)**				**Shift in equilibrium (right, left or no change)**
	CH_3OH	$HC\ell$	$CH_3C\ell$	H_2O	
-50					
40					
70					
110					

2. **[6 marks]** *1.9 (2012:29)*

The white solid bismuth oxychloride reacts with concentrated hydrochloric acid to establish the following equilibrium:

$$BiOC\ell(s) + 2\,H^+(aq) \rightleftharpoons Bi^{3+}(aq) + C\ell^-(aq) + H_2O(\ell)$$

Three test tubes of the equilibrium system, 'A', 'B' and 'C' were prepared by adding excess $BiOC\ell$ to concentrated hydrochloric acid.

Complete the table below by indicating the direction of the expected shift in equilibrium immediately following the changes stated in the table. Using Collision theory to explain your choice of shift.

Test tube	Change	Direction of shift in equilibrium ('left', 'right' or 'no change')	Explanation
A	3 mL of water is added		
B	A few drops of concentrated nitric acid are added		
C	A few drops of concentrated silver nitrate solution are added		

3. **[6 marks]** *(2012:30)*

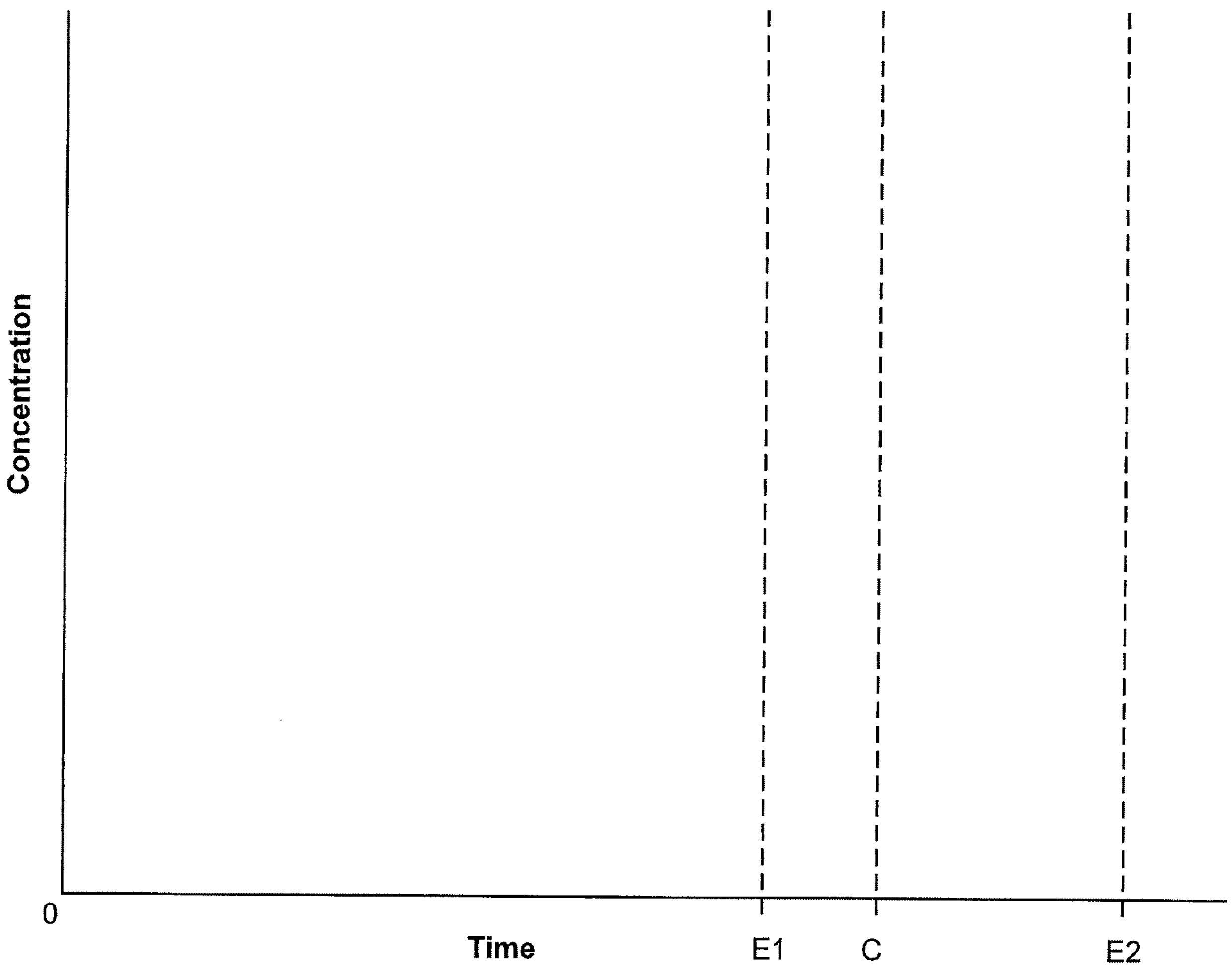
Silver chloride, AgCℓ(*s*), is very sparingly soluble in water. However, it is soluble in ammonia solutions, due to the formation of the $[Ag(NH_3)_2]^+$ ion as shown in the equilibrium below:

$$AgC\ell(s) + 2\,NH_3(aq) \rightleftharpoons [Ag(NH_3)_2]^+(aq) + C\ell^-(aq)$$

The equilibrium constant, K, for this system is greater than 1 (>1).

A student mixes the reactants at time t = 0.

(a) On the axes below, draw separate curves to show how the concentrations of $NH_3(aq)$ and $[Ag(NH_3)_2]^+(aq)$ change with time as the system approaches, and finally reaches, equilibrium (Time E1). Clearly label your curve for $NH_3(aq)$ and your curve for $[Ag(NH_3)_2]^+(aq)$. Continue your curves from Time E1 to Time C. *1.4* [3]



(b) At Time = C, as shown on the axis, a small quantity of concentrated NaCℓ solution is added to the system, and the system is then again allowed to reach equilibrium at Time E2. On the same axes above, show how the concentrations of $NH_3(aq)$ and $[Ag(NH_3)_2]^+(aq)$ would change in response to the addition of NaCℓ solution from Time C until equilibrium is reached at Time E2. *1.9* [3]

4. **[8 marks]** *1.8 (2013:30)*

Consider the following system at equilibrium.

$$4\,NH_3(g) + 5\,O_2(g) \rightleftharpoons 4\,NO(g) + 6\,H_2O(g) + 920\text{ kJ}$$

Indicate in the table below whether there would be an increase, decrease, or no change in the concentration of $NH_3(g)$ after the changes given in the table are imposed on the system and **equilibrium has been re-established**. Provide a brief explanation for the observation.

Change	**Change in concentration of $NH_3(g)$ (circle the correct response)**	**Brief explanation**
The volume of the reaction vessel is doubled	• increase • decrease • no change	
The temperature of the reaction system is doubled	• increase • decrease • no change	
$N_2(g)$ is injected into the reaction system while keeping the volume constant	• increase • decrease • no change	
Water vapour is injected into the reaction system while keeping the volume constant	• increase • decrease • no change	

5. **[6 marks]** *1.4, 1.7 (2015:30)*

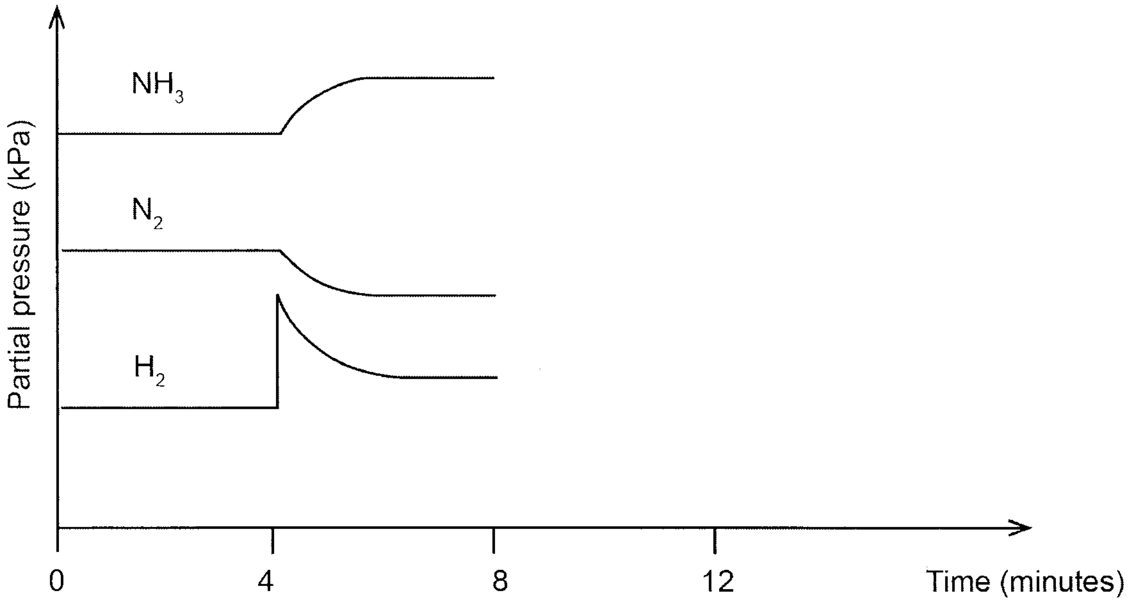
Ammonia exists in equilibrium with hydrogen and nitrogen as shown by the following exothermic equation.

$$N_2(g) + 3\ H_2(g) \rightleftharpoons 2\ NH_3(g) \qquad \Delta H = -\ 92\ kJ\ mol^{-1}$$

As they exist in the gaseous state, the relative concentrations can be given in terms of the partial pressure (kPa) of each gas.

Nitrogen, hydrogen and ammonia gases are placed in a rigid container and allowed to reach equilibrium. The graph below shows the partial pressures of the gaseous system initially at equilibrium. After the experiment operates for 4 minutes, a change is imposed upon it.

Partial pressures of NH_3, N_2 and H_2 over time



(a) What characteristic of equilibrium is indicated on the graph by the section from 0 to 4 minutes? [1]

....

(b) A change was imposed on the system at the 4 minute mark. What imposed change could have produced the results indicated on the graph? [1]

....

(c) The system was **suddenly** cooled at 8 minutes and then reached equilibrium again at 12 minutes. Using this information, complete the graph above from the 8 to the 12 minute mark. [4]

6. **[16 marks]** *(2015:38)*

The two different coloured cobalt(II) complex ions, $Co(H_2O)_6^{2+}$ and $CoC\ell_4^{2-}$, exist together in equilibrium in solution in the presence of chloride ions. This is represented by the equation below.

$$\underset{\text{pink}}{Co(H_2O)_6^{2+}(aq)} + 4\,C\ell^-(aq) \rightleftharpoons \underset{\text{blue}}{CoC\ell_4^{2-}(aq)} + 6\,H_2O(\ell)$$

An experiment is conducted to investigate the effects on the equilibrium position by imposing a series of changes on the system. The shift in equilibrium position can be indicated by any colour change of the solution.

Colour chart	
Species	**Colour**
$Co(H_2O)_6^{2+}(aq)$	pink
$CoC\ell_4^{2-}\ (aq)$	blue
Initial equilibrium mixture	purple

After a 3.00 mL sample of an initial equilibrium mixture was placed in each of three test tubes, changes to each system were made by adding a different substance, as indicated in the table below.

Test tube	**Substance added to the test tube**
1	10 to 12 drops of distilled water
2	20 to 25 drops of concentrated hydrochloric acid
3	20 to 25 drops of 0.200 mol L^{-1} silver nitrate solution, $AgNO_3(aq)$

(a) Complete the table below by predicting the:

- change in concentration, if any, of each of the ions in solution compared to the initial solution, after a new equilibrium position is reached.
- colour change, if any, that takes place from the initial purple-coloured solution. [6]

Additions to the test tube	**Change in concentration from initial equilibrium to final equilibrium (increase, decrease, unchanged)**			**Colour favoured (pink, blue or unchanged)**
	$[Co(H_2O)_6^{2+}]$	**$[C\ell^-]$**	**$[CoC\ell_4^{2-}]$**	
1. add $H_2O(\ell)$				
2. add $HC\ell(aq)$				
3. add $AgNO_3(aq)$				

(b) Other than a colour change, what else should be observed in test tube 3? [1]

CONTINUED NEXT PAGE

(c) Using Collision Theory, explain your predicted observations when hydrochloric acid is added to test tube 2 [3]

Another experiment was conducted to investigate the effect that changing the temperature had on the equilibrium mixture. When 3.00 mL of the original equilibrium mixture was placed in a test tube and then in an ice bath, the solution became pink.

(d) Determine whether the forward reaction, as illustrated by the equation below, is exothermic or endothermic. Use Le Châtelier's Principle to justify your answer. [4]

$$\underset{\text{pink}}{Co(H_2O)_6^{2+}(aq)} + 4\ C\ell^-(aq) \rightleftharpoons \underset{\text{blue}}{CoC\ell_4^{2-}(aq)} + 6\ H_2O(\ell)$$

(e) State **one** specific hazard to the environment that the disposal of chemicals from this experiment poses and state what could be done in the laboratory to reduce this hazard. [2]

7. **[6 marks]** *1.0 (2016 SP:34)*

Ocean acidification results from carbon dioxide dissolving in water and an equilibrium being established between the water and carbon dioxide to produce carbonic acid, (H_2CO_3).

(a) Write a balanced equation for this equilibrium. [2]

(b) The formation of carbonic acid leads to an increase in the hydronium ion (H_3O^+) concentration in water. Show the equilibrium that results in the formation of hydronium ions when carbonic acid reacts with water. [1]

(c) State **one** problem ocean acidification is causing for marine organisms. Explain how this problem arises and support your answer with an appropriate balanced equation. [3]

8. **[18 marks]** *1.11 (2016:41)*

Nitrogen dioxide is toxic to humans when inhaled and is a significant component of air pollution. It can be formed by the combustion of nitrogen in the air at high temperatures; firstly forming nitric oxide NO(*g*) and on further oxidation, forming nitrogen dioxide, $NO_2(g)$. The overall equation for this process is given here:

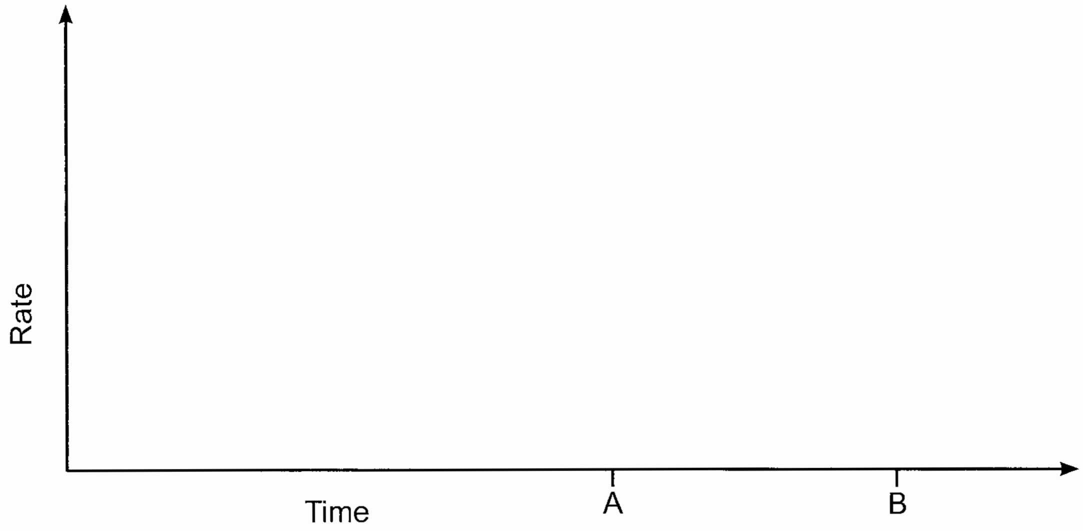
$$N_2(g) + 2\,O_2(g) \rightleftharpoons 2\,NO_2(g)$$

The following questions relate to the equilibrium system represented by this equation.

(a) Write the equilibrium expression for this reaction when it is in equilibrium. [2]

(b) Assuming all other conditions remain constant, what happens to the equilibrium constant after the pressure of the system is lowered and equilibrium is re-established? [1]

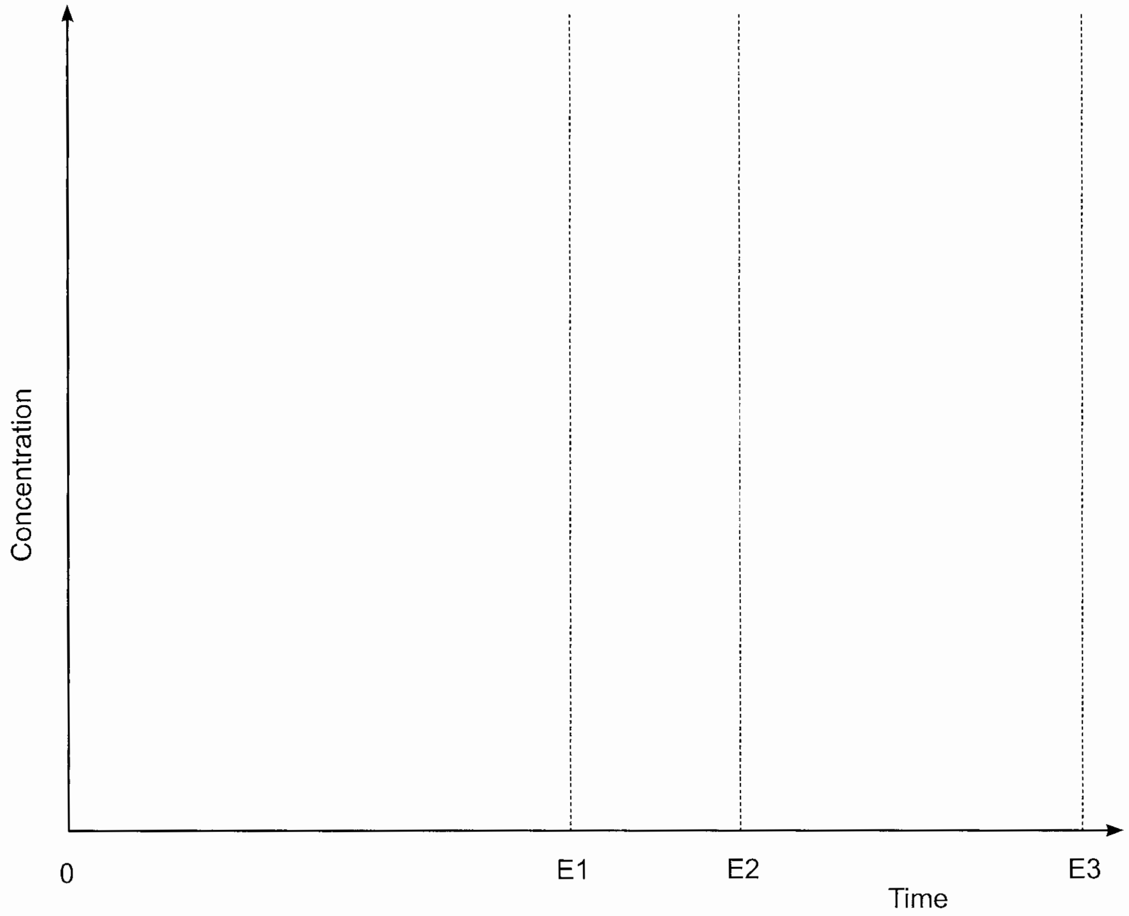
(c) (i) On the axes below, draw the forward (—) and reverse (- - -) reaction rates, starting at the moment the oxygen and nitrogen gases begin to react with each other until after equilibrium has been established at time A. Continue the graph until time B. [3]



(ii) On the same axes above, draw and label clearly the effect of conducting the same reaction at a higher temperature. [2]

d) On the axes below, draw separate curves to show how the concentrations of the **three** gases change with time, starting at the moment the oxygen and nitrogen gases begin to react with each other until the system reaches equilibrium at Time E1. Continue the graph from Time E1 to Time E2. Assume that the initial concentrations of oxygen and nitrogen are identical.

Label clearly the line for each gas. [5]



(e) At Time E2 shown on the axis, the reaction vessel is doubled in volume, and the system is then again allowed to reach equilibrium at Time E3. On the same graph above, show how the concentrations of the three gases would change in response to the change in volume, from Time E2 until equilibrium is re-established at Time E3. [3]

The reaction between nitrogen gas and oxygen gas occurs at high temperatures such as those found in the combustion engines of cars. The atmosphere is composed of 78% nitrogen and 21% oxygen and has been stable for millions of years.

(f) What does the stability of this composition indicate about the equilibrium constant and energy requirements of the reaction between nitrogen and oxygen gases? [2]

9. **[10 marks]** *1.8 (2017:28)*

A hydrogen sulfate/sulfate system is represented by the following equation.

$$HSO_4^-(aq) + H_2O(\ell) \rightleftarrows SO_4^{2-}(aq) + H_3O^+(aq)$$

(a) Predict how

- the forward reaction rate and
- the pH

will differ from their original values after the following changes are imposed on the system and equilibrium has been re-established. Use the terms increase, decrease, no change. [6]

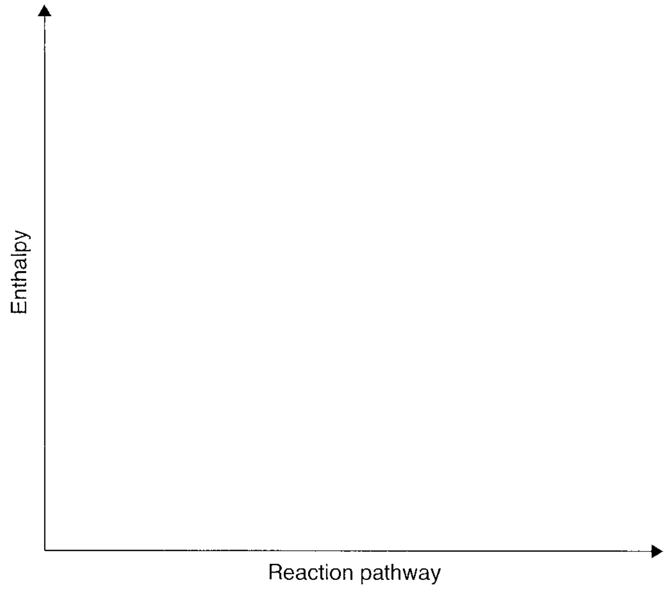
Change imposed by the addition of	**Effect on forward reaction rate when equilibrium**	**Effect on pH when equilibrium is re-established**
a few drops of concentrated hydrochloric acid		
a few drops of concentrated lead(II) nitrate solution		
distilled water		

(b) The reaction in part (a) is endothermic in the forward direction as written. Predict what will happen to the pH when the temperature is increased. Justify this prediction. [4]

10. **[9 marks]** *1.7 (2017:33)*

Both dynamite and TNT are explosive substances that are sometimes confused with each other. The active ingredient in dynamite is a stabilised form of nitroglycerine, $C_3H_5N_3O_9$, while TNT is the common name for the explosive compound 2,4,6-trinitrotoluene, $C_6H_2(NO_2)_3CH_3$.

(a) An explosion is a 'very fast and very exothermic reaction'. Use a solid line (——) to draw, and then label, an energy profile diagram reflecting an explosive reaction. [3]



Nitroglycerin is extremely shock-sensitive and readily becomes unstable. In dynamite the nitroglycerin is combined with inhibitors and stabilisers, making it safer to use. Typically, dynamite is between 25% to 50% nitroglycerin.

(b) An inhibitor is a substance that decreases the rate of, or prevents, a chemical reaction. On the diagram in part (a) above, indicate by way of a dashed line (----) any change/s that would be evident if an inhibitor were to be introduced. [2]

(c) The energy density of dynamite is 5.0 MJ kg^{-1} and the energy density of TNT is 4.0 MJ kg^{-1}. Show by calculation and by reasoning which of these two explosives produces more energy per mole of the active ingredient. [4]

$M(C_3H_5N_3O_9) = 227.10$ g mol^{-1} $M(C_6H_2(NO_2)_3CH_3) = 227.14$ g mol^{-1}

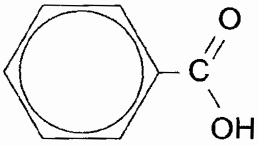
Chapter

8

Acids and Bases

1. **[5 marks]** *(2010:29)*

Benzoic acid is found in many berries and some other fruits, and is used as a food preservative. The structure of benzoic acid is shown below. In an aqueous environment, benzoic acid ionises and exists in equilibrium with the benzoate ion.



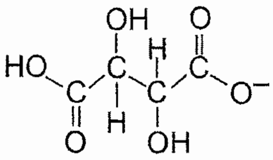
(a) Write the equation for the reaction between benzoic acid and water. *2.1* [1]

(b) Draw the structure (either benzoic acid or the benzoate ion) that would predominate in the acidic environment of the stomach. *2.5* [1]

(c) Show, using equations and the principles of equilibrium, how a solution of benzoic acid and the benzoate ion may behave as a buffer. 2.5 [3]

2. **[6 marks]** *2.3 (2011:27a)*

Complete the table by writing the formula or drawing the structure for the conjugate base, species X or conjugate acid in the blank spaces as appropriate. Species X is the species that is able to form both a conjugate base and a conjugate acid.

Conjugate base	**Species X**	**Conjugate acid**
		$CH_3NH_3^+$
$C_2O_4^{2-}$		
		

3. **[4 marks]** *2.4 (2011:29)*

Write a relevant equation or equations to explain each of the observations shown in the table below.

Observation	**Explanatory equation/s**
The pH of a $NaHSO_4$ solution is 5	
A solution of $Mg(OH)_2$ is basic	
A solution of Na_2HPO_4 is basic, while a solution of KH_2PO_4 is acidic	

4. **[12 marks]** *2.11 (2011:39)*

A student was given three bottles, A, B and C. Each bottle was labelled with its contents as shown in the table below.

Bottle	**Contents**
A	46.5 mL of 0.010 mol L^{-1} $HC\ell$
B	65.7 mL of 0.0555 mol L^{-1} HNO_3
C	20.9 mL of 0.4161 mol L^{-1} NaOH

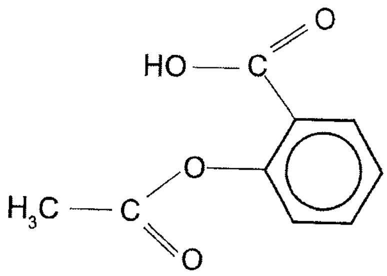
(a) Calculate the pH of the NaOH solution. [2]

(b) The contents of all three bottles are placed in one beaker and mixed thoroughly. Calculate the pH of the final mixture. [10]

5. **[3 marks]**

2.5 (2012:35a)

The active ingredient in aspirin tablets (acetylsalicylic acid) has the structure shown below. When acetylsalicylic acid is placed in water, some of it dissolves and ionises to form its conjugate base.



Write the equation for the ionisation of acetylsalicylic acid in the space below, and identify the conjugate acid and base pairs in the reaction. Connect the acid-base pairs with a line, and label the conjugate acid in the pair 'A', and the conjugate base 'B'.

6. **[6 marks]** *2.6 (2012:36)*

Water is able to react with itself in the process known as 'self-ionisation' or 'auto-ionisation'.

(a) Write the equation for the self-ionisation of water. [1]

(b) At 25°C, the value of K_w is approximately 1.0×10^{-14}. At 10°C, the value of K_w is approximately 2.9×10^{-15}. [2]

What are the relative concentrations of H^+ and OH^- ions in a neutral water solution at **25°C**? Circle the correct answer.

$[H^+] > [OH^-]$ $[H^+] < [OH^-]$ $[H^+] = [OH^-]$

What are the relative concentrations of H^+ and OH^- ions in a neutral water solution at **10°C**? Circle the correct answer.

$[H^+] > [OH^-]$ $[H^+] < [OH^-]$ $[H^+] = [OH^-]$

(c) Consider the values of K_w at 10°C and 25°C, and state whether the self-ionisation of water is an endothermic or exothermic process. Give a reason to support your answer. [3]

7. **[9 marks]** *2.10 (2012:37)*

Oxalic acid dihydrate ($H_2C_2O_4 \bullet 2\,H_2O$) is a primary standard used to standardise potassium permanganate solutions, which can be used for volumetric analysis.

(a) List **two** properties of oxalic acid that make it a good primary standard. [2]

(b) A student was asked to prepare a standard solution of oxalic acid of approximate concentration 0.05 mol L^{-1}. The equipment listed below was available.

electronic balance
beakers (20 mL, 50 mL, 100 mL, 250 mL)
volumetric flasks (250 mL, 500 mL)
oxalic acid ($H_2C_2O_4 \bullet 2\,H_2O$) (5 g)
distilled water (20 L)
stirring rod
wash bottle
weighing boats

Give a step-by-step, detailed description of a procedure for preparing the standard oxalic acid solution. Perform and include any necessary calculations. [7]

8. [12 marks] *(2012:42)*

Large public swimming pools are often chlorinated using chlorine gas. The gas is bubbled through the water forming the equilibrium reaction shown below:

$$C\ell_2(aq) + H_2O(\ell) \rightleftharpoons HOC\ell(aq) + H^+(aq) + C\ell^-(aq) \qquad \text{(Reaction 1)}$$

The equilibrium constant for this reaction at 25.0°C is 3.94×10^4.

(a) Compare the relative amounts of chlorine and hypochlorous acid at equilibrium at 25°C. [1]

The hypochlorous acid can dissociate as shown in the equilibrium below to give hypochlorite ion.

$$HOC\ell(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + OC\ell^-(aq) \qquad \text{(Reaction 2)}$$

(b) The pH of swimming pools is kept at approximately 7.5. A reason for this is to maximise the concentration of hypochlorous acid, the most effective disinfectant form of chlorine in water. Explain, using the appropriate chemistry concepts, why a pH of about 7.5 will maximise hypochlorous acid concentration. Your explanation should consider equilibrium reactions 1 and 2. [3]

CONTINUED NEXT PAGE

(c) If the concentration of hypochlorous acid is to be 1.50 mg L^{-1}, what volume of chlorine gas, at standard pressure and 25°C, is required for an Olympic size swimming pool with a volume of water of 2.50×10^6 L? Assume that all the chlorine gas reacts to produce hypochlorous acid. [5]

The hypochlorite ion can react with ammonia or amines in the water to form chloramines, which are responsible for the bad odour and eye irritation sometimes experienced in pools. Monochloramine is produced as shown in the reaction below:

$$NH_3(aq) + OC\ell^-(aq) \rightleftharpoons NH_2C\ell(aq) + OH^-(aq)$$

The removal of chloramines can be achieved by 'shock' chlorination – the addition of further chlorine to produce more hypochlorite ion, which oxidises chloramines to nitrogen trichloride, $NC\ell_3$. The nitrogen trichloride then decomposes to nitrogen gas and chlorine gas.

(d) Write a balanced equation showing the reaction of hypochlorite ion with ammonia to give nitrogen trichloride and hydroxide ion. [1]

(e) Organic chloramines are produced by the reaction of an amine with hypochlorite ion. Give the structure of, and name, the amine with 2 carbon atoms. Show all atoms in your structure, and draw your structure in the box below. [2]

Name: ....

9. **[7 marks]** *2.4 (2013:31)*

An aqueous solution is prepared that contains 0.1 mol L^{-1} Na^+ and 0.1 mol L^{-1} $HC_2O_4^-$.

(a) Write the **two** possible reactions for the hydrolysis of the $HC_2O_4^-$ ion. [3]

One: ____________________

Two: ____________________

(b) The pH of the solution was measured and found to be less than seven. Based on this observation, state which of the hydrolysis equations has the higher equilibrium constant. Use your understanding of equilibrium concepts to explain your choice fully. [4]

10. **[7 marks]** *2.8 (2015:29)*

A 25.0 mL solution of nitric acid at 25.0°C contains 8.50×10^{-3} moles of hydrogen ions.

(a) Calculate the hydrogen ion concentration and the pH of the solution. [2]

(b) Calculate the pH of the solution after 20.0 mL of 0.300 mol L^{-1} potassium hydroxide solution is added to the original 25.0 mL of nitric acid. [5]

11. **[15 marks]** *(2015:40)*

Hydrogen fluoride, HF, is a highly dangerous and corrosive liquid that boils at near room temperature. It readily forms hydrofluoric acid in the presence of water and is an ingredient used to produce many important compounds, including medicines and polymers.

(a) (i) Name the electrostatic attractive force that holds the hydrogen and fluorine atoms together **within** hydrogen fluoride molecules. [1]

(ii) Name the electrostatic attractive force **between** the hydrogen fluoride molecules. [1]

(iii) Explain the origin of the attractive force **between** the hydrogen fluoride molecules. [2]

(b) The equilibrium constant (K) for the dissociation of hydrofluoric acid is 6.8×10^{-4}, and for hydrochloric acid K is very large. To make a solution of hydrofluoric acid with the same pH as hydrochloric acid, a greater concentration of hydrofluoric acid is required. Explain why this is so. [3]

(c) The salts, sodium chloride and sodium fluoride, readily dissolve in water. At 25.0°C the pH of the sodium chloride solution is equal to 7 whereas the pH of the sodium fluoride solution is greater than 7. Explain this difference in pH. Include any relevant equation(s) to support your answer. [3]

Propanoic acid, CH_3CH_2COOH, is also a weak monoprotic acid. When 0.500 mol of sodium propanoate is dissolved in 1.00 L of 0.500 mol L^{-1} propanoic acid at 25.0°C a buffer solution is formed.

(d) (i) Addition of 10.0 mL of 1.00 mol L^{-1} $HC\ell(aq)$ to this buffer does not significantly change its pH. Explain this observation, including any relevant equation(s). [3]

(ii) State **two** conditions required to ensure that this system has a high buffering capacity. [2]

One:

Two:

12. **[6 marks]** *2.4 (2016:31)*

(a) Select **one** basic, **one** acidic and **one** neutral salt from the list below to complete the table. [3]

KCN, $NH_4C\ell$, $Mg_3(PO_4)_2$, $NaNO_3$, $KHCO_3$, $NaCH_3COO$, $KC\ell$

Acidic salt	**Neutral salt**	**Basic salt**

(b) Use the Brønsted-Lowry model to explain why the pH of ammonia solution is greater than 7.0 at 25°C. Incorporate at least **one** appropriate equation in your answer. [3]

13. **[6 marks]** *2.5 (2016:32)*

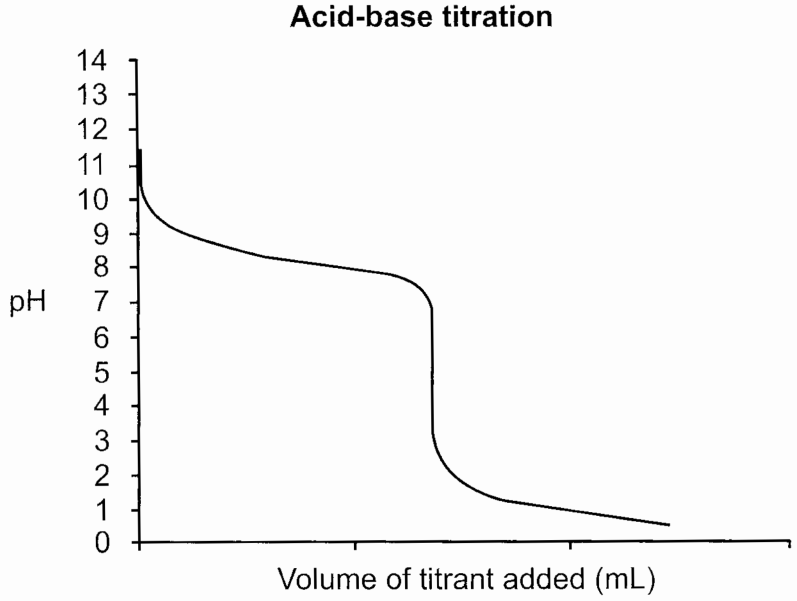
(a) A buffer of carbonic acid (H_2CO_3)/hydrogencarbonate (HCO_3^-) is present in blood plasma to maintain a pH between 7.35 and 7.45. Write an equation to show the relevant species present in a carbonic acid/hydrogencarbonate buffer solution. [2]

(b) Explain why 300.0 mL of 1.00 mol L^{-1} carbonic acid/hydrogencarbonate buffer does **not** change in pH significantly when 3 drops of 1.00 mol L^{-1} $HC\ell$ are added to it, yet when 3 drops of 1.00 mol L^{-1} $HC\ell$ are added to 300.0 mL of distilled water there is a significant change in pH. [4]

14. **[6 marks]** *2.01 (2016:34)*

The data below were collected from an acid-base titration.

(a) Label the equivalence point on the titration curve below using an arrow and record the pH value at this point. [2]



pH value at equivalence point: ______________________

(b) Select an indicator from the table below that would be **best** for this titration and justify your choice. [4]

Indicator	**Low pH colour**	**Transition pH range**	**High pH colour**
Methyl Yellow	red	2.1 – 3.3	yellow
Bromocresol Green	yellow	3.8 – 5.4	blue
Bromothymol Blue	yellow	6.0 – 7.6	blue
Phenolphthalein	colourless	8.3 – 10.0	pink
Alizarin Yellow R	yellow	10.2 – 12.0	red

Indicator: ____

Justification: ____

____

____

____

____

____

15. **[8 marks]** *2.5 (2017:31)*

Water is capable of self-ionisation.

(a) Write an equation for the self-ionisation of water. [2]

(b) Write the equilibrium constant expression for the self-ionisation of water. [1]

(c) The equilibrium constant for the self-ionisation of water Kw is 1.00×10^{-14} at 25 °C. What does this value indicate about this reaction? [1]

The K values for the self-ionisation of water at 100.0 kPa are given here for a number of different temperatures.

Temperature (°C)	**K value**
0	0.114×10^{-14}
25	1.00×10^{-14}
50	5.48×10^{-14}
75	19.9×10^{-14}
100	51.3×10^{-14}

(d) Calculate the pH of water at 50 °C. [2]

(e) Is water acidic, basic or neutral at 50 °C? State a reason for your answer. [2]

Oxidation–Reduction

Chapter

9

1. [7 marks] *(2011:35)*

A nickel-cadmium cell consists of a positive nickel(III) oxide-hydroxide, NiO(OH), electrode and a negative metallic cadmium electrode plate. The following processes occur during discharge:

(i) metallic cadmium reacts in the presence of hydroxide ions to produce cadmium(II) hydroxide; and

(ii) nickel(III) oxide-hydroxide reacts in the presence of water to produce nickel(II) hydroxide and hydroxide ions.

(a) Write the half-equations for the reactions occurring at the anode and cathode and the overall redox equation for the Ni-Cd cell. *3.2* [3]

Anode half-equation	
Cathode half-equation	
Overall redox equation	

(b) The electrolyte in the Ni-Cd cell is usually a solution of potassium hydroxide. State the role of an electrolyte in a Galvanic cell. *3.9* [1]

(c) The standard reduction potential for cadmium metal is –0.4 V. Explain the role of the hydrogen half-cell in determining this value. Comment on the significance of the negative value. You may use diagrams to aid your explanation. *3.8* [3]

2. **[13 marks]** *(2011 S2:33)*

In industry, sodium is extracted from molten sodium chloride by electrolysis. Likewise, potassium can be extracted from its molten salts.

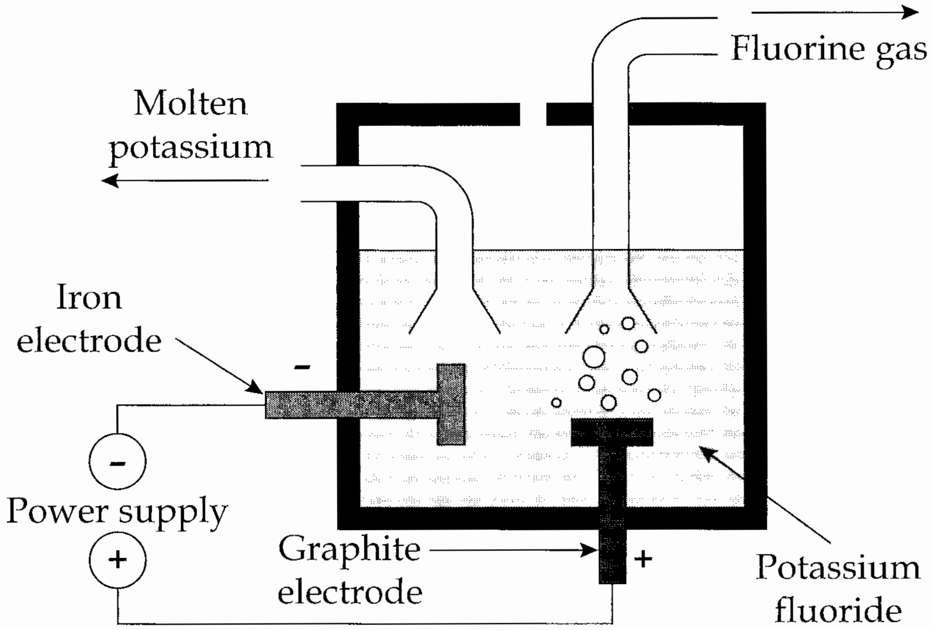
(a) When potassium fluoride is melted, it dissociates to release ions. Write the equation, including appropriate state symbols, to show this process. [2]

(b) Write the oxidation and reduction half equations for the electrolysis of molten potassium fluoride. [2]

Oxidation ....

Reduction ....

In the extraction of potassium from molten potassium fluoride, an apparatus similar to that shown in the diagram below is used. Refer to the diagram to answer the parts of the question that follow.



(c) Complete the table below by writing the electrode (anode or cathode) for which each of the substances shown is used. [1]

Graphite	Iron

(d) On the diagram, show the direction of flow of fluoride ions. [1]

(e) Name the substance that forms at the anode. [1]

....

(f) Explain why solid potassium fluoride cannot undergo electrolysis. [2]

....

....

....

(g) (i) List three potential hazards associated with the electrolysis of molten potassium fluoride. [3]

1 ....

2 ....

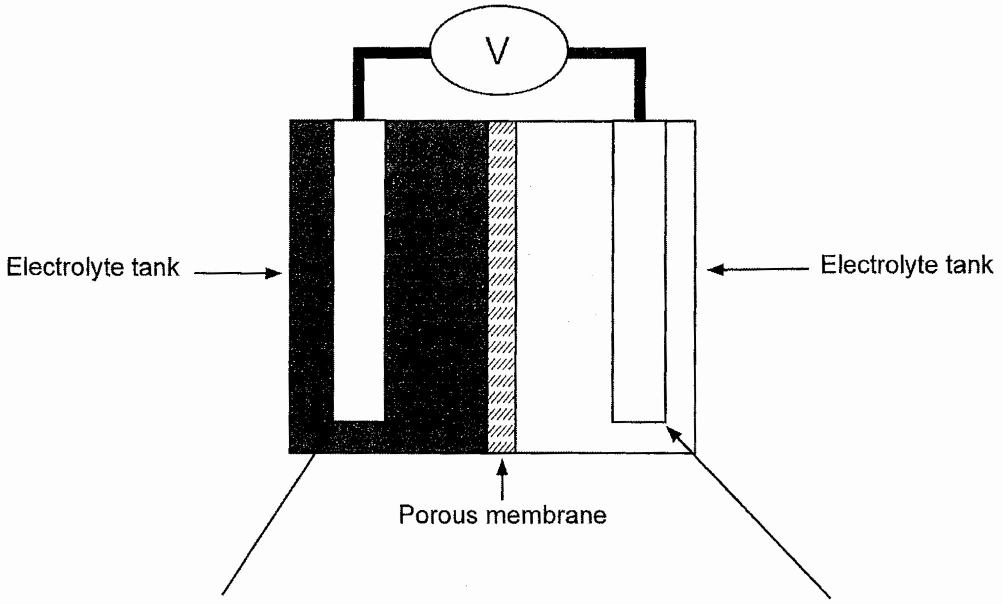
3 ....

(ii) State one safety precaution that workers using electrolysis to extract potassium from molten potassium fluoride should take. [1]

3. **[3 marks]** *3.9 (2012:32)*

The vanadium redox battery is a galvanic cell that is being developed to store electricity produced by solar or wind power on a large scale.

The general structure of the vanadium redox battery is shown below. In this battery, $VO^{2+}(aq)$ is converted to $VO_2^+(aq)$ at one electrode, while $V^{3+}(aq)$ is converted to $V^{2+}(aq)$ at the other.



$H_2O(\ell) + VO^{2+}(aq) \rightarrow VO_2^+(aq) + 2\,H^+(aq) + e^-$

$V^{3+}(aq) + e^- \rightarrow V^{2+}(aq)$

(a) In the boxes above, identify and label both the anode and cathode. [1]

(b) Draw an arrow on the diagram to indicate the direction of electron flow. [1]

(c) State briefly how the porous membrane functions to complete the circuit. [1]

4. **[6 marks]** *3.2 (2012:33)*

When a few drops of concentrated sodium bismuthate solution, $NaBiO_3(aq)$, are added to a small volume of manganese(II) chloride solution, a deep purple solution is formed. The purple colour of the solution suggests that manganese is transformed to the +7 oxidation state as the permanganate ion, MnO_4^-. The colourless bismuth ion, $Bi^{3+}(aq)$, is also formed.

Write the oxidation and reduction half equations, and the overall redox equation, for this reaction.

Oxidation half-equation	
Reduction half-equation	
Overall redox equation	

5. [12 marks] *(2012 S2:41)*

A traditional technique for cleaning the tarnish, $Ag_2S(s)$, off silverware without using an abrasive cleaner (which wears away the precious metal) involves setting up a simple electrolytic cell. The piece of silver to be cleaned can be placed on the bottom of a glass or enamel pan and covered with aluminium foil. A solution of baking soda, $NaHCO_3(aq)$ and table salt, $NaC\ell(aq)$, can be added and brought to the boil to the pan. The piece of silver must be in contact with the aluminium foil. The process takes some time but at the end the silverware is sparkling clean. This process works because tarnish on silver, $Ag_2S(s)$, is caused by sulfide ions. The salt and baking soda solution make an ion-carrying solution that transfers the sulfide ions from the silver to the aluminium foil.

(a) Write the half-equation where the silver sulfide, $Ag_2S(s)$, is converted to pure silver, $Ag(s)$. [2]

____

(b) Write the half-equation where aluminium forms aluminium ions. [2]

____

(c) Combine the two reaction half-equations to produce a balanced overall redox equation for the process. [2]

____

(d) Explain the purpose of the salt and baking soda solution. [1]

____

____

(e) Circle the substance that is acting as the cathode. [1]

the tarnished silver or the aluminium foil

(f) Circle the substance at which reduction is occurring. [1]

the tarnished silver or the aluminium foil

(g) Circle the arrow showing the correct direction in which electrons will flow during this process. [1]

$\overset{\Longrightarrow}{Ag_2S \quad A\ell}$ $\qquad$ $\overset{\Longleftarrow}{Ag_2S \quad A\ell}$

(h) State the oxidation number of silver: [2]

(i) in the Ag_2S tarnish. ______________

(ii) when it has been converted to the silver metal. ______________

6. **[18 marks]** *(2013:41)*

Lead-acid storage cells use Pb and PbO_2 electrodes. Pb is the reducing agent, while PbO_2 is the oxidising agent. Sulfuric acid solution is used as the electrolyte.

(a) The overall cell reaction during discharge is given below. Write and balance the anode and cathode reactions for the lead-acid storage cell. [2]

Anode reaction	
Cathode reaction	
Overall reaction	$Pb(s) + PbO_2(s) + 4\,H^+(aq) + 2\,SO_4^{2-}(aq) \rightarrow 2\,PbSO_4(s) + 2\,H_2O(\ell)$

(b) Draw a schematic diagram of the lead-acid cell showing the two half-cells. Label the anode, cathode and salt bridge, and indicate the direction of electron flow with an arrow. [4]

(c) (i) With reference to the 'electrical potential' of a galvanic cell, describe how the lead-acid storage cell produces current. [2]

(ii) What determines the magnitude of the electrical potential of a cell? [1]

CONTINUED NEXT PAGE

(d) (i) Determine the number of moles of $H^+(aq)$ in a lead-acid cell that contains 4.50 L of 3.55 mol L^{-1} sulfuric acid solution. [1]

(ii) Use the overall cell equation to determine the number of moles of $H^+(aq)$ consumed when discharge of this cell forms 138.1 g of $PbSO_4(s)$.

The molar mass of $PbSO_4$ is 303.26 g mol^{-1}. [2]

(iii) Use your answers to (i) and (ii) to determine the concentration of $H^+(aq)$ in the electrolyte in the discharged cell. Assume that the electrolyte volume remains constant, and ignore any changes due to the formation of water. [2]

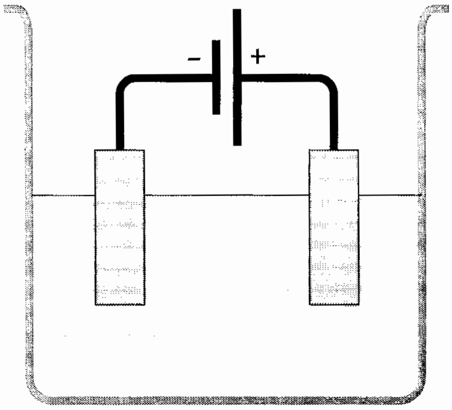
(iv) Use your answers to (i) and (iii) to show that when this cell discharges as described above, the change in pH of the electrolyte solution is negligible. Note that in any acid solution whose $H^+(aq)$ concentration is greater than 1 mol L^{-1}, the pH is negative. [3]

(e) A flat (fully discharged) lead-acid cell can be 'jump started' by connecting it to a cell in a car whose engine is running. The current forced through the cell in this way causes the formation of a mixture of hydrogen and oxygen gas through the hydrolysis of water. State why the formation of the hydrogen and oxygen gas mixture may be dangerous.[1]

7. **[18 marks]** *(2013 S2:42)*

A quantity of pure chromium chloride ($CrC\ell_3$) is melted and placed in a heatproof vessel. Two inert electrodes are inserted as shown below and a current flows through the molten liquid.

(a) Complete and label the diagram below, showing the:
- anode
- cathode
- direction of electron current
- ions present and the direction in which they are flowing. [5]



(b) Write the oxidation half equation. [2]

Oxidation ....

(c) Write the reduction half equation. [2]

Reduction ....

(d) Write the overall redox equation. [2]

Redox ....

(e) Indicate (by circling) which process occurs at the electrode that is connected to the negative terminal. [1]

Oxidation Reduction

(f) What is acting as the oxidant in this reaction? [1]

....

(g) What is produced at the anode? [1]

....

(h) State the oxidation number of: [4]

(i) Cr in solid chromium chloride ....

(ii) $C\ell$ in molten chromium chloride ....

(iii) Cr in chromium metal ....

(iv) $C\ell$ in chlorine gas ....

8. **[5 marks]** *3.5 (2014:31)*

(a) State the role of the standard hydrogen half-cell in determining the table of Standard Reduction Potentials. [2]

(b) State **three** limitations of Standard Reduction Potential tables. [3]

One:

Two:

Three:

9. **[6 marks]** *3.2 (2014:32)*

Nitrogen gas from the atmosphere undergoes a series of redox reactions to transform it into nitrate ions that are absorbed by plants. The process can be simplified into the following three steps.

Step 1 – Nitrogen-fixing soil bacteria reduce nitrogen gas to ammonium ions.
Step 2 – Nitrifying bacteria then oxidise ammonium ions to nitrite ions.
Step 3 – Nitrifying bacteria then oxidise nitrite ions to nitrate ions.

Write the half-equations for each of these steps. Assume acidic conditions.

Step 1

Step 2

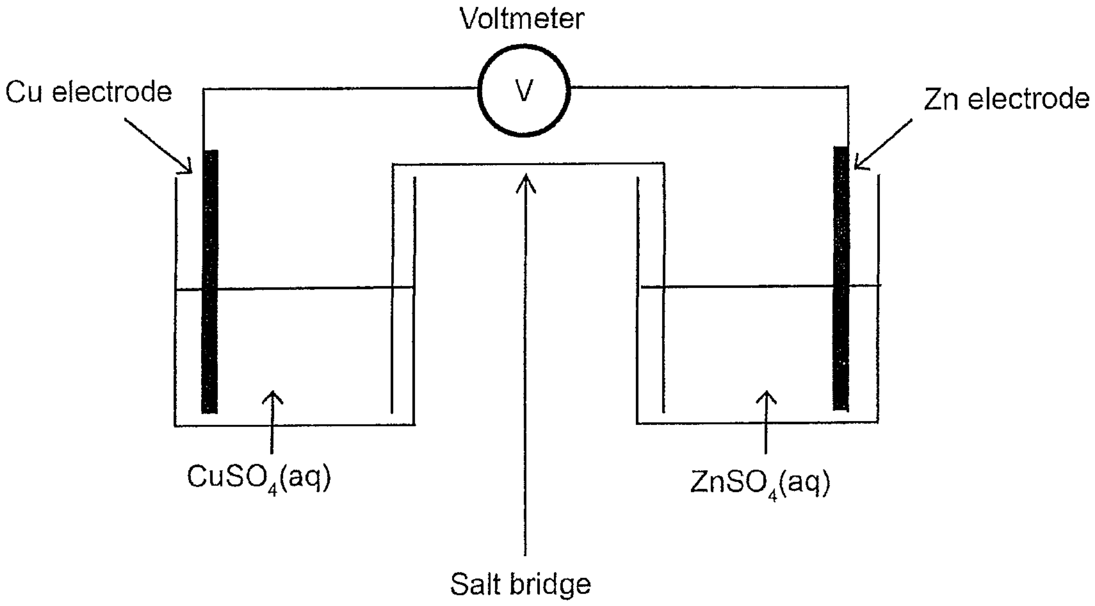
Step 3

10. **[9 marks]** *SIS (2014:36)*

A student investigated the effect of concentration of the electrolyte on the electrical potential of galvanic cells. The student measured the electrical potential for the cell shown in the diagram below. In all trials the volumes of solutions and their temperatures were the same and the surface areas of the copper and zinc electrodes were the same.

The overall cell reaction is as follows:

$$Zn(s) + Cu^{2+}(aq) \rightleftharpoons Zn^{2+}(aq) + Cu(s)$$



(a) What is the independent variable in this investigation? *6.2* [1]

(b) What is the dependent variable in this investigation? *6.2* [1]

(c) Why did the volumes and temperatures of solutions and surface areas of the electrodes need to be the same in each trial? *6.3* [1]

CONTINUED NEXT PAGE

The student found that as the concentration of Cu^{2+} ions increased, electrical potential increased, but as concentration of Zn^{2+} ions increased, electrical potential decreased, as shown in the table below.

Trial	Cu^{2+} concentration (mol L^{-1})	Zn^{2+} concentration (mol L^{-1})	Electrical potential, E(V)
1	0.00001	1.00	1.01
2	0.010	1.00	1.04
3	1.00	1.00	1.09
4	1.00	0.010	1.16
5	1.00	0.00001	1.26

(d) Explain the increase in electrical potential as the concentration of Cu^{2+} ions increased and the decrease in electrical potential as the concentration of Zn^{2+} ions increased. *3.8* [2]

(e) The student also observed that as the cells were allowed to run for a while their electrical potential slowly decreased from its maximum value. Why did this happen? *3.8* [2]

The student concluded:
'As the concentration of the oxidant increases, so does the cell voltage (electrical potential).'

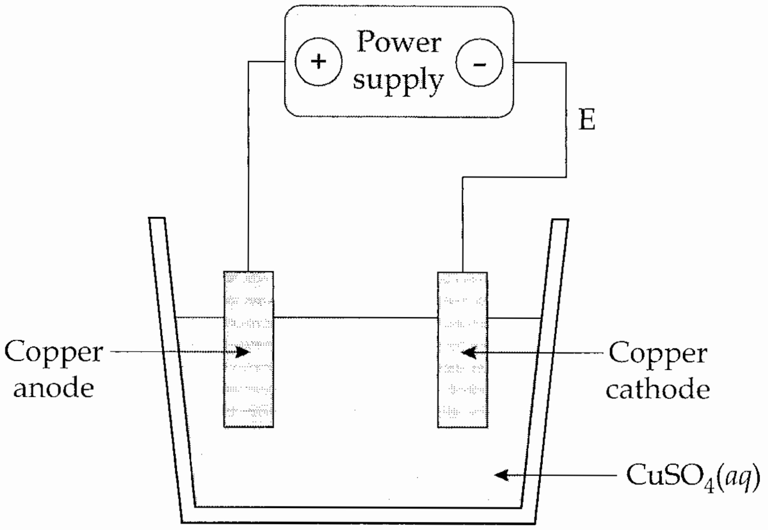
(f) List **two** ways to improve the investigation. *6.2* [2]

One:

Two:

11. **[5 marks]** *(2014 S2:40a,c)*

Copper is a widely used metal which can be refined by electrolysis. Look at the diagram below, which represents an electrolytic cell that can be used to produce pure copper from a solution of copper(II) sulfate ($CuSO_4$).



(a) (i) Draw an arrow on the diagram to show the direction of the movement of electrons in the external circuit at Point E. [1]

(ii) Draw an arrow on the diagram to show the direction of the movement of copper ions (Cu^{2+}) in the solution. [1]

(b) Explain why the copper(II) sulfate needs to be dissolved in water for the electrolysis process to work. [3]

12. **[6 marks]** *3.5 (2015:31)*

(a) Write a balanced ionic equation to represent the reaction described below. Include all state symbols.

0.100 mol L^{-1} aqueous solutions of silver nitrate and potassium carbonate are mixed. [3]

(b) Describe a chemical test that can be used to distinguish between magnesium solid and cobalt solid. State the observations expected for each of the solids when tested. [3]

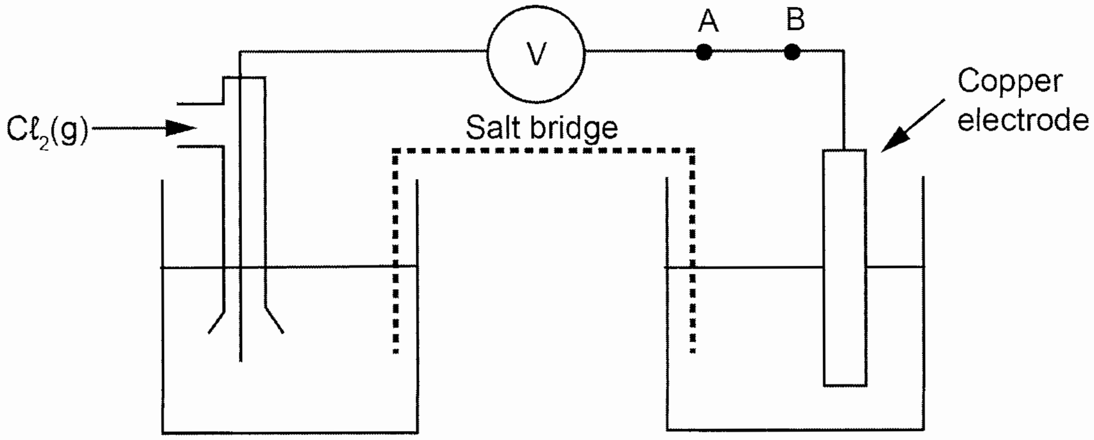
Chemical test

Observation with magnesium solid

Observation with cobalt solid

13. **[6 marks]** *3.7, 3.9 (2015:35)*

The following galvanic cell was set up under standard conditions.



1 mol L^{-1} sodium chloride solution 1 mol L^{-1} copper(II) nitrate solution

(a) Draw an **arrow** between **A** and **B** on the diagram to indicate the direction of electron flow. [1]

(b) Write a balanced equation to represent the overall reaction occurring in this cell. [2]

(c) State the reason for the reactants being kept in separate half-cells. [1]

(d) State the observation predicted to occur in the $C\ell_2$/NaCℓ half-cell. [1]

(e) Predict a metal/metal ion cell that could be used in place of the Cu/Cu^{2+} cell to give a higher emf (volts). [1]

14. **[16 marks]** *(2015:37)*

Sulfur compounds in sewage and industrial processes can cause problems due to their odours, often because they eventually form dihydrogen sulfide gas, also known as rotten egg gas.

One class of sulfur compounds that need to be removed from sewage is the thiosulfates. One step in their removal is the reaction of tetrathionate ions, $S_4O_6^{2-}$, with hydrogen peroxide, H_2O_2. The tetrathionate produces trithionate ions, $S_3O_6^{2-}$, and sulfate ions.

(a) (i) Complete the table below by writing balanced half-equations and the final redox equation for the reaction of tetrathionate and hydrogen peroxide. [6]

Half-equation one $S_4O_6^{2-} \rightarrow S_3O_6^{2-} + SO_4^{2-}$
Half-equation two $H_2O_2 \rightarrow$
Redox

(ii) Which substance is being oxidised? [1]

....

In some industrial processes, dihydrogen sulfide is a waste product. If the quantity of gas is large, then it becomes economical to extract for other production processes. The Claus process is one such example where dihydrogen sulfide is used to produce elemental sulfur.

One of the key reactions occurring in the process is the Claus reaction represented by the equation shown below.

$$2\,H_2S(g) + SO_2(g) \rightarrow 3\,S(\ell) + 2\,H_2O(g)$$

Modern Claus plants, using three catalytic converters, may achieve up to 99.8% conversion but typically the conversion of dihydrogen sulfide to sulfur is between 95 and 97%.

In one particular industrial plant, the following initial conditions were used:

dihydrogen sulfide (H_2S)	mass	= 19.5 kg
sulfur dioxide (SO_2)	pressure temperature volume	= 68.3 kPa = 791°C = 43.4 kL

(b) Calculate the maximum mass of sulfur that can be formed if the process is 96.8% efficient. Express your answer to **three** significant figures. [9]

15. **[6 marks]** *3.6 (2016:26)*

Galvanic cells and electrolytic cells are often constructed in the laboratory.

(a) List **four** characteristics or components that these two types of cells have in common with each other. [4]

One: ______________________________

____

Two: ______________________________

____

Three: ______________________________

____

Four: ______________________________

____

(b) List **two** characteristics or components that can be used to distinguish between the two types of cells. State the characteristic or component for each cell. [2]

One: ______________________________

____

Two: ______________________________

____

16. **[11 marks]** *3.11 (2016:40)*

To be used in wiring, copper must be at least 99.9% pure. To obtain 99.9% pure copper from its most common ore, chalcopyrite ($CuFeS_2$), two processes must take place.

(i) The first process occurs in a furnace where the chalcopyrite is converted to 'blister copper', which is approximately 98% pure due to impurities such as sand.

(ii) The second process occurs in an electrolytic cell where the 'blister copper' undergoes electrolysis to produce copper at or above 99.9% purity.

In the furnace, the ore is heated strongly with silica (silicon dioxide), calcium carbonate and air. The furnace reduces the copper(II) in the chalcopyrite first to copper(I) then to copper.

Below are the equations that represent the main processes occurring in the blast furnace.

Equation one: $2\ CuFeS_2 + 2\ SiO_2 + 4\ O_2 \rightarrow Cu_2S + 2\ FeSiO_3 + 3\ SO_2$

Equation two: $Cu_2S + O_2 \rightarrow 2\ Cu + SO_2$

(a) Equation two can be represented as half equations. Write the reduction half equation. [1]

Reduction: ____

Oxidation: $S^{2-} + O_2 \rightarrow SO_2 + 2\ e^-$

In the electrolytic cell, the copper produced from the blast furnace is purified.

(b) Explain the electrolytic process used to purify copper. Include:

- a brief overview of the process
- a labelled diagram of the electrolytic cell
- the relevant oxidation and reduction half equations
- a discussion of impurities and how they are separated from the copper. [10]

17. **[16 marks]** *3.3 (2016 SP:42)*

Use the following information about bleaching to answer the questions that follow.

Many chlorine-based compounds, such as sodium hypochlorite ($NaOC\ell$), chlorine ($C\ell_2$) and chlorine dioxide ($C\ell O_2$), are used as bleaches in household cleaning products and for industrial processes.

Their uses include:

- removing colour (for example, stain removal from clothes)
- whitening paper pulp in the process of making paper
- sterilising substances (for example, swimming pool water).

These compounds act by oxidising the compounds with which they come into contact. When chlorine gas is used for bleaching, the active ingredient is hypochlorous acid ($HOC\ell$). This is produced by reaction of the chlorine gas with water. Hydrochloric acid is also produced in the reaction.

To increase the amount of hypochlorous acid produced in this reaction, the water through which the chlorine is bubbled is usually made alkaline by the addition of a small amount of hydroxide ions. Chlorine-based bleaches react well at room temperatures.

A disadvantage of chlorine bleaches is the potential for highly poisonous dioxins to be produced by reaction with organic compounds. Peroxide bleaches are environmentally more acceptable because they produce only oxygen and water.

Hydrogen peroxide is a liquid, but sodium percarbonate ($2\ Na_2CO_3 \bullet 3\ H_2O_2$) and sodium perborate ($NaBO_3 \bullet H_2O$) are solid peroxide bleaches that release hydrogen peroxide when dissolved in water. A disadvantage of peroxide bleaches is the need for high temperatures for them to react.

The development of molecules known as tetra-amido macrocyclic ligand-activators (TAMLs) that function as catalysts has enabled the hydrogen peroxide bleaching reaction to occur at much lower temperatures.

(a) Write the balanced equation for the reaction of chlorine gas with water. [1]

(b) Explain briefly how the addition of hydroxide ions to the water through which the chlorine is bubbled will increase the amount of hypochlorous acid produced. [3]

(c) Give the oxidation state of chlorine in hypochlorous acid and the oxidation state of chlorine in hydrochloric acid. [2]

Oxidation state of $C\ell$ in hypochlorous acid	**Oxidation state of $C\ell$ in hydrochloric acid**

(d) Identify the species oxidised and the species reduced when chlorine gas reacts with water. [2]

Species oxidised	**Species reduced**

(e) Write the half-equation for the reduction of hypochlorous acid to chloride ion. [1]

(f) For every one mole of formula units of sodium percarbonate, how many mole of hydrogen peroxide are released when it is dissolved in water? [1]

(g) Compare the activation energy for oxidation reactions involving chlorine-based bleaches to those using peroxide-based bleaches (in the absence of catalysts). Explain the reasons for your answer. [2]

(h) Draw a fully labelled energy profile diagram showing the progress of the decomposition of hydrogen peroxide with and without TAML molecules. [4]

The equation for the reaction is $2\ H_2O_2 \rightarrow 2\ H_2O + O_2$ + energy.

18. **[13 marks]** *3.3 (2017:26)*

A limited amount of sodium metal was added to a beaker of distilled water containing a few drops of phenolphthalein.

(a) List three changes that would be observed. [3]

One: ....

....

Two: ....

....

Three: ....

....

Write the ionic equation for any reaction involving both sodium and water. Include all state symbols. [3]

Excess propene gas was bubbled through an aqueous bromine solution.

(b) (i) Identify, by name or formula, any new substance/s produced. [1]

(ii) Write descriptions of the substances before and after mixing. [2]

Before ....

....

After ....

....

A thick strip of lead metal was immersed into a small beaker containing a solution of 1.00 mol L^{-1} iron(III) nitrate.

(c) (i) Identify, by name or formula, any new substance/s produced. [1]

(ii) List all observations that would be made for any reaction, describing clearly the substances before and on completion of any reaction. [3]

....

....

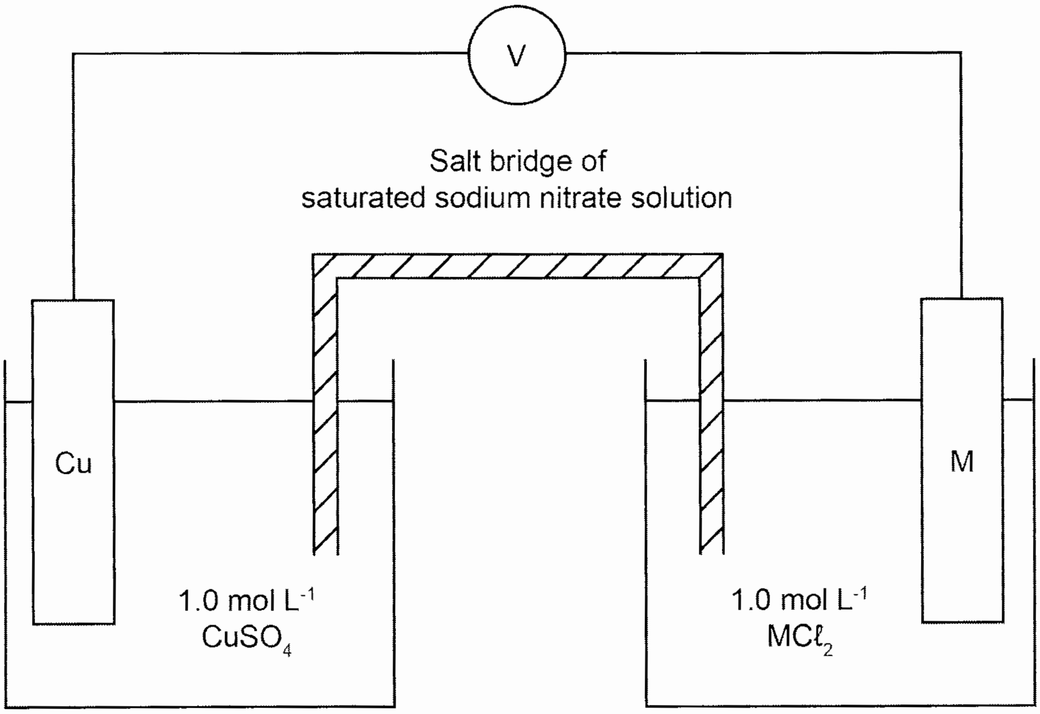
....

....

....

19. **[7 marks]** *3.7 (2017:34)*

The diagram below represents a simple galvanic cell set up at 25.0 °C.



One electrode/electrolyte pair is Cu/Cu^{2+}. The other electrode is of an unknown metal, represented as M/M^{2+}. It was observed, that over time, the unknown metal electrode reduced in size and the solution remained colourless.

(a) Write a chemical equation to show the reaction at the anode of the cell. [1]

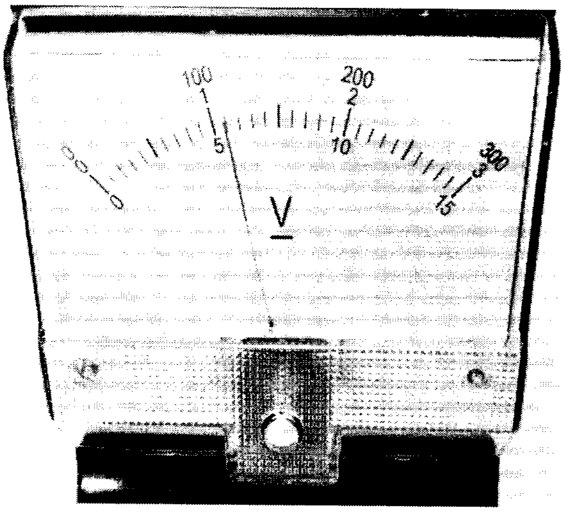
(b) List **two** observations that would be expected in the Cu/Cu^{2+} cell. [2]

One:

Two:

CONTINUED NEXT PAGE

Below is a photograph of the voltmeter attached to the diagram of the cell on the previous page. There are three scales on the voltmeter. The scale being used is the one with the range from 0 to 3 volts.



(c) (i) To the appropriate degree of accuracy, what is the reading on the voltmeter? [1]

(ii) Using the voltmeter reading and other relevant information, predict the identity of the unknown metal. Clear reasoning, including a calculation, must be provided. [3]

20. **[6 marks]** *3.2 (2017:27)*

Balance the following redox equation by determining and then combining the oxidation and reduction half-equations. State symbols are not required.

$$SCN^- + IO_3^- + C\ell^- \rightarrow SO_4^{2-} + HCN + IC\ell$$

Oxidation half-equation
Reduction half-equation
Overall equation

Organic Chemistry

Chapter 10

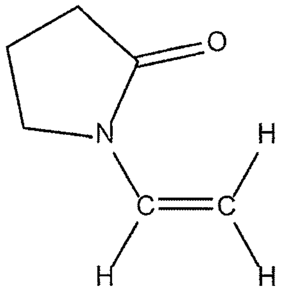
1. **[6 marks]** *4.6 (2011:30)*

Complete the table below by giving a brief description of a **chemical test** that could be used to distinguish between the substances listed. List the observations relating to the test for each of Substance 1 and Substance 2.

Substances to be distinguished		**Description of chemical test**	**Observation with Substance 1**	**Observation with Substance 2**
Substance 1	**Substance 2**			
butan-2-ol	2-methylpropan-2-ol			
methanol	methanal			

2. **[2 marks]** *4.10 (2011:31)*

Polyvinylpyrrolidone is a polymer with a wide range of applications including as a binder in tablets and hair styling agents. It is made from the monomer shown below.

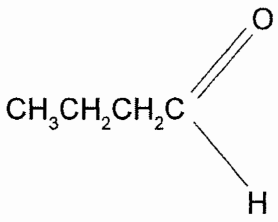
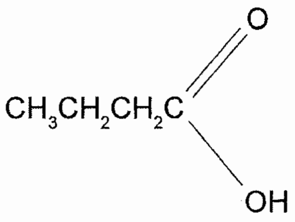


(a) Draw three units in the polymer formed from this monomer. [1]

(b) What type of polymerisation reaction occurs to form the polymer from the above monomer? [1]

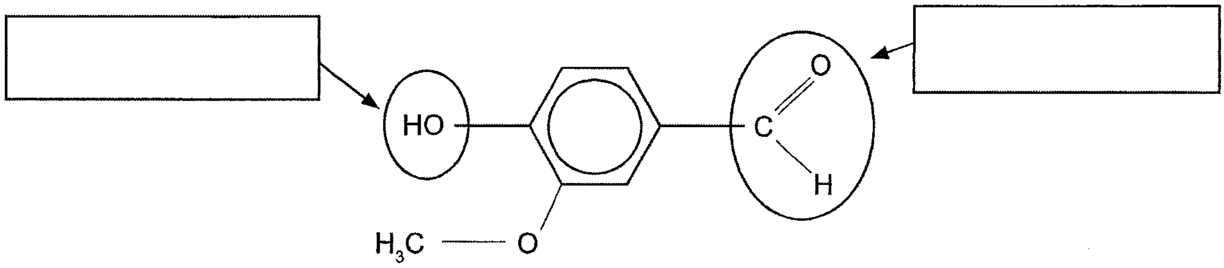
3. **[4 marks]** *4.8 (2012:27)*

Examine the data in the table below. Use your knowledge of intermolecular forces to explain the differences in boiling points of the three compounds listed in the table.

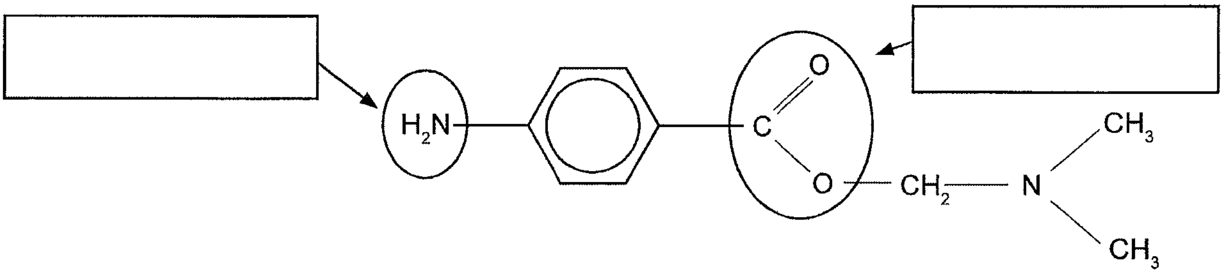
Compound	**Structure**	**Molar mass (g mol^{-1})**	**Boiling point (°C)**
Butan-1-ol	$CH_3CH_2CH_2CH_2OH$	74.24	118
Butanal		72.22	75
Butanoic acid		88.22	163

4. **[4 marks]** *4.1 (2012:31)*

Examine the two compounds below. Compound 1 is the naturally occurring flavouring agent vanillin. Compound 2 is the local anaesthetic procaine. Name the functional groups circled in these two compounds.



Compound 1: Vanillin

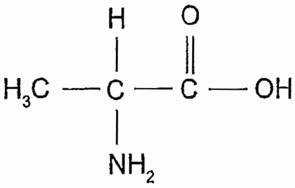


Compound 2: Procaine

5. **[8 marks]** *(2013:34)*

(a) The chemical formula of the α-amino acid glycine is $C_2H_5NO_2$. Draw the structure of glycine, showing all atoms. *4.14* [1]

(b) The structure for the α-amino acid alanine is given below.



$H_3C-CH(NH_2)-C(=O)-OH$

Give the structure for alanine under acidic, neutral and basic conditions by completing the table below. *4.15* [3]

pH	**Structure of alanine**
acidic	
neutral	
basic	

CONTINUED NEXT PAGE

(c) When crystallised from a neutral solution, alanine exists as a white crystalline solid. The solid has a melting point of 258°C. This contrasts with a melting point of –47°C for 2-methylpropanoic acid (molar mass 87 g mol^{-1}), a molecule of similar size to alanine. With reference to the appropriate structure in (b), explain why alanine has such a high melting point. *4.15* [4]

6. **[9 marks]** *(2014:33)*

(a) Methanoic acid, HCOOH, may be produced by oxidation of an alcohol with acidified potassium permanganate, MnO_4^-, solution.

Write the oxidation and reduction half-equations and the final redox equation for this reaction. *3.2* [5]

Oxidation half-equation	
Reduction half-equation	
Final redox equation	

(b) Methanoic acid reacts with ethanol in the presence of sulfuric acid to produce a fruity smelling compound.

Write the balanced equation for the reaction of methanoic acid with ethanol. *4.7* [2]

(c) Draw the structural formula for the fruity smelling compound and give its IUPAC name. Show **all** H atoms in the structure. *4.4* [2]

Name: ____________________

7. **[5 marks]** *4.6 (2014:34)*

Alcohols can be classified as primary, secondary or tertiary.

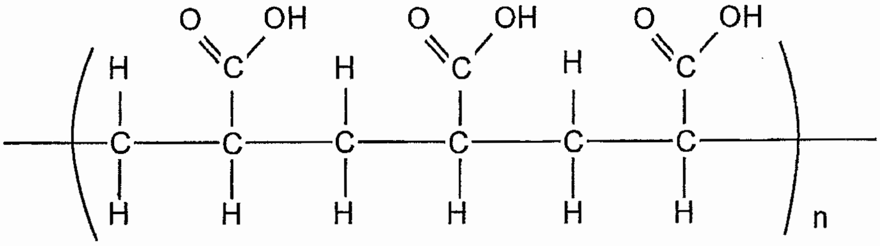
Complete the table below by drawing the structure for a primary alcohol, a secondary alcohol and a tertiary alcohol, each with the molecular formula $C_5H_{12}O$. Show **all** H atoms in your structures.

Give the IUPAC names for the primary and secondary alcohols you have drawn.

	Structure	**Name**
Primary alcohol		
Secondary alcohol		
Tertiary alcohol		**Name not required.**

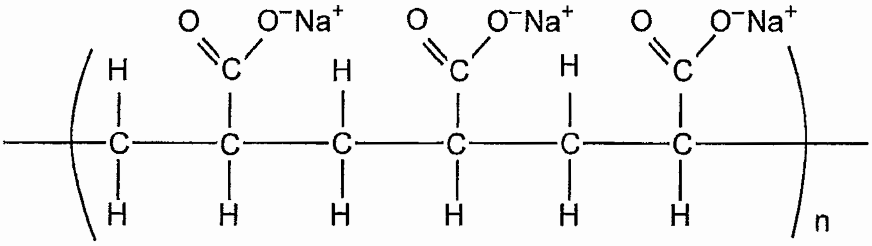
8. **[4 marks]** *(2014:35)*

(a) The structure below represents a segment of polyacrylic acid.



Draw the structure for the monomer of this addition polymer. *4.10* [1]

(b) The structure below represents sodium polyacrylate made by reacting polyacrylic acid with sodium hydroxide.



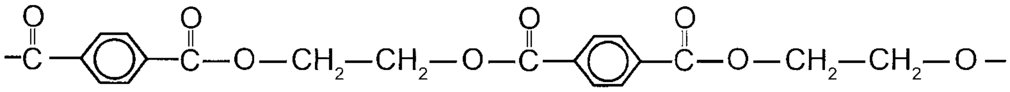
Sodium polyacrylate is a superabsorbent polymer that can absorb approximately 800 times its own weight in water. It is a white powder that swells when water is added. The sodium ions are removed from the polymer structure by interactions with water molecules and then other water molecules move into the swollen structure, where they are held.

(i) What is the name of the interactions occurring between water molecules and sodium ions to enable the removal of the latter from the polymer? *4.8* [1]

(ii) Explain how the polymer sodium polyacrylate can absorb large quantities of water. *4.8* [2]

9. **[7 marks]** *4.13 (2015:32)*

Dacron is the trade name for a common polyester used in making clothes and water bottles. Part of its structural formula is given below:



(a) Draw the structural formula for the **two** monomers that react to form this polymer. [2]

Monomer one:

Monomer two:

(b) Name the other product of this polymerisation reaction. [1]

(c) Predict and explain the effect on the polyester's rigidity and melting point as the polymer chains increase in length. [4]

10. **[10 marks]** *4.1, 4.7 (2015:34)*

Three different organic compounds were each tested with two reagents:
- acidified sodium permanganate solution and
- acidified propanoic acid.

Each organic compound has a molecular formula containing four carbon atoms, one oxygen atom and a number of hydrogen atoms.

The observations made are summarised in the following table.

Unknown organic compound	**Reagent added**	
	Acidified sodium permanganate solution	**Acidified propanoic acid**
1	no observable change	fruity smell
2	purple solution decolourises	no observable change
3	no observable change	no observable change

(a) Complete the table below, identifying the:
- functional group responsible for the observations made
- organic compound, by drawing its structural formula **or** giving its name. [6]

Unknown organic compound	**Functional group**	**Structural formula or name of the organic compound**
1		
2		
3		

CONTINUED NEXT PAGE

(b) Draw the structural formula, showing all atoms of the organic product of the reactions of Compound 1 and Compound 2.

(i) Organic Compound 1 with the acidified propanoic acid. [2]

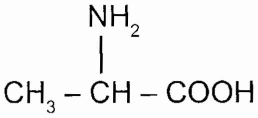
(ii) Organic Compound 2 with the acidified sodium permanganate solution. [2]

11. **[10 marks]** *(2015:39)*

Amino acids are biologically-important organic compounds containing both amine (-NH_2) and carboxylic acid (-COOH) functional groups.

An important amino acid is 2-aminopropanoic acid; usually known as alanine. It is a component in more than a thousand different proteins, found in an array of foods and can be produced within the body.

Structural formula for alanine



$$CH_3-\underset{}{\overset{\overset{\textstyle NH_2}{|}}{C}H}-COOH$$

(a) Alanine is an alpha (α) amino acid. State the structural feature of alanine that allows it to be classified as an **alpha** (α) amino acid. [1]

(b) Use the following information to demonstrate that the molecular formula of alanine is the same as its empirical formula.

When 1.86 g of alanine was vaporised at 550.0°C and 50.0 kPa pressure, it occupied a volume of 2.86 L. [4]

To consider the effect of having both an amine and a carboxylic acid functional group on the same molecule, amino acids can be compared with other organic compounds that have either:

- two amine functional groups on the same molecule (these compounds are called diamines)

or

- two carboxylic acid functional groups on the same molecule (these compounds are called dicarboxylic acids).

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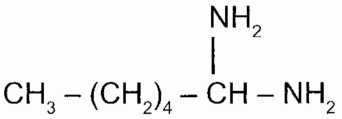
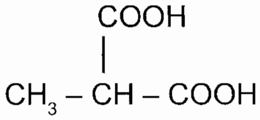
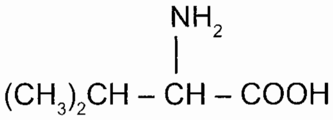
Amino acids have significantly higher melting points than diamines and dicarboxylic acids of similar mass and structure. This is illustrated in the table below.

Compound type	**Example**	**Molar mass g mol^{-1}**	**Melting point °C**
diamine	 $CH_3-(CH_2)_4-\overset{\overset{NH_2}{\vert}}{CH}-NH_2$ hexane-1,1-diamine	116.2	39
dicarboxylic acid	 $CH_3-\overset{\overset{COOH}{\vert}}{CH}-COOH$ methylpropanedioic acid	118.09	184
amino acid	 $(CH_3)_2CH-\overset{\overset{NH_2}{\vert}}{CH}-COOH$ 2-amino-3-methylbutanoic acid (valine)	117.15	298

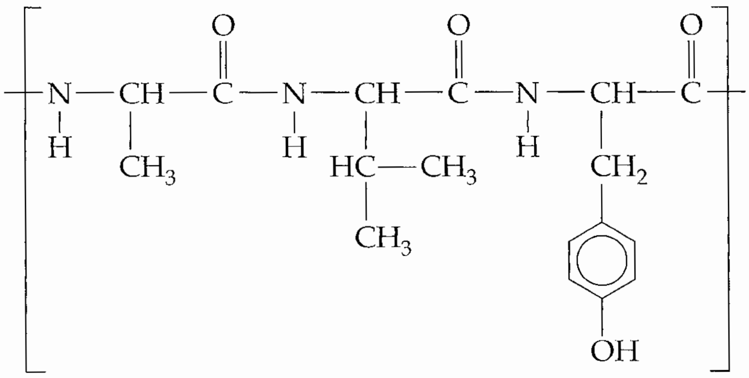
(c) Explain why amino acids form crystalline solids and have significantly higher melting points than other organic molecules of similar mass and structure. Refer to the information provided in the table above and include a labelled diagram using the amino acid valine to illustrate your answer. [5]

12. **[3 marks]** *4.8 (2016 SP:28b)*

Acetylsalicylic acid is a weak acid, and only partly ionises in water. It is poorly soluble in water, and far less soluble than a related compound, acetic acid (CH_3COOH). Explain why the water solubility of molecular acetylsalicylic acid is less than that of CH_3COOH.

13. [6 marks] *(2016 SP:31)*

Examine the structure below that represents a segment of the primary structure of insulin to answer the questions that follow.



(a) Circle **all** the peptide linkages (functional groups that link the monomers) represented in the above structure. *4.15* [1]

(b) Draw the molecular structures of the **three** α-amino acids that form this segment of insulin. *4.16* [3]

(c) The active form of insulin is made up of two polypeptide chains that contain five alpha helices. State the type of interactions that stabilises these secondary structures and the functional groups involved. *4.19* [2]

Type of interaction	**Functional groups**

14. **[6 marks]** *(2016 SP:33)*

Consider the following reactions and complete the tables that follow.

(a) An excess of butan-2-ol is oxidised by acidified $Na_2Cr_2O_7$ solution. *4.6* [3]

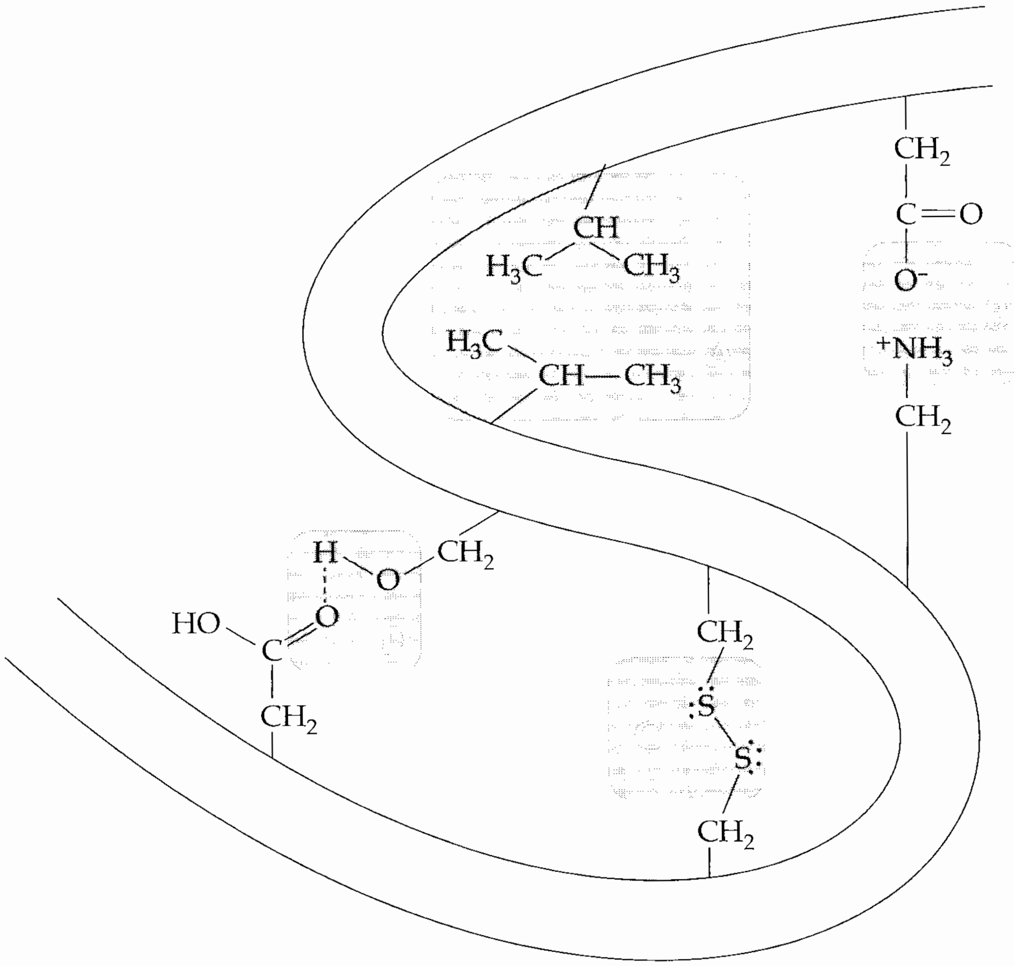
Observations	
Structural formula of organic product **(show all atoms)**	
Name of organic product	

(b) Butanoic acid reacts with methanol in the presence of concentrated H_2SO_4. *4.7* [3]

Observations	
Structural formula of organic product **(show all atoms)**	
Name of organic product	

15. **[5 marks]** *4.19 (2016 SP:36)*

The diagram below represents a segment of protein, showing the types of interactions that can occur between amino acid side chains to form the tertiary structure.



(a) Identify these types of interactions, labelled **A, B, C and D**, by completing the table below. [4]

Label	**Type of interaction**
A	
B	
C	
D	

(b) State what is meant by the 'tertiary structure' of a protein. [1]

16. **[9 marks]** *4.7 (2016:27)*

Write observations for the changes occurring when the substances below are mixed. In your answers include the appearance of the reactants and any product(s) that form.

(a) (i) methanol, pentanoic acid and sulfuric acid [2]

(ii) powdered magnesium carbonate and excess methanoic acid solution [2]

(iii) acidified potassium permanganate solution and excess propan-2-ol [2]

(b) Name the organic product and write the equation for the reaction when pentanal is added to a solution containing acidified sodium dichromate. [3]

Organic product: ____________________

17. [9 marks] *4.11 (2016:29)*

Addition and condensation polymers are used in industry to produce a vast range of plastics.

Select **one** addition polymer you have studied and use it to complete parts (a) to (c).

(a) Draw and name the structure of the monomer used to produce this polymer. [2]

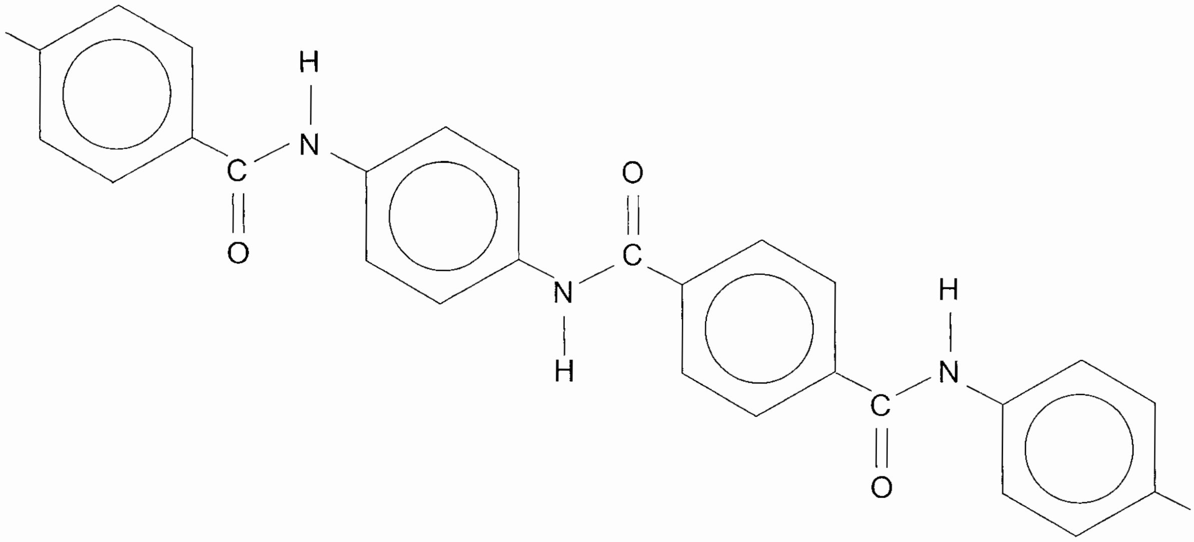
Name: ____________________

(b) Draw and name the polymer, including at least **three** repeating units. [2]

Name: ____________________

(c) State **one** use for this polymer, making reference to its relevant property/ies. [2]

Kevlar is a condensation polymer utilised for its high strength. A section of the Kevlar polymer is drawn below.



(d) Draw the **two** monomers from which Kevlar is derived. [2]

Kevlar's high strength can be attributed in part to the hydrogen bonding that occurs between neighbouring chains. This is similar to a secondary structure of proteins.

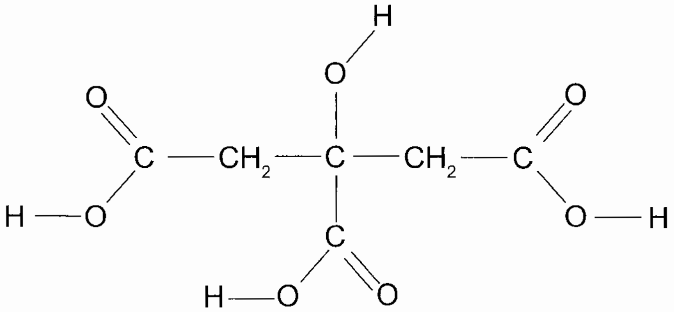
(e) To what secondary structure of proteins does this refer? [1]

18. **[5 marks]** *4.3 (2016:33)*

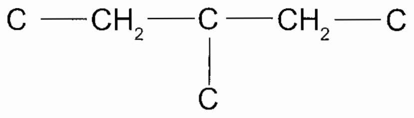
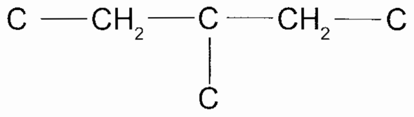
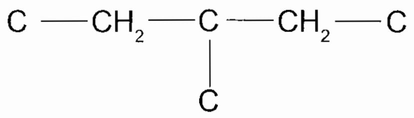
Citric acid, $C_6H_8O_7(aq)$, is a triprotic acid which reacts readily with solid sodium hydroxide, $NaOH(s)$.

(a) Write a balanced chemical equation for this reaction, showing all state symbols. [2]

The structure of $C_6H_8O_7$ is shown below.



(b) In the spaces below, complete the structures, showing **each** successive ionisation of the acidic hydrogen atoms. [3]

H^+ removed	**Structure**
First	 $C-CH_2-\underset{\overset{|}{C}}{C}-CH_2-C$
Second	 $C-CH_2-\underset{\overset{|}{C}}{C}-CH_2-C$
Third	 $C-CH_2-\underset{\overset{|}{C}}{C}-CH_2-C$

19. **[9 marks]** *4.8 (2016:35)*

For each of the three organic compounds identified in the table below:

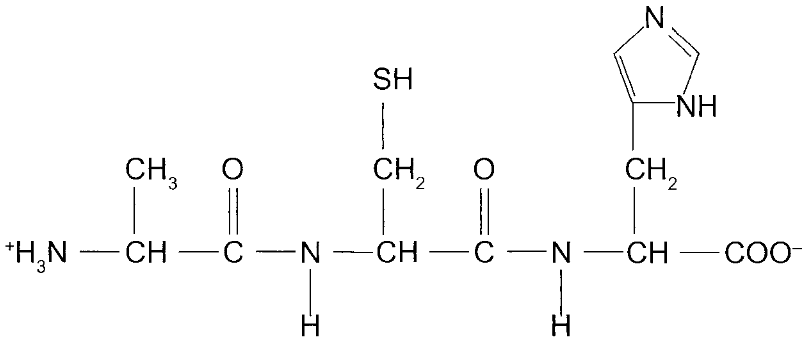
- use a structural formula to show the arrangement of **all** the atoms and **all** the bonds
- state **all** the intermolecular forces that exist between its molecules.

Organic compound	Full structural formula	All intermolecular forces
hexan-3-one		
1,1-difluoroethane		
butanamide		

20. **[11 marks]** *4.18 (2016:36)*

Condensation reactions will take place between different α-amino acids and results in them being joined by peptide bonds. Structures produced by two α-amino acids are called dipeptides, while those produced by three are called tripeptides.

(a) Below is the structure of a particular tripeptide.



(i) Circle the peptide bonds on the structure. [2]

(ii) Name the **three** α-amino acids that reacted to form this tripeptide. [3]

One: ______________________________

Two: ______________________________

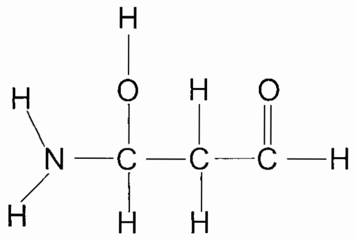
Three: ______________________________

(b) Using the symbols (abbreviations) for these three α-amino acids, give **one** other polypeptide that can be formed from them. [1]

____

Alanine is one of the simplest examples of the twenty α-amino acids found in the human body. The structure below is an isomer of alanine.

(c) Circle and name each of the **three** functional groups on the isomer of alanine drawn below. [3]



(d) Draw a different isomer of alanine, showing clearly **all** atoms and **all** bonds. [2]

Isomer of alanine structure

21. **[5 marks]** *4.8 (2016:37)*

Pentane, pentanal and pentanoic acid all contain the same number of carbon atoms but display different physical properties. Their boiling points are given in the table below.

Organic compound	Boiling point (°C)
pentane	36.1
pentanal	102
pentanoic acid	186

Account for the difference in boiling points of the three compounds.

22. **[9 marks]** *4.8 (2017:32)*

Ethanol and methanol are completely miscible (soluble) in water.

(a) By referring to any intermolecular forces present, describe the dissolving process as ethanol is added to water. [3]

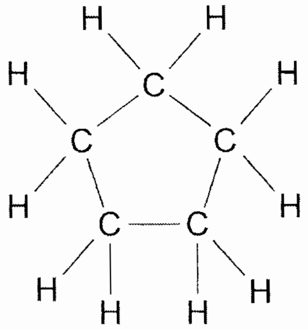
(b) Explain what happens to the solubility of alcohols in water as the hydrocarbon chain length increases. [3]

(c) For each of the following substances, list all force/s of attraction formed between the solute and solvent when each substance dissolves in water. [3]

Substance	**Force/s of attraction with water**
Propanal	
Methanoic acid	
Sodium chloride	

23. **[5 marks]** *4.5 (2017:35)*

There are a number of different isomers with the molecular formula of C_5H_{10}. These include chain isomers and cyclic isomers such as cyclopentane, which is shown here.



(a) Draw one chain isomer for C_5H_{10} that satisfies each of the following types. For each isomer, show all atoms and all bonds. [2]

Type	Diagram
trans isomer	
cis isomer	

Chemical tests (adding reagent/s) can be used to distinguish between chain and cyclic isomers in this question.

(b) In the table below suggest a distinguishing test by stating the reagent/s used and the observations expected for any reaction with each isomer. [3]

Reagent/s		
	Cis/trans chain isomer	**Cyclic isomer**
Observations		

Synthesis

1. **[13 marks]** *(2010:38)*

Sodium carbonate is produced by the five-step Solvay process.

Step 1
Brine (sodium chloride solution) is purified by the addition of sodium carbonate to precipitate calcium ion impurities and of sodium hydroxide to precipitate magnesium ion impurities.

Step 2
Limestone is heated in a kiln at between 950°C and 1100°C to decompose it to calcium oxide and carbon dioxide. This is shown below.

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

The calcium oxide is removed for use in Step 5.

Step 3
Ammonia gas is dissolved in the purified brine in a reaction tower. The resulting solution is passed to a second tower, where carbon dioxide is added to the solution. The reaction is shown below.

$$NaC\ell(aq) + NH_3(g) + H_2O(\ell) + CO_2(g) \rightarrow NH_4C\ell\ (aq) + NaHCO_3(s)$$

The reaction is performed at 0°C to precipitate the sodium hydrogencarbonate. The mixture is filtered, the sodium hydrogencarbonate washed and dried, and the ammonium chloride sent to the ammonia recovery plant.

Step 4
The sodium hydrogencarbonate is heated to approximately 300°C to decompose it to sodium carbonate. The reaction is shown below.

$$2\ NaHCO_3(s) + \text{heat} \rightarrow Na_2CO_3(s) + CO_2(g) + H_2O(g)$$

The carbon dioxide is recovered for use in Step 3.

Step 5
Calcium oxide produced in Step 2 is added to water.

$$CaO(s) + H_2O(\ell) \rightarrow Ca(OH)_2(aq)$$

The calcium hydroxide solution produced in this step is mixed with the ammonium chloride solution produced in Step 3, and the resulting solution is warmed to recover ammonia.

$$2\ NH_4C\ell\ (aq) + Ca(OH)_2(aq) \rightarrow CaC\ell_2(aq) + 2\ NH_3(g) + 2\ H_2O(\ell)$$

(a) (i) Write the equation for the precipitation of the calcium ions in Step 1. Show only those species participating in the reaction. [1]

CONTINUED NEXT PAGE

(ii) Write the equation for the precipitation of the magnesium ions in Step 1. Show only those species participating in the reaction. [1]

The reactions for Steps 2, 3 and 4 of the process are shown below.

Step 2 $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

Step 3 $NaC\ell(aq) + NH_3(g) + H_2O(\ell) + CO_2(g) \rightarrow NH_4C\ell(aq) + NaHCO_3(s)$

Step 4 $2\ NaHCO_3(s) + \text{heat} \rightarrow Na_2CO_3(s) + CO_2(g) + H_2O(g)$

(b) (i) How many moles of calcium carbonate are consumed to produce one mole of sodium carbonate? [1]

(ii) If a company plans to produce 1.00×10^4 tonnes of sodium carbonate each week, what mass of calcium carbonate will be needed if the overall process is 85.0% efficient?
Note: 1 tonne = 1×10^6 g [6]

The reactions for Step 5 are reproduced below.

Step 5 $CaO(s) + H_2O(\ell) \rightarrow Ca(OH)_2(aq)$

$2\ NH_4C\ell(aq) + Ca(OH)_2(aq) \rightarrow CaC\ell_2(aq) + 2\ NH_3(g) + 2\ H_2O(\ell)$

(c) What volume of ammonia gas at 40.0°C and 1.00 atm (101 kPa) pressure can be recovered if 8.50×10^3 tonnes of calcium oxide is obtained from Step 2? [4]

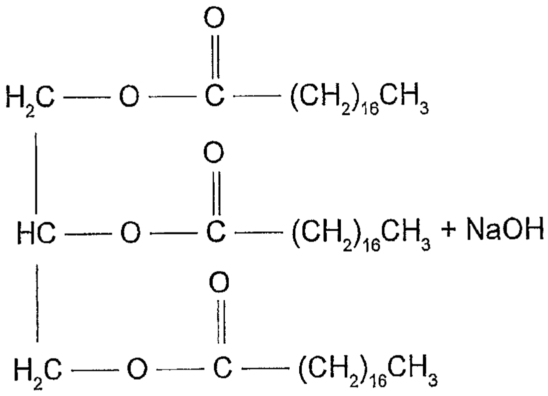
2. **[6 marks]** *(2013:36)*

Draw the structure in the box provided and name the organic product(s) for each of the following reactions. Include **all** H atoms in your structures.

(a) $CH_3CH_2CHCHCH_3 + Br_2$ *4.3* [2]

Name: ……………………………………

(b) Triglyceride of stearic acid esters heated with sodium hydroxide *5.7* [4]



Name: ……………………………………

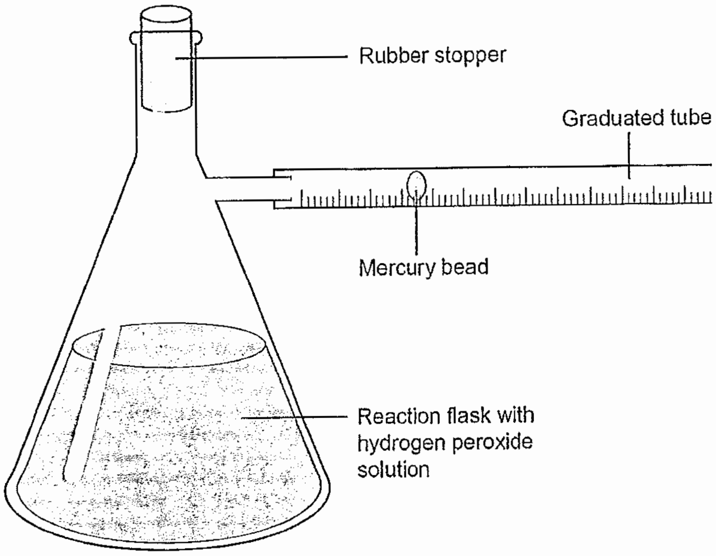
Name: ……………………………………

3. **[8 marks]** *(2013:37)*

Hydrogen peroxide can be decomposed, as shown in the equation below, by a range of catalysts, including enzymes.

$$2\,H_2O_2(aq) \rightarrow 2\,H_2O(\ell) + O_2(g)$$

A researcher set out to determine the effect of enzymes from different foods on the rate of decomposition of hydrogen peroxide. She added equal masses of liver, potato, capsicum and celery (each of which has an enzyme that decomposes hydrogen peroxide) to separate solutions of hydrogen peroxide. She then monitored the decomposition of hydrogen peroxide using the experimental apparatus shown in the diagram below. As the hydrogen peroxide decomposed the bead of mercury moved along the graduated tube, which was open to the atmosphere.



(a) What was being measured by the movement of the mercury bead? [1]

____

(b) What other quantity needed to be measured to determine the rate of decomposition? [1]

____

(c) List **three** variables that needed to be controlled in this experiment. [3]

	Variable
One	
Two	
Three	

(d) In this experiment, the rate of reaction was measured by the rate of formation of oxygen. What other parameter in the system changes as the reaction proceeded? [1]

____

(e) State the role of a catalyst in a chemical reaction and explain how its effect is achieved. [2]

____

____

____

____

____

____

____

4. **[9 marks]** *1.8 (2014:30)*

Hydrogen can be made by reacting methane (natural gas) with water (steam). The reaction can form the chemical equilibrium represented below.

$$CH_4(g) + H_2O(g) \rightleftharpoons 3\,H_2(g) + CO(g) \qquad \Delta H = +206 \text{ kJ mol}^{-1}$$

State the conditions of temperature and pressure that would optimise the yield of hydrogen at a reasonable rate of reaction. Using collision theory and principles of chemical equilibrium, explain your choice of conditions.

	Optimum conditions	**Explanation**
Temperature	(circle one only) high moderate low [1]	[3]
Pressure	(circle one only) high moderate low [1]	[4]

5. **[9 marks]** *5.8 (2015:33)*

Soaps and detergents are organic chemicals used to clean greasy material from surfaces.

(a) Draw the general structure of a typical detergent formula unit. [2]

(b) Explain why detergents are soluble in both water and grease. [6]

CONTINUED NEXT PAGE

(c) State why detergents are more effective in hard water than soaps. [1]

6. **[9 marks]** *5.10 (2016 SP:35)*

Complete the table below, which relates to the properties and uses of plastics.

Select from the list below to complete the 'Property' column of the table. A property may only be used **once**. State a different use for each polymer.

- hydrophobic
- high tensile strength
- biodegradable
- rigid
- chemically inert
- heat resistant

Plastic	**Type of polymer (addition or condensation)**	**Property**	**Use related to property**
High density polyethene (HDPE)			
Polytetrafluoroethene (Teflon)			
Polyethylene terephthalate (PET)			

7. **[6 marks]** *5.6, 5.5 (2016 SP:37)*

Ethanol may be produced by fermentation or the hydration of ethene. Conditions are indicated in the table below.

	Temperature (°C)	**Pressure (kPa)**	**Raw material**
fermentation	60	101.3	
hydration of ethene	300	7000	

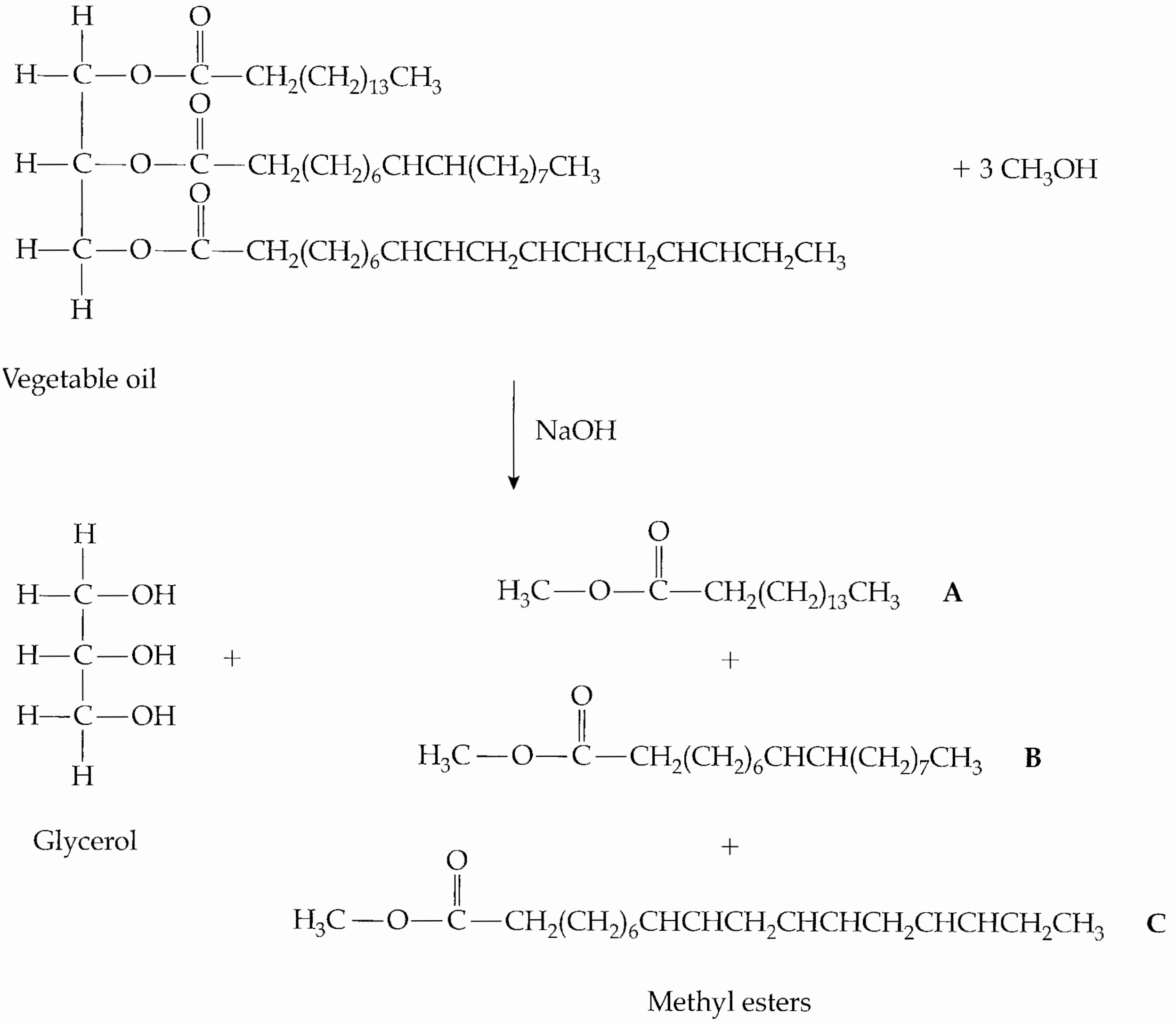
(a) Complete the table above to indicate the raw materials for each process. [2]

(b) Explain the lower temperature conditions of the fermentation process. [2]

(c) In addition to lower temperature conditions, state **two** other advantages of the fermentation process compared with the hydration of ethene. [2]

8. **[16 marks]** *5.0 (2016 SP:40)*

Biodiesel can be produced by a trans-esterification reaction between vegetable oil and an alcohol in the presence of sodium hydroxide catalyst. A typical trans-esterification reaction is shown below. The products are glycerol and three methyl esters.



$$CH_2(OCOCH_2(CH_2)_{13}CH_3)-CH(OCOCH_2(CH_2)_6CHCH(CH_2)_7CH_3)-CH_2(OCOCH_2(CH_2)_6CHCHCH_2CHCHCH_2CHCHCH_2CH_3) + 3\ CH_3OH \xrightarrow{NaOH}$$

$$HOCH_2-CH(OH)-CH_2OH + H_3C-O-CO-CH_2(CH_2)_{13}CH_3 + H_3C-O-CO-CH_2(CH_2)_6CHCH(CH_2)_7CH_3 + H_3C-O-CO-CH_2(CH_2)_6CHCHCH_2CHCHCH_2CHCHCH_2CH_3$$

(a) Name another catalyst that can be used in the production of biodiesel. [1]

(b) The vegetable oil in the reaction has a molar mass of 855.334 g mol^{-1}. If 1.50 tonnes of vegetable oil is reacted, what mass of methanol will be required to react with this amount of oil?
(1 tonne = 1 × 10^6 g) [3]

(c) Three different methyl esters, denoted by **A**, **B** and **C**, are produced from this reaction. What is the mass of Ester **A** produced in this process if the reaction is 78% efficient in production of this ester? Express your final answer to the appropriate number of significant figures. [5]

(d) The glycerol produced can be used as anti-freeze due to its high water solubility. Explain, with the aid of a diagram, why glycerol is soluble in water [5]

(e) To prevent different products forming in an alternative synthesis pathway, the quantity of sodium hydroxide present in the reaction must be kept low, compared with the vegetable oil. If the mole ratio of NaOH to vegetable oil approaches the ratio 3:1, the alternative pathway becomes significant.

(i) What type of organic product forms in this alternative pathway? [1]

(ii) Draw the structure for **one** organic product that forms in the alternative synthesis pathway from this vegetable oil. [1]

9. **[6 marks]** *5.4 (2016:28)*

While petroleum diesel and biodiesel are produced differently, they have similar structures to each other.

(a) The condensed structure of a petroleum diesel is given here.

$$CH_3-CH_2-(CH_2)_{12}-CH_2-CH_3$$

Draw the condensed structure of a biodiesel containing the same number of carbon atoms in the chain. [3]

(b) Biodiesel can be synthesised using a base-catalysed method or a lipase-catalysed method. Outline briefly an argument to justify the use of a lipase-catalysed method rather than a base-catalysed method to produce biodiesel. [3]

10. **[5 marks]** *5.6 (2016:31)*

The process of chemical synthesis may involve a sequence of reactions.

(a) Use equations to show how ethyl ethanoate can be produced from ethene through the successive processes of hydration and esterification. [4]

(b) Write the overall equation for the process of synthesising ethyl ethanoate from ethene. [1]

11. **[10 marks]** *5.2 (2017:29)*

In a beaker 12.00 mL of 0.0334 mol L^{-1} sulfuric acid solution, $H_2SO_4(aq)$, is added to 32.50 mL of 0.0288 mol L^{-1} potassium hydroxide solution, $KOH(aq)$.

(a) Identify the limiting reagent in this reaction. Show all workings. [5]

(b) Calculate the final concentration of the excess reagent. Show all workings. [3]

(c) Calculate the pH of the final solution. Show all workings. [2]

12. [8 marks] *5.4 (2017:30)*

Carbonyl chloride, $COC\ell_2$, is a colourless, poisonous gas that is used in the production of insecticides and a variety of plastics. It is produced through the exothermic reaction between carbon monoxide and chlorine gases. Carbonyl chloride is a liquid below 8 °C at 100.0 kPa.

The following equation is used to represent the reaction.

$$CO(g) + C\ell_2(g) \rightleftarrows COC\ell_2(g) \qquad \Delta H < 0$$

(a) For this industrial process state the conditions that would optimise the: [2]

- rate of reaction____

- yield____

(b) State one compromise in conditions that might be required to produce carbonyl chloride $COC\ell_2$, in an industrial process. Explain the effect of this condition and justify why this compromise is required. [6]

13. **[19 marks]** *5.2 (2017:36)*

Australia is a significant producer of antimony. Antimony, Sb, and its compounds have a wide range of uses. The metal is used to form alloys with other metals, such as lead, to increase their hardness, while compounds of antimony can be used in the manufacture of many substances such as plastics, pigments and match heads.

High-grade antimony ores are converted to the metal through the use of a blast furnace.

- Antimony sulfide ore is first heated to convert it to an oxide.
- Antimony oxide is then heated with carbon to convert it to a metal.

The following equations represent these two reactions.

Reaction one: $2\,Sb_2S_3(s) + 9\,O_2(g) \rightleftarrows 2\,Sb_2O_3(s) + 6\,SO_2(g)$

Reaction two: $2\,Sb_2O_3(s) + 3\,C(s) \rightleftarrows 4\,Sb(s) + 3\,CO_2(g)$

(a) What mass of ore would be required to produce 6.00 tonnes of antimony, assuming the ore contains 25.6% by mass of antimony(III) sulfide and the reactions go to completion? [6]

(b) Calculate the maximum volume of sulfur dioxide that could be produced in Reaction one at 525.0 °C and 105 kPa. Give the answer to the correct number of significant figures. [4]

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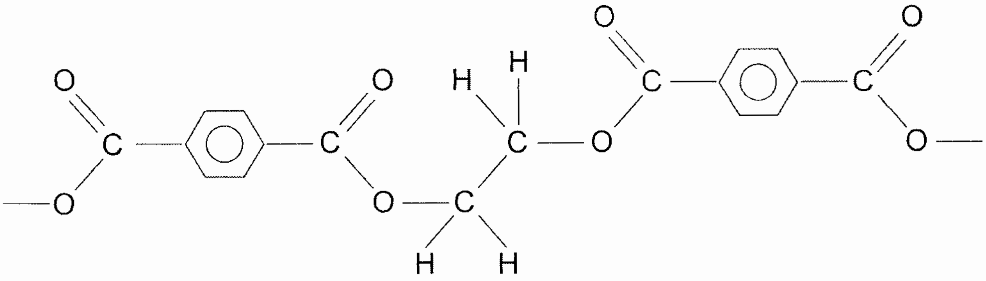
Pure antimony(III) oxide is used as a catalyst in the production of polyethylene terephthalate (PET).



A section of a PET polymer

(c) Draw the monomers required to produce this polymer. [4]

(d) State one common use for PET and state two properties that enable it to be used for this purpose. [3]

Use:

Properties

One:

Two:

PET is produced through condensation polymerisation; another type of polymer is produced through addition polymerisation. Each of these types of polymerisation uses different types of monomers.

(e) Distinguish between the types of monomers used for each type of polymerisation. [2]

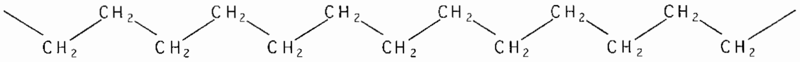
14. **[25 marks]** *5.8 (2017:39)*

A cosmetic company advertises a range of 'inspiring quality organic, natural and essential personal care ingredients' in its skin care, hair care, aromatherapy and soap products. It claims that the soaps it sells are made from different ingredients boasting 'an array of perfumes and cosmetic benefits'.

Soaps are a class of substances used to clean grease, dirt or oils from a surface such as skin. They do this because they are capable of dissolving in both aqueous and oily systems at the same time.

(a) (i) On the diagram below:

- complete the structure of a soap
- identify and label the key structural features of soap
- draw two molecules of water showing how they are orientated about soap. [5]



The process of dissolving is a consequence of attractive forces between solvent and solute. The different parts of soap are capable of producing different types of attractive forces.

(ii) Name and explain the origin of the predominant attractive force exhibited between the composite particles of soap and water. [3]

(iii) Name and explain the origin of the predominant attractive force exhibited between the composite particles of soap and oil. [3]

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(b) Explain why soaps do not function very effectively in hard water. [2]

Fats and oils are essentially esters of fatty acids. These esters are called 'triglycerides' and are derived from glycerol and three fatty acids.

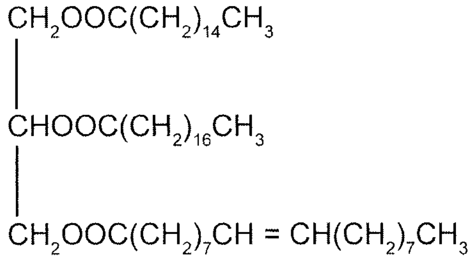
(c) (i) Name the functional group in glycerol. [1]

(ii) State the two distinctive parts of a fatty acid used to make soap. [2]

One:

Two:

Below is a typical animal fat (triglyceride).



$$\begin{array}{l} CH_2OOC(CH_2)_{14}CH_3 \\ | \\ CHOOC(CH_2)_{16}CH_3 \\ | \\ CH_2OOC(CH_2)_7CH = CH(CH_2)_7CH_3 \end{array}$$

To produce soap, the above fat can be hydrolysed with concentrated sodium hydroxide solution.

(d) Draw structural formulae of the four products from this saponification process. Names are not required. [4]

(e) Why are soap solutions basic? [2]

Under Australian law, any company wishing to make soap commercially using a saponification process must register with the National Industrial Chemicals Notification and Assessment Scheme (NICNAS) administered by the Department of Health.

(f) State one health risk caused by chemicals used in the saponification process that would require careful monitoring by NICNAS. [1]

The following table claims to list soaps in increasing order of cleaning effectiveness.

Soaps and their chemical structure

Common name	**Chemical structure**
Sodium caprylate	$CH_3(CH_2)_6COONa$
Sodium caprate	$CH_3(CH_2)_8COONa$
Sodium laurate	$CH_3(CH_2)_{10}COONa$
Sodium myristate	$CH_3(CH_2)_{12}COONa$
Sodium palmitate	$CH_3(CH_2)_{14}COONa$
Sodium stearate	$CH_3(CH_2)_{16}COONa$
Sodium arachidate	$CH_3(CH_2)_{18}COONa$
Sodium behenate	$CH_3(CH_2)_{20}COONa$
Sodium lignocerate	$CH_3(CH_2)_{22}COONa$
Sodium cerotic	$CH_3(CH_2)_{24}COONa$

least effective

↓

most effective

(g) Use the information in the table to write an hypothesis that could be used to investigate cleaning effectiveness. [2]

15. **[15 marks]** *4.17 (2017:40)*

The properties of human hair can be attributed to it being composed almost entirely of the strong fibrous protein, keratin.

Structure of keratin:
- Keratin is a polypeptide and consists of a repeating pattern of amino acids.
- Common amino acids in keratin, in order from most to least abundant, are: cysteine (17.5%), serine, glutamic acid, threonine, glycine, leucine, valine, arginine, aspartic acid and alanine (4.8%).

(a) Draw a section of the polypeptide that is composed of the three most abundant amino acids found in keratin. [4]

(b) With reference to the structure drawn in part (a), state three types of attractive forces/ bonding other than dispersion forces, that can occur between neighbouring keratin polypeptide chains. [3]

One:

Two:

Three:

(c) Describe the α-helix structure of keratin. [2]

One of the physical properties of hair is its capacity to absorb water, increasing a strand's diameter by roughly 20%.

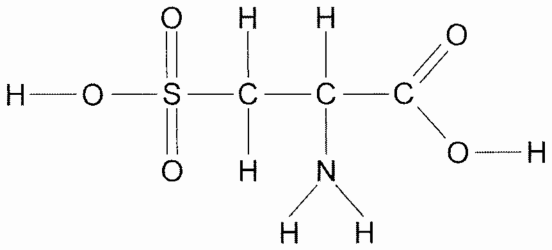
(d) State why hair can absorb water. [1]

Keratin is often chemically analysed for cysteine, due to its effect on the strength of hair. One method of determining the proportion of cysteine is titration with bromide in an acidic solution. Under these conditions, the cysteine is oxidised to cystine and then to cysteic acid.

Two cysteine molecules joined together by a disulfide bond is called cystine.

(e) Draw the structure of cystine. [2]

(f) On the structural formula of cysteic acid drawn below, circle and label any functional groups as acidic or basic. [3]



Chapter

12

Science Enquiry Skills

1. **[8 marks]** *2.10 (2009:06)*

A student titrated an approximate 0.1 mol L^{-1} solution of hydrochloric acid against a standard solution of 0.200 mol L^{-1} sodium carbonate in order to determine the exact concentration of the acid.

The reaction occurring in the titration is shown below:

$$Na_2CO_3(aq) + 2\,HC\ell(aq) \rightarrow 2\,NaC\ell(aq) + CO_2(g) + H_2O(\ell)$$

The student rinsed a 50 mL burette with distilled water and filled it with hydrochloric acid. He also rinsed a conical flask with distilled water and pipetted 25.0 mL of the sodium carbonate solution into the conical flask. A few drops of phenolphthalein (end point pH 9) were then added to the conical flask. He added the hydrochloric acid from the burette into the conical flask until there was a permanent colour change.

The student made two mistakes in his method. Complete the table below by stating

- each mistake
- the effect the mistake had on the volume of $HC\ell$ solution delivered from the burette
- why the volume of $HC\ell$ solution was affected in the way stated
- the correct technique

	Mistake 1	**Mistake 2**
Description of mistake		
Effect on volume of $HC\ell$		
Reason $HC\ell$ volume is affected as stated above		
Correct technique		

2. **[22 marks]** *(2016 SP:38)*

A student set out to compare the effectiveness of a given quantity of two antacid preparations, one containing $Mg(OH)_2$ and the other $A\ell(OH)_3$, purchased from his local pharmacy.

He titrated each preparation against a hydrochloric acid solution to determine how much acid each could neutralise and to determine the concentration of active ingredient in each preparation. He first standardised the hydrochloric acid solution available in the laboratory against a primary standard, and chose anhydrous sodium carbonate as the primary standard.

(a) Give **two** reasons why anhydrous sodium carbonate is an appropriate standard. *2.10* [2]

The student prepared 1.00 L of a 0.0248 mol L^{-1} Na_2CO_3 solution. He titrated three 25.0 mL aliquots of this solution against the $HC\ell$ and found an average titre of 24.35 mL.

(b) Calculate the concentration of the standardised $HC\ell$ solution. *2.11* [4]

(c) Below is a list of common errors that can occur in titrations. From this list select **one** source of random error and **one** source of systematic error and explain your choice in the tables below. *6.4* [4]

- reading of burette
- bubbles in the pipette
- not drying Na_2CO_3 in an oven prior to its use as a primary standard
- rinsing all glassware with distilled water
- incorrect indicator
- perception of colour change at the end point

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Random error	Why error is classified as random

Systematic error	Why error is classified as systematic

The antacid suspensions were thoroughly shaken and 20.0 mL of each transferred to separate 250.0 mL volumetric flasks. Both were made up to the mark with distilled water and shaken vigorously. 10.0 mL aliquots of the diluted suspensions were transferred to conical flasks for titration and an appropriate indicator added.

The titre values obtained for the $A\ell(OH)_3$ suspension are shown in the table below:

Titre volume $HC\ell$ (mL) Trials				**Average titre volume (mL)**
1	**2**	**3**	**4**	
22.62	21.98	21.94	21.90	21.94

(d) Account for the need for four trials in the titration. [1]

(e) (i) Calculate the concentration, in moles per litre (mol L^{-1}), of $A\ell(OH)_3$, in the original $A\ell(OH)_3$ suspension. [5]

(ii) From his titration of the $Mg(OH)_2$ diluted suspension, the student found the mass of $Mg(OH)_2$ in the 250 mL **diluted** suspension to be 1.13 g. Determine the concentration of $Mg(OH)_2$ in the original **undiluted** suspension and express your answer in moles per litre (mol L^{-1}). [2]

(f) Which of the preparations would be more effective (neutralise more $HC\ell$) for a given volume? Show your workings. [4]

Chapter 13

Volumetric Analysis

1. **[11 marks]** *(2013:39)*

Most food labels list the amount of protein in the food. Most of the nitrogen present in food is contained in the protein, so the quantity of protein in a food is determined from its nitrogen content. The standard approach to determining the amount of nitrogen in a sample is the Kjeldahl method, which consists of three steps:

1. A sample of food is heated in boiling sulfuric acid, which leads to ammonium sulfate among other products:

   Food sample + $H_2SO_4(aq) \rightarrow (NH_4)_2SO_4(aq) + CO_2(g) + SO_2(g) + H_2O(g)$

   The ammonium ions contain the nitrogen that was initially present in the sample.

2. The ammonium ions are then converted into ammonia gas by adding sodium hydroxide to the solution of ammonium sulfate:

   $(NH_4)_2SO_4(aq) + 2\ NaOH(aq) \rightarrow Na_2SO_4(aq) + 2\ H_2O(\ell) + 2\ NH_3(g)$

3. The ammonia gas goes inside a condenser and ends up in a flask that contains a solution of boric acid. The ammonia is neutralised by the boric acid, as follows:

   $B(OH)_3(aq) + H_2O(\ell) + NH_3(g) \rightarrow NH_4^+(aq) + B(OH)_4^-(aq)$

   When all the ammonia has reacted with the boric acid, the quantity of borate ions ($B(OH)_4^-$) is determined by titration with a strong acid such as hydrochloric acid.

   $B(OH)_4^-(aq) + H^+(aq) \rightarrow B(OH)_3(aq) + H_2O(\ell)$

The protein content of the food is then calculated by multiplying the amount of nitrogen by a conversion factor appropriate to the food class being analysed. The conversion factor for milk and milk products is 6.38: that is, the mass of nitrogen is multiplied by a factor of 6.38 to get the mass of protein.

An analytical chemist treated a 5.235 g sample of a powdered milk product as described above to determine its protein content. The borate solution from Step 3 was titrated with a standard 0.752 mol L^{-1} hydrochloric acid solution and the volume of acid used in the titration was 25.78 mL.

(a) Calculate the number of moles of ammonium ions formed from the treatment of the milk powder sample (Step 1). [4]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

(b) What was the mass of nitrogen in the sample? Express your answer to **three** significant figures. [3]

(c) Calculate the mass of protein in the powdered milk product. [1]

(d) Food labels usually give the protein content as the mass in a typical serving size. If the typical serving size for this product was 25 g, what mass of protein would be consumed in a single serving? [2]

(e) Suggest what the chemist might do to increase the reliability of the value of the protein content he found for the milk product. [1]

2. **[9 marks]** *(2014:37)*

Aqua regia is a mixture of concentrated hydrochloric acid and nitric acid that is able to dissolve gold. One of its uses is in the analysis of gold content in gold ore.

As part of quality control processes, a chemist in a gold analysis laboratory analysed aqua regia to ensure the required 3:1 mole ratio of hydrochloric acid to nitric acid. The chemist found that 20.0 mL of aqua regia needed 28.6 mL of 8.00 mol L^{-1} sodium hydroxide for complete neutralisation. The reaction for the neutralisation reaction between the sodium hydroxide and acid is represented by the equation below:

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(\ell).$$

(a) Calculate the moles of hydrogen ions present in the 20.0 mL sample of aqua regia. [2]

[illegible]

= [illegible]

$n(H^+)$ = [illegible]

The chemist analysed the chloride content of the aqua regia by adding excess silver nitrate solution to a separate 20.0 mL sample of aqua regia. This resulted in the precipitation of 24.6 g of solid.

(b) Write the balanced ionic equation for precipitation of silver chloride from aqua regia. [1]

Ag^+ [illegible]

(c) Calculate the moles of hydrochloric acid in the 20.0 mL of aqua regia. [3]

n(A[illegible]) = [illegible] / 143.35

= 0.176 mol

n([illegible]) = n([illegible]) = [illegible] mol

(d) Determine whether the aqua regia had the required ratio of hydrochloric acid to nitric acid. State clearly whether the ratio was as required and support your answer with clear workings. [3]

3. [15 marks] *2.11 (2014:40)*

Citric acid is the active ingredient in some bathroom and kitchen cleaning solutions. A student determined the content of citric acid in a cleaner by titration with sodium hydroxide solution.

The sodium hydroxide solution first needed to be standardised. To do this, the student dissolved approximately 4 g of sodium hydroxide pellets in water, to give an approximately 0.1 mol L^{-1} solution. This solution was standardised by titrating 20.00 mL of the NaOH solution with a 0.105 mol L^{-1} standard hydrochloric acid solution. The average titration volume was 17.45 mL.

(a) Explain why sodium hydroxide is not suitable as a primary standard. [2]

(b) Show that the concentration of the sodium hydroxide solution is 0.0916 mol L^{-1}. Show sufficient workings to justify your answer. [3]

The student then weighed a 10.00 mL aliquot of the cleaner and found it weighed 10.4 g. This 10.00 mL aliquot was next diluted to 100.0 mL in a volumetric flask. Against the standardised sodium hydroxide solution, 20.00 mL aliquots of the diluted cleaner were titrated. The table below shows the results of the titrations.

Titre	1	2	3	4
Final reading (mL)	25.30	23.55	22.40	22.25
Initial reading (mL)	3.50	2.70	1.50	1.30
Titre volume (mL)				

(c) Calculate the average titre volume to be used in the calculation of the citric acid content. [2]

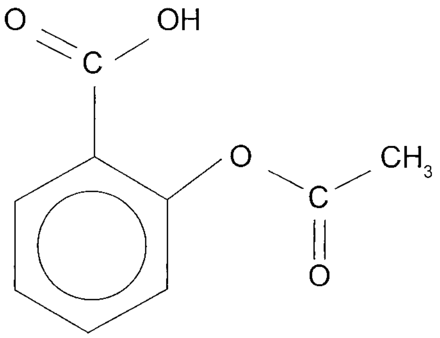
(d) Given that citric acid ($C_6H_8O_7$) is a weak triprotic acid, determine the percentage composition by mass of citric acid in the cleaner. The molar mass of citric acid is 192.124 g mol^{-1}. [6]

(e) Select a suitable indicator for this titration from the table below. Explain your choice. [2]

Indicator	**Colour change (low pH – high pH)**	**pH**
Methyl yellow	red-yellow	2.4–4.0
Litmus	red-blue	5.0–8.0
Bromothymol blue	yellow-blue	6.0–7.6
Thymol blue	yellow-blue	8.0–9.6

4. **[20 marks]** *2.11 (2015:36)*

Aspirin is one of the most popular and readily available pain-relieving drugs. The structure of aspirin is given below:



Aspirin contains two functional groups.

(a) (i) On the diagram of aspirin above, circle the **two** functional groups. Label them **A** and **B**. [2]

(ii) Name each functional group. [2]

Functional group **A**: ______________________________

Functional group **B**: ______________________________

(b) In one commercial brand of aspirin, each '300 mg tablet' is claimed to contain 100% aspirin. To determine the actual percentage by mass of aspirin in an aspirin tablet, the following procedure, involving a back titration, was used.

Step 1: Three aspirin tablets, each with a mass of 300.0 mg, were crushed and dissolved in excess sodium hydroxide solution. Exactly 100.0 mL of 0.204 mol L^{-1} solution of sodium hydroxide was used. The mixture was boiled to ensure complete reaction.

Step 2: The excess sodium hydroxide solution was titrated with hydrochloric acid as follows: 20.0 mL of the solution from step 1 was pipetted into a conical flask and 0.125 mol L^{-1} hydrochloric acid was placed in the burette. The indicator, phenolphthalein, was used and an average titre of 17.89 mL of hydrochloric acid was required to reach the end-point.

Notes:

- Assume that any other chemicals present in an aspirin tablet are inert and will not react with either NaOH(*aq*) or HCℓ(*aq*).
- Phenolphthalein is colourless at a pH less than 8.3 and pink at a pH greater than 10.0.

(i) This is a titration between a strong acid and strong base. Strong acid–strong base titrations typically result in an equivalence point with a pH close to 7. Phenolphthalein was chosen as the indicator for this titration. Considering all of the species present in the solution at the equivalence point, explain why phenolphthalein is a suitable indicator to show the end-point. Support your answer with a suitable equation. [3]

(ii) Calculate how many moles of hydroxide ions reacted with the aspirin. [5]

(iii) Each aspirin molecule requires two hydroxide ions for complete reaction. Calculate the percentage by mass of aspirin in one aspirin tablet. (The molar mass of aspirin is 180.154 g mol^{-1}.) [4]

CONTINUED NEXT PAGE

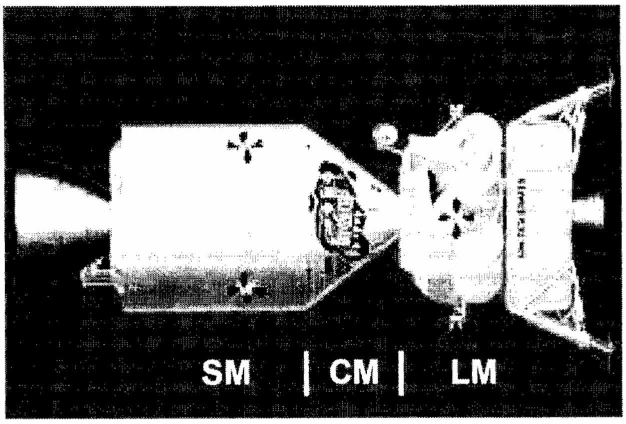
An important procedure in volumetric analysis is the washing of equipment with the appropriate solution prior to the titration in order to minimise experimental error.

(c) Before performing the experiment, the glassware was washed with the solutions given in the table. Complete the table below by stating the effect of the washing. [4]

Washing procedure	**Effect on the volume of hydrochloric acid used**	**Effect on the % of aspirin calculated**
The conical flask was washed with distilled water.		
The burette was washed with distilled water.		

5. **[24 marks]** *6.3 (2017:37)*

In 1971, the seventh manned Apollo mission, Apollo 13, was launched and expected to land on the moon. Two days into the mission, one of the oxygen tanks exploded. The mission was aborted, but in order for the spacecraft to return to Earth safely, many problems needed to be solved. A number of them involved chemistry.



The spacecraft consisted of three sections:

- the Service Module (SM)
- the Command Module (CM)
- the Lunar Module (LM).

The Lunar Module was designed to hold two astronauts for the short trip between lunar orbit and moon's surface. On the trip back to Earth, the astronauts were required to spend more time than expected in the lunar module.

One of the problems encountered was how to remove the carbon dioxide breathed out by the astronauts from the atmosphere in the spacecraft. This was done by reacting it with lithium hydroxide, which was housed in canisters.

(a) Write an equation for the reaction between carbon dioxide gas and lithium hydroxide to form lithium carbonate and water. [2]

(b) A typical lithium hydroxide canister contains 750.0 g of lithium hydroxide. What mass of carbon dioxide would be required to react completely with the lithium hydroxide in each canister? [3]

CONTINUED NEXT PAGE

On returning to Earth, a partially-used canister was analysed to determine the percentage of lithium hydroxide remaining.

A 12.33 g sample of the canister contents was dissolved in distilled water and sufficient barium nitrate solution was added to precipitate the carbonate ions. The solution was filtered and transferred to a 500.00 mL volumetric flask, which was then filled to the mark. 20.00 mL aliquots of the solution were transferred to conical flasks and titrated against a standardised 0.116 mol L^{-1} solution of hydrochloric acid.

The following results were obtained from the titrations.

Volume (mL)	1	2	3	4
Final Volume	18.55	34.90	18.50	34.85
Initial Volume	1.50	18.55	2.20	18.50
Titre				

(c) Complete the results table above and calculate the percentage of lithium hydroxide remaining in the canister. [6]

(d) From the list of indicators given below, identify two that could be used in the titration between lithium hydroxide and hydrochloric acid. Explain why both indicators are appropriate choices for this titration. [4]

Indicator	**Low pH colour**	**Transition pH range**	**High pH colour**
Methyl violet	yellow	0.0–1.6	blue
Bromothymol blue	yellow	6.0–7.6	blue
Phenolphthalein	colourless	8.3–10.0	pink
Thymolphthalein	colourless	9.4–10.6	blue

Indicator one: ______

Indicator two: ______

Explanation: ______

The tank that exploded during the mission provided oxygen for the fuel cells that powered the spacecraft.

(e) List two advantages that fuel cells have over primary and secondary cells. [2]

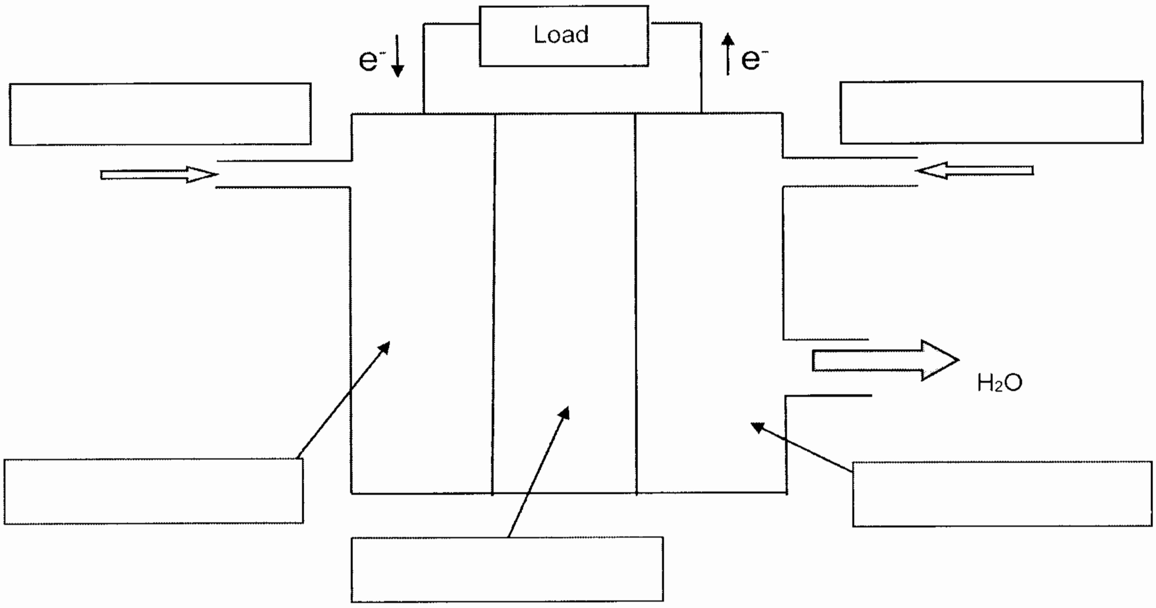
One: ____

____

Two: ____

____

(f) In the boxes provided, label the following diagram of a typical hydrogen-oxygen fuel cell. Include anode, cathode, electrolyte, hydrogen gas and oxygen gas. [3]



(g) Explain the function of the electrolyte. [2]

____

____

(h) From the table provided in the Chemistry Data booklet, calculate the EMF for the reaction between hydrogen gas and oxygen gas. [1]

____

(i) A hydrogen-oxygen fuel cell on the Apollo spacecraft generally produced an EMF of 1.21 V per cell. State one reason why the theoretical (calculated) value was not the same as the actual EMF generated by the fuel cells on the spacecraft. [1]

____

____

Chapter 14A

Calculations: Organic

1. **[11 marks]** *(2009:03)*

A polyester polymer was analysed to determine its empirical formula. Combustion of a 9.76 g sample of the polyester in excess oxygen produced 17.9 g of carbon dioxide and 4.88 g of water.

(a) Calculate the empirical formula of the polyester.

The polymer was then hydrolysed using sulfuric acid to split it into the diol and dicarboxylic acid monomers used in its preparation. The flow diagram below illustrates this.

$$\boxed{\text{polyester}} \xrightarrow{H_2SO_4} \boxed{\text{diol}} + \boxed{\text{dicarboxylic acid}}$$

2.20 g of the dicarboxylic acid monomer was isolated and dissolved in 250.0 mL of distilled water. 50.0 mL of the diacid solution required 15.3 mL of 0.487 mol L^{-1} sodium hydroxide solution for complete neutralisation.

(b) Calculate the molar mass of the dicarboxylic acid monomer.

(c) Draw a possible structure of the dicarboxylic acid that is consistent with your answer to part (b).

2. **[13 marks]** *(2010:40)*

A manufacturer of soft drink produces a diet version containing artificial sweetener. The quality assurance procedures of the soft drink manufacturer require that incoming batches of the artificial sweetener be analysed to ensure compliance with standards. A combustion analysis of a 1.021 g sample of sweetener produced 1.715 g CO_2, 0.2521 g H_2O, 0.2558 g NO_2 and 0.3568 g SO_2. The sweetener contains the elements C, H, O, N and S. Determine its empirical formula.

3. **[10 marks]** *(2011:36)*

Sevoflurane is a gaseous compound (at room temperature) used for inducing and maintaining general anaesthesia. It contains carbon, hydrogen, oxygen and fluorine.

Analysis of a 1.6328 g sample of sevoflurane yielded, on combustion, 866.0 mL of carbon dioxide at 50°C and 101.3 kPa and 0.220 g of water. The fluorine was released as hydrogen fluoride and absorbed by alkaline solution, revealing 5.71×10^{-2} mole of hydrogen fluoride. Determine the empirical formula of sevoflurane.

4. **[18 marks]** *(2012:39)*

Qualitative analysis of an organic compound showed that it contained only carbon, hydrogen and oxygen. A quantitative study of the same compound was performed, in which a 0.5096 g sample was burnt in excess oxygen to produce 0.4160 g of water and 700.7 mL of carbon dioxide, collected at 100.0°C and 102.8 kPa.

(a) Determine the empirical formula of the compound. [10]

CONTINUED NEXT PAGE

(b) A second 0.4832 g sample of the compound was heated to 261°C. The vaporised sample was found to exert a pressure of 241 kPa in a 100.0 mL container. Use this information to determine the molecular formula of the compound. [4]

(c) When the original compound was reacted with acidified ethanol it produced a fruity smelling liquid. Infer the structure of the original compound, and draw its structure in the box below. Name the original compound. [2]

Name: ______________________________

(d) Describe briefly and give observations for an additional chemical test to confirm the identity of the functional group in the original compound. [2]

5. **[7 marks]** *(2013:35)*

A white solid is analysed and found to have the empirical formula CHO and a molar mass of 116 g mol^{-1}.

(a) Determine the molecular formula of the compound. Justify your answer. *4.9* [2]

(b) Two tests were conducted on the white solid, as shown in the table below. Complete the table by drawing a possible functional group that is consistent with the finding of each of the tests. *4.3* [2]

Test	Observation	Possible functional group
Water solubility	788 g L^{-1}	
Add to bromine water	Bromine water decolourises rapidly	

CONTINUED NEXT PAGE

(c) A further 2.32 g sample of the white solid was analysed and shown to release 0.0400 mol of H^+ ions. Use this information and your answers to (a) and (b) to determine the structural formula of the white solid, and draw it in the box below. Show **all** atoms in your structure. *4.9* [3]

6. **[14 marks]** *(2014:39)*

An organic compound that contains only carbon, hydrogen, oxygen and bromine was analysed to determine its empirical formula. A combustion analysis of 1.50 g of the compound produced 1.58 g of carbon dioxide and 0.563 g water.

On treatment of 1.75 g of the compound to convert the bromine in the compound to bromide ions and further reaction with silver nitrate, 1.97 g of silver bromide was precipitated.

(a) Determine the empirical formula of the compound. [10]

(b) 1.95 g of the compound was vaporised and was found to occupy 0.387 L at 95.0 kPa and 105°C. Determine the molecular formula of the compound. [2]

(c) Further analysis of the organic compound revealed that it had a carboxylic acid functional group. Draw a possible structural formula of the organic compound. [2]

7. **[14 marks]** *4.9 (2016:38)*

A hydrolysis reaction is one that involves water being consumed as a reactant. Hydrolysis reactions can be represented by the following general equation.

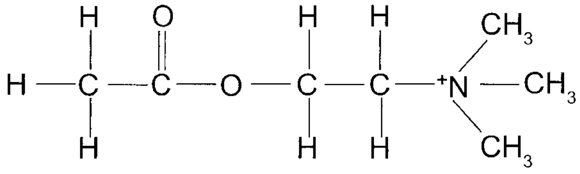
$$A-B + H_2O \rightarrow A-OH + H-B$$

Many processes within the human body involve hydrolysis reactions. These hydrolysis reactions usually require a catalyst; in living organisms that catalyst is an enzyme.

(a) What type of organic compound is an enzyme? [1]

Acetylcholinesterase is an enzyme that is used in the hydrolysis of acetylcholine, a neurotransmitter in the brain.

The structure of acetylcholine is drawn below.



(b) Two products are formed when acetylcholine undergoes hydrolysis in the presence of the enzyme acetylcholinesterase; one of these is a charged molecule called choline and the other is a carboxylic acid. Draw structures of these **two** products. [2]

A catalyst is said to be **active** if it is working to form the desired products. To ensure the acetylcholinesterase is **active** and so catalysing the hydrolysis of acetylcholine, the charged compound found in the reacting vessel is separated and analysed using a combustion reaction to determine its empirical formula.

A 4.270 g sample was combusted in the presence of pure oxygen until no solid remained.
9.020 g of carbon dioxide, 5.169 g of water and 1.886 g of nitrogen dioxide were produced.

(c) Calculate the empirical formula of the combusted sample. [9]

(d) Use your calculated empirical formula to demonstrate that the enzyme is **active**. [2]

8. **[17 marks]** *4.9 (2017:38)*

Caffeine is an organic molecule found in tea, coffee and energy drinks. It is a stimulant that also can be taken in tablet form. Pure caffeine is a white odourless powder that tastes bitter and contains carbon, hydrogen, nitrogen and oxygen.

A 2.55 g sample of caffeine was combusted to produce 4.623 g of carbon dioxide and 1.18 g of water. A second, 3.33 g sample of caffeine was treated to convert all of the nitrogen to 1.17 g of ammonia.

(a) Determine the empirical formula of caffeine. [13]

Empirical formula

A third, 1.05 g sample of caffeine was converted to the gaseous phase. Measurement showed that 100.0 mL of the gas exerted 370 kPa pressure at a temperature of 550 °C.

(b) Calculate the molar mass of caffeine. [2]

(c) From your answers to part (a) and part (b), determine the molecular formula of caffeine, showing clearly how this was determined. [2]

Chapter 14B Calculations: General

1. **[20 marks]** *(2011:38)*

The sandy soils of Western Australia are deficient in several elements essential to the growth of plant life. One of these elements is nitrogen, and there are a number of nitrogen-containing fertilisers available on the market. Urea, $CO(NH_2)_2$, is a commonly-used fertiliser that contains nitrogen. Urea is produced as crystals by the reaction of ammonia with carbon dioxide. Water is also produced in the reaction. The equation for this reaction is shown below.

$$2\,NH_3 + CO_2 \rightarrow CO(NH_2)_2 + H_2O$$

A reaction vessel designed for the synthesis of urea is operated at 200°C and 148 atmospheres. It has a total volume capacity of 5000 L, and ammonia and carbon dioxide are fed into it in batches so that ammonia occupies 62.0% of the volume and carbon dioxide occupies the remainder. (1 ATM = 101 kPa)

(a) Determine the limiting reagent for the reaction under the above operating conditions. Show **all** your workings. [5]

(b) What mass of urea is theoretically produced in this reaction? [3]

(c) Calculate the mass of the excess reactant remaining after reaction. [3]

(d) Calculate the pressure of the remaining gas in the reactor after the reactor is allowed to cool to room temperature (25°C). [2]

(e) 376 kg of impure crystals are formed in the above reaction and found, on analysis, to contain 83.0% urea. Calculate the percentage yield of the above process. [2]

CONTINUED NEXT PAGE

(f) Urea is added to fertiliser preparations at about 45.0% by mass. Ammonium sulfate is an alternative source of nitrogen often used in fertilisers.

(i) What mass of nitrogen is contained in 5.00 tonne of fertiliser that is 45.0% by mass urea? (1 tonne = 1×10^6 g) [2]

(ii) What mass of ammonium sulfate, $(NH_4)_2SO_4$, is needed to prepare 5.00 tonne of fertiliser with the same mass of nitrogen as your answer in (i) above? [3]

2. **[12 marks]** *(2012:41)*

The Pilbara iron ore industry uses vast amounts of ammonium nitrate explosive to break up the rock and ore. Much of the ammonium nitrate is produced in Kwinana, Western Australia, using the following process:

Step 1: Natural gas (from the North West Shelf) is reacted with steam.

$$CH_4(g) + H_2O(g) \rightleftharpoons 3\,H_2(g) + CO(g)$$

Step 2: Hydrogen produced in the above process is reacted with nitrogen from the air using the Haber Process.

$$3\,H_2(g) + N_2(g) \rightleftharpoons 2\,NH_3(g)$$

Step 3: Ammonia is reacted with oxygen in air.

$$4\,NH_3(g) + 5\,O_2(g) \rightleftharpoons 4\,NO(g) + 6\,H_2O(g)$$

Step 4: Nitrogen monoxide is reacted with oxygen in air.

$$2\,NO(g) + O_2(g) \rightleftharpoons 2\,NO_2(g)$$

Step 5: The nitrogen dioxide produced in the reaction above is reacted with water and oxygen to form nitric acid.

$$4\,NO_2(g) + 2\,H_2O(\ell) + O_2(g) \rightleftharpoons 4\,HNO_3(aq)$$

Step 6: Finally, nitric acid is reacted with ammonia to form ammonium nitrate.

$$HNO_3(aq) + NH_3(g) \rightleftharpoons NH_4NO_3(aq)$$

(a) How many moles of NH_4NO_3 are produced by the reaction of one mole of CH_4? [1]

CONTINUED NEXT PAGE

(b) Calculate the mass of CH_4 required to produce 2.50×10^5 tonnes of NH_4NO_3. Assume all reactions are 100% efficient, and express your answer to three significant figures. [6]

(c) The equation for Step 3 of the process is reproduced below. It is an exothermic reaction ($\Delta H = -1130$ kJ) and is carried out at 900°C and atmospheric pressure. Use your understanding of reaction rates and Le Châtelier's principle to predict why these conditions are employed for this reaction. [5]

$$4\ NH_3(g) + 5\ O_2(g) \rightleftharpoons 4\ NO(g) + 6\ H_2O(g)$$

3. **[16 marks]** *(2012:43)*

Soaps function because their molecules dissolve in both grease and water. Water containing significant quantities of calcium and magnesium ions will not lather properly with soap, and will form an insoluble 'scum' according to the reaction below. Water that does not lather effectively is referred to as 'hard' water, and calcium ions are the primary cause of water hardness:

$$Ca^{2+}(aq) + 2\ CH_3(CH_2)_{16}COO^-(aq) \rightarrow (CH_3(CH_2)_{16}COO)_2Ca(s)$$

If water is hard due to the presence of calcium ions together with hydrogencarbonate ions (temporary hardness), then the hardness can be reduced by boiling the water. The calcium ions are removed from solution by precipitating as calcium carbonate:

$$Ca^{2+}(aq) + 2\ HCO_3^-(aq) \rightarrow CaCO_3(s) + H_2O(\ell) + CO_2(g)$$

Boiling hard water causes the build-up of 'scale', and can lead to failure of the heating elements in kettles and other devices.

(a) The domestic water supply in Perth contains 65.0 mg L^{-1} calcium ions together with hydrogencarbonate ions. A large, tea-drinking family boils and consumes, on average, 4.20 L of water per day. Determine the mass of scale that will deposit in the household kettle during a 365-day year. Assume all calcium ions are removed from solution during boiling. [5]

CONTINUED NEXT PAGE

(b) What volume of $CO_2(g)$, measured at the boiling point of water, is produced during the boiling of 1.00 L of this water at standard pressure? [3]

Water containing calcium and magnesium together with sulfates and/or chlorides cannot be made 'soft' by boiling. There are a number of methods that may be used to soften such water. One of these involves the addition of $Ca(OH)_2$ to the water in the process known as 'liming'.

In the liming process, the pH of water is raised when $Ca(OH)_2(s)$ is added.

(c) Calculate the pH of 1.05×10^3 L of water solution to which 125 mg of $Ca(OH)_2$ have been added. Assume all added $Ca(OH)_2$ dissolves. [3]

The increase in pH (i.e., addition of OH^-) of the water shifts the equilibria of the carbonate species in the water so that first HCO_3^- predominates, and as the pH is raised further, CO_3^{2-} predominates.

Hard water containing HCO_3^- has significant buffering capacity.

(d) Explain what is meant by the term 'buffering capacity'. [1]

(e) Write two equations that demonstrate the buffering capacity of hard water containing HCO_3^-. [2]

(f) Write equations to show how the addition of OH^- shifts the equilibria of the carbonate species in water. [2]

4. [24 marks] *(2014:41)*

Rock phosphate is a non-renewable source of phosphate fertiliser. Because of concerns about its eventual depletion, urine is being investigated as an alternative renewable source for phosphate.

The phosphate in urine will precipitate as calcium hydroxyapatite, $Ca_{10}(PO_4)_6(OH)_2$, and struvite, $MgNH_4PO_4.6H_2O$, as the pH of the urine increases. The pH increases due to the hydrolysis of urea, $CO(NH_2)_2$, in urine to ammonia and carbon dioxide.

(a) Write the balanced equation for the hydrolysis of urea. [2]

(b) Explain briefly why hydrolysis of urea causes an **increase** in pH. Include an appropriate balanced equation in your answer. [2]

To determine phosphorus concentration in urine, a researcher collected 5.00 L of urine. After allowing the pH to increase to about 9 and adding excess magnesium ions to complete precipitation, 25.3 g of calcium hydroxyapatite and struvite precipitate were collected.

Analysis showed that 82.3% by mass of the precipitate was struvite and the rest calcium hydroxyapatite.

(c) Determine the concentration, in grams per litre, of the phosphorus in the urine. Express your answer to **three** significant figures. (Assume all phosphorus has been precipitated.) [9]

Molar masses (in g mol^{-1}): struvite 245.418; calcium hydroxyapatite 1004.636.

Once all the phosphorus has been removed, the nitrogen present can be recovered from the urine in the form of ammonium ions and converted to a nitrogen fertiliser. Recovery of the nitrogen can be achieved as follows:

Step 1
Sodium hydroxide is added to the phosphorus-depleted urine to increase its pH.

Step 2
The solution is heated to 40°C to convert the aqueous ammonia to the gas phase and a stream of air is passed through the solution.

Step 3
The ammonia-enriched air is allowed to come into contact with a room-temperature solution of sulfuric acid. The ammonia is absorbed by the solution to react with the acid to give ammonium sulfate.

CONTINUED NEXT PAGE

(d) Explain, using collision theory, why increasing the pH of the phosphorus-depleted urine converts the ammonium ions to ammonia. Support your answer with a balanced equation. [3]

(e) State the purpose of heating the solution to 40°C. [1]

(f) Write a balanced equation for the reaction in Step 3. [2]

(g) The amount of ammonium sulfate recovered from the 5.00 L of urine in this experiment is 72.65 g. If the process is 78% efficient, what is the concentration of nitrogen, in grams per litre, in the phosphorus-depleted urine? [5]

5. **[16 marks]** *5.2 (2016:39)*

Pentlandite, $Fe_9Ni_9S_8$, is a common nickel sulfide ore that can be used to obtain the materials required to produce sulfuric acid. This metal sulfide ore is combusted in air to form sulfur dioxide according to the following equation.

$$Fe_9Ni_9S_8 + 17\ O_2 \rightarrow 9\ NiO + 9\ FeO + 8\ SO_2$$

(a) What is the volume of sulfur dioxide produced if 2.2 tonne of pentlandite is combusted in air? The process has a yield of 72.0%, and takes place at 300.0°C and 165.0 kPa. Express your answer to the appropriate number of significant figures.

Molar mass of $Fe_9Ni_9S_8 = 1287.42\ g\ mol^{-1}$. [7]

CONTINUED NEXT PAGE

This sulfur dioxide is then passed over four beds of a vanadium pentoxide or platinum catalyst at 450°C to produce sulfur trioxide.

$$2\,SO_2(g) + O_2(g) \rightleftharpoons 2\,SO_3(g) \qquad \Delta H = -197.78 \text{ kJ}$$

(b) State **two** justifications for the use of catalysts in this process. [2]

One:

Two:

(c) State the effect of raising the pressure of the system on both the rate and yield. [2]

Effect on rate:

Effect on yield:

(d) Use the Collision Theory to explain the effect of raising the total pressure on the yield. [5]

6. [26 marks] *2.11 (2016:42)*

Acid rain is a significant issue in many industrialised areas of the world; particularly around power stations using fossil fuels. Legislation has been developed in Australia to minimise the formation of sulfur dioxide, $SO_2(g)$, such as from the use of low-sulfur fuels in automobiles, which can cause acid rain. Normal rain has a pH of about 5.6; it is slightly acidic because carbon dioxide, $CO_2(g)$ dissolves into it, forming weak carbonic acid. Rain with a pH less than 4.4 is usually classified as acid rain.

Testing was carried out on a rainwater sample taken near a coal-fired power station by titration, using sodium hydroxide solution, $NaOH(aq)$. Standardisation of the sodium hydroxide solution was carried out before it was used in the titration. An anhydrous sodium carbonate, $Na_2CO_3(s)$, primary standard was used to standardise a hydrochloric acid solution, $HC\ell(aq)$ and subsequently used to standardise the $NaOH(aq)$ solution.

Sodium carbonate, $Na_2CO_3(s)$ was heated at 110°C in a drying oven for 1 hour before 6.08×10^{-4} g was dissolved in distilled water to make 2.00 L of the primary standard. Three 25.0 mL aliquots of $HC\ell(aq)$ were titrated and an average titre of 16.4 mL was required for neutralisation.

(a) Demonstrate, by means of calculation, that the concentration of $HC\ell(aq)$ solution is 3.76×10^{-6} mol L^{-1}. [5]

(b) Outline **two** reasons why sodium hydroxide, $NaOH(s)$ is **not** a suitable primary standard for this titration. [2]

One:

Two:

CONTINUED NEXT PAGE

An average titre of 21.3 mL of the standardised (3.76×10^{-6} mol L^{-1}) $HC\ell(aq)$ solution was required to neutralise 25.0 mL aliquots of $NaOH(aq)$ solution.

(c) Calculate the concentration of the $NaOH(aq)$ solution. [3]

The standardised $NaOH(aq)$ solution was then used for the titration of a rainwater sample. A 100.0 mL sample of rain water was collected near a coal-fired power station and diluted to 250.0 mL with distilled water in a volumetric flask. 25.0 mL aliquots of the diluted rainwater were used in the titration.

(d) Complete the table below to state with what the following pieces of glassware should be rinsed for this titration. [3]

Glassware	**Final rinse**
Burette	
Conical flask	
Pipette	

The titre values obtained for the rainwater sample are shown in the table below:

Titre volume of NaOH (mL)				**Average titre volume (mL)**
Trial 1	**Trial 2**	**Trial 3**	**Trial 4**	
21.81	19.64	19.67	19.66	

(e) Calculate the average titre volume and record it in the table above. [1]

(f) Calculate the pH of the undiluted rainwater sample. Determine if it would be classified as acid rain or not. [6]

(g) If carbon dioxide, $CO_2(g)$ alone accounts for rain with a pH of 5.60, then calculate the volume of sulfur dioxide, $SO_2(g)$ at 16.0°C and 97.2 kPa, that would also need to be dissolved to produce 0.100 L of an acid rain sample with a pH of 4.0. Use the equation below.

$$SO_2(g) + H_2O(\ell) \rightleftharpoons H_2SO_3(aq)$$

For this calculation, assume the complete ionisation of $H_2SO_3(aq)$. [6]

Chapter 15 | Extended Responses

1. [10 marks] *(2010:42)*

Nitric acid is manufactured by the Ostwald process.

In the first step, ammonia gas reacts with oxygen gas to produce nitric oxide in the presence of a catalyst such as platinum with 10% rhodium. This reaction is carried out at a temperature of approximately 900°C and at a pressure of approximately 10 atmospheres.

$$4\,NH_3(g) + 5\,O_2(g) \rightleftharpoons 4\,NO(g) + 6\,H_2O(g) + \text{heat}$$

The nitric oxide is next oxidised at approximately 50°C.

$$2\,NO(g) + O_2(g) \rightleftharpoons 2\,NO_2(g) + \text{heat}$$

The nitrogen dioxide then enters an absorption tower, where water is added through a sprinkler system in the presence of air to give nitric acid.

$$4\,NO_2(g) + O_2(g) + 2\,H_2O(\ell) \rightleftharpoons 4\,HNO_3(aq)$$

Use your understanding of reaction rates and chemical equilibrium to explain the conditions used in the Ostwald process. Your answer should include at least three (3) paragraphs, and should be 1 to $1\frac{1}{2}$ pages in length.

2. [10 marks] *(2011:41)*

Soaps and detergents are common organic substances. Discuss the chemistry of these two classes of organic substances, including their structure, manufacture and how they act as cleaning agents.

Your answer should

- include relevant chemical content. [8]
- display coherence and clarity of expression. [2]

A comprehensive answer should consist of at least three (3) paragraphs and be at least one page in length.

3. **[12 marks]** *(2013:42)*

Using examples, describe 'condensation' and 'addition polymerisation'.

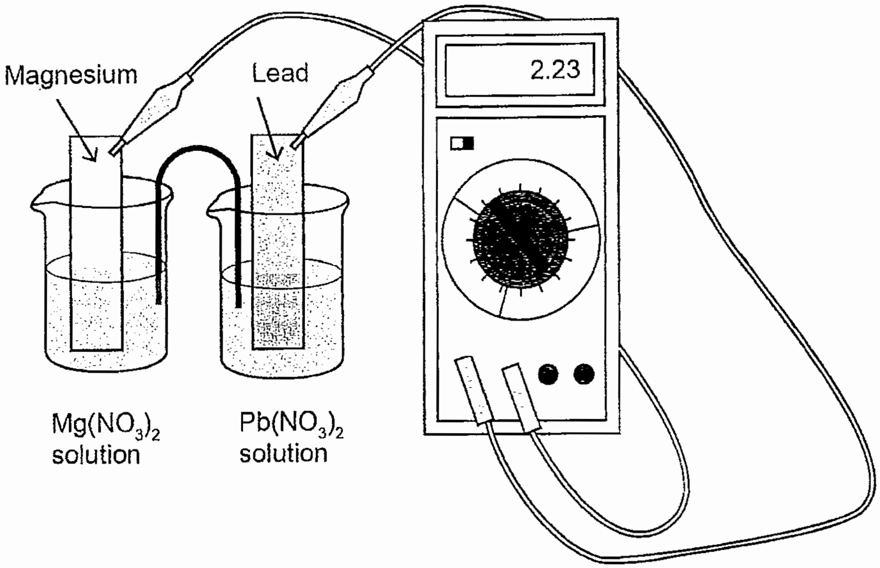
Your answer should include:

- an explanation of the term 'polymer'
- the structure and name of an example of each polymer type
- structures of starting materials for the production of each example of a polymer type
- polymerisation reactions.

4. **[8 marks]** *(2014:42)*

Using the diagram below, explain the role of the following in the operation of a galvanic cell:

- anode process
- cathode process
- lead(II) nitrate electrolyte
- salt bridge
- electron flow in external circuit.



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5. **[10 marks]** *3.3 (2016 SP:41)*

You are supplied with strips of three unknown metals, **A**, **B** and **C**, and are required to determine the order in which they are reduced, from most easily to least easily.

Using a voltmeter, electrical leads and clips, standard laboratory glassware and the typical range of chemicals found in most laboratories, design an investigation and describe the procedures to be followed to determine the order of reduction for the metals. Use a labelled diagram to support your description. Ensure that you explain the purposes of substances or equipment (excluding beakers or other glassware) used.

Indicate the data you will collect and explain how these data give the order of reduction.

Government of **Western Australia**
School Curriculum and Standards Authority

CHEMISTRY
ATAR COURSE

DATA BOOKLET

2018

This document is valid for teaching and examining until 31 December 2018.

Periodic table

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 **H** hydrogen 1.008																	2 **He** helium 4.003
3 **Li** lithium 6.968	4 **Be** beryllium 9.012											5 **B** boron 10.82	6 **C** carbon 12.01	7 **N** nitrogen 14.01	8 **O** oxygen 16.00	9 **F** fluorine 19.00	10 **Ne** neon 20.18
11 **Na** sodium 22.99	12 **Mg** magnesium 24.31											13 **Aℓ** aluminium 26.98	14 **Si** silicon 28.09	15 **P** phosphorus 30.97	16 **S** sulfur 32.07	17 **Cℓ** chlorine 35.45	18 **Ar** argon 39.95
19 **K** potassium 39.10	20 **Ca** calcium 40.08	21 **Sc** scandium 44.96	22 **Ti** titanium 47.88	23 **V** vanadium 50.94	24 **Cr** chromium 52.00	25 **Mn** manganese 54.94	26 **Fe** iron 55.85	27 **Co** cobalt 58.93	28 **Ni** nickel 58.69	29 **Cu** copper 63.55	30 **Zn** zinc 65.38	31 **Ga** gallium 69.72	32 **Ge** germanium 72.59	33 **As** arsenic 74.92	34 **Se** selenium 78.96	35 **Br** bromine 79.90	36 **Kr** krypton 83.80
37 **Rb** rubidium 85.47	38 **Sr** strontium 87.62	39 **Y** yttrium 88.91	40 **Zr** zirconium 91.22	41 **Nb** niobium 92.91	42 **Mo** molybdenum 95.94	43 **Tc** technetium	44 **Ru** ruthenium 101.1	45 **Rh** rhodium 102.9	46 **Pd** palladium 106.4	47 **Ag** silver 107.9	48 **Cd** cadmium 112.4	49 **In** indium 114.8	50 **Sn** tin 118.7	51 **Sb** antimony 121.8	52 **Te** tellurium 127.6	53 **I** iodine 126.9	54 **Xe** xenon 131.3
55 **Cs** caesium 132.9	56 **Ba** barium 137.3	57–71 ***La** lanthanum 138.9	72 **Hf** hafnium 178.5	73 **Ta** tantalum 180.9	74 **W** tungsten 183.9	75 **Re** rhenium 186.2	76 **Os** osmium 190.2	77 **Ir** iridium 192.2	78 **Pt** platinum 195.1	79 **Au** gold 197.0	80 **Hg** mercury 200.6	81 **Tℓ** thallium 204.4	82 **Pb** lead 207.2	83 **Bi** bismuth 209.0	84 **Po** polonium	85 **At** astatine	86 **Rn** radon
87 **Fr** francium	88 **Ra** radium 226.0	89–103 ****Ac** actinium	104 **Rf** rutherfordium	105 **Db** dubnium	106 **Sg** seaborgium	107 **Bh** bohrium	108 **Hs** hassium	109 **Mt** meitnerium	110 **Ds** darmstadtium	111 **Rg** roentgenium	112 **Cn** copernicium	113 **Uut** ununtrium	114 **Fℓ** flerovium	115 **Uup** ununpentium	116 **Lv** livermorium	117 **Uus** ununseptium	118 **Uuo** ununoctium

Key:

Atomic number
Symbol
Name
Standard atomic weight

* Lanthanide series	58 **Ce** cerium 140.1	59 **Pr** praseodymium 140.9	60 **Nd** neodymium 144.2	61 **Pm** promethium	62 **Sm** samarium 150.4	63 **Eu** europium 152.0	64 **Gd** gadolinium 157.3	65 **Tb** terbium 158.9	66 **Dy** dysprosium 162.5	67 **Ho** holmium 164.9	68 **Er** erbium 167.3	69 **Tm** thulium 168.9	70 **Yb** ytterbium 173.0	71 **Lu** lutetium 175.0
** Actinide series	90 **Th** thorium 232.0	91 **Pa** protactinium	92 **U** uranium 238.0	93 **Np** neptunium	94 **Pu** plutonium	95 **Am** americium	96 **Cm** curium	97 **Bk** berkelium	98 **Cf** californium	99 **Es** einsteinium	100 **Fm** fermium	101 **Md** mendelevium	102 **No** nobelium	103 **Lr** lawrencium

[Data source: The International Union of Pure and Applied Chemistry Periodic Table of the Elements (2016)]

Formulae

Number of moles	n	$= \frac{m}{M} = \frac{\text{mass}}{\text{molar mass}}$
Number of moles of solute	n	$= cV$
Number of moles of a gas at STP	n	$= \frac{V}{22.71}$
Ideal gas law	PV	$= nRT$
Parts per million	ppm	$= \frac{\text{mass of solute (mg)}}{\text{mass of solution (kg)}}$
pH of a solution	pH	$= -\log [H^+]$

Units

Volumes are given in the units of litres (L), or millilitres (mL)
Temperatures are given in the units of degrees Celsius (°C) or kelvin (K)
It may be assumed that 0.0 °C = 273.15 K
Energy changes are given in kilojoules (kJ)
Pressures are given in kilopascals (kPa)
Solution concentrations are given in the units moles per litre (mol L^{-1}), grams per litre (g L^{-1}) or parts per million (ppm)

Constants

Universal gas constant, $R = 8.314$ J K^{-1} mol^{-1}
Avogadro constant, $N = 6.022 \times 10^{23}$ mol^{-1}
Volume of 1.00 mol of an ideal gas at 0.0 °C and 100.0 kPa is 22.71 L
S.T.P. is 0.0 °C and 100.0 kPa
Equilibrium constant for water at 25 °C, $K_w = 1.00 \times 10^{-14}$

Solubility rules for ionic solids in water

Soluble in water

Soluble	**Exceptions**	
	Insoluble	**Slightly soluble**
Most chlorides	$AgC\ell$	$PbC\ell_2$
Most bromides	$AgBr$	$PbBr_2$
Most iodides	AgI, PbI_2	
All nitrates	No exceptions	
All ethanoates		
Most sulfates	$SrSO_4$, $BaSO_4$, $PbSO_4$	$CaSO_4$, Ag_2SO_4

Insoluble in water

Insoluble	**Exceptions**	
	Soluble	**Slightly soluble**
Most hydroxides	$NaOH$, KOH, $Ba(OH)_2$ NH_4OH*, $AgOH$**	$Ca(OH)_2$, $Sr(OH)_2$
Most carbonates	Na_2CO_3, K_2CO_3, $(NH_4)_2CO_3$	
Most phosphates	Na_3PO_4, K_3PO_4, $(NH_4)_3PO_4$	
Most sulfides	Na_2S, K_2S, $(NH_4)_2S$	

* NH_3 dissolves in water to form both NH_3 (aq) and NH_4^+(aq)/OH^-(aq)
** Ag^+(aq) reacts with OH^-(aq) to form insoluble Ag_2O

Soluble = more than 0.1 mole dissolves per litre
Slightly soluble = between 0.01 and 0.1 mole dissolves per litre
Insoluble = less than 0.01 mole dissolves per litre

Colours of selected substances

In general, ionic solids have the same colour as that of any coloured ion they contain. Two colourless ions in general produce a white solid. Selected exceptions to these two basic rules are noted below.

Ionic Solid	**Colour**
copper(II) carbonate	green
copper(II) chloride	green
copper(II) oxide	black
copper(II) sulfide	black
lead(II) iodide	yellow
lead(II) sulfide	grey
manganese(IV) oxide	black
silver carbonate	yellow
silver iodide	pale yellow
silver oxide	brown
silver sulfide	black

Other coloured substances

Most gases and liquids are colourless, and most metals are silvery or grey. Selected exceptions to these basic rules are noted below.

Substance	**Colour**
copper(s)	salmon pink
gold(s)	yellow
nitrogen dioxide(g)	brown
sulfur(s)	yellow

Coloured halogens

Halogen	**Colour of free element**
$F_2(g)$	yellow
$C\ell_2(g)$	greenish-yellow
$Br_2(\ell)$	red
$I_2(g)$	purple

Halogen	**Colour of halogen in aqueous solution**
$C\ell_2(aq)$	pale yellow
$Br_2(aq)$	orange
$I_2(aq)$	brown

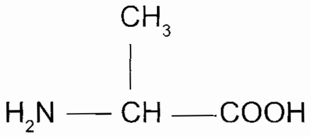
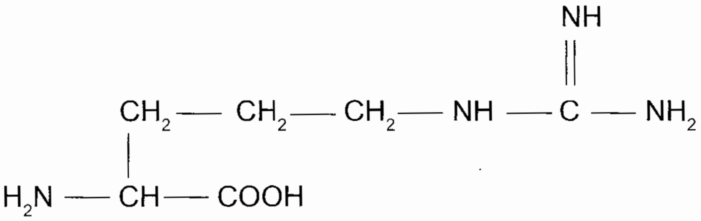
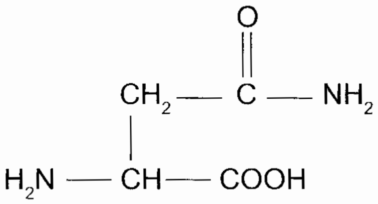
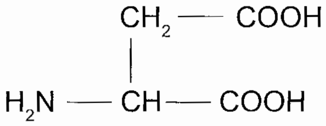
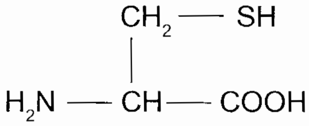
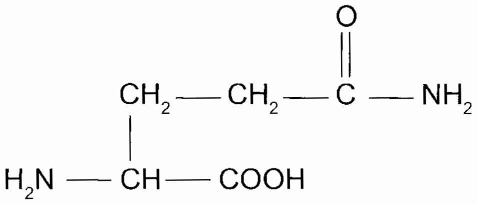
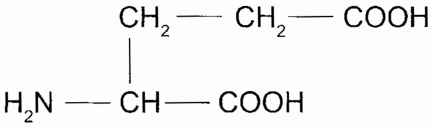
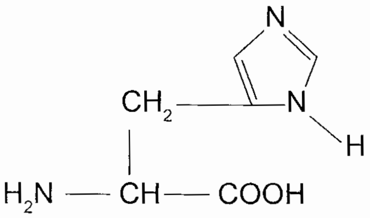
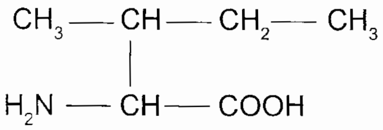
Halogen	**Colour of halogen in organic solvent**
Br_2	red
I_2	purple

Coloured ions in aqueous solution

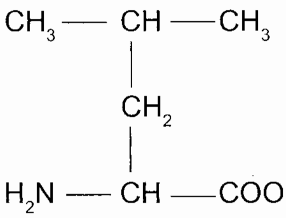
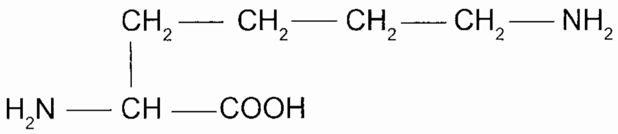
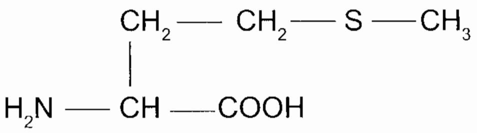
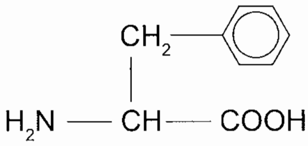
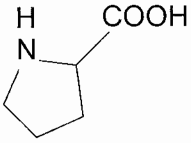
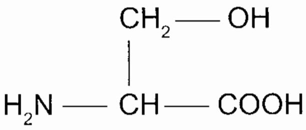
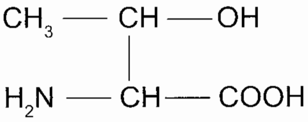
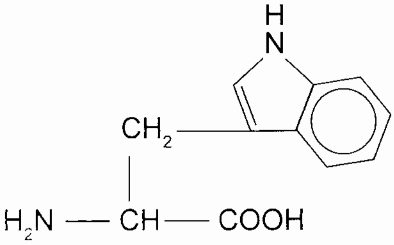
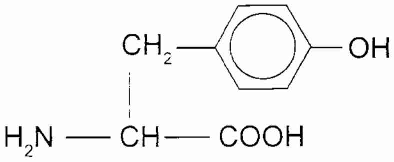
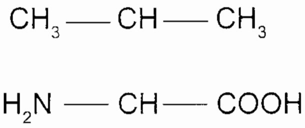
Cation	**Colour**
Cr^{3+}	deep green
Co^{2+}	pink
Cu^{2+}	blue
Fe^{2+}	pale green
Fe^{3+}	pale brown
Mn^{2+}	pale pink
Ni^{2+}	green

Anion	**Colour**
CrO_4^{2-}	yellow
$Cr_2O_7^{2-}$	orange
MnO_4^{-}	purple

α–amino acids

Name	Symbol	Structure
alanine	Ala	 $\begin{array}{l} \quad\;\; CH_3 \\ \quad\;\; \vert \\ H_2N-CH-COOH \end{array}$
arginine	Arg	 $\begin{array}{l} \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\quad NH \\ \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\quad \Vert \\ \qquad CH_2-CH_2-CH_2-NH-C-NH_2 \\ \qquad \vert \\ H_2N-CH-COOH \end{array}$
asparagine	Asn	 $\begin{array}{l} \qquad\qquad\quad O \\ \qquad\qquad\quad \Vert \\ \qquad CH_2-C-NH_2 \\ \qquad \vert \\ H_2N-CH-COOH \end{array}$
aspartic acid	Asp	 $\begin{array}{l} \qquad CH_2-COOH \\ \qquad \vert \\ H_2N-CH-COOH \end{array}$
cysteine	Cys	 $\begin{array}{l} \qquad CH_2-SH \\ \qquad \vert \\ H_2N-CH-COOH \end{array}$
glutamine	Gln	 $\begin{array}{l} \qquad\qquad\qquad\qquad\quad O \\ \qquad\qquad\qquad\qquad\quad \Vert \\ \qquad CH_2-CH_2-C-NH_2 \\ \qquad \vert \\ H_2N-CH-COOH \end{array}$
glutamic acid	Glu	 $\begin{array}{l} \qquad CH_2-CH_2-COOH \\ \qquad \vert \\ H_2N-CH-COOH \end{array}$
glycine	Gly	H_2N-CH_2-COOH
histidine	His	
isoleucine	Ile	 $\begin{array}{l} CH_3-CH-CH_2-CH_3 \\ \qquad\;\; \vert \\ H_2N-CH-COOH \end{array}$

α–amino acids

Name	**Symbol**	**Structure**
leucine	Leu	 $\begin{array}{ccccc} CH_3 & - & CH & - & CH_3 \\ & & \vert & & \\ & & CH_2 & & \\ & & \vert & & \\ H_2N & - & CH & - & COOH \end{array}$
lysine	Lys	 $\begin{array}{ccccccccccc} & & CH_2 & - & CH_2 & - & CH_2 & - & CH_2 & - & NH_2 \\ & & \vert & & & & & & & & \\ H_2N & - & CH & - & COOH & & & & & & \end{array}$
methionine	Met	 $\begin{array}{ccccccccc} & & CH_2 & - & CH_2 & - & S & - & CH_3 \\ & & \vert & & & & & & \\ H_2N & - & CH & - & COOH & & & & \end{array}$
phenylalanine	Phe	
proline	Pro	
serine	Ser	 $\begin{array}{ccccc} & & CH_2 & - & OH \\ & & \vert & & \\ H_2N & - & CH & - & COOH \end{array}$
threonine	Thr	 $\begin{array}{ccccc} CH_3 & - & CH & - & OH \\ & & \vert & & \\ H_2N & - & CH & - & COOH \end{array}$
tryptophan	Trp	
tyrosine	Tyr	
valine	Val	 $\begin{array}{ccccc} CH_3 & - & CH & - & CH_3 \\ & & & & \\ H_2N & - & CH & - & COOH \end{array}$

Standard Reduction Potentials at 25 °C

Half-reaction			E°(volts)
$F_2(g) + 2\,e^-$	$\rightleftharpoons$	$2\,F^-(aq)$	+ 2.89
$H_2O_2(aq) + 2\,H^+(aq) + 2\,e^-$	$\rightleftharpoons$	$2\,H_2O(\ell)$	+ 1.76
$PbO_2(s) + SO_4^{2-}(aq) + 4\,H^+(aq) + 2\,e^-$	$\rightleftharpoons$	$PbSO_4(s) + 2\,H_2O(\ell)$	+ 1.69
$2\,HC\ell O(aq) + 2\,H^+(aq) + 2\,e^-$	$\rightleftharpoons$	$C\ell_2(g) + 2\,H_2O(\ell)$	+ 1.63
$MnO_4^-(aq) + 8\,H^+(aq) + 5\,e^-$	$\rightleftharpoons$	$Mn^{2+}(aq) + 4\,H_2O(\ell)$	+ 1.51
$Au^{3+}(aq) + 3\,e^-$	$\rightleftharpoons$	$Au(s)$	+ 1.50
$HC\ell O(aq) + H^+(aq) + 2\,e^-$	$\rightleftharpoons$	$C\ell^-(aq) + H_2O(\ell)$	+ 1.49
$PbO_2(s) + 4\,H^+(aq) + 2\,e^-$	$\rightleftharpoons$	$Pb^{2+}(aq) + 2\,H_2O(\ell)$	+ 1.46
$C\ell_2(g) + 2\,e^-$	$\rightleftharpoons$	$2\,C\ell^-(aq)$	+ 1.36
$Cr_2O_7^{2-}(aq) + 14\,H^+(aq) + 6\,e^-$	$\rightleftharpoons$	$2\,Cr^{3+}(aq) + 7\,H_2O(\ell)$	+ 1.36
$O_2(g) + 4\,H^+(aq) + 4\,e^-$	$\rightleftharpoons$	$2\,H_2O(\ell)$	+ 1.23
$Br_2(\ell) + 2\,e^-$	$\rightleftharpoons$	$2\,Br^-(aq)$	+ 1.08
$Ag^+(aq) + e^-$	$\rightleftharpoons$	$Ag(s)$	+ 0.80
$Fe^{3+}(aq) + e^-$	$\rightleftharpoons$	$Fe^{2+}(aq)$	+ 0.77
$O_2(g) + 2\,H^+(aq) + 2\,e^-$	$\rightleftharpoons$	$H_2O_2(aq)$	+ 0.70
$I_2(s) + 2\,e^-$	$\rightleftharpoons$	$2\,I^-(aq)$	+ 0.54
$O_2(g) + 2\,H_2O(\ell) + 4\,e^-$	$\rightleftharpoons$	$4\,OH^-(aq)$	+ 0.40
$Cu^{2+}(aq) + 2\,e^-$	$\rightleftharpoons$	$Cu(s)$	+ 0.34
$S(s) + 2\,H^+(aq) + 2\,e^-$	$\rightleftharpoons$	$H_2S(aq)$	+ 0.17
$2\,H^+(aq) + 2\,e^-$	$\rightleftharpoons$	$H_2(g)$	0 exactly
$Pb^{2+}(aq) + 2\,e^-$	$\rightleftharpoons$	$Pb(s)$	– 0.13
$Sn^{2+}(aq) + 2\,e^-$	$\rightleftharpoons$	$Sn(s)$	– 0.14
$Ni^{2+}(aq) + 2\,e^-$	$\rightleftharpoons$	$Ni(s)$	– 0.24
$Co^{2+}(aq) + 2\,e^-$	$\rightleftharpoons$	$Co(s)$	– 0.28
$PbSO_4(s) + 2\,e^-$	$\rightleftharpoons$	$Pb(s) + SO_4^{2-}(aq)$	– 0.36
$Cd^{2+}(aq) + 2\,e^-$	$\rightleftharpoons$	$Cd(s)$	– 0.40
$2\,CO_2(g) + 2\,H^+(aq) + 2\,e^-$	$\rightleftharpoons$	$H_2C_2O_4(aq)$	– 0.43
$Fe^{2+}(aq) + 2\,e^-$	$\rightleftharpoons$	$Fe(s)$	– 0.44
$Cr^{3+}(aq) + 3\,e^-$	$\rightleftharpoons$	$Cr(s)$	– 0.74
$Zn^{2+}(aq) + 2\,e^-$	$\rightleftharpoons$	$Zn(s)$	– 0.76
$2\,H_2O(\ell) + 2\,e^-$	$\rightleftharpoons$	$H_2(g) + 2\,OH^-(aq)$	– 0.83
$Mn^{2+}(aq) + 2\,e^-$	$\rightleftharpoons$	$Mn(s)$	– 1.18
$A\ell^{3+}(aq) + 3\,e^-$	$\rightleftharpoons$	$A\ell(s)$	– 1.68
$Mg^{2+}(aq) + 2\,e^-$	$\rightleftharpoons$	$Mg(s)$	– 2.36
$Na^+(aq) + e^-$	$\rightleftharpoons$	$Na(s)$	– 2.71
$Ca^{2+}(aq) + 2\,e^-$	$\rightleftharpoons$	$Ca(s)$	– 2.87
$Sr^{2+}(aq) + 2\,e^-$	$\rightleftharpoons$	$Sr(s)$	– 2.90
$Ba^{2+}(aq) + 2\,e^-$	$\rightleftharpoons$	$Ba(s)$	– 2.91
$K^+(aq) + e^-$	$\rightleftharpoons$	$K(s)$	– 2.94

[Data source: Aylward, G.H., & Findlay, T. (2008). *SI Chemical Data* (6th ed.). Queensland: John Wiley & Sons Australia, Ltd.]

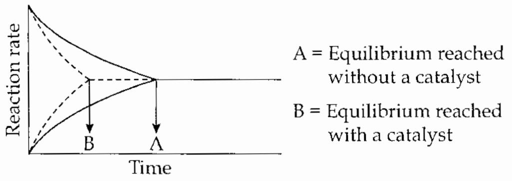
Solutions

These answers and solutions not only give the answers but also in many cases, provide the relevant background, elaboration and explanations of how the answers are arrived at. This is expected to provide a greater insight in order to comprehend the questions and meet the expectations of the examiners.

Chapter 1: Chemical Equilibrium

1.(2010:18-c) The rate of formation of Fe^{3+} increases rapidly at first. The rate at which the concentration increases gradually slows down as reactants are used up until the concentration becomes constant. The graph should show the initial forward reaction relatively fast but then slowing down and eventually becoming constant. The answer is 'c'.

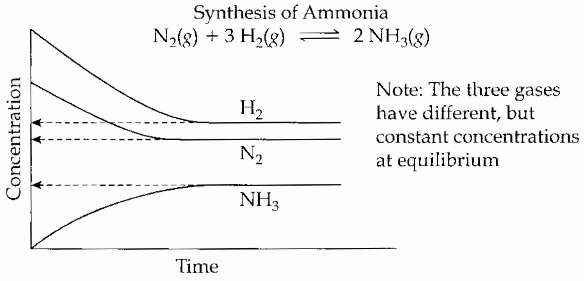
2.(2011:10-b) Enzymes are biological catalysts which increase the rate of both the forward and the reverse reactions. Apart from enabling the reaction to reach equilibrium sooner, they do not affect equilibrium. See the diagram below. Answer is 'b'.



3.(2011:11-c) The reaction is: $CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3\,H_2(g)$. $\Delta H > 0$

In this reaction, the products occupy a larger volume. In accordance with LCP, an increase in pressure will shift the equilibrium towards the reactants as they occupy a smaller volume. This will effectively decrease the yield of hydrogen. Decreasing the partial pressure of water vapour will have a similar effect. Furthermore, this is an endothermic reaction and so a decrease in temperature will decrease the yield of H_2. Therefore, one way to increase the yield of hydrogen is to remove carbon monoxide. This will drive the reaction forward to produce more CO along with H_2. The answer is 'c'.

4.(2011:12-c) When a reaction has reached equilibrium, all the observable and measurable properties of the reactants and the products remain constant. However, it is better to remember that they are not equal. The answer is 'c'. See the diagram below.



5.(2012:17-b) In this reaction ($Fe_2O_3(s) + 3\,CO(g) \rightleftharpoons 2\,Fe(\ell) + 3\,CO_2(g)$), by decreasing the volume, the pressure on the gases increase, increasing the rate of reaction on both directions. Decreasing the particle size would increase the rate of reaction due to an increase in the surface area of the reacting particles. By decreasing the concentration of CO_2, the forward reaction rate is increased. By decreasing the pressure of carbon monoxide, the gas particles have less effective collisions per unit time and hence the rate decreases. The answer is 'b'.

6.(2012:18-c) Since the reaction readily takes place at room temperature, the activation energy requirement is very small. Since heat energy is absorbed from the environment and the beaker becomes cold, the reaction is endothermic. The answer is 'c'.

7.(2013:12-a) A reading of the graph indicates that the system reaches equilibrium at about 35 minutes. It is important to realise that the equilibrium ratio of molar concentrations is not the same as the stoichiometric ratio of the reactants. Also, the equilibrium constant is not affected by factors other than a change in temperature of the system. Furthermore, the rates of the forward and the reverse reactions are equal at equilibrium. This leaves only alternative 'a' which is the correct response.

8.(2013:13-b)

The reaction is: $[Cu(H_2O)_6]^{2+}(aq) + 4\,NH_3(aq) \rightleftharpoons [Cu(NH_3)_4]^{2+}(aq) + 6\,H_2O(\ell)$

The addition of a small amount of HNO_3, will reduce the concentration of NH_3. The NH_3 reacts with H^+ to form NH_4^+ and so decreases the concentration of NH_3. The reverse reaction that follows decomposes $[Cu(NH_3)_4^{2+}](aq)$. This results in the solution becoming pale blue. The answer is 'b'.

9.(2013:14-a) The reaction is: $2\,SO_2(g) + O_2(g) \rightleftharpoons 2\,SO_3(g) + 198$ kJ

Catalysts tend to reduce the activation energy requirements and create a new reaction pathway with a lower activation energy. This will increase both the forward and the reverse reaction rates. On the other hand, increasing the concentration of SO_2 and, cooling the system, will increase the rate of the forward reaction. Introducing an inert gas into the system does not change any concentrations and so has no effect. The answer is 'a'.

10.(2014:10-c) The value of the equilibrium constant for a chemical reaction depends only on the temperature. An increase in temperature increases the numerical value of the equilibrium constant for that reaction and a decrease in temperature decreases its numerical value. Equilibrium shifts to the product side as [NO] increases and the $[N_2O]$ and $[NO_2]$ decreases. The answer is 'c'.

11.(2014:11-a) Removing $H_2O(\ell)$ from the equation, the equilibrium law expression for the reaction is,
$K_{eq} = \{[Cr_2O_7^{2-}] \div [CrO_4^{2-}] \times [H^+]^2\}$. The answer is 'a'.

12.(2014:12-b) The reaction equation is: $Fe^{3+}(aq) + SCN^-(aq) \rightleftharpoons [Fe(SCN)]^{2+}(aq)$
pale brown colourless deep red

Adding water dilutes the mixture and both the colours becomes paler and no other effect can be noticed.

Adding aqueous Na_2CO_3 will precipitate some Fe^{3+} ions as $Fe_2CO_3(s)$. In accordance with LCP the equilibrium shifts to the reactant side to produce more Fe^{3+} ion to make up the loss and the colour becomes more brownish. Adding solid $FeC\ell_3$ will dissolve and increase the Fe^{3+} concentration. This will shift the equilibrium to the product side making the solution deep red. Since this is an exothermic reaction, cooling the solution will shift the equilibrium to the product side making the solution deep red. The answer is 'b'.

13.(2015:04) Answer 'c'. Remember the graph is showing Rate – both increase with temperature and then a new equilibrium is established.

14.(2015:06) Answer 'a'. K = [products]/[reactants]. We do not include species with (s) or (ℓ).

15.(2015:07) Solid lead does not appear in the K expression. Adding Na_2SO_4will increase pH. Lead sulfate is a solid. Answer 'd'. Barium sulfate is insoluble and removes sulfate ions moving the equation to the LHS.

16.(2016:01-c) The reaction is exothermic – cooling the system would give more oxygen as the reaction moves to the RHS. Adding inert gas would have no effect, as $[O_2]$ does not change. Decreasing the conc of H_2O_2 would lead to a lower forward rate and less O_2. Increasing the pressure would increase $[O_2]$ which would result in less O_2 forming. The answer is 'c'.

17.(2016:02-a) Note the question asks for decrease in rate. Answers 'b', 'c' and 'd' always increase reaction rate. Decreasing the partial pressure of H_2S will decrease the rate of collisions and thus the rate of formation of sulfur. The answer is 'a'.

18.(2016:03-b) Answer 'a' is wrong. At equilibrium the forward and reverse reaction rates are equal. Answer c would suggest a much larger K value. Answer d would be correct for a large Kc reaction. The value of Kc is very small. Thus [products]/[reactants] is small i.e. there are few products. The answer is 'b.'

19.(2016:04-b) This is a classic question. If you are told something not in the equation is added, be sure it will probably react with something in the equation either as acid/base or a precipitate. The added solution is concentrated so there is no need to worry about diluting the reactants and products. Here the H^+ is destroyed so the equation moves to the right – the answer is 'b'.

20.(2016:08-a) The words spontaneous, exothermic means a reaction with a small E_a and a negative ΔH. The answer is 'a'.

21.(2017:05-a) The question is based on the fact that all reactions have a higher rate at higher temperatures. The answer is 'a'.

22.(2017:06-a) This question involves the use of Le Châtelier's Principle and remembering that esterification requires a strong acid catalyst. The answer is 'a'.

23.(2017:07-d) This question covers the multiple properties of catalysts that you should know. All are valid. The answer is 'd'.

24.(2017:12-b) Another LCP question. The addition of heat will favour the endothermic reaction which is the reverse reaction. The answer is 'b'.

25.(2017:18-b) This question is taken directly from the syllabus 'Acidification shifts the equilibrium of carbonate chemistry in seawater, decreasing the rate and amount of calcification'. Answer (b) shows the destruction of carbonate ions that are essential to the process of calcification. The answer is 'b'.

Chapter 2: Acids and Bases

1.(2012:06-c) In the reaction, $HS^-(aq) + CO_3^{2-}(aq) \rightleftharpoons S^{2-}(aq) + HCO_3^-(aq)$, HS^- acts as a Brønsted-Lowry acid as it gives away a proton to CO_3^{2-}. Hence S^{2-} is a conjugate base. CO_3^{2-}, on the other hand acts as a Brønsted-Lowry base as it accepts the proton to become a Brønsted-Lowry conjugate acid, HCO_3^-. The question is asking as to which statement is **not true**. The only incorrect statement is 'HS^- acting as a conjugate base'. This is not true because it is giving away a proton in this reaction rather than accepting one. The answer is 'c'.

2.(2012:07-b) A buffer solution consists of a weak acid and its conjugate base or a weak base and its conjugate acid in roughly equimolar amounts to react with added H_3O^+ or OH^-. NaH_2PO_4 (ii) and Na_2HPO_4 (v) fit this criterion. See the equation below:

$H_2PO_4^-(aq) + H_2O(\ell) \rightleftharpoons HPO_4^-(aq) + H_3O^+(aq)$ The answer is 'b'.

3.(2012:08-c) Na_3PO_4 is a basic salt: $PO_4^{3-} + H_2O \rightleftharpoons HPO_4^{2-} + OH^-$ (strong base + weak acid)
Na_2S is a basic salt: $S^{2-} + H_2O \rightleftharpoons HS^- + OH^-$ (strong base + weak acid)
$Ba(OH)_2$ is a base: $Ba(OH)_2 \rightarrow Ba^{2+} + 2\,OH^-$ (strong base)
Only the above three would give a basic solution.
KNO_3 is neutral. It hydrolyses: $KNO_3(aq) \rightarrow K^+(aq) + NO_3^-(aq)$ (no hydrolysis)
$Fe_2O_3(s)$ is insoluble.
$A\ell C\ell_3$ is an acidic salt and would give an acidic solution: $A\ell C\ell_3(s) + 6\,H_2O \rightleftharpoons [A\ell(H_2O)_6]^{3+} + 3\,C\ell^-(aq)$
$A\ell(H_2O)_6^{3+} + H_2O \rightleftharpoons A\ell(OH)(H_2O)_5^{2+} + H_3O^+$ (strong acid+ weak/amphoteric base)
$Ca(NO_3)_2$ is a neutral salt: It hydrolyses. $Ca(NO_3)_2(s) \rightarrow Ca^{2+}(aq) + 2\,NO_3^-(aq)$ (no hydrolysis) The answer is 'c'.

4.(2013:15-d) H_2O_2 cannot gain a proton but can lose one to become the conjugate base, H_2O_2 can act only as an acid.
NH_4^+ can act as an acid by giving away a proton to become the conjugate base, NH_3, but it cannot gain a proton to become a conjugate acid.
CH_3NH_2 can act as a base to accept a proton to become $CH_3NH_3^+$. It cannot act as an acid and lose a proton.
$H_2PO_4^-$ can act both as an acid and as a base.
As an acid: $H_2PO_4^-(aq) + H_2O(\ell) \rightleftharpoons HPO_4^{2-}(aq) + H_3O^+(aq)$
As a base: $H_2PO_4^-(aq) + H_2O(\ell) \rightleftharpoons H_3PO_4(aq) + OH^-(aq)$
In general, anions which contain hydrogen atoms and are derived from polyprotic acids undergo separate hydrolysis reactions which produce both hydronium ions and OH^- ions. The answer is 'd'.

5.(2013:16-c) For the same concentration, $HC\ell$ ionises fully as it is a strong acid. On the other hand, CH_3COOH ionises only partially and releases fewer ions as it is a weak acid. The extent of ionization is indicated by the Equilibrium ionization constant (Kc).

6.(2013:17-b) In order to reduce the pH, more H_3O^+ ions are to be added to water. The best way to represent this reaction is: $HSO_4^-(aq) + H_2O(\ell) \rightarrow H_3O^+(aq) + SO_4^{2-}(aq)$. The answer is 'b'.

7.(2013:18-a) The reaction for the buffer solution described here can be represented by the following equation:
$CH_3COOH(aq) + H_2O(\ell) \rightleftharpoons CH_3COO^-(aq) + H_3O^+(aq)$
Alternatives 'b' and 'd' are incorrect. Sodium ions do not play any significant role (except dissociating and supplying the acetate ions) in the buffering action and water does not supply hydrogen ions. Addition of water will still affect the buffering capacity. Addition of concentrated nitric acid however, increases the concentration of the H_3O^+ ions with immediate effect and this shifts the equilibrium to the left producing more acetic (ethanoic) acid molecules. The answer is 'a'.

8.(2013:19-c) $HC\ell$ and K_2CO_3 are a strong acid-weak base combination. The equivalence point in this reaction lies in the acidic pH range of 3.1 to 4.6. Bromocresol green is the most suitable indicator from this list as its end point lies closer to the equivalence point in this titration. The answer is 'c'.

9.(2014:13-d) Equilibrium constant gives an indication of the extent to which an acid ionises in aqueous solutions. A high dissociation constant indicates that the dissociation proceeds to a larger extent. Therefore, $H_2C_2O_4$ with an acid dissociation constant of 5.4×10^{-2}, is the strongest acid, as this acid dissociates to a largest extent among the four given. The answer is 'd'.

10.(2014:14-c) $(NH_4)_2SO_4$ is the salt of a strong acid and a weak base. Therefore, it is acidic with a pH of less than 7. It hydrolyses to give H_3O^+ ion. ($NH_4^+ + H_2O(\ell) \rightleftharpoons NH_3 + H_3O^+(aq)$).
$HC\ell$ is a strong acid with a very low pH. It hydrolyses. ($HC\ell(g) + H_2O(\ell) \rightarrow H_3O^+(aq) + C\ell^-(aq)$).
$NaNO_3$ is a neutral salt of a strong acid and a strong base and has a pH of 7.
K_3PO_4 is a basic salt of a strong base and a weak acid with a pH of more then 7, as the resulting solution is more basic. ($PO_4^{3-}(aq) + H_2O(\ell) \rightarrow HPO_4^{2-}(aq) + OH^-(aq)$). Therefore, the answer is 'c'.

11.(2014:15-d) In the equation, $OBr^-(aq) + H_2O(\ell) \rightleftharpoons HOBr(aq) + OH^-(aq)$, H_2O is the species that donates a proton to OBr^- and becomes OH^-. Therefore, $H_2O(\ell)$ is the acid and $OH^-(aq)$ is the conjugate base. The answer is 'd'.

12.(2014:16-d) Statements I, II and IV are correct. As temperature increases, a neutral solution produces more but equal number of H^+ and OH^- ions. As the hydrogen ion concentration increases, the pH decreases. Statement III is incorrect because it is contrary to the fact if $[H_3O^+]$ is greater than $[OH^-]$, the pH must be less than 7. The answer is 'd'.

13.(2014:19-c) In the reaction, $NH_3(aq) + H_2O(\ell) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$, the added acid reacts with the OH^- ions, thus lowering its concentration. Equilibrium, then, shifts to the product side producing more NH_4^+ and OH^- ions. Net result is an overall increase in the concentration of NH_4^+ ions. The answer is 'c'.

14.(2015:15-d) Answer 'd'. Irrespective of the strength of an acid or base the mol ratio does not change.

15.(2015:16-b) Answer 'b'. pH of < 0 suggests [H+] of > 1 mol L^{-1} pH + pOH still = 14.

16.(2015:18-d) Answer 'd'. HCO_3^- gains a proton in the forward reaction and HS^- gains one in the reverse reaction.

17.(2015:19-c) Answer 'c'. All demonstrate change in pH with hydrolysis except $NaC\ell$ – a neutral salt.

18.(2015:21-c) Answer 'c'. The others can be considered as outliers.

19.(2016 SP:04-d) The Brønsted-Lowry model is about accepting and losing protons. Answer 'd' is an acid/carbonate reaction. The answer is 'd'.

20.(2016 SP:10-a) Original pH was 8.2 = $[H^+]$ of 6.31×10^{-9} and the new $[H^+] = 7.94 \times 10^{-9}$ so there was a 20% change. The answer is 'a'.

21.(2016:07-b) Leaving the funnel in place will add drops after the initial reading, having many people making readings will add random errors, rinsing with distilled water will dilute the titrant but measuring from the bottom of the meniscus for both the initial and final reading is not an error so the answer is 'b.'

22.(2016:09-a) A diprotic acid has two protons e.g. H_2SO_4. As the mol ratio of $NaOH:H_2SO_4$ is 2:1 we need half the mol. The answer is 'a'.

23.(2016:10-b) A conjugate acid base pair must differ by only one hydrogen. So a and d are eliminated. Answer c is a redox reaction. The answer is 'b'.

24.(2016:11-d) The Brønsted-Lowry model deals with gain and loss of H^+ and uses H_2O and H_3O^+ so answer 'a' is wrong. Answers 'b' and 'c' are not balanced so the answer is 'd'.

25.(2016:12-d) The question seeks to clarify the difference between end point and equivalence point so answer 'a' is wrong. Answer 'b' is only right if the stoichiometric ratio is 1:1 and the concentrations are 1:1 or the stoichiometric ratio × 1/concentration is a constant. Answer 'c' is wrong because the pH is not 7 when weak acids or bases are titrated against strong ones. The answer is 'd'.

26.(2017:01-d) This question combines knowing of what an acid is and knowing the names of a very limited number of strong acids; including nitric, hydrochloric and sulfuric. The answer is 'd'

27.(2017:08-d) The question reinforces the need to write an equation before starting a chemistry problem. The mol ratio is 2:1 so the volumes will be in the same ratio. You should also note the base was in the flask so the answer is 'd'.

Chapter 3: Oxidation–Reduction

1.(2011:24-c) In order to be a reducing agent, an element should have a very low reduction potential. Chlorine has a higher reduction potential of +1.36 V among the four listed and hence is better suited as an oxidising agent rather than a reducing agent. The answer is 'c'.

2.(2011 S2:10-b) Answer b: As copper changes from +2 to 0 it is reduced. So therefore carbon was the reductant.

3.(2011 S2:11-c) Answer c: Manganese has been oxidised and the lead reduced. So as oxidation is loss of electrons they have been transferred to the lead.

4.(2011 S2:12-c) Answer c: $C\ell$ has a negative oxidation number. All the others are positive.

5.(2012:09-b) In the reaction, $2\,A\ell(s) + Cr_2O_3(s) \rightarrow A\ell_2O_3(s) + 2\,Cu(s)$, Aluminium (Oxidation state of $A\ell = 0$) is oxidised to $A\ell_2O_3$ (Oxidation state of $A\ell = +3$) by Cr_2O_3. Therefore, Cr_2O_3 is the oxidant (oxidising agent). In this oxidation process, Cr_2O_3 (Oxidation state Cr = +6) is reduced to metallic chromium (Oxidation state of Cr = 0).

6.(2012:10-c) MnO_4^- is commonly used as an oxidising agent. On some industrial and laboratory processes, others such as H_2O and CO_2 are sometimes used, but they are not common.

7.(2012:11-c) Using the half-cell potentials provided in the Standard Reduction Potential Table, it is easy to identify the reaction that is **most** spontaneous. In this reaction as in any other redox reactions, a species of a lower reduction potential supplies electrons to a species of a higher reduction potential. This occurs in the reaction, $Cu^{2+}(aq) + Ni(s) \rightleftharpoons Cu(s) + Ni^{2+}(aq)$. The net reaction potential is +0.58 V. The relevant half-reactions and the redox reaction are:

$Cu^{2+}(Aq) + 2\,e^- \rightarrow Cu(s)$	+0.34 V	Reduction	
$Ni(s) \rightarrow Ni^{2+}(aq) + 2\,e-$	+0.24 V	Oxidation	
$Cu^{2+} + Ni(s) \rightleftharpoons Ni^{2+} + Cu(s)$	+0.58 V	Redox	The answer is 'c'.

8.(2012 S2:09-c) Answer c: The element to the right on the Periodic Table takes the negative ON.

9.(2012 S2:14-c) Answer c: At the knife we want silver ion to become silver atoms. Thus we want reduction and the knife must be the cathode. To supply silver ions we need an electrolyte of silver ions.

10.(2013:09-b) The following changes in oxidation number occur in this equation:

$2\,H^+(aq) + 2\,NO_3^-(aq) + H_2S(g) \rightarrow 2\,NO_2(aq) + S(s) + 2\,H_2O(\ell)$

In this equation, the changes in the oxidation numbers are:

H = No change

N = Changes from +5 to +4

O = No change

S = Changes from –2 to zero.

Therefore, the oxidation number of 'N' decreases from +5 to +4. The answer is 'b'.

11.(2013:10-a) Using the E° values from the Standard Reduction Potentials at 25°C, you can calculate the nett cell potentials for the following: A negative nett cell potential indicates no reaction.

MnO_4^- and I^-	+0.97 V
$C\ell_2$ and H_2S	+1.19 V
$Cr_2O_7^{2-}$ and F^-	–1.53 V
Fe^{2+} and Ni	–0.20 V
Cu and $HC\ell$	–0.34 V

Therefore, only the first two reactions will occur. The answer is 'a'.

12.(2013:11-d) Using the E° value for the reaction, $O_2(g) + 2\,H^+(aq) + 2e^- \rightarrow H_2O_2 = +0.70$ V, you can notice that all the E° values given in the additional table for the six reactions are higher. Therefore, H_2O_2 will be oxidized in all the reactions to produce oxygen gas. The answer is 'd'.

13.(2013 S2:20-b) Answer b: The anode is the site of oxidation. There electrons are produced. They are consumed in reduction at the cathode. So electrons flow anode to cathode.

14.(2014:17-a) Statement I is correct. S in SO_2 (+4) is oxidised to S in SO_4^{2-}(+6).

Statement II is incorrect. The oxidation state of H^+ remains unchanged.

Statement III is incorrect. $C\ell O^-$ is, in fact, the oxidising agent. It oxidises SO_2 to SO_4^{2-}.

Statement IV is incorrect. Water is not oxidised. It is, in fact, reduced.

The correct answer is 'a'.

15.(2014:18-c) The first three reactions will occur as they have a net positive reaction potential.

I	$I_2 + 2\,e^- \rightarrow 2\,I^-$	+0.54 V	
	$H_2S \rightarrow S + 2\,H^+ + 2\,e^-$	–0.17 V	Net reaction potential = +0.37 V
II	$Br_2 + 2\,e^- \rightarrow 2\,Br^-$	+1.08 V	
	$Fe^{2+} \rightarrow Fe^{3+} + e^-$	–0.77 V	Net reaction potential = +0.31 V
III	$A\ell \rightarrow A\ell^{3+} + 3\,e^-$	–1.68 V	
	$2\,H^+ + 2\,e^- \rightarrow H_2$	0.00 V	Net reaction potential = +1.68 V
IV	$Co \rightarrow Co^{2+} + 2\,e^-$	+0.28 V	
	$Cr^{3+} + 3\,e^- \rightarrow Cr$	–0.74 V	Net reaction potential = –0.46 V

The last reaction (IV) will not occur as it has a net negative cell potential. In other words, cobalt has a greater tendency to be reduced and chromium has a greater tendency to be oxidised. The answer is 'c'.

16.(2014 S2:12-b) Answer b: At the anode oxidation occurs. Oxidation is loss of electrons. The chloride ions lose electrons to form chlorine.

17.(2014 S2:14-b) Answer d: Hydrogen ON is +1 except in hydrides, oxygen ON is –2 except in peroxides. The sum of oxidation numbers is zero as the molecule has no charge. The ON of S is +6.

18.(2015:01-a) Answer 'a'. Using rules for assigning ON.

19.(2015:05-b) Answer 'b'. E° = +0.59.

20.(2015:08-a) Answer 'a'. No precipitate and no reaction.

21.(2015:10-c) Answer 'c'. Nickel and chromium are green but lead will not react.

22.(2015:17-b) Answer 'b'. 1.28 V.

23.(2016 SP:15-c) In this cell Mn will be oxidised and Ag^+ will be reduced.

E° values: Mn + 1.18
Ag^+ + 0.80
Total E° = +1.98. The answer is 'c'.

24.(2016 SP:16-c) A fuel cell is a REDOX cell utilising gases. So answer (i) is correct. Answer (ii) is correct. As the main product of hydrogen fuel cells is water vapour it is a low-emission technology. They cannot be recharged by reversing the flow of electricity. The answer is 'c'.

25.(2016:13-d) Calculation of oxidation numbers is specifically mentioned in the syllabus. The negative ON is awarded to the element closest to fluorine. So for nitrogen, Step 1: $0 \rightarrow -3$, Step 2: $-3 \rightarrow +2$, Step 3: $+2 \rightarrow +4$, Step 4: $+4 \rightarrow +5$ a change of 1. The answer is 'd'.

26.(2016:14-a) Students might see chromate and dichromate and assume it is a redox reaction in part a. It is in fact acid/base. In all other cases the ON of chromium changes. The answer is 'a'.

27.(2016:15-c) This question can be solved using the Data Book. Reducing agents get oxidised so we need to look at equations where the substance is losing electrons. Check the E° values of the reactions making sure you have them all as oxidation reactions. The answer is 'c'.

28.(2016:16-c) This question can be solved using the Data Book. Find the E° values of each of the half-equations. Add them and find which total is negative – i.e. it is NOT spontaneous. The answer is 'c'.

29.(2016:17-a) The element C reduced both A^{2+} and B^{2+}. Thus it is the most powerful reducing agent. A reduced B^{2+} so the answer is 'a'.

30.(2017:02-b) An exercise in using the oxidation number rules that you should know. The answer is 'b'.

31.(2017:03-b) This question involves the understanding that for a fixed quantity of electrons the valency of an ion will determine how many mol of product will form. The answer is 'b'.

32.(2017:04-c) This question appeared in the 2016 examination as well. It recognises that both galvanic and electrolytic cells have external wires, electrodes and redox reactions. The answer is 'c'.

33.(2017:09-c) Corrosion is a redox process and this question is essentially asking which of these is not a redox process. Iron(III) chloride dissolving is not redox. The answer is 'c'.

34.(2017:10-a) Before wasting time in calculating the E° for every equation perhaps stop and think. In (d) iodine cannot displace chlorine (it is further down the group). In (c) silver ion and bromide ion will not form elements. In (b) gold does not rust we know that. Then using E° check (a). The answer is 'a'

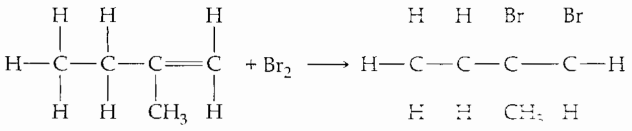
Chapter 4: Organic Chemistry

1.(2011:08-d) Here is an analysis of the four structural formulae given.
Compound I is an ester. The 'COO' functional group can be recognised.
Compound II is a carboxylic acid. The 'COOH' functional group can be recognised.
Compound III is a ketone. The 'CO' functional group can be recognised.
Compound IV is an aldehyde (alkanal). The 'CHO' functional group at the end can be recognised.
Therefore, the correct order is provided in alternative 'd'.

2.(2011:09-d) propan-1-ol ($CH_3CH_2CH_2OH$) is a primary alcohol. On mild oxidation, it can become propanal (CH_3CH_2CHO).
The half-reaction is $CH_3CH_2CH_2OH \rightarrow CH_3CH_2CHO + 2\,H^+ + 2\,e^-$
On strong oxidation, it can become propanoic acid (CH_3CH_2COOH).
The half-reaction is $CH_3CH_2CH_2OH + H_2O \rightarrow CH_3CH_2COOH + 4\,H^+ + 4\,e^-$
The answer is 'd'.

3.(2012:22-c) A *cis/trans* isomer results from the presence of a double bond and is also called a *cis/trans* isomer which exists only in alkenes. An examination of the four given alternatives indicates that structures 'i' and 'iv' are *cis/trans* isomers. The answer is 'c'.

4.(2012:24-a) The reaction of bromine with compound iii (2-methylbut-1-ene), is an addition reaction. The bromine atoms bond with the carbon atoms on either side of the double bond to form 1,2-dibromo-2-methylbutane.
The structural equation is presented below. The answer is 'a'.



2-methylbut-1-ene 1, 2-dibromo-2-methylbutane

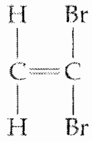
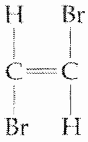
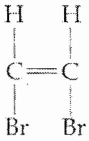
5.(2013:22-d) The functional groups are
I) Aldehyde (–CHO) II) ketone (R-CO-R) III) carboxylic acid (–COOH) IV) ester (RCOOR) The answer is 'd'.

6.(2013:23-b) Compound II is a ketone (pentan-2-one). Ketones are produced by the oxidation of secondary alcohols. The 'CO' functional group is located as the second carbon atom in the ketone. This ketone is formed by the removal of the two hydrogen atoms from this carbon atom in the alcohol chain. Therefore, the secondary alcohol should be $CH_3CH_2CH_2CHOHCH_3$ which gives the ketone, $CH_3CH_2CH_2COCH_3$. The answer is 'b'.

7.(2013:24-c) A carboxylic acid would react with an alcohol in the presence of an acid which would obviously form an ester. Therefore, the compound is III, $CH_3CH_2CH_2CH_2COOH$. The answer is 'c'.

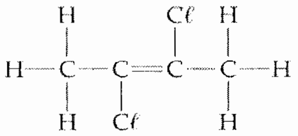
8.(2013:25-d) The compound is *cis*-pent-2-ene. It additively combines with iodine decolourising it to form 2,3-dibromopentane. As a non-polar substance it will dissolve in non-polar hexane. Following the addition, it can react with chlorine to form a substituted product. Therefore, all statements are true. The answer is 'd'

9.(2014:21-b) The compound $C_2H_2Br_2$ has three isomers. The answer is 'b'.

 1,1-dibromoethene	 *trans*-dibromoethene	 *cis*-dibromoethene

10.(2014:23-b) The reaction that produces $C_4H_8Br_2$ is, $C_4H_8 + Br_2 \rightarrow C_4H_8Br_2$.
This is bromination – an addition reaction of butene.
The hydrogenation reaction for butene produces butane. $C_4H_8 + H_2 \rightarrow C_4H_{10}$.
Therefore, X = C_4H_8, and Y = C_4H_{10}. The answer is 'b'.

11.(2014:24-a) The redrawn structure of the compound is shown below showing the linearity of the carbon chain.



The IUPAC name of the compound is 2,3-dichloro-*trans*-but-2-ene. The answer is 'a'.

12.(2015:14-a) Answer 'a'. Hydrogen bonding causes more solubility in water than dispersion forces.

13.(2015:22-b) Answer 'b'. Dispersion forces < hydrogen bonding < hydrogen bonding and dipole bonding.

14.(2015:23-d) Answer 'd'. Double bonds engage in addition polymerisation.

15.(2015:24-d) Answer 'd'. Addition is always across the double bond.

16.(2015:25-b) Answer 'b'. III cannot accept or donate H bonds.

17.(2016 SP:17-c) Secondary alcohols can be oxidised to form ketones. $CH_3CH(OH)CH_3$ is a secondary alcohol. The answer is 'c'.

18.(2016 SP:20-c) Barium sulfate is insoluble. Number (iv) can donate hydrogen bonds and accept them in two places so wi be very soluble. Number (ii) can accept and donate hydrogen bonds so will be quite soluble. The answer is 'c'.

19.(2016 SP:23-a) To form a polymer we need a link to be formed between monomers. Substance (a) has carboxylic acid groups and could form ester linkages. So with (iv) this could form a polymer. (ii) and (iii) cannot form linkages. The answer is 'a'.

20.(2016 SP:24-a) The primary structure of a protein is the covalently bonded polypeptide polymer. Its 'R' groups are determined by the amino acids in the polymer. The functional groups in the 'R' groups determine the tertiary structure. If two polymers have similar functional groups they will have similar tertiary structures and hence similar shape. Function is dependent on shape. The answer is 'a'.
The strength of the interaction between ethanol molecules and water molecules are stronger than the internal interactions of both so ethanol dissolves in water – therefore they are miscible.

21.(2016:18-b) The –CH = O group is an aldehyde. Aldehydes always appear at the end of a chain. The base substance is therefore butanal. The answer is 'b'.

22.(2016:19-d) The reactions are addition to an alkene, oxidation of an aldehyde, esterification, and neutralisation acid with a carbonate. The answer is 'd'.

23.(2016:20-c) To make a polymer either an alkene is needed (to make an additional polymer) or the necessary groups to form a condensation polymer (polyester or polyamide). Addition is possible with I and III, while a polyester can form with II, III and V. The answer is 'c'.

24.(2016:21-d) An α-amino acid has a central α carbon a COOH, one side group (or an H) and an NH_2. In 'a' there is no central C, 'b' has two central carbons, 'c' has two groups. The answer is 'd'.

25.(2017:14-c) To be isomers the molecules must have the same molecular formula. The answer is 'c'.

26.(2017:15-b) The question checks recognition of the fact that an amino acid contains a COOH acid group that will react with a strong base to form COO^-. The answer is 'b'.

27.(2017:16-b) The syllabus requires knowledge of the chemical properties of functional groups and 'these reactions can be used to identify the functional group present within the organic compound'. In turn the tests show it can be oxidised, it is flammable, it has an OH group and it is either a carboxylic acid or an alcohol. The answer is 'b'.

28.(2017:17-a) A question straight from the syllabus: 'the sequence of α-amino acids in a protein is called its primary structure.' The answer is 'a'.

29.(2017:19-a) This question is taken directly from the syllabus and identifies the acid and base properties of amino acids. The NH_2 accepts a proton and the COOH loses one. The answer is 'a'

30.(2017:20-d) This question is taken directly from the syllabus. The 'lock and key' model of protein function means the shape is the essential characteristic in protein function and this is due to the structure or shape. The answer is 'd'.

Chapter 5: Synthesis

1.(2016 SP:22-b) To form an ester an alcohol and a carboxylic acid are required. The ethene can form ethanol by an addition reaction in the presence of water, and the ethanol can be oxidised to form ethanoic acid. These two substances can react to form ethyl ethanoate. The answer is 'b'.

2.(2016:05-b) This is an equation mentioned in syllabus and should be known. NaOH produces soap while methanol produces the transesterification reaction making biodiesel. The answer is 'b'.
3.(2016:22-a) Hardness is a measure of calcium ion concentration. This is measured by volume of soap reacted. Other salts (chlorides etc.) will respond to silver ions or raise the boiling point but they have nothing to do with hardness. Only soap solution is indicative of hardness. The answer is 'a'.
4.(2016:23-b) Reaction X is a REDOX reaction with catalyst but this is not one of the answers offered. The best answer is 'b'.
5.(2016:24-c) This is a known reaction from the syllabus. The answer is 'c'.
6.(2016:25-a) This is a known reaction from the syllabus. The answer is 'a'.
7.(2017:11-d) There are 12 principles of green chemistry you should have read. The minimising toxic waste and by-products is essential. The answer is 'd'.
8.(2017:13-c) Rate determining steps have not been examined previously in the WACE. The idea is that in a sequence of reactions the overall reaction rate is dependent on the slowest step. The answer is 'c'.
9.(2017:21-c) The syllabus states 'the structure of the anionic detergents derived from dodecylbenzene contains a non-polar hydrocarbon chain and a sulfonate group'. You should know what a sulfonate group is. The answer is 'c'.

Chapter 6: Science Enquiry Skills

1.(2012:13-c) $NaHCO_3$ powder is used as conc sulfuric acid reacts violently with water. Solutions cannot be used. It neutralises the acid according to the reaction, $NaHCO_3(s) + H_2SO_4(aq) \rightarrow Na^+(aq) + HSO_4^-(aq) + CO_2(g) + H_2O(\ell)$. The answer is 'c'
2.(2016 SP:11-b) Systematic error is caused by faulty equipment or faulty methodology and cannot be reduced by repeating an experiment. A pipette offers more sig figs and will lower random error. Answer is 'b'.
3.(2016:06-d) A systematic error can be identified by data that is precise (many values close together) but wrong. The answer is 'd'.
4.(2017:22-d) The independent variable was varied and the effect on the other variables was measured. This makes it the independent variable. The answer is 'd'.
5.(2017:23-c) The data involved numbers (quantitative) and was collected by the experimenter (thus it was primary data). The answer is 'c'.
6.(2017:24-a) The data was consistently wrong which means it was not random error. It was systematic caused by a wrong technique or poor equipment. The answer is 'a'.
7.(2017:25-d) The technique would mean there were differing methods used and the data would be less reliable. The answer is 'd'.

Chapter 7: Chemical Equilibrium

1.(2011:28)

Temperature (°C)	**Phase**				**Shift in equilibrium (right, left or no change)**
	CH_3OH	**$HC\ell$**	**$CH_3C\ell$**	**H_2O**	
-50	L	G	L	S	Right
40	L	G	G	L	No change
70	G	G	G	L	Right
110	G	G	G	G	No change

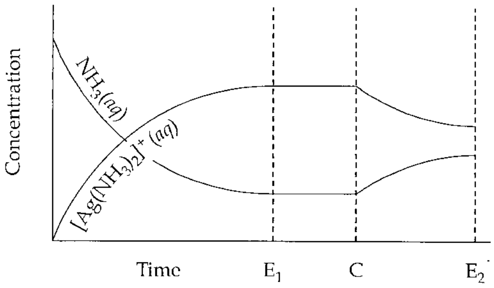
2.(2012:29) The white solid in this reaction is in equilibrium with concentrated $HC\ell$. The reaction is:
$BiOC\ell(s) + 2\,H^+(aq) \rightleftharpoons Bi^{2+}(aq) + C\ell^-(aq) + H_2O(\ell)$
Three test tubes of equilibrium solutions A, B and C were prepared by adding excess $BiOC\ell$ to concentrated H_2SO_4. When changes are made as shown in column two, completion of the table is required.

Test tube	**Change**	**Direction of shift in equilibrium ('left' 'right' or 'no change')**	**Explanation**
A	3 mL of water is added	No change	The water lowers the concentration of all species. As there are equal moles on each side both sides are equally affected and both the forward and reverse rates are lowered equally.
B	A few drops of concentrated nitric acid are added	Shifts to the right	Adding concentrated nitric acid does not dilute the solution as in (A) but increases the concentration of H^+ ions. Thus the forward reaction rate increases while the backward is unchanged. So the equilibrium shifts to the right.
C	A few drops of concentrated silver nitrate are added	Shifts to the right	Added Ag^+ ions react with $C\ell^-$ ions to produce $AgC\ell(s)$ precipitate. Therefore the concentration of $C\ell^-$ falls and the reverse rate of reaction falls. The forward reaction is unchanged and thus the equilibrium shifts to the right resulting in more $BiOC\ell$ dissolving

3.(2012:30) AgCℓ solid dissolves in ammonia solution to form a complex ion as shown in the following equilibrium reaction: AgCℓ(*s*) + 2 NH_3(*aq*) ⇌ $[Ag(NH_3)_2]^+$(*aq*) + $C\ell^-$(*aq*). The equilibrium constant (K_c) is greater than 1. This means that the concentration of the products is greater than the concentration of the reactants.

a) The following graph shows how the concentrations change as the system approaches equilibrium at time E, and continues on to time C. The graph also shows the concentration changes to NH_3 and $[Ag(NH_3)_2]^+$(*aq*) wher NaCℓ is added to the system.

AgCℓ(*s*) + 2 NH_3(*aq*) ⇌ $[Ag(NH_3)_2]^+$ (*aq*) + $C\ell^-$(*aq*)



b) As NaCℓ is added to the system, the chloride ion concentration increases and the equilibrium shifts to the left. decreasing the $[Ag(NH_3)_2]^+$ and increasing the concentration of $[NH_3]$. More AgCℓ is precipitated.

4.(2013:30) Note sections of syllabus 1.7 to 1.9 make it clear that you cannot use Le Châtelier's Principle to 'explain' only to 'predict'.

The reaction should be written like this.

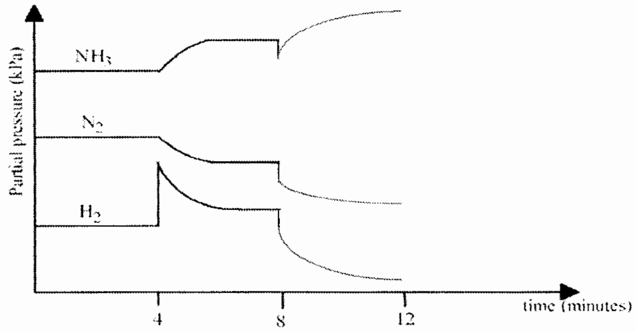
$$4\ NH_3(g) + 5\ O_2(g) \rightleftharpoons 4\ NO(g) + 6\ H_2O(g) + \text{Heat}$$

Change	**Change in concentration of NH_2(g)**	**Brief explanation**
The volume of the reaction vessel is doubled	Decrease	The pressure in the system decreases. Therefore the volume of the system increases. As c = n/V the concentrations decrease for all species. So both the forward and reverse reactions will have a lower rate. The reverse more so because there are 10 mol on the RHS. Therefore there will be more product formed.
The temperature of the reaction system is doubled	Increase	The increase in temperature of the system favours the endothermic reaction. In an energy diagram for this reaction the E_a of the reverse reaction is larger than the E_a of the forward reaction. At an elevated temperature more product particles can achieve E_a and the reverse rate will rise. Thus the reaction moves to the LHS.
N_2(*g*) is injected into the reaction system while keeping the volume constant	No change	You will often see questions with an unusual substance added. Sometimes it reacts (sometimes by precipitation) but in this case N_2 gas does not participate in any reaction. It increases the pressure but does not change the volume. So as c = n/V there is no change in the concentration and no change in the rate of reaction. No change in NH_3 concentration.
Water vapour is injected into the reaction system while keeping the volume constant	Increase	Usually water is in the (ℓ) liquid state and does not take part in the equilibrium considerations. Here, however, it is in the vapour state, there is an increase in the concentration of product. This increases the rate of the reverse reaction increasing the concentration of ammonia. The equilibrium moves to the LHS.

5.(2015:30) a) Between 0 and 4 minutes, the partial pressures of all gases were constant.

b) H_2 gas was added.

c) There was an immediate decrease, then the [NH_3] rose and the others fell in stoichiometric ratios, then equilibrium was established.



6.(2015:38) a)

Additions to the test tube	Change in concentration from initial equilibrium to final equilibrium (increase, decrease, unchanged)			Colour favoured (pink, blue or unchanged)
	[$Co(H_2O)_6^{2+}$]	[$C\ell^-$]	[$CoC\ell_4^{2-}$]	
1. add $H_2O(\ell)$	decrease	decrease	decrease	pink
2. add $HC\ell$ (*aq*)	decrease	increase	increase	blue
3. add $AgNO_3$(*aq*)	increase	decrease	decrease	pink

b) A white precipitate forms

c) Adding $HC\ell(aq)$ increases the concentration of chloride ions and the number of collisions between $Co(H_2O)_6^{2+}$ and $C\ell^-$ increases. The rate of the forward reaction increases relative to the reverse reaction and hence equilibrium shifts to the right. This leads to a greater concentration of the blue $CoC\ell_4^{2-}$ and a lower concentration of the pink $Co(H_2O)_6^{2+}$ ion, so the solution looks more blue.

d) Decreasing the temperature shifts the equilibrium position to the left favouring the production of $Co(H_2O)_6^{2+}(aq)$, a pink solution. According to Le Châtelier's Principle decreasing the temperature favours the exothermic reaction to oppose the change. Since the reverse reaction has been favoured, that is the exothermic reaction. So the forward reaction is endothermic.

e) Any hazard relevant to this specific experiment. eg the disposal of concentrated hydrochloric acid. Any method that is relevant eg dilute with large amounts of water when emptying down the sink.

7.(2016 SP:34) Calcium carbonate does dissolve at the rate of 0.13 g/L and the ocean is a saturated solution of calcium carbonate (equation 3) and it is this source of carbonate ions that corals and shellfish use to create their exoskeleton.

Equation 1 $\quad CaCO_3\,(s) \rightleftharpoons Ca^{2+}(aq) + CO_3^{2-}(aq) \quad K = 3.3 \times 10^{-9} = \dfrac{[Ca^{2+}]\,[CO_3^{2-}]}{1}$

Atmospheric carbon dioxide is in equilibrium with dissolved carbon dioxide in the ocean

Equation 2 $\quad CO_2(g) \rightleftharpoons CO_2(aq)$

The dissolved carbon dioxide undergoes hydrolysis (equation 2).

Equation 3 $\quad CO_2(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + HCO_3^-(aq) \quad K_1 = \dfrac{[H_3O^+]\,[HCO_3^-]}{[CO_2]}$

As the concentration of dissolved CO_2 increases the pH of the ocean falls, becoming more acidic.

The excess H^+ formed as the ocean becomes more acidic (equation 3) reacts with soluble carbonate in the ocean (equation 4) resulting in an increase in the concentration of HCO_3^- (equation 4).

Equation 4 $\quad CO_3^{2-}(aq) + H_3O^+(\ell) \rightleftharpoons HCO_3^-(aq) \quad K_2 = \dfrac{[H_3O^+]\,[CO_3^{2-}]}{[HCO_3^-]}$

Coral body is built from calcium carbonate when the coral combine with carbonate ions from the water.

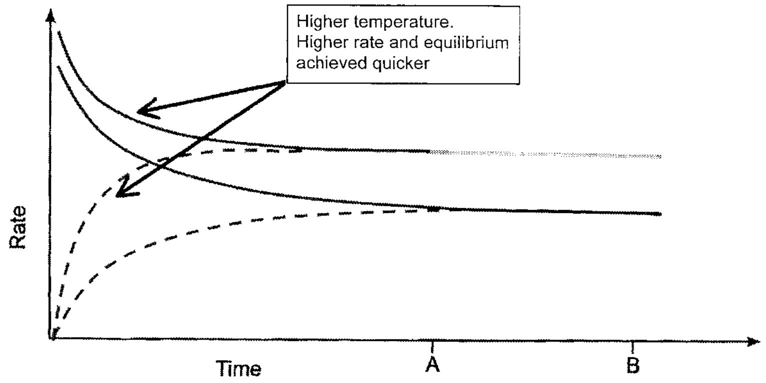
Equation 5 $\quad Ca^{2+}(aq) + CO_3^{2-}(aq) \rightarrow CaCO_3(s)$

In accordance with Le Châtelier's Principle as the hydrogen ion removes carbonate ion in equation 4 it will force equation 1 to the right to replace some of the carbonate. Not all is replaced because the [Ca^{2+}] is rising and to maintain K the carbonate decreases. There is an effective lowering of carbonate ion concentration.

8.(2016:41) a) $K = \dfrac{pNO_2(g)^2}{pN_2(g)pO_2(g)^2}$ or $K = \dfrac{[NO_2]^2}{[N_2][O_2]^2}$

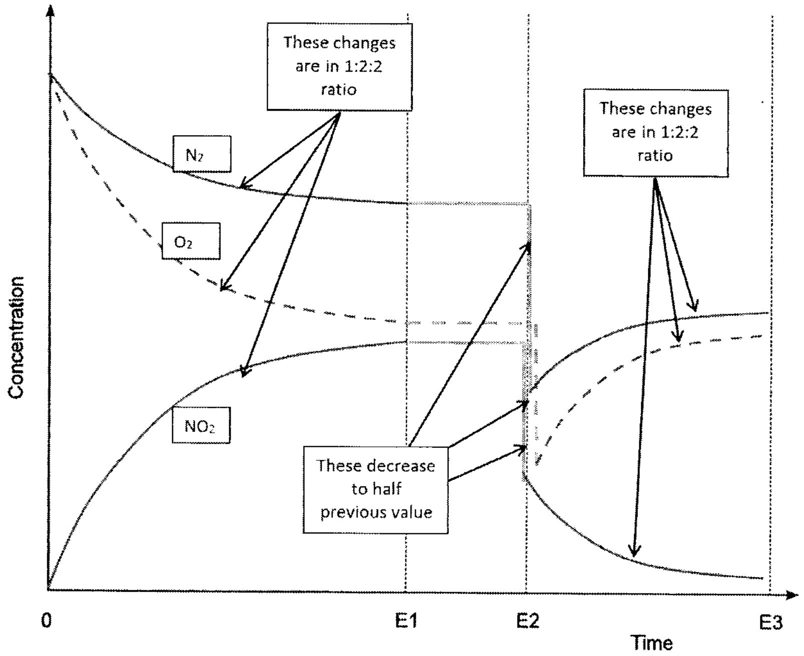
b) No change in K

c) i) and ii)



Higher temperature.
Higher rate and equilibrium achieved quicker

d) and e)



These changes are in 1:2:2 ratio

These changes are in 1:2:2 ratio

These decrease to half previous value

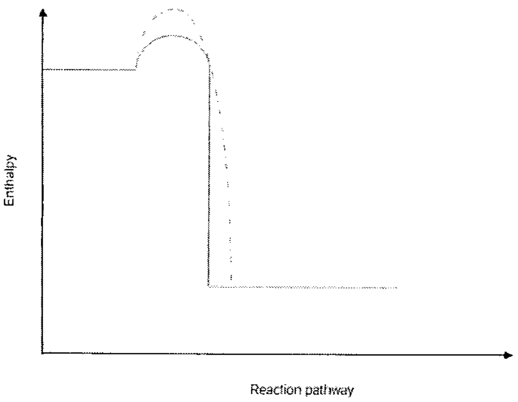
f) As the reactants are favoured, the equilibrium constant would be small. The activation energy would be large.

9.(2017:28) a)

Change imposed by the addition of	Effect on forward reaction rate when equilibrium	Effect on pH when equilibrium is re-established
a few drops of concentrated hydrochloric acid	increase	decrease
a few drops of concentrated lead(II) nitrate solution	decrease	decrease
distilled water	decrease	increase

b) The pH will decrease (fall). The increase in temperature provides more heat to the reaction. According to LCP the endothermic reaction will be favoured. This is the forward reaction. So there will be more products and the $[H_3O^+]$ will rise. Thus the pH will decrease.

10.(2017:33) a)

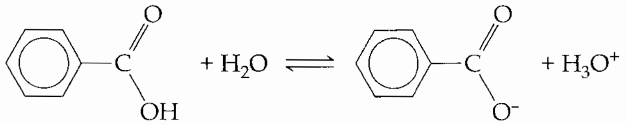


b) on diagram

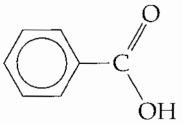
c) The secret to this question is the phrase 'Typically, dynamite is between 25% to 50% nitroglycerin.' Given the molar masses are nearly identical we can see that for the same mass we will have the same mol. So dynamite gives 5 MJ and TNT gives 4MJ for the same number of mol. But the question asks for 'active ingredient' and in dynamite that is nitroglycerin at … say 25%. So the nitroglycerine gives us 20MJ/mass. So the answer is nitroglycerine (not dynamite) produces 5 times as much energy as TNT.

Chapter 8: Acids and Bases

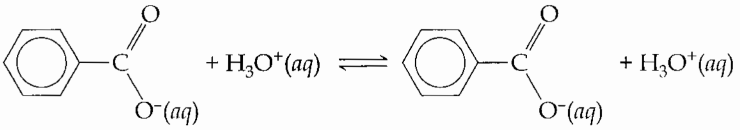
1.(2010:29) a) $C_6H_5OH + H_2O \rightleftharpoons C_6H_5COO^- + H_3O^+$



b) In the acidic environment of the stomach which produces gastric juice that contains hydrochloric acid, the concentration of H_3O^+ ions is rather high. This shifts the equilibrium to the left favouring more reactants. Furthermore, benzoic acid is an organic acid and the extent of its ionisation is much less than inorganic acids. Therefore, the predominant species in the acidic environment of the stomach would be benzoic acid. The structure of benzoic acid is given below.



c) Benzoic acid and benzoate ion can exist as a buffer system as they are a weak acid-conjugate base pair. It can resist a change in pH by reacting with both OH^- ions and H_3O^+ ions as shown below, resulting in equilibrium shifts either way.
Reaction with H_3O^+ ions: $H_3O^+ + C_6H_5COO^- \rightleftharpoons H_2O + C_6H_5COOH$
Reaction with OH^- ions: $OH^- + C_6H_5COOH \rightleftharpoons H_2O + C_6H_5COO^-$
The equilibrium reaction that occurs both ways is shown by a single equation below.



2.(2011:27a) Completing the following table by writing the formula for the conjugate base, species X, or, conjugate acid in the blank spaces.

Conjugate base	Species X	Conjugate acid
CH_3NH^-	CH_3NH_2	$CH_3NH_3^+$ (supplied)
$C_2O_4^{2-}$ (supplied)	$HC_2O_4^-$	$H_2C_2O_4$
$^-OOCCHOHCHOHCOO^-$	$HOOCCHOHCHOHCOO^-$ (supplied)	HOOCCHOHCHOHCOOH

3.(2011:29) Relevant equations to explain each of the observations shown in the table below:

Observation	Explanatory equation/s
The pH of a $NaHSO_4$ solution is 5	$HSO_4^-(aq) + H_2O(l) \rightleftharpoons SO_4^{2-}(aq) + H_3O^+(aq)$
A solution of $Mg(OH)_2$ is basic	$Mg(OH)_2(aq) \rightleftharpoons Mg^{2+}(aq) + 2OH^-(aq)$
A solution of Na_2PO_4 is basic, while A solution of KH_2PO_4 is acidic	$HPO_4^{2-}(aq) + H_2O(l) \rightleftharpoons H_2PO_4^-(aq) + OH^-(aq)$ $H_2PO_4^{2-}(aq) + H_2O(l) \rightleftharpoons HPO_4^{2-}(aq) + H_3O^+(aq)$

4.(2011:39) This calculation is based on determining the pH of individual solutions and that of the combined mixture. A 'limiting-excess reagent' analysis is to be applied for part b) of this calculation.

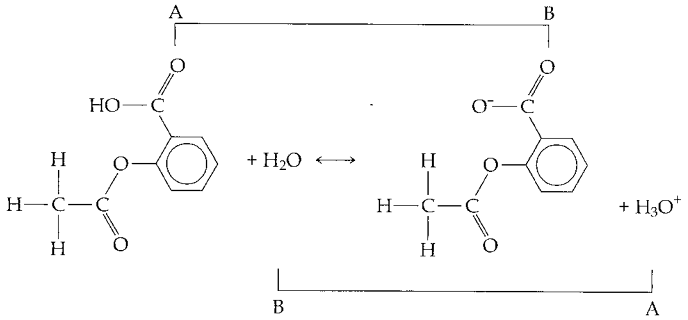
a) $[NaOH] = 0.4161\ mol\ L^{-1}$; Therefore, $[OH^-] = 0.4161\ mol\ L^{-1}$.
Therefore, $[H^+] = [(1.0 \times 10^{-14}) \div 0.4161] = 2.403 \times 10^{-14}\ mol\ L^{-1}$.
Therefore, $pH = -\log [2.403 \times 10^{-14}] = 13.619$ or, **13.6**

Alternative method
[OH] = 0.4161 mol L^{-1}; Therefore, pOH = –log [0.4161] = 0.381
Therefore, pH = 14.0 - 0.381 = 13.619 or, **13.6**

b) n ($HC\ell$) = c × V = 0.010 × 0.0465 = 4.65×10^{-4} mol
Therefore, n (H^+) in $HC\ell$ = 4.65×10^{-4} mol
n (HNO_3) = c × V = 0.0555 × 0.0657 = 0.003646 mol
Therefore, n (H^+) in HNO_3 = 3.636×10^{-3} mol
Therefore, Total number of mols of (H^+) = ($4.65 \times 10^{-4} + 3.636 \times 10^{-4}$) = 4.111×10^{-3} mol
n (NaOH) = c × V = 0.4161 × 0.0209 = 8.696×10^{-3} mol
Therefore, n (OH^-) are in excess by (8.696×10^{-3} mol - 4.111×10^{-3} mol) 4.585×10^{-3} mol.
Concentration of excess OH^- = [n (OH^-) ÷ Total volume]
= [(4.585×10^{-3}) ÷ (0.0465 + 0.0657 + 0.0209)] = [(4.585×10^{-3}) ÷ 0.1331] = 3.444×10^{-2} mol L^{-1}
Therefore, [H^+] = [(1.0×10^{-14}) ÷ 3.444×10^{-2}] = 2.904×10^{-13}
Therefore, pH = –log [H^+] = –log [2.904×10^{-13}] = 12.537 = **12.5**

Alternative method
[excess OH^-] = 3.44×10^{-2}mol L^{-1}
Therefore, pOH = –log [3.44×10^{-2}] = 1.463
Therefore, pH = (14.0 – 1.463) = 12.537 = **12.5**

5.(2012:35a) Structural equation for the ionisation of acetylsalicylic acid.



6.(2012:36) a) The reactions for the self-ionisation of water can be represented by:

$$2\,H_2O(\ell) \rightleftharpoons [H_3O^+](aq) + [OH^-](aq)$$

b) The relative concentrations of H_3O^+ and OH^- ions at 25°C are
[H_3O^+] = 1.0×10^{-7} mol L^{-1}; [OH^-] = 1.0×10^{-7} mol L^{-1}
Therefore, [H^+] = [OH^-]
The relative concentrations of H^+ and OH^- ions at 10°C are:
[H_3O^+] = 5.39×10^{-8} mol L^{-1} [OH^-] = 5.39×10^{-8} mol L^{-1}
Therefore, [H_3O^+] = [OH^-]

c) At 10°C, the concentrations of H^+ and OH^- are 5.39×10^{-8} mol L^{-1} each whereas as 25°C, the concentrations are 1.0×10^{-7} mol L^{-1} each. This indicates that water ionises more at a higher temperature. This shows that as temperature increases, the extent of ionisation increases favouring the products. Therefore, the self-ionisation of water is an endothermic process.

7.(2012:37) a) Properties of oxalic acid ($H_2C_2O_4 \bullet 2\,H_2O$) that makes it suitable as a good primary standard in volumetric analysis are:
i) It has a relatively high molar mass enabling a greater accuracy in determining concentrations.
ii) It is highly soluble and is obtained with a high degree of purity.
iii) It does not absorb moisture and does not react with any gases in the air when exposed and therefore maintains a stable concentration.
b) Steps to prepare a standard solution of an approximate 0.05 mol L^{-1} oxalic acid.
i) Calculate the mass required to prepare a 500.0 mL solution of Oxalic acid ($H_2C_2O_4 \bullet 2\,H_2O$)
n (acid) = c × v = 0.05 × 0.500 = 0.0250 mol
m (acid) = n × M = 0.0250 × 126.048 = 3.1512 g
ii) Weigh out 3.15 g of oxalic acid powder in a filter paper.
iii) Recalculate the concentration to be prepared:
n = (3.15 ÷ 126.048) = 0.0250 mol
c [Acid] = (0.0250 mol ÷ 0.500 L) = 0.050 mol L^{-1}
iv) Transfer the powder into a 50.0 mL beaker, washing the paper a few times to remove all the solid particles of the acid into the beaker. Stir the mixture in the beaker.
v) Transfer the solution into a 500.0 mL volumetric flask which is clean and dry. Wash the beaker with some distilled water a few times and transfer all the washings into the flask.
vi) Nearly half-fill the volumetric flask with distilled water. Closing the lid tightly and invert the flask a few times to make sure that all the solid dissolves.
vii) After the bubbles disappear, fill the flask up to the mark in the neck of the flask with a teat pipette until the lower level of the concave meniscus levels with the mark on the neck.
viii) Transfer the standard oxalic acid solution into a reagent bottle and label the bottle with the concentration and the date prepared.

8.(2012:42) a) The equilibrium constant expression for the reaction

$$C\ell_2(aq) + H_2O(\ell) \rightleftharpoons HOC\ell(aq) + H_3O^+(aq) + C\ell^-(aq) \text{ is,}$$

$$K_c\ (25°C) = \{[HOC\ell] \times [H_3O^+] \times [C\ell^-]\} \div [C\ell_2] = 3.94 \times 10^4$$

A very high value of K_c indicates a large amount of products, $HOC\ell$, H_3O^+ and $C\ell^-$ compared to the reactant ($C\ell_2$) at equilibrium at this temperature.

b) Consider the reaction,

$$HOC\ell(aq) + H_2O(\ell) \rightarrow H_3O^+(aq) + OC\ell^-(aq)$$

The introduction to this part of the question states that a pH of 7.5 maximises the concentration of hypochlorous acid ($HOC\ell$). You are asked to study both the equations and explain how this can happen.

Eqm. Reaction 1: $C\ell_2(aq) + H_2O(\ell) \rightleftharpoons HOC\ell(aq) + H_3O^+(aq) + C\ell^-(aq)$

Eqm. Reaction 2: $HOC\ell(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + OC\ell^-(aq)$

In equilibrium 1, if the pH is kept at less than 7, the increased concentration of H_3O^+ ions will shift the equilibrium to the left. This will result in less $HOC\ell$ being produced.

In equilibrium 2, When the concentration of $HOC\ell$ decreases (as is the case in reaction equilibrium 1), equilibrium now shifts to the left producing more hypochlorous acid ($HOC\ell$) and the pH decreases to less than 7.

At a pH of slightly more than 7 (which is a compromise), equilibrium 1 shifts to the right, but equilibrium 2 shifts to the left. This produces more hypochlorous acid ($HOC\ell$).

In summary, a relatively high pH will produce more hypochlorous acid.

c) The hypochlorous acid concentration needs to be 1.50 mg L^{-1}.

1.00 L needs 1.50 mg L^{-1}.

Therefore, 2.50×10^6 L needs $[(2.50 \times 10^6) \div (1.5 \div 1000)] = 3750$ g of $HOC\ell$

$n(HOC\ell) = (m \div M) = (3750\ g \div 52.458\ g\ mol^{-1}) = 71.49$ mol

According to reaction 1, $\{C\ell_2(aq) + H_2O(\ell) \rightleftharpoons HOC\ell(aq) + H^+(aq) + C\ell^-(aq)\}$

One mole of $C\ell_2$ produces one mole of $HOC\ell$ and 1 mole of $C\ell^-$.

Therefore, $n(C\ell_2) = n(HOC\ell) = 71.49$ mol

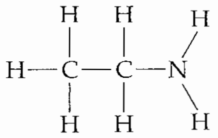
Applying the relationship, $PV = nRT$ and $V = (nRT \div P)$,

$V = [(71.49 \times 8.314 \times 298.15) \div 100] = 1772.111 = \mathbf{1.77 \times 10^3\ L}$

d) The balanced equation for the reaction of hypochlorite ion to give nitrogen trichloride and hydroxide ion is:

$$3\ OC\ell^-(aq) + NH_3(aq) \rightleftharpoons NC\ell_3(aq) + 3\ OH^-(aq)$$

e) The structure of a primary amine with two carbon atom.



$CH_3CH_2NH_2$

Ethanamine

9.(2013:31) a) Equation One: $HC_2O_4^-(aq) + H_2O(\ell) \rightleftharpoons C_2O_4^{2-}(aq) + H_3O^+(aq)$

Equation Two: $HC_2O_4^-(aq) + H_2O(\ell) \rightleftharpoons H_2C_2O_4(aq) + OH^-(aq)$

b) The pH is less than 7. This means the solution is acidic indicating a relative excess of H_3O^+ ions over OH^- ions. Therefore, the first reaction (Equation One) is quite possible. Therefore, the first equation should have a higher equilibrium constant. This constant is expressed as

$K = \{[C_2O_4^{2-}]\ [H_3O^+] \div [HC_2O_4^-]\}$

$HC_2O_4^-$ acts as a stronger acid compared to water.

Whether an anion shows acidic or basic properties in solution depends on the relative tendencies of these competing hydrolysis reactions. $HC_2O_4^{-1}$ is an acidic anion because it is a better proton donor than proton acceptor.

10.(2015:29) a) $c(H^+) = n/v = 8.50 \times 10^{-3}/\ 0.025 = 0.340$ mol L^{-1}

$pH = -\log[H^+] = -\log(0.340) = 0.469$

b) $n(OH^-) = cv = 0.3 \times 0.02 = 0.006$ mol

OH^- and H^+ react in 1:1 ratio

$n(H^+)$ in excess $= 0.0085 - 0.006 = 2.5 \times 10^{-3}$ mol

$c(H^+) = 2.5 \times 10^{-3}/0.045 = 0.0556$ mol L^{-1}

$pH = -\log\ [H^+] = -\log(0.0556) = 1.26$

11.(2015:40) b) The same pH means the same $[H^+]$. HF is a weak acid and does not ionise to the same extent as $HC\ell$. So a greater concentration of HF is needed to give the required $[H^-]$

c) Fluoride hydrolyses resulting in the formation of hydroxide ions producing a solution with a pH >7

$F^-(aq) + H_2O(\ell) \rightleftharpoons HF(aq) + OH^-(aq)$

The chloride ion is the weak conjugate base of a strong acid ($HC\ell$) and is a neutral ion

d) i) Hydrolysis of propanoic acid:

$CH_3CH_2COOH + H_2O \rightleftharpoons CH_3CH_2COO^-(aq) + H_3O^+(aq)$

When hydrogen ions are added to the buffer, the equilibrium will (by LCP) shift left to use up the added H^+ ions. So the overall change to $[H^+]$ is minimised and so the pH change is insignificant.

ii) Equal concentrations of acid /conjugate base and high concentrations of acid and conjugate base.

12.(2016:31) a)

Acidic	Neutral	Basic
$NH_4C\ell$	$KC\ell$, $NaNO_3$	KCN, $Mg_3(PO_4)_2$

b) This question has two key parts you must address. It asks you to use Brønsted-Lowry theory (so $NH_3 + H^+ \rightarrow NH_4^+$ is not adequate) and to explain why the pH of ammonia solution is greater than 7.0 (you must explain the significance of these numbers and not just say it's basic).

Example:

$NH_3(g) + H_2O(\ell) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$ – note the states are included and the equilibrium arrow is used.

Brønsted-Lowry discussion: Ammonia acts as a weak base accepting a proton from water, acting as an acid, to form the ammonium ion and hydroxide ions.

pH discussion: In water the concentration of H^+ and OH^- are both 10^{-7} mol L^{-1} This reaction means the concentration of OH^- will increase above the H^+ so the pH will be above 7.

13.(2016:32) a) $H_2CO_3(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + HCO_3^-(aq)$ – note the equilibrium arrow.

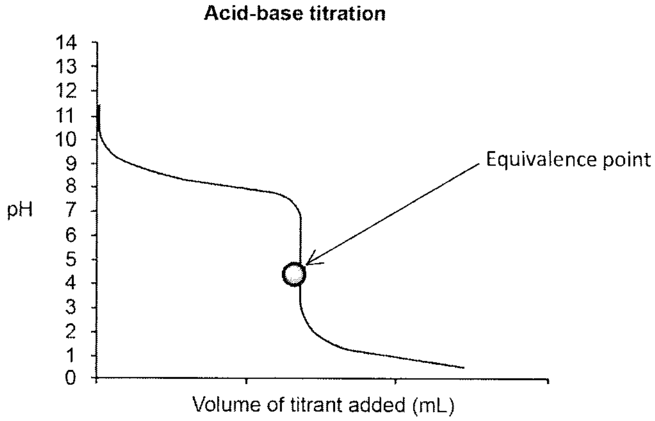
b) This question tests your understanding of buffers. Most students know a buffer is a mixture of a weak acid (or base) and its conjugate in high concentration eg 1 mol L^{-1}.

In this question the H_2CO_3/HCO_3^- meets this requirement. Here $HC\ell$ forms H_3O^+ in water

$HC\ell(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$

The HCO_3^- accepts protons from H_3O^+ to form H_2CO_3 removing the newly added H_3O^+ions and so there is little change in the pH because the BUFFER CAPACITY has not been reached. But in the case of water the species are at 10^{-7} mol L^{-1} concentration. Thus their BUFFER CAPACITY is small. Hence the very poor buffer is easily overwhelmed by the addition of the small quantity of $HC\ell$ which increases the concentration of H_3O^+ ions, lowering the pH.

14.(2016:34) a)



b) The syllabus does not mention any indicators you need to know specifically. This question requires you to know how to pick an indicator for a titration.

We have a weak base/strong acid titration which has an equivalence point at about pH 4.5. So we need an indicator with an end point of 4.5.

Bromocresol Green because …

- Its colour change is at a suitable end point pH to show the equivalence point has been reached
- That a change in colour of the indicator (end point) indicates that the equivalence point has been reached
- Other indicators like Phenolphthalein, Alizarin Yellow R change too early while others like Methyl Yellow, Bromocresol Blue change too late and miss the equivalence point)
- Wrong indicator use will not be corrected by repeating the experiment therefore wrong indicator use is a systematic error

15.(2017:31) a) $2\ H_2O(\ell) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$

b) $K = [H_3O^+][OH^-]$

c) It tells us that there are very few ions produced. The ratio of reactant to product is huge. The constant says nothing about the rate of reaction.

d) At 50°C, $K = 5.48 \times 10^{-14}$

Since $K = [H^+] \times [OH^-]$ and they are equal then $[H^+] = \sqrt{5.48 \times 10^{-14}} = 2.34 \times 10^{-7}$

$pH = -\log 2.34 \times 10^{-7} = 6.63$

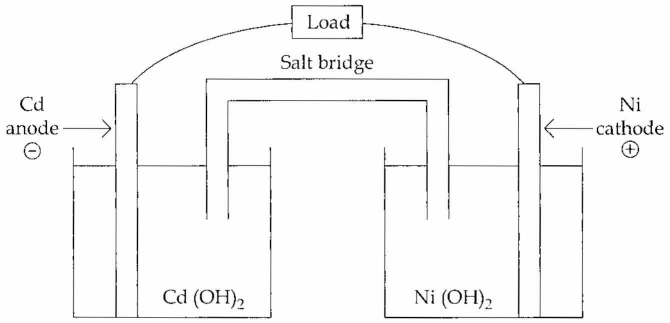
e) Water is neutral because $[H^+] = [OH^-]$ at all temperatures

Chapter 9: Oxidation–Reduction

1.(2011:35) a) Writing half equations for the reactions occurring at the anode and the cathode and the overall redox equation for the Ni-Cd cell.

Anode half equation	$Cd(s) + 2\ OH^-(aq) \rightarrow Cd(OH)_2\ (s) + 2\ e^-$
Cathode half equation	$NiO(OH)(l) + H_2O(l) + e^- \rightarrow Ni(OH)_2(s) + OH^-(aq)$
Overall redox equation	$Cd(s) + 2\ NiO(OH)(s) + 2\ H_2O(l) \rightarrow Cd(OH)_2 + 2\ Ni(OH)_2(s)$

Basic plan of the Ni-Cd cell



b) The potassium hydroxide electrolyte allows for the migration of ions and thus completes the circuit through the electrolyte.

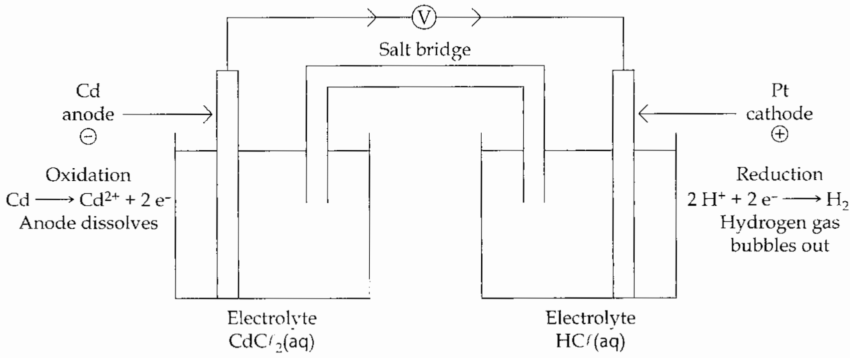
Background: An electrolyte is a substance that produces ions in solution. These ions move in an electrochemical cell that becomes the current. The cations (or cathode moving ions, Cd^{2+} ions), and the anions (anode moving ions, OH^- ions) conduct the current in the solution. The flow of current in the external circuit is by electrons from the cadmium anode to the nickel cathode and, the ions in the internal circuit. Cd^{2+} is oxidised at the anode and Ni^{2+} is reduced at the cathode.

c) The role of the hydrogen half-cell in determining the standard potential for the cadmium metal.

The voltage of an electrochemical cell is the difference in the reduction potentials for the two metals making up the cell. A measure of the reduction potential for a half cell can only be obtained by joining it with a common reference couple. The selected reference is the H^+/H_2 couple. For this reference half-cell, a E° value of exactly zero volt is assigned. The standard reduction potentials for other half-cells are obtained by measuring the total cell voltage when attached to a standard hydrogen half-cell. Compared with hydrogen, cadmium has a greater tendency to oxidise, indicated by its half-cell potential, –0.40 V. When a cadmium half-cell is connected to a hydrogen half-cell, cadmium is oxidised and hydrogen is reduced and the voltmeter reading (at standard conditions of 25°C and 1.00 atmospheric pressure) will be 0.40 V. This cell voltage is due to the following half reactions.

Oxidation of cadmium:	$Cd(s) \rightleftharpoons Cd^{2+}(aq) + 2\,e^-$	= 0.40 V
Reduction of hydrogen:	$2\,H^+(aq) + 2\,e^- \rightleftharpoons H_2(g)$	= 0.00 V
Redox reaction:	$Cd(s) + 2\,H^+(aq) \rightleftharpoons Cd^{2+}(aq) + H_2(g)$	= 0.40 V

While the half-cell or reduction potential for cadmium is –0.4 V, the cell potential when coupled with a hydrogen half-cell is +0.4 V.



2.(2011 S2:33)

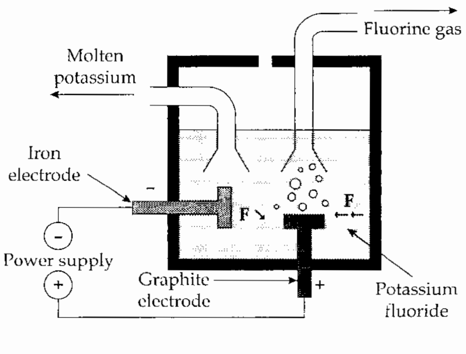
a) $KF(s) \rightarrow K^+(\ell) + F^-(\ell)$

b) **Oxidation** $2\,F^-(\ell) \rightarrow F_2(g) + 2\,e^-$

Reduction $K^+(\ell) + e^- \rightarrow K(\ell)$

c)

Graphite	Iron
Anode	**Cathode**



d) on diagram

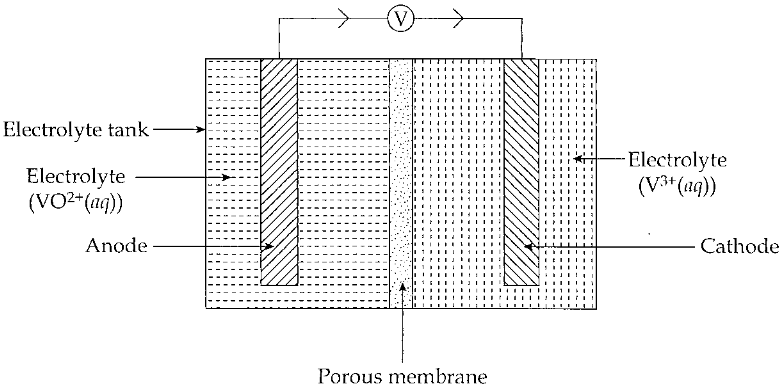
e) Fluorine gas

f) Electrolysis requires ions taking part in the reaction to be mobile. In the solid state, K^+ and F^- ions are in fixed positions within the ionic lattice and are not free to move

g) i) High temperature, Use of electricity, Use of high current flows for 'good' reaction rate, Toxic fluorine gas, Molten metal

ii) Breathing apparatus, gloves, protective clothing, Ventilation, Dry environment, Extraction/safe storage of fluorine gas

3.(2012:32) The general structure of the vanadium redox battery is shown below:



a) The anode and the cathode are shown in the diagram.

The oxidation reaction: $H_2O(\ell) + VO^{2+}(aq) \rightarrow VO_2^{+}(aq) + 2\ H^+(aq) + e^-$

The reduction reaction: $V^{3+}(aq) + e- \rightarrow V^{2+}(aq)$

Since VO^{2+} is converted to VO_2^+ at one electrode, this is the oxidation site and is the anode where oxidation takes place.

Since V^{3+} is reduced to V^{2+}, this is the reduction site and is the cathode where reduction takes place.

b) Electrons flow from the anode to cathode as shown.

c) The porous membrane separates the two solutions from directly coming into contact and reacting and transferring electrons directly. However, the membrane allows the migration of ions to complete the circuit. Electrical neutrality is maintained by the migration of ions through the membrane.

4.(2012:33) a)

Oxidation half-equation: $Mn^{2+} + 4\ H_2O \rightarrow MnO_4^- + 8\ H^+ + 5\ e^-$

Reduction half-equation: $BiO_3^- + 6\ H^+ + 2\ e^- \rightarrow Bi^{3+} + 3\ H_2O$

Redox equation: $2\ Mn^{2+} + 14\ H^+ + 5\ BiO_3^- \rightarrow 2\ MnO_4^- + 5\ Bi^{3+} + 7\ H_2O$

5.(2012 S2:41)

a) $Ag_2S + 2\ e^- \rightarrow 2\ Ag + S^{2-}$

b) $A\ell \rightarrow A\ell^{3+} + 3\ e^-$

c) $3\ Ag_2S(s) + 2\ A\ell \rightarrow 6\ Ag + 2\ A\ell^{3+} + 3\ S$

d) To allow the flow of ions

e) The tarnished silver

f) The tarnished silver

g) Left

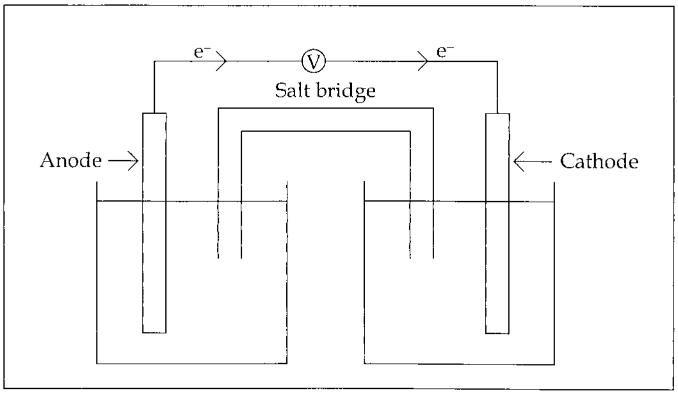
h) i) +1, ii) 0

6.(2013:41) a) The reactions that occur in a lead-acid storage cell:

Anode reaction: $Pb(s) + SO_4^{2-}(aq) \rightarrow PbSO_4(s) + 2\ e^-$

Cathode reaction: $PbO_2(s) + SO_4^{2-}(aq) + 4\ H^+(aq) + 2\ e^- \rightarrow PbSO_4(s) + 2\ H_2O(\ell)$

b) A schematic diagram for the lead-acid cell



c) i) How the lead-acid cell produces current:

The electrodes are made out of lead alloy grids packed with spongy lead or finely divided PbO_2. These electrodes are arranged alternatively and suspended in dilute sulfuric acid.

When the circuit is closed during the discharging process, lead at the anode is oxidized to form $PbSO_4$. The anode reaction is: $Pb(s) + SO_4^{2-}(aq) = PbSO_4(s) + 2\,e^-$

The electrons released reduce PbO_2 in the presence of H^+ ions and SO_4^{2-} ions. $PbSO_4$ forms on the cathode. The cathode reaction is: $PbO_2(s) + SO_4^{2-}(aq) + 4\,H^+(aq) + 2\,e^- \rightarrow PbSO_4(s) + 2\,H_2O(\ell)$. The result of the discharge is the formation of $PbSO_4$ and a decrease in the concentration of H_2SO_4 which results in the lowering of its density of the electrolyte.
The cell is charged when the car is running and the reactions are reversed during this process.

ii) The electrical potential of the cell is determined by the difference between the two half-cell potentials, the temperature and, the concentration of the electrolytes.

d) i) Given the concentration and volume of the H_2SO_4 solution, the number of moles of H^+ ions in the lead-acid cell is = c × v = 3.55 mol L^{-1} × 4.50 L × 2 = 31.957 mol = **32 mol**

ii) Calculating the number of moles of H^+ consumed when the discharge of the cell forms 138.1 g of $PbSO_4$.
n ($PbSO_4$) = (m ÷ M) = (138.1 g ÷ 303.26 g mol^{-1}) = 0.455 mol
n (H^+) = 2 × n ($PbSO_4$) = 2 × 0.455 = **0.911 mol**

iii) Calculating the concentration of H^+ in the discharged cell.
n (H^+) left over = 31.957 mol – 0.911 mol = 31.046 mol
c [H^+] = (n ÷ v) = (31.046 ÷ 4.5 L) = 6.899 = **6.9 mol L^{-1}**

iv) To show that the change in pH is negligible when the cell discharges.
The initial concentration of the H^+ ions = 2 × 3.55 mol L^{-1} = 7.1 mol L^{-1} (See section d, i)
The initial pH = –log [7.1] = –0.851
The final pH = –log [6.899] = –0.839. There is a very **small difference of 0.012 pH units.**

e) Hydrogen gas is flammable and oxygen supports combustion. The mixture can explode and cause fire hazards.

7.(2013 S2:42)

a)
- anode – on right
- cathode – on left
- direction of electron current – towards the left
- the ions present – chromium III and chloride
- the direction in which they are flowing – chloride to the anode, chromium III to the cathode

b) $2\,C\ell(\ell)^- \rightarrow C\ell_2(g) + 2\,e^-$
c) $Cr^{3+}(\ell) + 3\,e^- \rightarrow Cr(\ell)$
d) $2\,Cr^{3+}(\ell) + 6\,C\ell^-(\ell) \rightarrow 2\,Cr(\ell) + 3\,C\ell_2(g)$
e) reduction
f) chromium III ion
g) chlorine gas
h) i) +3 , ii) -1 , iii) 0, iv) 0

8.(2014:31) a) The role of the standard hydrogen half cell in determining the table of the Standard Reduction Potentials.
Standard Reduction potentials (E°) are measured with solutions of 1.0 mol L^{-1} concentrations, (with gases at a pressure of one atmosphere) and at a temperature of 25°C. They are a measure of the relative capacity of the more oxidisable form of the couple to gain electrons, and are called reduction potentials. The hydrogen half cell is assigned a E° value of exactly zero volt because this is used as a reference reaction. Standard Reduction Potentials for all other reduction reactions are obtained by measuring the total cell voltage or emf when attached to a standard hydrogen half cell. Thus H – half cell, acts as a standard reference for all other cells.
Example: If a zinc half cell is connected to a hydrogen half cell, (under standard conditions) the voltmeter (which measures the emf or cell potential) will read 0.76 V. The cell reaction is

$$Zn(s) + 2\,H^+(aq) \rightarrow Zn^{2+}(aq) + H_2(g)$$

Because zinc is oxidised and donates electrons to hydrogen through the external circuit, the oxidation half reaction is $Zn(s) \rightarrow Zn^{2+}(aq) + 2\,e^-$. This has an *oxidation potential* of 0.76 V.
Therefore, the reduction half reaction, $Zn^{2+} + 2\,e^- \rightarrow Zn(s)$ has a standard reduction potential of –0.76 V.
In the Standard Reduction Potential table, the half reactions are arranged in the order of decreasing reduction potentials.

b) Limitations of the Reduction Potential table:
- The half-reactions given in the table apply to aqueous solutions only.
- The E° values are given for concentrations of 1.0 mol L^{-1}.
- The electrode reactions depend on the nature of the electrode surface.
- The table does not provide any information on the rate of reactions.
- Only applies to 25°C and 101 kPa.
- Experimentation is the only way to make sure that a reaction will occur.

9.(2014:32) Step 1: Reduction of nitrogen gas to ammonia.

$N_2(g) + 8\ H^+(aq) + 6\ e^- \rightarrow 2\ NH_4^+(aq)$

Step 2: Oxidation of ammonium ions to nitrite ions.

$NH_4^+(aq) + 2\ H_2O(\ell) \rightarrow NO_2^-(aq) + 8\ H^+(aq) + 6\ e^-$

Step 3: Oxidation of nitrite ions to nitrate ions.

$NO_2^-(aq) + H_2O(\ell) \rightarrow NO_3^-(aq) + 2\ H^+(aq) + 2\ e^-$

10.(2014:36) a) The independent variable (the variable that is altered at the discretion of the investigator) is the concentrations of the solutions.

b) The dependent variable (the variable that is affected as a direct result) is the electrical potential or voltage of the cell.

c) All the other variables which can have an impact on the electrical potential such as the volume of the solution the temperature of the solution and the surface area of the electrodes – need to be kept constant. This is to enhance the reliability of the findings in this investigation.

d) Explanation for the increase in electrical potential due to changes in the concentrations of Cu^{2+} ions and Zn^{2+} ions. In general, in any electrochemical cell, if the concentration of the reactants increases relative to the concentration of the products, the cell reaction becomes more spontaneous and the cell emf increases. An increase in the concentration of the reactant ions (Cu^{2+}) increases the rate of the forward reaction. If the concentration of the products (Zn^{2+}) increases relative to the reactants, the cell emf decreases. An increase in the concentration of the product ions decreases the rate of the forward reaction and increases the rate of the reverse reaction.

e) As the cell operates, the concentration of the reactant ions decreases. This decreases the rate of the forward reaction and the cell emf decreases.

f) Two ways to improve the investigation:

- Since different cells require different electrolytes, it is important to test a number of different cells with different electrolytes to verify if the relationship is general to all cells.
- For the same cell, evidence from one set of data will not be sufficient to make the relationship reliable. Results from at least a few other trials would be necessary to verify the relationship.

11.(2014 S2:40a,c) a) i) Draw arrow downward towards the copper cathode.

ii) Arrow drawn pointing to the right towards the copper cathode.

b) Electrolysis requires the movement of charge around the complete circuit, (electrons in the wiring and electrodes) and ions in the electrolyte. In the solid state, the ions within copper(II) sulfate are not free to move so no current can flow. When dissolved in water the copper(II) ions and sulfate ions are now free to move through the electrolyte and so complete the circuit.

12.(2015:31) a) $2\ Ag^+_{(aq)} + CO_3^{2-}{}_{(aq)} \rightarrow Ag_2CO_{3(s)}$

b) To a sample of each metal in a different test tube add 0.100 mol L^{-1} solution of chromium nitrate solution.
Magnesium: green solution decolourises
Cobalt: no visible reaction

13.(2015:35) a) arrow to left

b) $C\ell_2(g) + Cu(s) \rightarrow Cu^{2+}(aq) + 2\ C\ell^-(aq)$

c) The electrons that are transferred can pass through an external circuit (rather than being transferred through direct contact)

d) Greenish yellow gas disappears

e) Any metal/metal ion below 0.34 V eg Zn/Zn^{2+} : must not be K, Na, Ca, Sr, Ba as they react with cold water.

14.(2015:37) a) i) Half-equation one:

$4\ H_2O(\ell) + S_4O_6^{2-}(aq) \rightarrow S_3O_6^{2-}(aq) + SO_4^{2-}(aq) + 8\ H^+(aq) + 6e^-$

Half-equation two:

$2\ e^- + 2\ H^+(aq) + H_2O_2(aq) \rightarrow 2\ H_2O(\ell)$

Redox:

$S_4O_6^{2-}(aq) + 3\ H_2O_2(aq) \rightarrow S_3O_6^{2-}(aq) + SO_4^{2-}(aq) + 2\ H_2O(\ell) + 2\ H^+(aq)$

ii) tetrathionate or $S_4O_6^{2-}$

b) $n(H_2S) = 19.5 \times 10^3/34.086 = 572.08$ mol
$n(SO_2) = PV/RT = (68.3 \times 43.4 \times 1000)/(8.314 \times 1064.15) = 335.04$ mol
$n(H_2S)$ required $= 2\ n(SO_2) = 2 \times 335.04 = 670.08$ mol
There is insufficient H_2S (572 mol) for all SO_2 to react, the SO_2 is in excess and H_2S is the limiting reagent
$n(S) = 3/2 \times n(H_2S) = 3/2 \times 572.08 = 858.12$ mol
$m(S) = 858.12 \times 32.07 = 27\,519.9$ g = 27.5 kg or 2.75×10^4g
For 96.8% efficiency: $m(S) = 27.5 \times 0.968 = 26.6$ kg

15.(2016:26) a)

- both have an external wire for electron flow
- both have a cathode and an anode
- positive ions flow towards the cathode
- electrons flow through an external circuit from anode to cathode
- an electrolyte/liquid/solution is needed
- one substance is oxidised and the other reduced
- oxidation occurs at the anode and reduction occurs at the cathode
- both have electrodes

b)

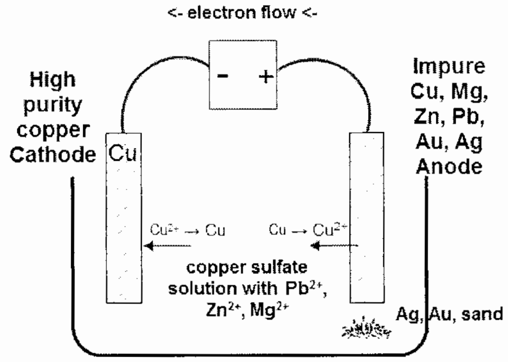
- a galvanic cell is linked to a load while an electrolytic cell is linked to a power supply

- galvanic cells are spontaneous while electrolytic are not
- there is only one beaker (cell) in an electrolytic cell and two half beakers (cells) in a galvanic cell
- galvanic has a salt bridge while electrolytic cell does not
- the galvanic cell has a spontaneous reaction while an electrolytic cell requires an emf to be applied to force a reaction (non-spontaneous)
- the electrolytic cell has an external emf applied (battery/power source) while the galvanic cell produces the emf
- galvanic cell has a positive E_0 while electrolytic the E_0 is negative
- in a galvanic cell, chemical energy is converted to electrical energy and in an electrolytic cell, electrical energy is converted to chemical. 1–2.

16.(2016:40) a) $Cu^+(aq) + e^- \rightarrow Cu(s)$

b) This question is taken directly from the syllabus. It is required knowledge and so this is fairly straight forward.

Diagram:



The electrolytic refining of copper involves the dissolution of an impure blister copper sample (used as the anode) in a copper sulfate solution, and the subsequent deposition of copper ions as solid on the pure copper electrode used as the cathode.

A potential difference is applied across the electrodes giving a positive change to the anode and a negative charge to the cathode.

This induces an otherwise non-spontaneous redox reaction in which the copper is oxidised and reduced.

Oxidation equation: $Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$

Reduction equation: $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$

The electrons flow from the ionised blister copper via the eternal circuit to the copper cathode.

The dissolved copper ions will then flow towards the negatively charged cathode due to electrostatic attraction. where they are deposited as metallic solid.

Impurities in the original blister copper sample are either dissolved preferentially in solution and stay there (such as zinc or magnesium) or alternatively drop down and form a mud (gold and silver do this) as copper is preferentially oxidised and they do not react.

The voltage is chosen so not to oxidise gold or reduce zinc etc.

17.(2016 SP:42) a) $C\ell_2 + H_2O \rightarrow HOC\ell + HC\ell$

b)

- recognition that the hydroxide will react with the H^+
- recognition that removal of H^+ will prevent reverse reaction from occurring
- recognition that the forward reaction will thus continue until close to completion thus increasing yield of $HOC\ell$

c)

Oxidation state of $C\ell$ in hypochlorous acid +1

Oxidation state of $C\ell$ in hydrochloric acid –1

d)

Species oxidised $C\ell_2$

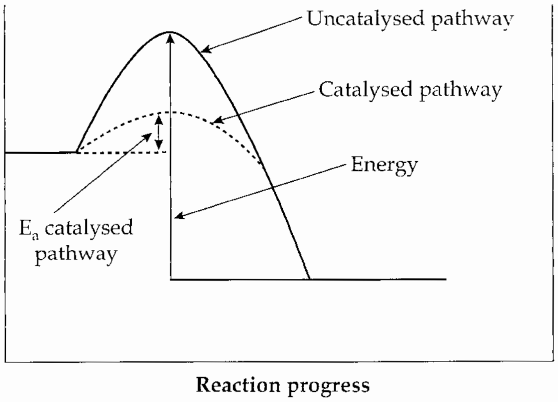
Species reduced $C\ell_2$

e) $HOC\ell + H^+ + 2e^- \rightarrow C\ell^- + H_2O$

f) 3 moles

g) activation energy for oxidation of peroxides is higher than E_a of chlorine based bleaches the oxidation of peroxide based bleaches requires higher temperatures than for oxidation of chlorine based bleaches

h)



18.(2017:26) a) i) There are many suitable observations that can be made here.

- The metal will react violently with the water
- A colourless odourless gas will be produced
- The solution will become warm
- The indicator will change to pink

ii) This is a displacement reaction and must be written as an ionic equation
$2\,Na(s) + 2\,H_2O(\ell) \rightarrow 2\,Na^+(aq) + 2\,OH^-(aq) + H_2(g)$

b) i) 1,2-dibromopropane - remember the bromine atoms add each side of the double bond and cannot form 1,1-dibromopropane

ii) The test for a double bond using bromine water was seen in year 11. Here a colourless gas mixes with an orange solution which turns colourless. Interestingly the 1,2-dibromopropane will lie as an oily layer on the surface of the water.

c) i) By consulting the E° table you will see the Fe(III) will reduce to Fe(II) but not Fe. So we will see Pb^{2+} and Fe^{2+} form.

ii) You would see the grey lead added to brown Fe(III) solution which will turn green while the lead will partly dissolve.

19.(2017:34) a) $M \rightarrow M^{2+} + 2\,e^-$

b) One: The electrode becomes larger being covered by a salmon pink metal
Two: The solution becomes less blue

c) i) 1.08 V - you should read to 2 decimal places

ii) The E° for the cell is 1.08 and copper is 0.34 so the element must have an E° around 0.76. It is colourless so cannot be Cr - the other electrode must be zinc.

20.(2017:27) Oxidation half-equation: $SCN^- + 4\,H_2O \rightarrow SO_4^{2-} + HCN + 7\,H^+ + 6\,e^-$
Reduction half-equation: $IO_3^- + 6\,H^+ + 4\,e^- + C\ell^- \rightarrow IC\ell + 3\,H_2O$
Balanced Equation: $2\,SCN^- + 3\,IO_3^- + 3\,C\ell^- + 4\,H^+ \rightarrow 2\,SO_4^{2-} + 2\,HCN + 3\,IC\ell + H_2O$

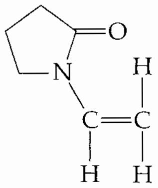
Chapter 10: Organic Chemistry

1.(2011:30)

Substances to be distinguished		**Description of chemical test**	**Observation with Substance 1**	**Observation with Substance 2**
Substance 1	**Substance 2**			
1. Butan-2-ol	2. 2-methylpropan-2-ol	Add acidified $KMnO_4$ solution or, acidified $K_2Cr_2O_7$ solution to each.	The purple $KMnO_4$ is decolourised. The orange $K_2Cr_2O_7$ turns green.	There is no observable colour change for either test.
1. Methanol	2. Methanal	Add a few drops of acidified ethanoic acid to each, or, add a piece of sodium metal to each.	With the acid, a substance of fruity odour is produced. With sodium a vigorous evolution of a colourless, odourless gas occurs.	No observable change occurs with either ethanoic acid or with the sodium metal.

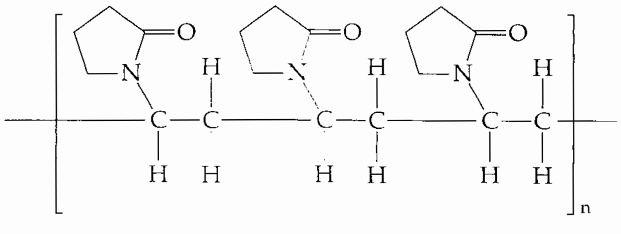
2.(2011:31) a) Three units in the polymer formed by the monomer, 'Polyvinylpyrrolidone'.
The monomer:

Monomer



The polymer:

A polymer chain of 3 monomer units



b) The type of polymerisation reaction that occurs to form this polymer is **addition** polymerisation.

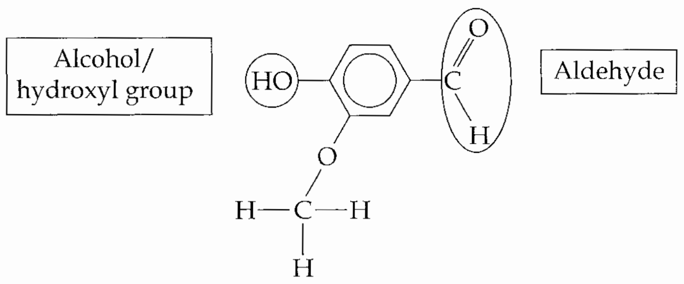
3.(2012:27) Butanoic acid ($CH_3CH_2CH_2COOH$) has the highest boiling point. This is due to hydrogen bonding between molecules, dipole-dipole interaction forces as well as strong dispersion forces.

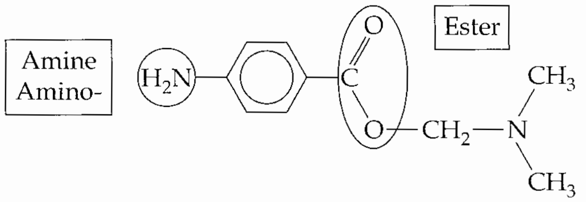
Butan-1-ol ($CH_3CH_2CH_2CH_2OH$) has a lower boiling point than butanoic acid because it has hydrogen bonding and dispersion forces only.

Butanal ($CH_3CH_2CH_2CHO$) has the lowest boiling point of the three. There are no hydrogen bonding sites in the molecule. It has dipole-dipole forces and dispersion forces only.

As the molar masses are not very much different, dispersion forces do not significantly contribute to any difference in the boiling points among the three compounds.

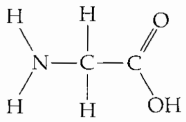
4.(2012:31)





5.(2013:34) a) Chemical formula of glycine is $C_2H_5NO_2$, also written as a condensed structure, NH_2CH_2COOH. Its structural formula is given below:

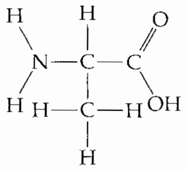
Chemical formula of Glycine, NH_2CH_2COOH



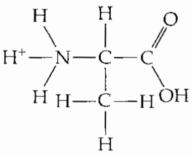
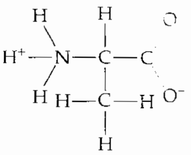
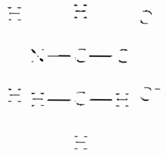
or, H_2NCH_2COOH

b) The structural formula for α - amino acid, alanine is given below.

Structural formula of Alanine, H_2NCHCH_3COOH



The structure for alanine in acidic, neutral and basic conditions.

Acidic species	Neutral species	Basic species
	 Zwitterion	

6.(2014:33) a) Equations for the oxidation of methanoic acid by acidified MnO_4^- solution.

Oxidation half equation	$CH_3OH(aq) + H_2O(\ell) \rightarrow HCOOH(\ell) + 4\ H^+(aq) + 4\ e^-$
Reduction half equation	$MnO_4^-(aq) + 8\ H^+(aq) + 5\ e^- \rightarrow Mn^{2+}(aq) + 4\ H_2O(\ell)$
Final redox equation	$4\ MnO_4^-(aq) + 12\ H^+(aq) + 5\ CH_3OH(\ell) \rightarrow 5\ HCOOH(\ell) + 4\ Mn^{2+}(aq) + 11\ H_2O(\ell)$

b) Balanced reaction between methanol and ethanoic acid in the presence of sulfuric acid to produce a fruity-smelling compound.

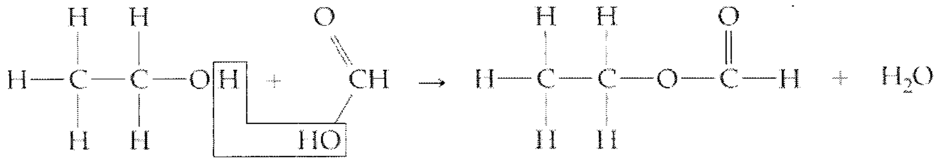
$$HCOOH(\ell) + CH_3CH_2OH(\ell) \rightarrow HCOOCH_2CH_3(aq) + H_2O(\ell)$$

$$CH_2O_2(\ell) + C_2H_6O(\ell) \rightarrow HCOOC_2H_5(aq) + H_2O(\ell)$$

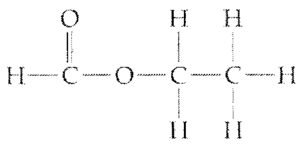
or

$$HCOOH(\ell) + CH_3CH_2OH(\ell) \rightarrow HCOOCH_2CH_3(\ell) + H_2O(\ell)$$

or

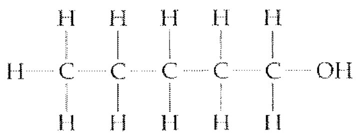
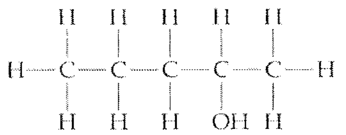
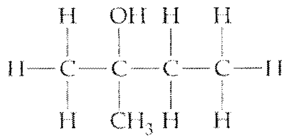


c) The structural formula for the fruity-smelling compound

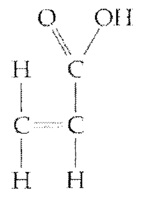


Ethyl methanoate

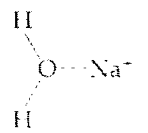
7.(2014:34)

	Primary alcohol Pentan-1-ol There are several other examples available
	Secondary alcohols Pentan-2-ol There are several other examples available
	Tertiary alcohol 2-methylbutan-2-ol

8.(2014:35) a)

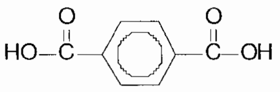
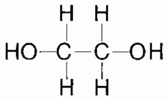


b) i) Name of the interactions occurring between water molecules and sodium ions Ion–dipole interactions.



ii) Reason why the polymer absorbs so much of water.

- Ion-dipole interaction between the '-COOH' group and water molecules forms hydrogen bonds.
- Because there is a large number of carboxylic acid groups in the polymer, a large number of water molecules can bond with the polymer. This accounts for the polymer's capacity to absorb large quantities of water.

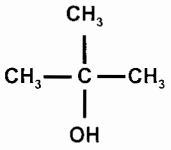
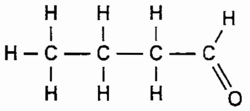
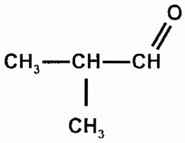
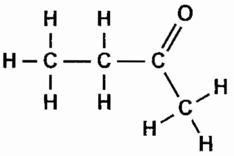
9.(2015:32) a)  and 

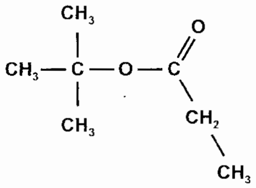
b) Water

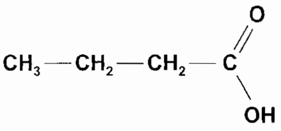
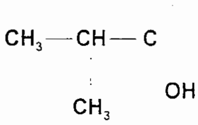
c) Increasing the length of the polymer chain increases the dispersion forces of the polymers. The number of =O dipoles increases so the number of dipole attractions along the length of the polymer chains increases.

- This increases the magnitude of its interactions with neighbouring chains making the polymer more rigid
- More energy is required to overcome the attraction of the chains of the polymer from each other thereby raising the melting point

10.(2015:34) a)

Unknown organic compound	**Functional group**	**Structural formula or name of the organic compound**
1	alcohol	methylpropan-2-ol 
2	aldehyde	butanal or methylpropanal  
3	ketone	Butanone 

b) i) 

ii) either of  

11.(2015:39) a) The $-NH_2$ group and the -COOH group must be attached to the same (α) carbon atom

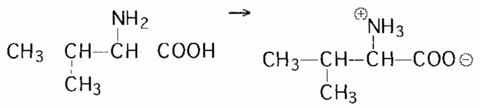
b) From the given formula, the empirical formula is $C_3NH_7O_2$

Empirical formula mass ($C_3NH_7O_2$) = 89.094

$n_{(alanine)}$ = PV/RT = (50.0 × 2.86) / (8.314 × 823.15) = 0.020895 mol

$M_{(alanine)}$ = m/n = 1.86 / 0.02089 = 89.02 g mol^{-1}

The empirical formula mass is the same as the calculated molecular formula mass c)



$CH_3CH(CH_3)CH(NH_2)COOH \rightarrow CH_3{-}CH(CH_3){-}CH(NH_3^{\oplus}){-}COO^{\ominus}$

This transfer produces a zwitterion. It has a positive and a negative ionic charge. It has no overall electrical charge. This strong ionic attraction between ions forms a crystalline lattice in the solid state. The di-amine and di-carboxylic acid bond using weaker hydrogen bonding. These ionic attractions require more energy to break and so the zwitterions have high melting points.

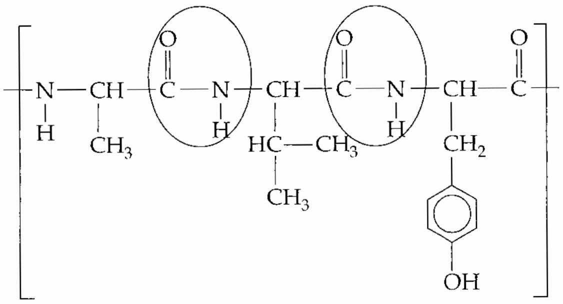
12.(2016 SP:28b) To dissolve well the bonds between solutes must be broken and the bonds between solvents must be broken and the new solute solvent bond must form.

Acetylsalicylic acid bonds with itself with strong dispersion forces (due to the large molecular size). Acetic acid molecules engage with each other with weak dispersion forces (small molecule), hydrogen bonding and dipole dipole forces. Water engages with itself primarily with hydrogen bonding.

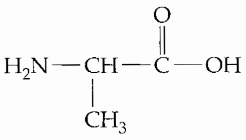
Acetylsalicylic acid and water molecules and water cannot overcome the large dispersion forces of acetylsalicylic acid and interact poorly thus are immiscible.

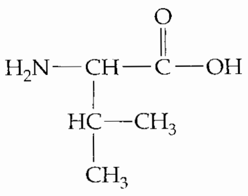
Acetic acid forms hydrogen bonds with water using the OH group and the carbonyl group as well as weak dispersion forces and so dissolves well.

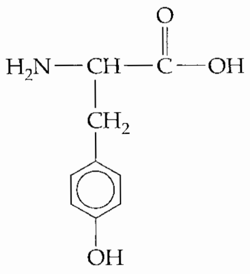
13.(2016 SP:31) a)



b)



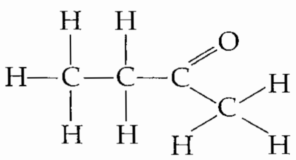




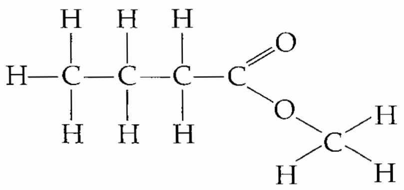
c)

Type of interaction	Functional groups
hydrogen bonding	carbonyl and amide groups

14.(2016 SP:33) a)

Observations	the solution turns from orange to green
Structural formula of organic product	
Name of organic product	butanone

b) Butanoic acid reacts with methanol in the presence of H_2SO_4 solution.

Observations	a fruity smell develops (and a new layer forms above the reactants)
Structural formula of organic product (show all atoms)	
Name of organic product	methylbutanoate

15.(2016 SP:36) a)

Label	Type of interaction	Label	Type of interaction
A	dispersion forces	**C**	covalent bond or disulfide bond
B	ionic bond	**D**	hydrogen bond

b) The 'tertiary structure' is the overall 3-dimensional shape

16.(2016:27) a)

i)

- three colourless liquids mix
- an immiscible layer appears on the surface
- a fruity smell produced

ii)

- Note the acid is inxs – this means there will be no $MgCO_3$ left over
- a white solid is added to colourless liquid
- a colourless odourless gas is produced
- the white powder dissolves and a colourless solution is formed

iii)

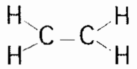
- Note the alcohol is inxs which means all the MnO_4^- will react
- a purple liquid is mixed with a colourless liquid
- the purple colour fades to very pale pink (almost colourless)
- a new paint smell can be detected

b)

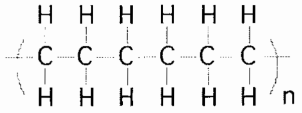
- Pentanoic acid
- $Cr_2O_7^{2-} + 3\ C_5H_{10}O + 8\ H^+ \rightarrow 2\ Cr^{3+} + 3\ C_5H_{10}O_2 + 4\ H_2O$

17.(2016:29) a) As it is an addition polymer it must have a double bond. The simplest and easiest answer is ethene and polyethene but you could use PVC, styrene, propene, Teflon etc.

Example.

Ethene	

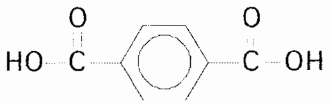
b) Note that the polymer has bonds on each end.

Polyethene	

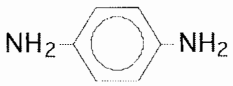
c) This answer is taken from the syllabus. Note you need to say what it is used for and why.

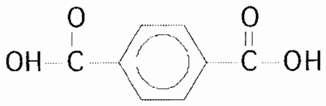
If you used polyethene you could say cling-wrap, or take-away containers BECAUSE it is strong, transparent, flexible and cheap.

d) 



Note these structures below would be wrong if we wrote them. Can you see why?





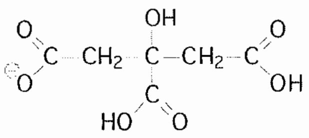
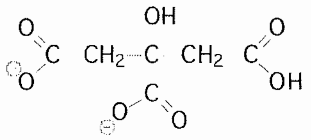
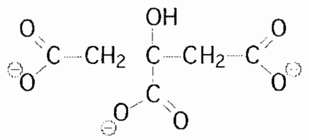
e) ß-pleated sheets

18.(2016:33) a) $C_6H_8O_7(aq) + 3\ NaOH(s) \rightarrow Na_3C_6H_5O_7(aq) + 3\ H_2O(\ell)$

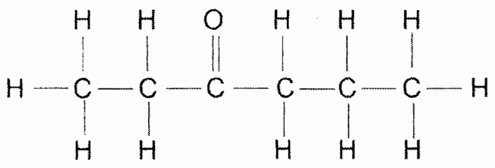
or

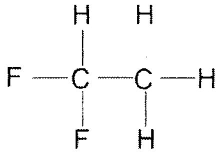
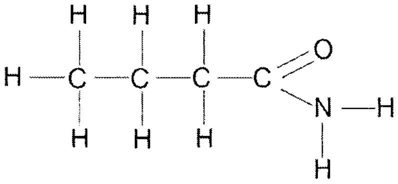
$C_6H_8O_7(aq) + 3\ NaOH(s) \rightarrow 3\ Na^+ + C_6H_5O_7^{3-}(aq) + 3\ H_2O(\ell)$

b)

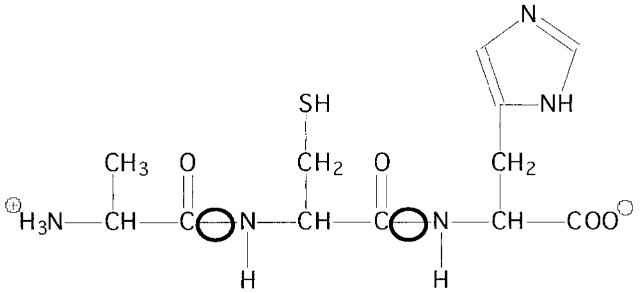
		
Note the alcohol group is not considered acidic in this situation		

19.(2016:35)

Organic compound	**Full structural formula**	**All intermolecular forces**
hexan-3-one		dispersion dipole-dipole

1,1-difluoroethane		dispersion dipole-dipole
butanamide		dispersion hydrogen bonding dipole-dipole

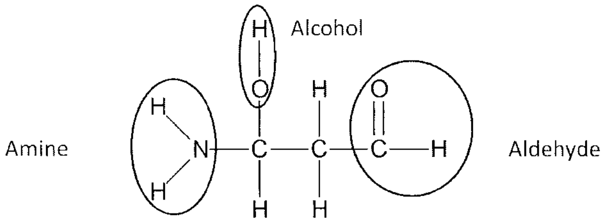
20.(2016:36) a) i)



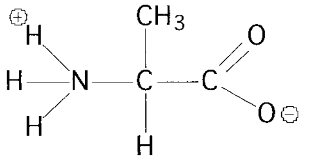
ii) Alanine, Cysteine, Histidine

b) This question requires you to understand amino acids can polymerise in any order. The answer must be different from the example given AlCysHis so Ala-His-Cys or His-Ala-Cys or any other combination is fine.

c)



d)



Any isomer is acceptable including the zwitterion. Be careful not to draw alanine on the isomer from part c)

21.(2016:37) To boil a molecular substance such as these three examples we must overcome the total secondary forces between the molecules.

Pentane, pentanal and pentanoic acid all exhibit dispersion forces due to the presence of electrons. As they contain the same number of carbon atoms the dispersion forces will be about equal.

Both pentanal and pentanoic acid have a carbonyl group that has a polar C=O bond. This gives these molecules dipole-dipole forces between them. Thus they have a higher boiling point than pentane. (note pentanal can accept hydrogen bonds from water but in this question there aren't any so it's irrelevant)

Only pentanoic acid has an -O-H configuration that allows the molecules to hydrogen bond to each other. Thus as it has dispersion forces, dipole-dipole bonds and hydrogen bonds it has the highest boiling point.

Please note that the desk you are writing on probably has a plastic top made of long carbon chains held together by dispersion forces. It is very strong. It is not correct to say substances with hydrogen bonds have higher boiling points than substances with dispersion forces so pentanoic acid has a higher BP. It is the sum of all three that counts.

22.(2017:32) a) This is a typical question asked about solubility. It demands you talk about bond breaking in the solvent and the solute and bond forming in the solution. You need to discuss breaking and forming all the types of bonds including hydrogen bonds, dipole/dipole and dispersion forces. You should offer evidence of disruption of existing forces and formation of new forces.

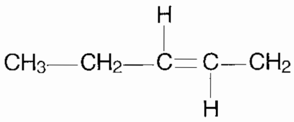
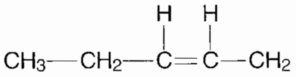
Ethanol interacts with ethanol by dispersion forces and hydrogen bonding. Water interacts with water molecules by hydrogen bonding and dispersion forces. The strength of the interaction between ethanol molecules and water molecules are stronger than the internal interactions of both so ethanol dissolves in water - therefore they are miscible

b) The solubility of alcohols in water decreases as the hydrocarbon chain length increases. This is due to the decreasing dominance of the hydrogen bond and the growing influence of the dispersion forces. As in the previous question the discussion turns on the idea that the difference between the energy released in the formation of new forces of attraction and the energy required to overcome the existing forces of attraction increases and so alcohols become more dispersion force predominant and less hydrogen bond dominant so they are less attractive to water as water interacts very poorly with dispersion forces so the solubility decreases.

c) The question asked for <u>all</u> secondary forces

Propanal	Hydrogen Bonding, dispersion forces, dipole-dipole forces
Methanoic acid	H Bonding, dipole-dipole, dispersion forces, and, when ionized,- ion-dipole
Sodium chloride	Ion-dipole forces, dispersion forces

23.(2017:35) a) Draw one chain isomer for C_5H_{10} that satisfies each of the following types. For each isomer, show all atoms and all bonds.

Type	Diagram
trans isomer	 $CH_3-CH_2-\overset{H}{C}=\underset{H}{C}-CH_2$
cis isomer	 $CH_3-CH_2-\overset{H}{C}=\overset{H}{C}-CH_2$

b)

Reagent/s	Br_2 (*aq*)	
	Cis/trans chain isomer	**Cyclic isomer**
Observations	The orange bromine solution will quickly decolourise	The orange colour will remain.

Chapter 11: Synthesis

1.(2010:38) This is a straight forward stoichiometry problem based on the production of sodium carbonate by the Solvay process incorporating the efficiency principles.

a) Impure NaCℓ is purified by the addition of Na_2CO_3 to precipitate Ca^{2+} ions and NaOH to precipitate Mg^{2+} ions.

i) $Ca^{2+}(aq) + CO_3^{2-}(aq) \rightarrow CaCO_3(s)$

ii) $Mg^{2+}(aq) + 2\ OH^-(aq) \rightarrow Mg(OH)_2(s)$

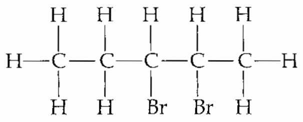
b) i) Calculating the moles of $CaCO_3$ consumed to produce one mole of Na_2CO_3. By standardizing the coefficients of the three equations given, it can be established that 2 moles of $CaCO_3$ are needed to produce one mole of Na_2CO_3

ii) 1 mole of Na_2CO_3 needs 2 moles of $CaCO_3$ at 100% efficiency.
Therefore, 1×10^4 tonnes (1.0×10^{10} g) or, $(1.0 \times 10^{10} \div 105.99) = 9.4349 \times 10^7$ moles of Na_2CO_3 needs,
$2 \times 9.4349 \times 10^7 = 18.87 \times 10^7$ moles of $CaCO_3$ at 100% efficiency.
At 85% efficiency, n ($CaCO_3$) required will be = $[18.87 \times 10^7 \times (100 \div 85)] = 22.2 \times 10^7$ moles. Therefore, m($CaCO_3$) required = $22.2 \times 10^7 \times 100.09 = 2.222 \times 10^{10}$ g = **2.22×10^4 tonne**.

c) Calculating the volume of the ammonia gas that can be recovered:
From the equation supplied in step 5, one mole of CaO gives 2 moles of ammonia (NH_3).
m (CaO) = 8.50×10^3 tonne = 8.50×10^9 g
n (CaO) = (m ÷ M) = $(8.50 \times 10^9 \div 56.08) = 1.516 \times 10^8$ mole.
Therefore, n (NH_3) produced = 2 × n (CaO) = $2 \times 1.516 \times 10^8 = 3.032 \times 10^8$ moles. Using the relationship, PV = nRT, we obtain, V = (nRT ÷ P)
= $[(3.032 \times 10^8 \times 8.315 \times 313) \div 1.00 \times 101.3)]$ = **7.79×10^9 L of Ammonia**.

2.(2013:36) Organic products for the following reactions:

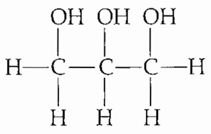
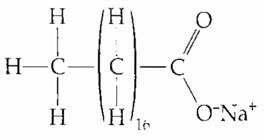
a) $CH_3CH_2CHCHCH_3 + Br_2 \rightarrow CH_3CH_2CHBrCHBrCH_3$ (2,3-dibromopentane)



or, $CH_3CH_2CHBrCHBrCH_3$

Name: 2,3-dibromopentane

b) The products

 Name: Propan-1,2,3-triol or, Glycerol	 Name: Sodium Stearate

3.(2013:37) This is a descriptive question requiring you to analyse the laboratory procedure of a simple experiment to determine the effect of enzymes on the rate of decomposition of hydrogen peroxide.

a) The mercury bead in the graduated tube measures the volume of the oxygen gas produced in the decomposition reaction. The movement of the mercury bead ensures that the pressure is maintained at a constant level while the volume is changing. ('Amount of hydrogen' is unacceptable because 'amount' is measured in moles)

b) Since the purpose is to determine the rate of generation of the gas, time is the other factor that needs to be measured.

c) i) The concentration of the H_2O_2 solution

ii) Temperature

iii) The volume of the solution

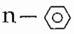
d) The concentration of the H_2O_2 solution will decrease as the reaction progresses.

e) A catalyst (biological enzymes are catalysts) increases the rate of the reaction by lowering the activation energy requirements by creating a new alternative reaction pathway. Catalysts are recoverable at the end of the reaction for reuse as they are not consumed during the course of the reaction.

4.(2014:30) Conditions of temperature and pressure that will optimise the yield of hydrogen and a reasonable rate in the following reaction.

$$CH_4(g) + H_2O(g) \rightleftharpoons 3\,H_2(g) + CO(g) \qquad \Delta H = +206 \text{ kJ mol}^{-1}$$

	Optimum conditions	Explanation
Temperature	High	This is an endothermic reaction. An increase in temperature will shift the equilibrium to the right and this increases both the yield and the rate. The increase in temperature increases the number of effective collisions per second due to an increase in the kinetic energy of the particles (hovering below the activation energy barrier) and hence the rate of both the forward and the reverse reaction. The yield increases as the reactants use up the heat energy supplied by the raising of the temperature.
Pressure	Moderate	In this reaction, there are more gaseous moles on the product side compared to the reactant side. Therefore, a decrease in pressure creates more space, favouring the forward reaction. This, however, will reduce the number of effective collisions per second. As a compromise, a slight pressure is applied to bring the molecules closer to facilitate an increase in the number of effective collisions per second. While a low pressure will increase the yield, it will decrease the rate. A moderate pressure, therefore will maintain the rate and produce a reasonable yield.

5.(2015:33) a) $CH_3-(CH_2)n-$  $-SO_3^-Na^+$ or $CH_3-(CH_2)n-SO_3-Na^+$

b) The long chain hydrocarbon tail is non-polar so its main force of attraction is through dispersion forces. This end of the detergent is most soluble in non-polar substances such as oil, fats and grease.

The charged end of the detergent is ionic so the predominant forces of attraction are ion-dipole forces. Thus detergent is most soluble in polar substances such as water.

c) Soaps combine with Ca^{2+} and/or Mg^{2+} ions in hard water to form a precipitate while detergents do not form precipitates

6.(2016SP:35)

Plastic	Type of polymer (addition or condensation)	Property	Use related to property
High density polyethene (HDPE)	addition	high tensile strength	furniture
Polytetrafluoroethene (Teflon)	addition	heat resistance	coating on frypans etc
Polyethylene terephthalate (PET)	condensation	chemically inert	drink bottles

Note: The use must relate to the property to be awarded a mark. A property cannot be used a second time.

7.(2016SP:37) a)

	Temperature (°C)	Pressure (kPA)	Raw material
fermentation	60	101.3	plant material
hydration of ethene	300	7000	crude oil

b) The process uses enzymes to catalyse reactions at lower temperatures where the ethanol does not boil off and the enzymes do not die. The reaction procures economic rates at lower temperatures lower than industrial catalysts

c) The process uses renewable raw materials, has lower emissions, and can be produced from waste material

8.(2016 SP:40) a) lipase

b) n(veg oil) = $1.50 \times 10^6/855.334 = 1.754 \times 10^3$ mol

n(CH_3OH) = 3 × n(veg oil) = 5.261×10^3 mol

m(CH_3OH) = $5.261 \times 10^3 \times 32.042 = 1.69 \times 10^5$ g

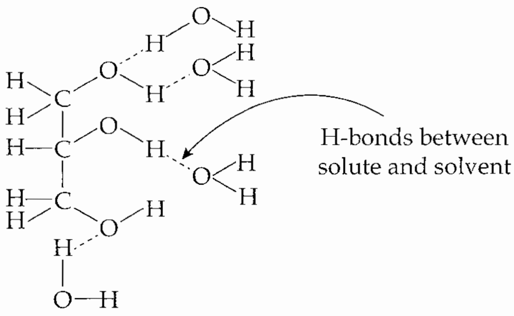
c) for 100% efficient: n(A) = n(Veg oil) = 1.754×10^3 mol

78% efficient, thus n(A) = $0.78 \times 1.754 \times 10^3 = 1.368 \times 10^3$ mol

MF Ester A is $C_{17}H_{34}O_2$ thus M(A) = 270.442 g mol^{-1}

m(A) = $1.368 \times 10^3 \times 270.442 = 3.70 \times 10^5$ g

d) Possible diagram



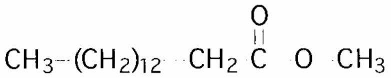
H-bonds between solute and solvent

e) i) soap/sodium salt of long chain fatty acid

ii) sodium salt for long chain fatty acid component of either A, B or C

9.(2016:28) a) Petroleum diesel is a hydrocarbon (alkane) while biodiesel is an ester. You would expect biodiesel to be the methyl ester but with this question you could offer any ester. i.e. offer a methyl, ethyl, or propyl ester but the total number of carbons must be 16.

For example – This is the methyl ester which is normally formed in making biodiesel....



$$CH_3{-}(CH_2)_{12}\ CH_2\ \overset{\overset{O}{\|}}{C}\ O\ CH_3$$

b) Using a lipase catalysed method to produce biodiesel is a more 'green' method of chemical synthesis. The specificity of the enzyme allows no side reactions to occur, giving a higher yield of biodiesel and no soap production as seen in base catalysed methods. This means there are no costly separation processes needed to remove the soaps and separation of biodiesel from glycerol is easier. The soap causes the biodiesel to dissolve in the glycerol. This method requires a milder pH temperature and pressure – hence the cost of production is lower and reaction conditions are safer. The use of lipase removes the need to dispose of highly caustic (high pH) waste material.

10.(2016:30)

a)

1: Hydration

ethene to ethanol

$CH_2{=}CH_2(g) + H_2O(g) \rightleftharpoons CH_3CH_2OH(g)$

2: Esterification

ethanol to ethyl ethanoate

$CH_3COOH(g) + CH_3CH_2OH(g) \rightleftharpoons CH_3COOCH_2CH_3(g) + H_2O(g)$

b)

$CH_2{=}CH_2(g) + CH_3COOH(g) \rightleftharpoons CH_3COOCH_2CH_3(g)$

11.(2017:29) a) $H_2SO_4 + 2\ KOH \rightarrow K_2SO_4 + 2\ H_2O$

H_2SO_4 : n = cV = $0.0334 \times 0.012 = 4.00 \times 10^{-4}$ mol

So mol $H^+ = 2 \times 4.00 \times 10^{-4} = 8.01 \times 10^{-4}$ mol of H^+

KOH : n = cV = $0.0288 \times 0.0325 = 9.39 \times 10^{-4}$ mol of OH^-

As $H^+ + OH^- \rightarrow H_2O$ there is a 1:1 ratio

The H^+ is the lesser quantity so H_2SO_4 is the limiting reagent

b) the OH^- inxs is $9.36 \times 10^{-4} - 8.016 \times 10^{-4} = 1.344 \times 10^{-4}$ mol

Total volume = 0.012 + 0.0325 = 0.0445 L

So the $[OH^-]$= n ÷ V = $1.344 \times 10^{-4} \div (0.0445) = 3.02 \times 10^{-3}$ mol L^{-1}

c) pOH = $-\log 3.02 \times 10^{-3} = 2.520$

pH = 14 - pOH = 11.48

12.(2017:30) a) rate of reaction : High temperature and high pressure

yield : low temperature and high pressure

b) This question involves the same logic as the Haber Process.

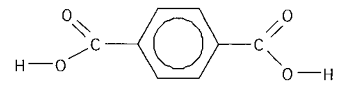
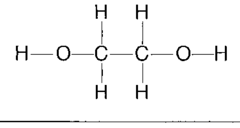
A moderate heat would have to be used as a compromise.

Rate : The reaction rate is maximised at high temperatures because more particles have sufficient energy to overcome the activation energy and the frequency of collisions is raised allowing more successful collisions.

Yield : However at low temperatures the yield is maximised as the forward reaction is exothermic, so lower temperatures favours the exothermic reaction.

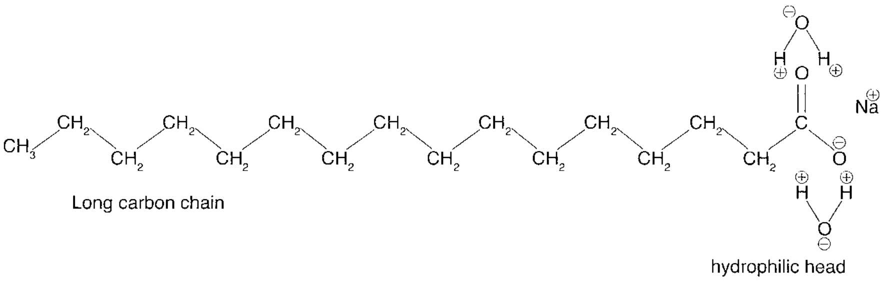
Therefore a moderate temperature is a compromise because it allows the reaction rate to be reasonable along with yield being reasonable, making the process more economical by balancing rate and yield.

13.(2017:36) a) m(Sb) = 6 × 10^6 g so n(Sb) = m/M = 6 × 10^6/121.8 = 49261 mol
There is a 2:4 ratio of Sb_2O_3 : Sb so n(Sb_2O_3) = n(Sb) × 0.5 = 24,631 mol
There is a 1:1 ratio of Sb_2O_3 : Sb_2S_3 so n(Sb_2S_3) = 24,631 mol
M(Sb_2S_3) = 339.81 g mol^{-1}
∴ m(Sb_2S_3) = n × M = 8.37 × 10^6 g
∴ m(ore) = 100/25.6 × 8.37 × 10^6 = 3.27 × 10^7 g = 32.7 tonne of ore
b) T = 798.15 K   P = 105 kPa   R = 8.314 J K^{-1} mol^{-1} n = 24631 mol
n(SO_2) = 3/2 × n(Sb) = 3/2 × 49261 = 73891 mol
PV = nRT so V = nRT/P = 73891 × 8.314 × 798.15/105 = 4669783 = 4.67 × 10^6 L
c)

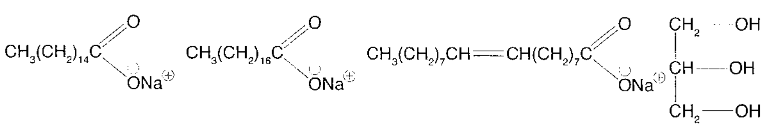
	

d) Use: Best answer is drink bottles
Properties: Rigid and strong, chemically inert, water barrier
e) Condensation polymerisation requires two base monomers each monomer having two reactive functional groups. Condensation polymers react to eject a small molecule, often water – but can be many other things, so your description must not be exclusively about polyamides and polyesters. Addition monomers involved bonding between alkenes only as the monomer.

14.(2017:39) a) i)

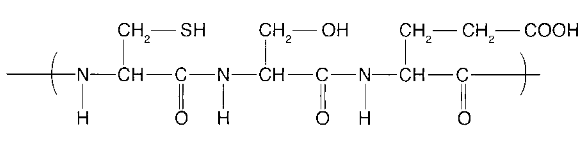


ii) Hydrogen Bonds and Ion-Dipole Bonds:
Hydrogen Bonds: The negative carboxylate ion and the positive hydrogen end of the water dipole are attracted to each other. The OH in water donates a hydrogen bond and the COO^- accepts it
Ion-Dipole Bonds: The Na^+ ion is attracted to the dipole of water and forms an ion-dipole bond.
iii) Dispersion forces: Both oil and soap are large molecules with no dipole changes. Thus they have a large number of electrons and demonstrate instantaneous temporary weak dipoles and attract each other.
b) Stearate ions (soap) precipitate with calcium ions and are no longer available to react with water to form micelles with oil. So the soap is no longer available and does not work.
c) i) Alcohol
ii) A long carbon chain that might have been derived from a fat (hence fatty acid) and a carboxylate group
d) This fat has three different fatty acid groups thus it forms three different soaps and glycerol.



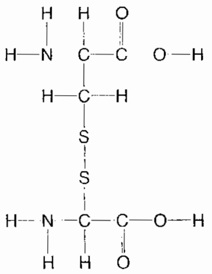
e) Soaps are the sodium salt of a fatty, weak acid. They are a conjugate of a fatty acid. So when they undergo hydrolysis they form the weak acid and the OH^- ion. Thus the number of OH^- ions exceed the H^+ ions and the solution is basic.
f) Sodium hydroxide is 'caustic' which means it dissolves flesh. Care must be taken in its use.
g) As the hydrocarbon chain length increases its effectiveness as a soap increases.

15.(2017:40) a)



b) Disulfide bridges, Hydrogen bonding, Dipole-dipole interactions
c) This is a secondary bond. It is a hydrogen bond between two amide groups in the primary structure. The hydrogen is between the N–H and the O in the C= O bond and causes a spiral to form.
d) Water can donate and accept hydrogen bonds with the amide group in hair.

e)



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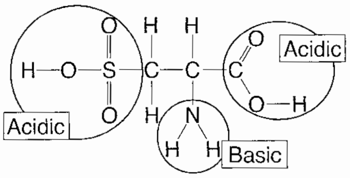


Chapter 12: Science Enquiry Skills

1.(2009:06)

	Mistake 1	**Mistake 2**	**Mistake 3**
Description of mistake	Burette was rinsed with water.	Phenolphthalein was used as the indicator.	Pipette was not rinsed with the correct solution.
Effect on volume of $HC\ell$	More $HC\ell$ would have been added to reach the equivalence point.	Less $HC\ell$ would have been added as the end point appears early at a pH of around 9.	Less $HC\ell$ would have been added.
Reason $HC\ell$ volume is affected as stated above	The water in the burette has diluted the $HC\ell$ and more of the $HC\ell$ would be required to neutralise Na_2CO_3.	The colour change that shows the end point occurs earlier than the equivalence point.	Because less Na_2CO_3 is added to the conical flask, an equivalent, but lesser, amount of $HC\ell$ would have been added.
Correct technique	Burette should have been rinsed with $HC\ell$.	Methyl orange should have been used for this strong acid – weak base titration.	The pipette should have been rinsed with Na_2CO_3 solution.

2.(2016 SP:38) a) Any two of the following:

- it can be obtained with a high degree of purity and has a known formula
- it undergoes reactions according to known chemical equations
- it is stable (to air)
- it has a high formula mass
- reacts rapidly with acids
- dissolves readily to give standard solutions

b) Calculate the concentration of the standardised $HC\ell$ solution.

$$Na_2CO_3 + 2\,HC\ell \rightarrow CO_2 + H_2O + 2\,NaC\ell$$

$n(Na_2CO_3) = 0.025\text{ L} \times 0.0248\text{ mol L}^{-1} = 6.2 \times 10^{-4}\text{ mol } Na_2CO_3$

$n(HC\ell) = 2 \times 6.2 \times 10^{-4} = 1.24 \times 10^{-3}\text{ mol}$
$c(HC\ell) = 1.24 \times 10^{-3}\text{ mol}/0.02435\text{ L} = 5.09 \times 10^{-2}\text{ mol L}^{-1}$

c)

Random error

- reading of burette – there is random uncertainty when reading the analogue scale.

Systematic error

- rinsing all glassware in distilled water – will dilute burette and pipette contents lowering their solution concentration.
- incorrect indicator – the endpoint will not coincide with the equivalence point.
- not drying Na_2CO_3 – will give incorrect concentration of primary standard and so alter the titre volume.
- perception of colour change – if readings are taken beyond the point of colour change consistently it will increase titre.

d) to increase precision (reliability)

e) i) $A\ell(OH)_3 + 3\,HC\ell \rightarrow A\ell C\ell_3 + 3\,H_2O$

$n(HC\ell) = 0.05092\text{ mol L}^{-1} \times 0.02194\text{ L} = 1.1171848 \times 10^{-3}\text{ mol}$

$n(A\ell(OH)_3) = 1.1171848 \times 10^{-3}/3 = 3.723949 \times 10^{-4}\text{ mol in 10 mL}$

x = mol in 250 mL
$x = 3.723949 \times 10^{-4}/10 = 9.3098733 \times 10^{-3}$ mol $A\ell(OH)_3$ in 20 mL of antacid
$c(A\ell(OH)_3) = 9.3098733 \times 10^{-3}$ mol/0.020 L
$= 0.47549$ mol L^{-1}
$= 0.475$ mol L^{-1} (3 s.f.)
ii) $n(Mg(OH)_2) = 1.13/58.326 = 0.0193739$ mol
$c(Mg(OH)_2) = 0.0193739$ mol/0.020 L = 0.968693 mol L^{-1} = 0.969 mol L^{-1}
f) $n(Mg(OH)_2)$ in 20 mL of antacid = 0.0193739 mol
$Mg(OH)_2$ neutralises 2 mol of $HC\ell$ per mole = 2 x 0.0193739 mol = 3.87×10^{-2} mol $HC\ell$ neutralised
$n(A\ell(OH)_3)$ in 20 mL of antacid = 9.3098733×10^{-3} mol
$A\ell(OH)_3$ neutralises 3 mol of $HC\ell$ per mole = 3 x 9.3098733×10^{-3} mol = 2.79×10^{-2} mol $HC\ell$ neutralised
Thus $Mg(OH)_2$ will be more effective

Chapter 13: Volumetric Analysis

1. (2013:39) This calculation requires you to calculate the amount of protein in a sample of milk powder food by determining the mass of the nitrogen content and then multiplying it by a conversion factor. The standard approach using the Kjeldahl method is summarised in four equations:
1) Food sample + $H_2SO_4(aq) \rightarrow (NH_4)_2SO_4(aq) + CO_2(g) + SO_2(g) + H_2O(g)$
2) $(NH_4)_2SO_4(aq) + 2\ NaOH(aq) \rightarrow Na_2SO_4(aq) + 2\ H_2O(\ell) + 2\ NH_3(g)$
3) $B(OH)_3(aq) + H_2O(\ell) + NH_3(g) \rightarrow NH_4^+(aq) + B(OH)_4^-(aq)$
4) $B(OH)_4^- + H^+(aq) \rightarrow B(OH)_3(aq) + H_2O(\ell)$
Information given:
1. The conversion factor to convert mass of nitrogen to mass of protein is 6.38
2. Mass of milk powder sample taken for analysis = 5.235 g.
3. The borate solution in step 3 is treated with 0.732 mol L^{-1} $HC\ell$ and the volume used is 25.78 mL.

a) Calculating the number of moles of ammonium ions formed from the treatment of the milk powder sample.
$n(H^+) = n(HC\ell) = c \times v = 0.752 \times 0.02578 = 1.9487 \times 10^{-2}$ mol
$n(NH_3) = n(B(OH)_3) = n(B(OH)_4^-) = n(H^+) = 1.9837 \times 10^{-2}$ mol (mole ratio is 1:1:1)
Therefore, $n((NH_4)_2SO_4) = \frac{1}{2}\ n(NH_3) = 9.6933 \times 10^{-3}$ mol (2 mols of NH_3 to 1 mol of $((NH_4)_2SO_4)$)
Therefore, $n(NH_4^+) = 2 \times n\,[((N_4^+)_2SO_4)] = (1.9387 \times 10^{-2}) =$ **1.94×10^{-2} mol**
b) Calculating the mass of nitrogen in the sample.
$n(N) = n(NH_4^+) = 1.9387 \times 10^{-2}$ mol
$m(N) = n \times M = 1.9387 \times 10^{-2} \times 14.01 = (0.2716) =$ **0.272** g
c) Calculating the mass of protein in the sample.
m (protein) = 6.38 x 0.2716 = (1.733) = **1.73 g**
d) Typical serving size for the product = 25 g.
If 5.235 g of the sample contains 1.73 g
25 g of the sample contains = [(25 x 1.73) ÷ 5.235] = (8.276) = **8.28 g**
e) Reliability requires consistent values for repeated trials. Repeating the analysis a couple more times would confirm the result providing an average value.

2.(2014:37) The problem requires quantitative confirmation of the mole ratio of hydrochloric acid and nitric acid in **aqua regia** which has the unique property to dissolve gold.
The expected mole ratio of hydrochloric acid to nitric acid in aqua regia is 1 : 3.
In the laboratory analysis, 20.0 mL of Aqua regia required 28.6 mL of 8.00 mol L^{-1} NaOH for complete neutralisation.
a) Calculating the number of moles of H^+ ions in the 20.0 mL sample of Aqua regia:
$n(OH^-)$ used in the reaction = (c x v) = (8.00 mol L^{-1} x 0.0286 L) = 0.2282 mol
= **0.229 mol**
b) The balanced ionic equation for the precipitation of $AgC\ell$ when Aqua regia was treated with excess silver nitrate solution.
$Cl^-(aq) + Ag^+(aq) \rightarrow AgC\ell(s)$
c) $m(AgC\ell)$ obtained from the 0.020 L sample = 24.6 g
$n(AgC\ell)$ obtained = (m ÷ M) = (24.6 ÷ 143.35) = 0.1716 mol
$n(C\ell^-) = n(AgC\ell) = 0.1716$ mol
Since $n(HC\ell) = n(C\ell^-) = 0.1716$ mol = **0.172 mol**
d) Determining if the sample Aqua regia has the required mole ratio of the two acids.
Total moles of H^+ in the 20.0 mL sample = 0.229 mol
$n(HC\ell) = 0.172$ mol
Therefore $n(HNO_3)$ in the sample = (0.229 - 0.172) = 0.0572.
The mole ratio of $HC\ell$ to HNO_3 (by this analysis) = (0.1716 ÷ 0.0572) = **3.00**

The mole ratio of $HC\ell$ to HNO_3 required is 3 mol $HC\ell$ to 1 mol HNO_3. The quantitative analysis confirms the ratio as correct.

(Note: If the unrounded values are used, you will get a ratio of 3.0318 $HC\ell$ to 1.000 HNO_3. This is still acceptable within the limitations of experimental errors.)

3.(2014:40) This problem requires the determination of the content of a sample of citric acid applying volumetric analysis calculations.

a) Explanation why sodium hydroxide cannot be used as a primary standard and has to be standardised prior to using it.

A good primary standard is a chemical that should be available in a pure form with a precise formula. It should not react with the moisture or carbon dioxide in the air and should have a relatively high molar mass to ensure a greater degree of accuracy in weighing. Sodium hydroxide has a low formula mass (39.998). It is not obtained pure as it is highly reactive. As solid pellets, NaOH gradually absorbs water from the air and become a liquid (deliquescent). It also loses its purity as it reacts with carbon dioxide in the air to gradually form Na_2CO_3. If NaOH is to be used as a standard solution for any titration, it should be standardised first using a solution that is either a primary standard or one that has been standardised very recently, such as $HC\ell$.

b) To show that the concentration of the solution used in this calculation is 0.0916 mol L^{-1}.

m (NaOH) pellets taken = about 4 g.

Approximate concentration of the solution made: 0.1 mol L^{-1}.

The reaction with $HC\ell$ is: $NaOH + HC\ell \rightarrow NaC\ell + H_2O(\ell)$

$n(HC\ell) = c \times v = 0.105 \text{ mol } L^{-1} \times 0.01745 \text{ L} = 1.83225 \times 10^{-3} \text{ mol}$

$n(NaOH) = n(HC\ell) = 1.83225 \times 10^{-3} \text{ mol}$

Therefore, $c[NaOH] = (n \div v) = (1.83225 \times 10^{-3} \text{ mol} \div 0.020 \text{ L}) = 0.0916 \text{ mol } L^{-1}$ = **9.16×10^{-2} mol L^{-1}**.

c) Calculation of the average titre of NaOH solution:

Final volume (mL)	25.30	23.55	22.40	22.25
Initial volume (mL)	3.50	2.70	1.50	1.30
Titre (mL)	21.80	20.85	20.90	20.95

Discarding the first titre of 21.80 mL (an outlier), the average titre of NaOH = **20.90 mL**

d) Determining the percentage composition of citric acid by mass.

Volume of the cleaner liquid taken = 10.0 mL
Volume of the stock solution made by dilution = 100.0 mL
Volume of the aliquot used for titration = 20.0 mL

Citric acid is a triprotic acid. This means that one mole of citric acid requires 3 mols of NaOH for complete neutralisation.

$n(NaOH) = (c \times v) = (0.0916 \text{ mol } L^{-1} \times 0.02090 \text{ L}) = 1.91444 \times 10^{-3} \text{ mol}$

Therefore n (citric acid in 20.0 ml dilute) = $(1.91444 \times 10^{-3} \div 3) = 6.3815 \times 10^{-4}$ mol

Therefore, 100.0 mL dilute stock solution contains

= $[(6.3815 \times 10^{-4} \div 20) \times 100] = 3.19073 \times 10^{-3}$ mol of citric acid.

Therefore, the mass of citric acid in 10.0 mL of the original solution = $(n \times M) = 3.19073 \times 10^{-3} \times 192.184) = 0.6130$ g

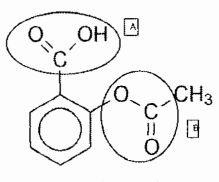
Therefore, the mass of citric acid in the original undiluted solution is 0.6130 g.

Since the mass of the 10.0 mL of the original solution is 10.4 g,

% by mass of citric acid in the cleaner = $[(0.6130 \div 10.4) \times 100]$ = **5.89%**

e) Since citric acid is a weak acid and NaOH is a strong base, the equivalence point occurs on the basic side of the pH scale which is between 8 and 10. The hydrolysis of citrate ion will produce OH^- ions according to the equation, $C_6H_5O_7^{3-}(aq) + 3\,H_2O(\ell) \rightarrow C_6H_8O_7(aq) + 3\,OH^-(aq)$. The most suitable indicator from the given list is 'thymol blue' (pH = 8.00 to 9.6).

4.(2015:36) a) i)



ii) Group A: carboxylic acid, Group B: ester

b) i) At the equivalence point the Na^+ and $C\ell^-$ ions are neutral. The carboxylate ions react with water to form the carboxylic acid and hydroxide ions

$RCOO^-(aq) + H_2O(\ell) \rightarrow RCOOH(aq) + OH^-(aq)$

The basic solution means that it is necessary to use an indicator that changes colour higher than 7.

ii) $n(H^+) = cv = 0.125 \times 0.01789 = 2.236 \times 10^{-3}$ mol

$n(OH^-)_{excess}$ in 20 mL = $n(H^+) = 2.236 \times 10^{-3}$ mol

$n(OH^-)_{excess}$ in 100 mL = $2.236 \times 10^{-3} \times 5 = 1.118 \times 10^{-2}$ mol

$n(OH^-)_{initially}$ in 100 mL = $cv = 0.204 \times 0.1 = 0.0204$ mol

$n(OH^-)_{\text{reacting with aspirin}} = 0.0204 - 0.01118 = 0.00921$ or 9.21×10^{-3} mol

iii) $n_{(aspirin)} = \int n(OH^-) = \int \times 0.00921 = 0.00461$ mol

$m_{(aspirin)} = 0.00461 \times 180.154 = 0.8304$ g

$m_{(aspirin)}$ in 1 tablet = 0.8304 ÷ 3 = 0.2768 g
% aspirin in 1 tablet = 0.2768/0.3 × 100 = 92.3%

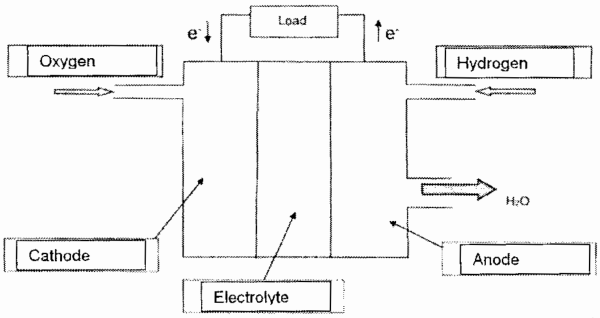
c)

Description		
Washing procedure	**Effect on the volume of hydrochloric acid used**	**Effect on the % of aspirin calculated**
The conical flask was washed with distilled water	No effect	No effect
The burette was washed with distilled water	Increase	Decrease

5.(2017:37) a) $CO_2 + 2\,LiOH \rightarrow Li_2CO_3 + H_2O$
b) n(LiOH) = m/M = 750/23.976 = 31.28 mol
$N(CO_2) = \frac{1}{2}n(LiOH) = 15.64$ mol
$M(CO_2) = nM = 15.64 \times 44.01 = 6.88 \times 10^2$ g

Volume (mL)	1	2	3	4
Final Volume	18.55	34.90	18.50	34.85
Initial Volume	1.50	18.55	2.20	18.50
Titre	17.05	16.35	16.30	16.35

c) Average titre = 16.33 mL
$n(HC\ell) = cV = 0.01633 \times 0.116 = 1.895 \times 10^{-3}$ mol
$nN(LiOH) = n(HC\ell) = 1.895 \times 10^{-3}$
$n(LiOH \text{ in } 500 \text{ mL}) = 500/20 \times 1.895 \times 10^{-3} = 4.737 \times 10^{-2}$ mol
$m(LiOH) = nM = 4.737 \times 10^{-2} \times 23.976 = 1.14$ g
∴ percentage LiOH = 1.14/12.33 × 100 = 9.211%
d) Indicator one: Bromothymol blue Indicator two: Phenolphthalein
Explanation: As LiOH is a strong base and $HC\ell$ is a strong acid, at equivalence they will have a pH of approximately seven because the resulting ions do not undergo hydrolysis to form weak acids or weak bases. The change in pH at equivalence will be large and the vertical part of the pH graph will be many pH units. Any indicator with a pH transition between about 4 and 10 will have appropriate end points for use in this titration.
e) Fuel cells can include CH_4/O_2 and they can even use chemicals such as chlorine. They are not necessarily safe nor always have environmentally friendly products – only the hydrogen oxygen cell does. So the answer must be 'highly efficient' and 'produce constant voltage as the concentration (partial pressure) of the reactants is constant'.
f)



g) The electrolyte completes the circuit and maintains charge balance
h) 1.23 volts
i) The above figure is only true at standard conditions (101 kPa and 25°C). The space vehicle might have been at a lower pressure or lower temperature.

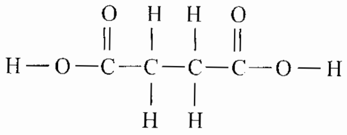
Chapter 14A: Calculations: Organic

1.(2009:03) a) Calculating the empirical formula:
mass of the sample = 9.76 g; mass of carbon dioxide = 17.9 g; mass of water = 4.88 g.
m (C) = [17.9 × (12.01 ÷ 44.01)] = 4.88 g.
m (H) = [4.88 × (2.016 ÷ 18.016)] = 0.546 g.
Therefore m (O) = [9.76 – (4.88 + 0.546)] = 4.33 g.

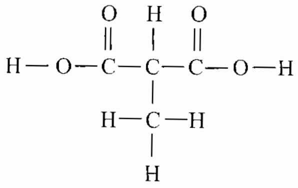
	C	**H**	**O**
Mass ratio (g)	4.88	0.546	4.38
Mole ratio	4.88 ÷ 12.01	0.546 ÷ 1.008	4.33 ÷ 16.00
	0.406	0.542	0.271
Simple ratio	0.406 ÷ 0.271	0.542 ÷ 0.271	0.271 ÷ 0.271
Simple ratio	1.5	2.00	1.00
Empirical ratio	3	4	2

Therefore the empirical formula is $\mathbf{C_3H_4O_2}$

b) Calculating the molar mass of the dicarboxylic acid monomer:
n (NaOH) = c × v = 0.487 × 0.0153 = 7.451×10^{-3} mol
n (acid) in 0.050 L =($\frac{1}{2}$ × 7.451×10^{-3} mol) = 3.725×10^{-3} mol
n (acid) in 0.250 L = [3.725×10^{-3} × (0.250 ÷ 0.050)] = 1.863×10^{-2} mol
Therefore the molar mass of the acid = (m ÷ n) = (2.20 ÷ 1.863×10^{-2}) = **118.1 g mol^{-1}**
c) A possible structure for the dicarboxylic acid:
The monomer has four oxygen atoms as it has two 'COOH' groups in it. Taking away the mass of the four oxygen atoms from the molar mass of 118, the residual mass is (118 – 64) 54 which is shared by 4 carbon atoms and 6 hydrogen atoms. This gives a molecular formula of $C_4H_6O_4$.
The following are two possible structures:



$H-O-\overset{\overset{O}{\|}}{C}-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-\overset{\overset{O}{\|}}{C}-O-H$



$H-O-\overset{\overset{O}{\|}}{C}-\underset{\underset{H-\underset{\underset{H}{|}}{C}-H}{|}}{\overset{\overset{H}{|}}{C}}-\overset{\overset{O}{\|}}{C}-O-H$

2.(2010:40)

m (sample sweetener) = 1.021 g; m (CO_2) = 1.715 g, m (H_2O) = 0.2521 g; m (NO_2) = 0.2558 g; m (SO_2) = 0.3568 g

m (C) = [1.715 × (12.01 ÷ 44.01)] = 0.4680 g
Therefore, n (C) = (0.4680 ÷ 12.01) = *0.03897*

m (H) = [0.2521 × (2.016 ÷ 18.016)] = 0.02821 g
Therefore, n (H) = (0.02821 ÷ 1.008) = *0.02799*

m (N) = [0.2558 × (14.01 ÷ 46.01)] = 0.07789 g
Therefore, n (N) = (0.07789 ÷ 14.01) = *0.00556*

m (S) = [(0.3568 × (32.06 ÷ 64.06)] = 0.17857 g
Therefore, n (S) = (0.17857 ÷ 32.06) = *0.00557*

Therefore, m (O) = [1.021 – (0.4680 + 0.02821 + 0.07789 + 0.17857)] = 0.2683 g
n (O) = (0.2683 ÷ 16.0) = *0.01677*

	C	H	N	S	O
Mole ratio	0.03897	0.02799	0.00556	0.00557	0.01677
Dividing each by the smallest mole of 0.00556					
Simple ratio	6.959	4.998	1.000	1.002	3.016
	7	5	1	1	3

Therefore, the empirical formula is **$C_7H_5NSO_3$**

3.(2011:36) This is an empirical-molecular formula calculation in which gas volume calculation steps are involved. The compound contains carbon, hydrogen, oxygen and fluorine.

m (sample) = 1.6328 g.
The volume of CO_2 produced at 50°C and 101.3 kPa = 0.866 L.
Since, PV = nRT, n = (PV ÷ RT),
n = [(101.3 × 0.866) ÷ (8.315 × 323)] = 0.03266 mol
Therefore, n (C) = **0.03266 mol** and, m (C) = n × M = 0.03266 × 12.01 = **0.3923 g**

m (H_2O) = 0.220 g; n (H_2O) = (0.220 ÷ 18.016) = 0.0122 mol
Therefore, n (H) = 2 × 0.0122 = **0.02442 mol** and, m (H) = 0.02442 × 1.008 = **0.02462 g**

n (HF) = 0.0571 mol
Therefore, n (F) = **0.0571 mol** and, m (F) = 0.0571 × 19.00 = **1.0849 g**

m (O) = [1.638 –(0.3923 + 0.02462 + 1.0849)] = **0.131 g**
Therefore, n (O) = (0.131 ÷ 16.0) = **0.008188 mol**

	C	H	O	F
Mass ratio	0.3923	0.02462	0.131	1.0849
Mole ratio	0.03266	0.0244	0.008188	0.0571
Simple ratio	÷ 0.008188	÷ 0.008188	÷ 0.008188	÷ 0.008188
	3.989	2.98	1	6.97
Whole No. ratio	4	3	1	7

Empirical Formula = **$C_4H_3OF_7$**

Alternative Method using the percentage composition

% C = [(0.0923 ÷ 1.6328) × 100] = 24.03%; Mol ratio = (24.03 ÷ 12.01) = 2.00
% H = [(0.02462 ÷ 1.632) × 100] = 1.51%; Mol ratio = (1.51 ÷ 1.008) = 1.50
% O = [(0.131 ÷ 1.632) × 100] = 8.03%; Mol ratio = (8.03 ÷ 16.00) = 0.50
% F = [(1.0849 ÷ 1.632) × 100] = 66.48%; Mol ratio = (66.48 ÷ 19.00) = 3.5

Fractional mole ratio of the elements in the compound: C = 2.00, H = 1.50; O = 0.50 and F = 3.5
Multiplying this ratio throughout by 2, in order to get whole numbers,
we get the empirical formula: **$C_4H_3OF_7$**

4.(2012:39)

a) The compound contains carbon, hydrogen and oxygen only.
m (sample) = 0.5096 g
n (H_2O) = 0.4160 g
n (H_2O) = 0.4160 ÷ 18.016 = 0.0231 mol
n (H) = 2 × 0.0231 = 0.0462 mol
m (H) = n × M = 0.0462 × 1.008 = 0.04655 g

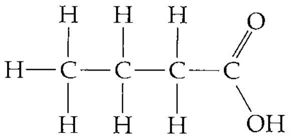
V (CO_2 – 100°C & 102.8 kPa) = 0.7007 L
Using the equation, PV = nRT
n = (PV ÷ RT) = [(102.8 × 0.7007) ÷ (8.314 × 373.15)] = 0.02322 mol of CO_2
Therefore, n (C) = n (CO_2) = 0.02322 mol
Therefore, m (C) = n × M = 0.02322 × 12.01 = 0.2789 g

Therefore, m (O) = [0.5096 g – (0.04655 g + 0.2789 g)] = 0.1842 g
Therefore, n (O) = (m ÷ M) = (0.1842 ÷ 16) = 0.01151 mol

	C	H	O
Mass ratio	0.2789 g	0.04655 g	0.1842 g
Mole ratio	0.2789 ÷ 12.01	0.04655 ÷ 1.008	0.01842 ÷ 16
	0.02322	0.04618	0.01151
Dividing by the smallest mole of 0.01151,			
Simple ratio	0.02322 ÷ 0.01151	0.04618 ÷ 0.01151	0.01151 ÷ 0.01151
	2.017	4.012	1
Rounded mole ratio	2	4	1
Empirical Formula:	**C_2H_4O**	(Empirical Mass = 44.052 g)	

b) Determining the molecular mass.
m (second sample) = 0.4832 g
This sample at 261°C, has a pressure of 241 kPa in a 100.0 mL container.
Using the relationship, PV = nRT, and, n = PV ÷ RT,
n = [(241 × 0.100) ÷ (8.314 × 534.15)] = 5.4268×10^{-3} mol
Since, 5.4268×10^{-3} mol has a mass of 0.4832 g
One mole has a mass = $[(1 \times 0.4832) \div (5.4268 \times 10^{-3})] = 89.04$ g mol^{-1}.
The ratio of molecular mass ÷ empirical mass = (89.04 ÷ 44.052) = Nearly 2.
Therefore, the **molecular formula** = 2 × C_2H_4O = **$C_4H_8O_2$**

c) Since a fruity smell is characteristic of an ester and the ester is the product of an alcohol and a carboxylic acid, this compound is most likely to be butanoic acid with the following Lewis structure.
Structure of butanoic acid



d) Additional chemical tests for butanoic acid:
i) Reaction with metallic carbonates such as $CaCO_3$ would produce a colourless, odourless gas and the test tube (if the reaction is carried out in a test tube) will get warm.
$CaCO_3(s) + CH_3CH_2CH_2COOH(\ell) \rightarrow Ca(CH_3CH_2CH_2COO)_2(aq) + CO_2(g) + H_2O(\ell)$
Other minor tests for consideration:
ii) Litmus test: acids turn litmus red. This confirms that the compound is an acid.
A large amount of heat is produced when butanoic acid is mixed with water.

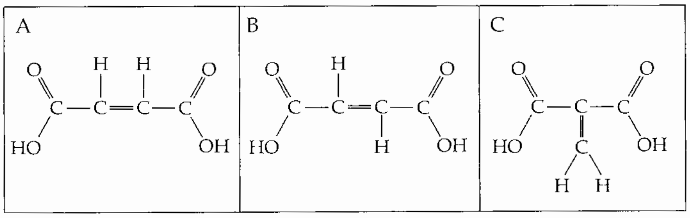
5.(2013:35) a) Empirical formula = CHO
Empirical mass = 12.01 + 1.008 + 16.00 = 29.018
Molecular mass = 116 g mol^{-1}
Molecular mass to empirical mass ratio = 116 ÷ 29.018 = 3.9975 ≈ 4
Molecular formula = Empirical formula × 4 = CHO × 4 = **$C_4H_4O_4$**

b)

Test	Observation	Possible functional group
Water solubility	788 g L^{-1}	R–COOH = carboxylic acid or, R–OH = alcohol
Add to bromine water	Bromine water decolourises rapidly	Can be a double bond or a triple bond.

c) m (sample of the white solid) = 2.32 g
n (H^+) ions in the above sample = 0.0400 mol
n (in 2.32 g sample) = (2.32 ÷ 116) = 0.0200 mol
Therefore, the ratio of the moles of the compound to the moles of hydrogen = 0.0200 ÷ 0.0400
= 1:2

Therefore, the substance is a diprotic acid
Three possible structures are shown below:



6.(2014:39) This is a straightforward empirical-molecular formula calculation.

a) The organic compound contains C, H, O and Br. The mass of the sample is 1.50 g.
m (CO_2) produced on combustion = 1.58 g
n (CO_2) produced = (1.58 ÷ 44.01) = 0.03590 mol
Therefore, n (C) = n (CO_2) = 0.03590 mol
Therefore, m (C) = 0.03590 × 12.01 = 0.4312 g. Therefore, carbon is **28.7%** of the compound.

m (H_2O) produced on combustion = 0.563 g.
n (H_2O) produced = (0.563 ÷ 18.016) = 0.03125 mol
Therefore n (H) produced = 2 × 0.03125 = 0.0625 mol
Therefore, m (H) produced = 0.0625 × 1.008 = 0.0630 g. Therefore, hydrogen is **4.2%** of the compound.

Another sample of mass 1.75 g results in 1.97 g of AgBr.
Therefore, the original mass, 1.50 g sample would have produced, [(1.50 × 1.97) ÷ 1.75] = 1.6886 g of AgBr.
Therefore, n (Br) = n (AgBr) = 1.6886 ÷ (107.9 + 79.90) = 0.008991 mol.
Therefore, m (Br) produced = 0.008991 × 79.90 = 0.7184 g. Therefore, bromine is **47.9%** of the compound.

Therefore, the mass of oxygen in the compound is = [1.50 – (0.4313 + 0.0630 + 0.7184)] = 0.2874 g. Oxygen is **19.2%** of the compound.
n (O) = (0.2874 ÷ 16.0) = 0.01796 mol.

Calculation of the empirical formula

	28.7%	4.2%	19.2%	47.4%
Elements present	C	H	O	Br
Mass ratio (g)	0.04312	0.0630	0.2874	0.7184
Mole ratio	0.03590	0.0625	0.01796	0.008991
Simple ratio	3.993	6.951	1.998	1
Whole No. ratio	4	7	2	1

Therefore, the empirical formula is $\mathbf{C_4H_7O_2Br}$

b) The empirical mass of the compound is = 48.04 + 7.056 + 32.0 + 79.9 = 167.0

Using the relationship, PV = nRT and [n = (PV ÷ RT)], the number of moles of the compound of mass 1.95 g is calculated as follows:

n = {(95.0 × 0.387) ÷ [8.314 × (273 + 105)]} = [36.765 ÷ (8.314 × 378)] = 0.01170 mol

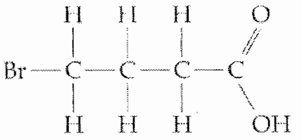
Since 0.01170 mol of the compound has a mass of 1.95 g

1.00 mol of the compound (the molecular mass) is = (1.95 ÷ 0.01170) = 166.7 g mol^{-1}

As the empirical mass (167.0 g) and the molar mass (166.7 g) are equal within the limits of the experimental error, the molecular formula is the same as the empirical formula.

The molecular formula of the compound is = **$C_4H_7O_2Br$**.

c) A possible structure for the formula is given below.

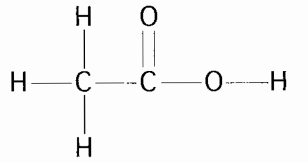
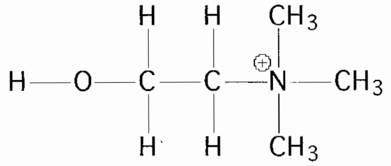


4-bromobutanoic acid

This compound could be 4-bromobutanoic acid. Other position isomers involving the –Br functional groups are also possible.

7.(2016:38) a) Enzymes are proteins which act as biological catalysts. They are more efficient than inorganic catalysts.

b)

Ethanoic acid	Choline
	

c)

CHNO	+	O_2	→	CO_2	+	H_2O	+	NO_2
4.270 g				9.020 g		5.169 g		1.886 g
				n = 9.020/44.01 = 0.2050 mol m = 0.2050 × 12.01 = 2.461 g		n = 5.169/18.016 = 0.2869 mol of H But there are 2 × H m = 0.2869 × 2 × 1.008 = 0.5784 g		n = 1.886/46.01 = 0.0410 mol m = 0.0410 × 14.01 = 0.5743 g
Mass of oxygen = total mass – mass of C – mass of H – mass of N = 4.270 – 2.4614 – 0.5784 – 0.5743 = 0.6559 g								

Ratio of mol =

	C	H	O	N
n	0.20495	0.57382	0.04099	0.04099
÷ n(O)	5	14	1	1

Therefore the empirical formula is $C_5H_{14}ON$

d) The acetylcholine produced 4.270 g of a compound with the molecular formula $C_5H_{14}NO$. This compound matches the structure of choline, so it is evident that the enzyme is active as it has produced the product of the equation rather than the reactant.

8.(2017:38) a) n(C) = n(CO_2) = m/M = 4.623/44.01 = 0.105 mol : m(C) = nM = 0.105 × 12.01 = 1.26 g

%C = 1.26/2.55 × 100 = 49.97%

n(H) = 2 × n(H_2O) = m/M = 1.18/18.016 = 0.131 mol : m(H) = nM = 0.131 × 1.008 = 0.132 g

%H = 0.132/2.55 × 100 = 5.178%

n(N) = n(NH_3) = m/M = 1.17/17.034 = 0.0687 mol : m(N) = nM = 0.0687 × 14.01 = 0.962 g

%O = 100 – (49.47 + 5.178 + 28.90) = 16.45%

	C	H	N	O
Mass	49.47	5.178	28.90	16.45
n	4.119	5.137	2.063	1.028
ratio	4	5	2	1

b) n = PV/RT = n = (0.100 × 370)/(8.314 × (550 + 273.15)) = 5.41 × 10^{-3} mol

M = m/n = 1.05 / 5.41 × 10^{-3} = 194.21 = 194 g mol^{-1}

c) Molecular formula = M/empirical mass × empirical formula

= 194.1 / 97.1 × $C_4H_5N_2O$

= 2 × $C_4H_5N_2O$

= $C_8H_{10}N_4O_2$

Chapter 14B: Calculations: General

1.(2011:38) This is a limiting-excess reagent problem. You are asked to determine the limiting reagent, the theoretical mass of the product and, the amount of the excess reagent left, among other things. There are two ways to sections of this problem. Both are presented here where they are appropriate.

a) Determining the limiting reagent:

Total volume of NH_3 and CO_2 together at 200°C and 148 atmospheric pressure = 5000 L

Volume of NH_3 under the same conditions = $[(5000 \times 62) \div 100] = 3100$ L

Volume of CO_2 under the same conditions = $[(5000 \times 38) \div 100] = 1900$ L

Here we can apply the law of combining volumes of gases which states that under the same conditions, reacting volume ratio is the same as the stoichiometric ratio. This eliminates the problem of converting them into moles at this stage of the calculation.

To determine the limiting reagent, find the reacting mole ratio from the balanced equation: The reacting mole (here, it is volume) ratio is

$2\ NH_3 + CO_2 \rightarrow CO(NH)_2 + H_2O$. That is $V\ [(NH_3) \div V\ (CO_2)] = 2:1$.

But, the mixture ratio, $[(3100 \div 1900)] = 1.63$: This clearly indicates that there is not enough ammonia to fully react with all the CO_2.

This makes **NH_3 the limiting reagent** and CO_2 the excess reagent.

b) From the equation the mol ratio is 2:1 so $n(NH_2CONH_2) = \frac{1}{2} \times n(NH_3) = 0.5 \times 1.182 \times 10^4 = 5.909 \times 10^3$ mol

The molar mass of urea $M(NH_2CONH_2) = 60.062\ g\ mol^{-1}$

$\therefore$ using m = n × M, $m(NH_2CONH_2) = 60.062 \times 5.909 \times 10^3 = 3.55 \times 10^5$ g

Of course if you had a different answer for part (a) you would be awarded follow through marks.

c) Many SCSA chemistry questions never have a 1:1 mol ratio. This is one of them. The $n(CO_2)$ used = $\frac{1}{2} \times n(NH_3)$ = $0.5 \times 1.182 \times 10^4 = 5.909 \times 10^3$ mol so the amount of CO_2 remaining is = $7.243 \times 10^3 - 5.909 \times 10^3 = 1.334 \times 10^3$ mol

The M of CO_2 is 44.01 so the mass = $44.01 \times 1.334 \times 10^3 = 5.87 \times 10^4$ g

d) SCSA questions using PV = nRT give you data in the wrong units. You need to convert to kelvin, kPa and litre if needed. The unit atm should no longer be used. An atm =101.1 kPa.

$$P = \frac{nRT}{V} = \frac{1.334 \times 10^3 \times 8.315 \times 298}{5000} = 6.61 \times 10^2 \text{ kPa (or 6.53 atm)}$$

e) Yield is calculated as the actual yield ÷ the theoretical yield × 100.

The actual mass of urea formed is = $3.76 \times 10^5 \times 0.83 = 3.121 \times 10^5$ g

$$\text{Yield} = \frac{3.121 \times 10^5}{3.55 \times 10^5} \times 100 = 87.9\%$$

f) i) 1 tonne = 1×10^6 g so $m(NH_2CONH_2)$ in the fertiliser batch = $0.45 \times 5 \times 10^6 = 2.25 \times 10^6$ g

We use the % composition × the mass

$$m(N) \text{ in fertiliser} = \frac{28.02}{60.062} \times 2.25 \times 10^6 = 1.05 \times 10^6 \text{ g}$$

ii) If you did not find a solution for part (i) you can still do this part. Just state 'assuming the answer was eg 1 tonne' and they will mark it for you and you can get full marks.

$$\text{Following from (i) above, } n(N) \text{ in fertiliser} = \frac{1.05 \times 10^6}{14.01} = 7.492 \times 10^4 \text{ mol}$$

$\therefore n((NH_4)_2SO_4) = 0.5 \times 7.492 \times 10^4 = 3.746 \times 10^4$ mol

$\therefore m((NH_4)_2SO_4) = 132.144 \times 3.746 \times 10^4 = 4.95 \times 10^6$ g

2.(2012:41) This is a stoichiometry problem using sequential equations. The first step is to standardise the coefficients so that the mole ratios of reactants and the products can be seen all through the pathway from the reactant to the product.

a) One way to standardise the coefficients is shown below:

The pathway: $CH_4 \rightarrow H_2 \rightarrow NH_3 \rightarrow NO \rightarrow NO_2 \rightarrow HNO_3 \rightarrow NH_4NO_3$

$CH_4(g) + H_2O(g) \rightleftharpoons 3\ H_2(g) + CO(g)$

$3\ H_2(g) + N_2(g) \rightleftharpoons 2\ NH_3(g)$

$4\ NH_3(g) + 5\ O_2(g) \rightleftharpoons 4\ NO(g) + 6\ H_2O(g)$ Divide this equation by 2 throughout

$2\ NO(g) + O_2(g) \rightleftharpoons 2\ NO_2(g)$

$4\ NO_2(g) + 2\ H_2O(\ell) + O_2(g) \rightleftharpoons 4\ HNO_3(aq)$ Divide this equation by 2 throughout

$HNO_3(aq) + NH_3(g) \rightleftharpoons NH_4NO_3(g)$

After standardising it can be seen that **two moles of NH_4NO_3** are produced by the reaction of **one mole of CH_4**.

b) Calculating the mass of CH_4 required to produce 2.50×10^5 tonnes of NH_4NO_3 assuming 100% efficiency.

m (NH_4NO_3 required) = 2.50×10^5 tonne $\times 10^6 = 2.50 \times 10^{11}$ g

n (NH_4NO_3 required) = $(m \div M) = (2.50 \times 10^{11} \div 80.052) = 3.123 \times 10^9$ mol

Therefore, n (CH_4 required) = $\frac{1}{2} \times 3.123 \times 10^9$ mol = 1.5615×10^9 mol

m (CH_4 required) = (n × M) = 1.5615×10^9 mol × 16.042 = 2.505×10^{10} g

= **2.51×10^4 tonnes**

c) You are required to explain the reaction conditions of one atmospheric pressure and 900°C for step 3 of the reaction which is an exothermic reaction.

$$4\,NH_3(g) + 5\,O_2(g) \rightleftharpoons 4\,NO(g) + 6\,H_2O(g)$$

Using atmospheric pressure: There are 9 and 10 gaseous moles on the reactant side and the product side respectively. According to Le Châtelier's principle, a slight decrease in pressure will favour the forward reaction. However, atmospheric pressure is maintained even though there is a slight reduction in the yield. The difference in the number of moles of gases on the different sides is not significant enough to warrant a change in pressure, and, the yield at atmospheric pressure is deemed to be acceptable from the economic rationalist and industrial point of view.

Using a temperature of 900°C: From the Le Châtelier's point of view, a lower temperature will favour the forward reaction. However, a much higher temperature than normal is used for two reasons. Firstly, it is likely that this reaction has a high activation energy requirement and if temperature is lowered the rate of the reaction may become too slow to produce any product. A temperature of 900°C is used as a compromise in order to increase the rate while sacrificing some yield.

3.(2012:43) Calcium ions are one of the primary causes of hardness in water as these ions react with soap to form a scum as the following reaction shows:

$$Ca^{2+}(aq) + 2\,CH_3(CH_2)_{16}COO^- \rightarrow Ca(CH_3(CH_2)_{16}COO)_2(s)$$

This kind of hardness can be reduced by boiling the hard water and precipitating Ca^{2+} ions.

a) In this section of the question you are asked to determine the mass of $CaCO_3$ deposited in 365 days if 1.0 L of water contains 65.0 mg of Ca^{2+} ions and a family uses 4.20 L of water a day.

1.0 L of water contains 65.0 mg of Ca^{2+} ions.

4.20 L contains = 4.20 × 65.0 mg = 273 mg of Ca^{2+} ions (0.273 g)

n (Ca^{2+}) ions in 4.20 L = (0.273 g ÷ 40.08 g mol^{-1}) = 6.8114×10^{-3} mol

Since n (Ca^{2+}) = n ($CaCO_3$),

n ($CaCO_3$) in 4.20 L = 6.8114×10^{-3} mol

m ($CaCO_3$) = (n × M) = (6.8114×10^{-3} mol × 100.09 g mol^{-1}) = 0.68175 g per day.

m ($CaCO_3$) produced in 365 days = 365 × 0.68175 = 248.84 g = **249 g**

b) Calculating the volume of CO_2 produced by the boiling of 1.00 L of water at standard pressure.

From the reaction,

$$Ca^{2+}(aq) + 2\,HCO_3^-(aq) \rightarrow CaCO_3(s) + H_2O(\ell) + CO_2(g)$$

n (CO_2) = n (Ca^{2+})

Since 1.0 L of water contains 65.0 mg of Ca^{2+} ions, or, (0.065 g ÷ 40.08 g mol^{-1}) 0.0016218 mol of Ca^{2+} ions,

n (CO_2) in 1.0 L = 0.0016218 mol

Applying the relationship, PV = nRT, (T= 100°C; P = 100 kPa)

V = (nRT ÷ P) = [($1.6218 \times 10^{-3} \times 8.314 \times 373$) ÷ 100] = 0.050293 L = **5.03×10^{-2} L of CO_2**

c) Calculating the pH of 1.05×10^3 L of water to which 125 mg of $Ca(OH)_2$ is added, and assuming that all $Ca(OH)_2$ dissolves.

n ($Ca(OH)_2$) = (m ÷ M) = (0.125 ÷ 74.096) = 0.001687 mol

c [$Ca(OH)_2$] = (n ÷ V) = (0.001687 mol ÷ 1.05×10^3 L) = 1.606×10^{-6} mol L^{-1}

Therefore, [OH^-] = 2 × 1.606×10^{-6} = 3.213×10^{-6} mol

Therefore, [H^+] =[(1.0×10^{-14}) ÷ (3.213×10^{-6} mol L^{-1})] = 3.112×10^{-9} mol L^{-1}

pH = –log [3.112×10^{-9}] = **8.52**

d) Buffering capacity is the ability of a solution to resist changes in pH. Quantitatively, buffering capacity is defined as the number of moles of a strong acid or strong base that are required to change the pH of a 1.0 L of the solution by 1 pH unit. The more concentrated the components of a buffer, the greater the buffer capacity which means you can add more H_3O^+ or OH^- to a buffer of higher capacity than to one of lower capacity. In other words, adding the same amount of H_3O^+ or OH^- to a buffer of higher capacity exhibits a smaller change in the ratio of the component concentrations than for a buffer of low capacity.

e) Equations to show the buffering capacity of hard water containing HCO_3^- ions.

Equilibrium 1 $HCO_3^-(aq) + H_3O^+(aq) \rightleftharpoons H_2CO_3(aq) + H_2O(\ell)$

Addition of acid shifts the equilibrium to the right to restore balance.

Equilibrium 2 $HCO_3^-(aq) + OH^-(aq) \rightleftharpoons CO_3^{2-}(aq) + H_2O(\ell)$

Addition of a base shifts the equilibrium to the right to restore balance.

f) Equations to show how the addition of OH^- ions shifts the equilibria of the carbonate species in water.

Equation 1 $H_2CO_3(aq) + OH^-(aq) \rightleftharpoons HCO_3^-(aq) + H_2O(\ell)$

Equation 2 $HCO_3^-(aq) + OH^-(aq) \rightleftharpoons CO_3^{2-}(aq) + H_2O(\ell)$

4.(2014:41) Rock phosphate is a non-renewable source of fertiliser. Because of the concern that it will run out eventually, urine is investigated as an alternative source of phosphate. This calculation deals with the analysis of urine as an alternative source.

a) Balanced equation for the hydrolysis of urea ($CO(NH_2)_2$) producing NH_3 and CO_2. (Hydrolysis is the decomposition of a compound with water.)

$$CO(NH_2)_2(aq) + H_2O(\ell) \rightarrow 2\,NH_3(aq) + CO_2(g)$$

b) Explanation: Why does the hydrolysis of urea cause an increase in pH?
Ammonia is produced during the hydrolysis of urea. Ammonia is further hydrolysed to produce OH^- ions. The reaction is:

$NH_3(aq) + H_2O(\ell) \rightarrow NH_4^+(aq) + OH^-(aq)$

The increase in the concentration of OH^- ions increases the pH of the solution.
c) Determining the concentration in grams per litre of phosphorus in the urine.
Supplied: Molar masses: struvite = 245.418 g mol^{-1}; calcium hydroxyapatite = 1004.636 g mol^{-1}.
Note: The second paragraph of the question tells us that the phosphate in urine will precipitate as calcium hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$), and struvite ($MgNH_4PO_4 \cdot 6\ H_2O$).

m ($MgNH_4PO_4 \cdot 6\ H_2O$) = 82.3% of the precipitate of 25.3 g = [(25.3 × 82.3) ÷ 100] = 20.823 g.
m ($Ca_{10}(PO_4)_8(OH)_2$) = 17.7% of the precipitate of 25.3 g = (25.3 - 20.823) = 4.478 g.
n (P) in struvite = n (struvite) = (20.823 ÷ 245.418) = 8.484×10^{-2} mol

n ($Ca_{10}(PO_4)_6(OH)_2$) = [(4.478 ÷ 1004.636) × 6] = 4.457×10^{-3} mol.
n (P) in $Ca_{10}(PO_4)_8(OH)_2 \times 6 = 4.457 \times 10^{-2} \times 6 = 2.674 \times 10^{-2}$ mol

Total amount of P in both = 8.484×10^{-3} mol + 2.674×10^{-2} mol = 1.116×10^{-1} mol
Total mass of P in both = n × M = 1.116×10^{-1} mol × 30.97 = 3.456 g

The statement for part b) states the volume of urine taken for analysis is 5.00 L.
Therefore, the concentration of P in urine in g L^{-1} = (m ÷ v) = (3.456 ÷ 5.00) = 0.691 g L^{-1}.
= $\mathbf{6.91 \times 10^{-1}\ g\ L^{-1}}$

d) Since the concentration of the OH– ion increases, there is also an increase in the rate of collisions between the OH^- ions and the NH_4^+ ions. However, the rate of the forward reaction is higher than the rate of the reverse reaction which shifts the equilibrium towards the products which increases the yield of ammonia. See the following equation:

$NH_4^+(aq) + OH^-(aq) \rightleftharpoons NH_3(aq) + H_2O(\ell)$

e) The conversion of a liquid to a gas involves absorption of heat energy. Also, solubility of gases decreases with an increase in temperature. This releases ammonia as a gas. An increase in temperature favours gas formation and an equilibrium shift to the right.
f) Equation for the reaction of ammonia absorption by the acid to form ammonium sulfate.

$2\ NH_3(aq) + H_2SO_4(aq) \rightarrow 2\ NH_4^+(aq) + SO_4^{2-}(aq)$, or
$NH_3^+(aq) + HSO_4^-(aq) \rightarrow NH_4^+(aq) + SO_4^{2-}(aq)$

g) Determining the concentration of nitrogen in g L^{-1} in the phosphorus depleted urine.
n ($(NH_4)_2SO_4$) = (m ÷ M) = (72.65 ÷ 132.144) = 0.5498 mol
n (N) = n ($(NH_4)_2SO_4$) × 2) = 0.5498 × 2 = 1.0996 mol
m (N) obtained at 78% efficiency = 1.0996 × 14.01 = 15.405 g
Therefore, m (N) at 100% efficiency = (15.405 ÷ 78) × 100 = 19.75 g.
Concentration in mol L^{-1} = (m ÷ v) = (19.75 g ÷ 5.00 L) = **3.95 g L^{-1}**.

5.(2016:39) a)
Pentlandite
The number of mol = m/M = 2.2×10^6 / 1287.42 = 1.70884×10^3 mol
Sulfur dioxide
The mol ratio is 1:8 so there is 8 × n($Fe_2Ni_9S_8$) = 1.36707×10^4 mol of SO_2
The process is only 72% efficient so it will produce 0.72 × 1.3671×10^4 = 9.8429×10^3 mol of SO_2
To find the volume of the gas use PV = nRT converting temperature to kelvin
So V = nRT/P = (9.8429×10^3 × 8.314 × 573.15) / 165.0 = 284262 L
As the mass of pentlandite has just 2 sig fig
2.8×10^5 L
b) This question is quite specific that it asks about catalysts in this process not about catalysts in general.
Reference to Le Châtelier's Principle quickly shows the reaction is favoured by high pressure and low temperature.
High pressure is expensive and low temperature slows the rate of reaction.
The use of a catalyst removes the need for high pressure as it increases the rate. Lower pressure also makes the plant cheaper and less likely to explode and is thus safer.
A catalyst increases the rate of reaction at low temperature.
The catalyst can be reused whereas the energy expended in raising the pressure cannot be reused.
On a green note saving the energy used to create pressure cuts use of fossil fuels and heat pollution of waterways and the atmosphere.
c) The forward and reverse rates increase
The yield increases
In this case you could have used LCP

d)
Raising the pressure of the system on the rate
Increasing pressure raises concentration. The particles being closer together raises the number of collisions per second. So both the forward and reverse rates increase.
Raising the pressure of the system on the yield
The increase in pressure causes n/V to increase so concentration rises. The left hand side is more affected as it has more mol so the forward rate increases more than the reverse until equilibrium is re-established. Thus the yield increases.
In this case you could NOT have used LCP.

6.(2016:42) a) Always write the equation first: $2\ HC\ell + Na_2CO_3 \rightarrow 2\ NaC\ell + H_2O + CO_2$
Exam questions usually are not 1:1 ratios and without an equation you will not see that here Na_2CO_3: $HC\ell$ is 1:2.
Find the mol Na_2CO_3
$n = m/M = 6.08 \times 10^{-4}/106.0 = 5.736 \times 10^{-6}$ mol of Na_2CO_3
$c(Na_2CO_3) = n/V = 5.736 \times 10^{-6}/2 = 2.868 \times 10^{-6}$ mol L^{-1}
so the mol Na_2CO_3 used in the titration was $= c \times V = 2.868 \times 10^{-6} \times 0.0164 = 4.7804 \times 10^{-8}$ mol
Find the mol of $HC\ell$ used in the titration
As the mol ratio is 1:2, $n(HC\ell) = 2 \times n(Na_2CO_3) = 9.408 \times 10^{-8}$ mol
$\therefore$ the concentration of the $HC\ell$ is $n/V = 9.408 \times 10^{-8}/0.025 = 3.76 \times 10^{-6}$ mol L^{-1}
b) There are many answers but you need to provide two reasons only

- deliquescent (it forms a solution with moisture from the air)
- absorbs CO_2 from the air forming Na_2CO_3 so is unavailable in a pure form
- has a low molar mass.

And if you used the Nelson book – it IS cheap so that is not a reason!
c) Always start with an equation.
$HC\ell + NaOH \rightarrow NaC\ell + H_2O$
So the mol ratio is 1:1
$HC\ell$
$n = cV = 3.76 \times 10^{-6} \times 0.0213 = 8.0088 \times 10^{-8}$ mol
NaOH
As mol ratio is 1:1 $n(NaOH) = 8.0088 \times 10^{-8}$ mol
$c = n/V = 8.0088 \times 10^{-8}/0.025 = 3.20 \times 10^{-6}$ mol L^{-1}
d)

Glassware	**Final rinse**
Burette	NaOH solution
Conical flask	distilled water (not just 'water')
Pipette	diluted rainwater

e) The first value is an outlier – average the other three = 19.66 mL (4 sig figs)
f)
NaOH
$c = 3.20 \times 10^{-6}$ mol L^{-1}
V = 19.66 mL (4 sig figs)
$n = c \times V = 3.20 \times 10^{-6} \times 0.01966 = 6.2912 \times 10^{-8}$
H+ ions
Mol ratio H^+ : NaOH = 1:1
$\therefore$ in 25 mL aliquot the $c = n/V = 6.2912 \times 10^{-8}/0.025 = 2.51648 \times 10^{-6}$ mol L^{-1}
$\therefore$ the no of mol in the 250 mL sample was $= n = c \times V = 2.51648 \times 10^{-6} \times 0.250 = 6.291 \times 10^{-7}$ mol
$\therefore$ the $pH = -\log(6.291 \times 10^{-7}) = 5.201 = 5.20$ (3 sig figs)
$\therefore$ the pH is above 4.4 and would not constitute acid rain
g) For a solution to have a pH = 4 then $[H^+] = 10^{-4} = 1 \times 10^{-4}$ mol L^{-1}
For a solution to have a pH = 5.6 then $[H^+] = 10^{-5.6} = 2.512 \times 10^{-6}$ mol L^{-1}
The change in concentration is $1 \times 10^{-4} - 2.512 \times 10^{-6} = 9.75 \times 10^{-5}$ mol
But this would for a whole litre – we have 100 mL so need only 9.75×10^{-6} mol

$$SO_2(g) + H_2O(\ell) \rightleftharpoons H_2SO_3(aq) \rightleftharpoons 2\ H^+ + SO_3^{2-}$$

From the above equation the mol ratio of H^+ to SO_2 is 2:1 so we need only $9.75 \times 10^{-6}/2$
$= 4.874 \times 10^{-6}$ mol of SO_2
Using PV = nRT we convert °C to kelvin and find the volume as V = nRT/P
$= 4.874 \times 10^{-6} \times 8.314 \times 289.15/97.2 = 1.206 \times 10^{-4}$ L $= 1.21 \times 10^{-4}$ L (3 sig figs)

Chapter 15: Extended Responses

1.(2010:42) This is a mini-essay question which requires you to analyse the Ostwald process of producing nitric acid from the point of view of rates of reactions and chemical equilibrium principles. There are three steps in this process.

Step 1 occurs at 900°C and at 10 atmospheric pressure:
$4\ NH_3(g) + 5\ O_2(g) \rightleftharpoons 4\ NO(g) + 6\ H_2O(g)$ + heat.

Step 2 occurs at 50°C: $2\ NO(g) + O_2(g) \rightleftharpoons 2\ NO_2(g)$ + heat.

Step 3 is a dissolving//reacting process which produces the acid:
$4\ NO_2(g) + O_2(g) + 2\ H_2O(l) \rightleftharpoons 4\ HNO_3(aq)$.

Step 1 is an exothermic reaction. According to the Le Châtelier's principle, an increase in temperature (viz., 900°C) will favour the formation of reactants. However, the rate of both the forward and the reverse reaction will increase. The advantage of an increase in temperature is the increase in the rate of effective collisions with adequate energy to form both reactants and the products in equal amounts. An increase in pressure (viz., 10 atmosphere) will also increase the reaction rate and, the application of pressure brings the molecules closer and increase the rate of collisions as well as the rate of both forward and the reverse reactions. However, the reactant side of the equation has less gaseous moles and hence the equilibrium will shift to the reactant side and decrease the yield of the products. The catalyst (viz., platinum with rhodium) lowers the activation energy barrier by providing an alternate pathway by removing the relatively higher rate determining step of the uncatalysed reaction. The overall effect is a sustained, but slow yield of the product.

Step 2 is also an exothermic reaction. The temperature used (50°C) is a low enough temperature to shift the equilibrium forward and increase the yield. The downside is the decrease in rate of the yield. This step is the slowest of the three steps in the Ostwald process. The yield from this process will increase under high pressure as the molecules come closer and increase the rate of effective collisions.

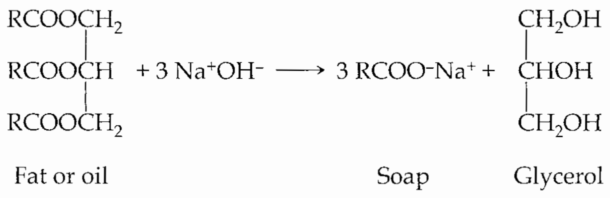
Step 3 involves the dissolving of NO_2 in water. And its reaction with the oxygen in the air. The use of sprinklers in this step, which sprays water on to the gas, is to increase the surface area of the particles that come into contact which increases the rate of effective collisions. Oxygen is also added through air at this stage. The 20% content of oxygen in air will reduce the rate and the yield as the concentration of the reactant (oxygen) is less than if it had been available pure. The NO_2 gas with the air-mixture introduced at the bottom of the tower rises to react with the sprinkler water coming from the top. This produces nitric acid. (In the industrial process, however, all the NO_2 does not get converted to HNO_3. Some NO in the reaction mixture is left over and this is separated and sent back to the bottom of the tower again for its complete oxidation to nitric acid.)

The Ostwald process is a good example of an industrial chemical process where a simplistic application of the Le Châtelier's principle cannot predict the actual conditions for the maximum yield of nitric acid. Some conditions need to be compromised in order to obtain the optimum yield at the best conditions that favour this.

2.(2011:41) The Chemistry of Soaps and Detergents

This question requires you to discuss the manufacture, cleaning process and the effectiveness of detergents compared with soaps.

Soaps are substances prepared by the hydrolysis of animal fat or oils with sodium hydroxide or potassium hydroxide. The hydrolysis of fats and oils (and esters) by alkalis is known as saponification. The general structural equation of a saponification reaction is:



$$\begin{array}{lcccl} RCOOCH_2 & & & & CH_2OH \\ | & & & & | \\ RCOOCH & + 3\ Na^+OH^- & \longrightarrow & 3\ RCOO^-Na^+ + & CHOH \\ | & & & & | \\ RCOOCH_2 & & & & CH_2OH \\ \text{Fat or oil} & & & \text{Soap} & \text{Glycerol} \end{array}$$

General equation of a saponification reaction

As an example, the hydrolysis of palm oil (glyceryl palmitate) with sodium hydroxide is shown below:

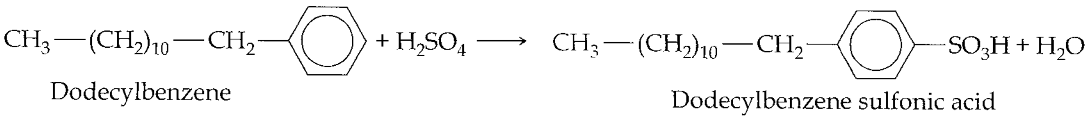
$$(C_{15}H_{31}COO)_3\,C_3H_5 + 3\ NaOH \longrightarrow 3\ C_{15}H_{31}COO^-Na^+ + C_3H_5(OH)_3$$

Glyceryl palmitate	Sodium hydroxide	Sodium palmitate (soap)	Glycerol

The hydrolysis of glyceryl palmitate

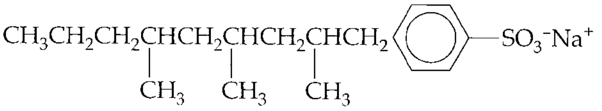
The oil is mixed with sodium hydroxide solution and is heated with steam. Sodium chloride is added to salt out the soap. The soap is washed and mixed with substances like perfume and anti-septic chemicals. Distillation of the aqueous solution produces glycerol.

Sodium dodecylbenzene sulfonate is an example of a common detergent. It is first prepared from the polymerisation of propene. It is then reacted with benzene to form dodecylbenzene. Reaction with concentrated sulfuric acid produces dodecylbenzyl sulfonic acid.



The production of dodecylbenzyl sulfonic acid

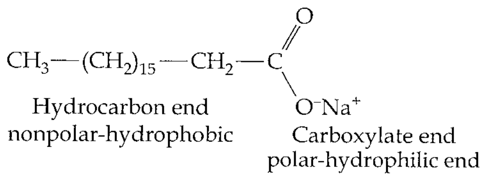
This is neutralised with sodium carbonate or sodium hydroxide to produce the detergent, dodecylbenzyl sulfonate.

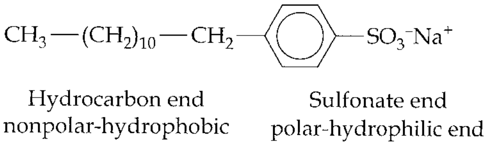


Sodium dodecylbenzyl sulfonate

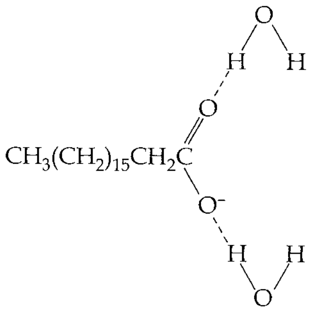
Cleaning action of soaps and detergents:

A soap molecule or a detergent molecule is made up of two components: a hydrocarbon component and a carboxylate component in the case of soap, and a hydrocarbon component and a sulfonate component in the case of detergent. The hydrocarbon component is the hydrophobic or water repelling end and the other component is the hydrophilic component or water attracting component. The following diagrams show the formation of a hydrogen bond between water molecules and a) the carboxylate ion, or b) the sulfonate ion.

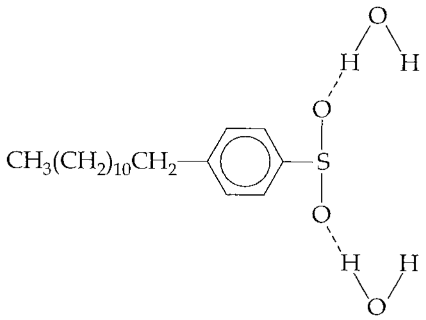




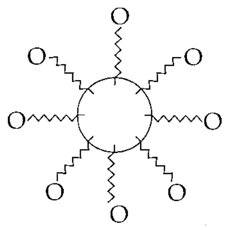
When a soap or detergent is added to water and a fabric with an oil stain, the hydrophobic ends attaches itself to the oil molecule with strong dispersion forces and the hydrophilic end attaches itself to water with strong dipole-dipole forces. Agitation of water detaches the oil from the fabric surface and the emulsification of grease as shown by the following sketches.



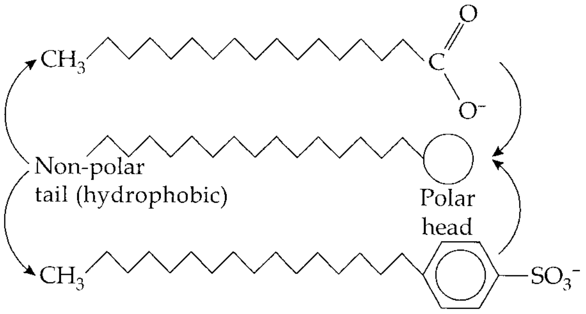
Carboxylic end bonding with H_2O



Sulfonate end bonding with H_2O



Emulsification of grease



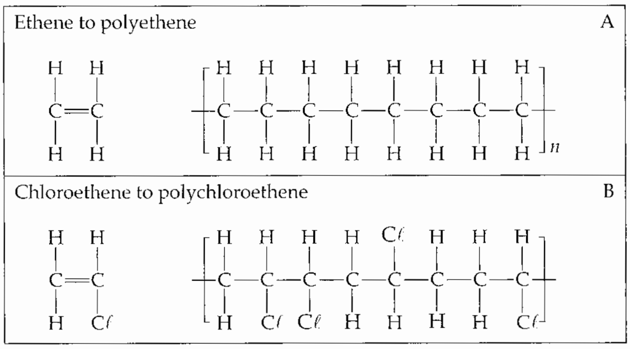
A detergent has an advantage over soap when it comes to hard water which contains dissolved Ca^{2+} and Mg^{2+} ions in the form of hydrogen carbonate, chlorides or sulfate salts. These salts produce a sticky solid with soap which is generally called scum. This reaction not only uses up soap, but also leaves scales in containers where this water is used, such as boilers and kettles. The sulfonate part of the detergent does not react with the calcium or magnesium ions in hard water. Due to this property of detergents, the problem of hard water no longer occurs when a detergent is used.

3.(2013:42) This is a mini-essay question. You are asked to explain what a polymer is and the different types of polymerisation reactions with examples.

Polymers are very large molecules made up of small repeating units called monomers. Natural substances such as rubber, silk, cotton and synthetic substances such as PVC, Teflon, rayon etc. are all polymers. The ability of monomers to combine to form a long chain compound is called polymerisation. The long chain molecule is called a polymer or macromolecule.

Polymerisation reactions are of two kinds: addition polymerisation and condensation polymerisation.

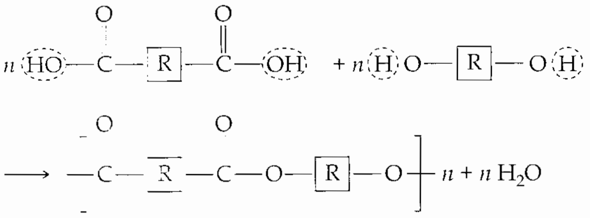
Addition polymerisation: Certain small organic molecules containing carbon-carbon double bond can undergo addition polymerisation. In this type of reaction one of the bonds in the C=C double bond is broken and resulting parts join up to form a long chain. Breaking up the double bond gives each carbon with additional bonding capacity which is used to form bonds between carbon atoms to form long, continuous chain. The number of monomer units can vary from 100 to 10,000 and more. This type of reaction requires an initiator to start the reaction. Two examples are shown below:



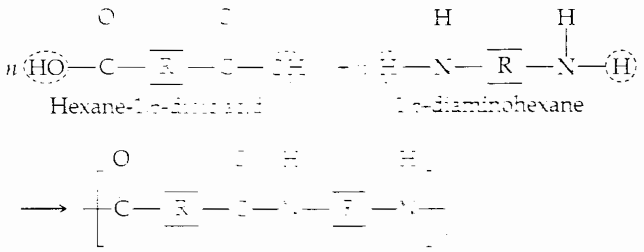
In addition to polymerisation, the polymer has the same empirical formula as the monomer. These kinds of polymers are also called plastics and are very durable. They are easily shaped and moulded and are inexpensive. They do not corrode, rust or decay. They are lighter. But, many are non-biodegradable and produce poisonous fumes when they burn.

Condensation polymerisation: This kind of polymerisation involves a reaction between two different monomers in which a molecule of water is condensed out and the two molecules link together. It can also occur between the same kind of molecule which contain two different functional groups at either ends. The two most common type of condensation polymerisation occurs between a carboxylic group and an alcohol or an amine group. Three examples are provided below:

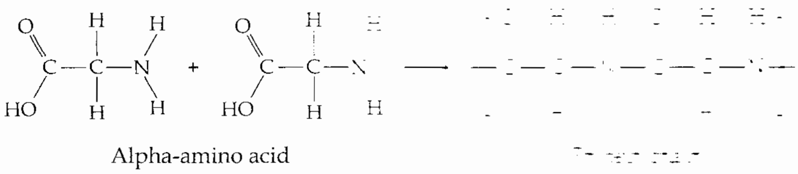
A dicarboxylic acid and a diol



A dicarboxylic acid and a diamine



Between amino acid molecules



Polyamides, commonly known as nylons are condensation polymers formed from dicarboxylic acids and diamines. These are extensively used in hosiery, clothing, fibres, ropes and netting. There are different types of nylons used for different purposes. A general reaction for the formation of polyamides is given below:

$$n(\text{HOOC—R—COOH} + \text{H}_2\text{N—R'—NH}_2) \longrightarrow n(\text{HOOC—R—CONH—R'—NH}_3) + \text{H}_2\text{O}$$

Dicarboxylic acid + diamine

$$\longrightarrow \text{—}\!\left(\text{OC—R—CONH—R'—NH}\right)\!\text{—}_{n} \quad + \; 2n\,\text{H}_2\text{O}$$

Polyamide Water

4.(2014:42) This is a mini-essay question which requires an explanation of the role played by different components of an electrochemical cell. The question can be interpreted as requiring answers both at a general level and at a specific level as applied to the cell and electrolytes represented in the diagram supplied.

Introduction: In this cell, Mg and Pb are used as the electrodes. Both are reacting electrodes. Their reduction equations and reduction potentials are:

$Mg^{2+}(aq) + 2\,e^- \rightleftharpoons Mg(s)$ E° = -2.36 V
$Pb^{2+}(aq) + 2\,e^- \rightleftharpoons Pb(s)$ E° = -0.13 V

Anode process: Since Mg has the lower reduction potential of the two, it oxidises in preference to the lead electrode and supplies electrons. Mg^{2+} ions have a lesser tendency to gain electrons than Pb^{2+} ions. Therefore, the reaction for Mg is, $Mg(s) \rightleftharpoons Mg^{2+}(aq) + 2\,e^-$ and releases electrons. The Mg^{2+} ions migrate towards the cathode which is lead. As a result, the mass of the anode decreases.

Cathode process: Pb has the higher reduction potential of the two and stays in the reduced metallic form. However, the Pb^{2+} ions in the electrolyte ($Pb(NO_3)_2$), are reduced at the cathode forming Pb atoms which adhere to the Pb cathode. As a result, the mass of the Pb cathode increases.

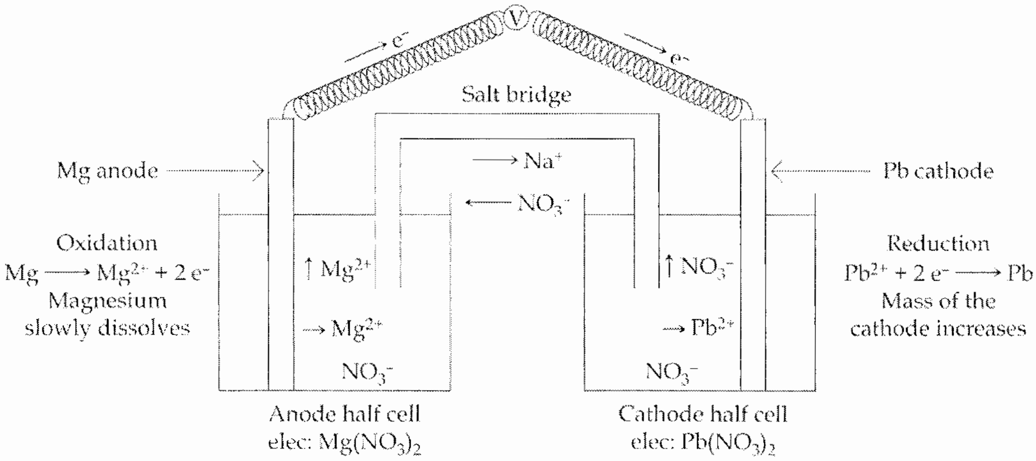
Electrolytes: An electrolyte is a substance, the water solution or molten form of which conducts current through their ions. Electrolytes are electrically neutral, but contains ions which are free to move.

There are two electrolytes in the $Mg/Mg^{2+}//Pb^{2+}/Pb$ cell. $Pb(NO_3)_2$ supplies the Pb^{2+} ions for current flow and $Mg(NO_3)_2$ supplies the Mg^{2+} ions for migration and current flow. The electrolytes allow the passage of ions through them. The concentration of the electrolyte is an important factor in determining the cell potential. Temperature is another important variable. Electrical neutrality is maintained by the migration of cation (Pb^{2+}) towards the lead half cell and anions (Mg^{2+}) away from the Mg half cell.

The salt bridge: A salt-bridge has a general design consisting of paper that contains an electrolyte solution such as $NaNO_3(aq)$. Electrical neutrality is maintained by the migration of ions through the bridge. The solution used in the salt bridge should be such that it does not react with any of the other ions in the cell. The salt bridge also serves to complete the circuit.

Electron flow in the external circuit: In an electrochemical cell, electrons released at the anode travel through the external circuit to the cathode half cell due to the potential difference that exists between the two electrodes.

Cell emf: At 1.00 mol L^{-1} concentration of the electrolytes and at 25°C, the cell will yield an emf of 2.23 V.



5.(2016 SP:41)

- 3 Galvanic cells with A and B as electrodes, then A and C as electrodes and B and C as electrodes need to be constructed
- cells will need an electrolyte (eg. NaCℓ dissolved in water or 0.1 mol L^{-1} HCℓ)
- role of ions as electrolyte to complete the circuit
- voltmeter needs to be connected in the external circuit to measure potential difference between electrodes
- E(A/B), E(A/C) and E(B/C) is the data that needs to be collected
- direction of current flow can be used to identify the anode and cathode in each of the cell couples and the magnitude of voltage can be used to order the 3 metals from most easily to least easily reduced
- labelled diagram to show typical Galvanic cell (electrodes, voltmeter, salt bridge if 2 beakers used)
- variables to control. any 2 variables e.g. temp, conc. of electrolyte soln, surface area of electrodes in contact with electrolyte

Acknowledgements

Chapter	Question Reference and Acknowledgement
Insert: Chemistry Data Book	Aylward, G.H., & Findlay, T. *SI Chemical Data* (6th ed.). Queensland: John Wiley & Sons Australia, Ltd.
15	Image for question (2014:42) adapted from: Megna, R. *Electrochemical cell*. Retrieved June 23, 2014, from http://fphoto.photoshelter.com/search?I_DSC=45859901=2RMG_ACT=search

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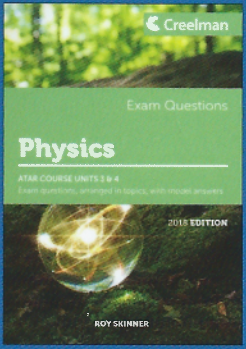

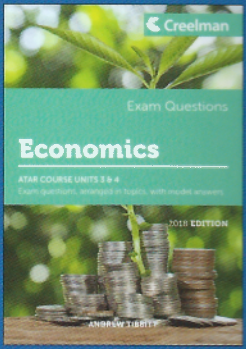

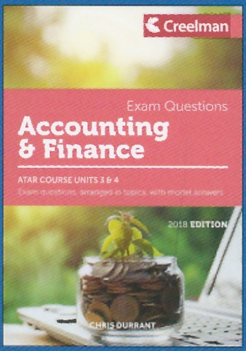

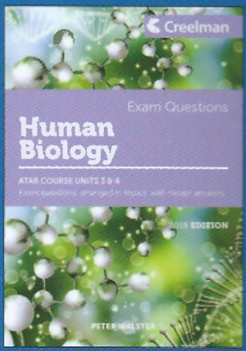

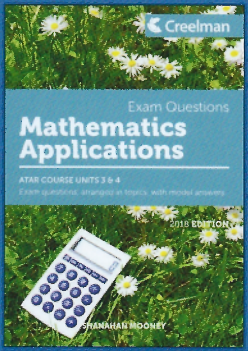

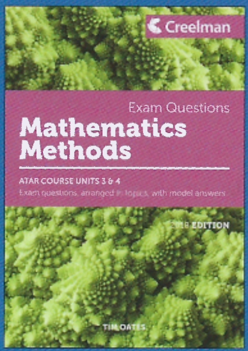

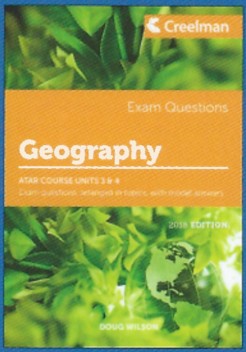

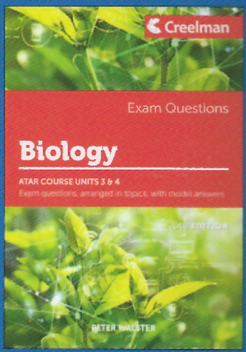

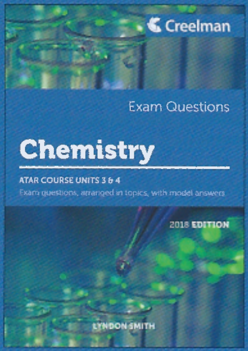

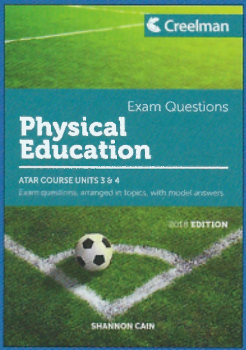

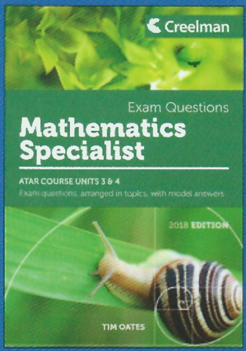

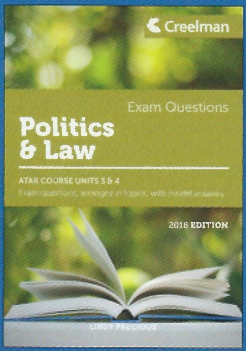

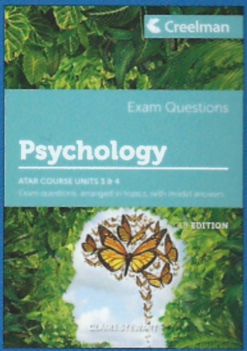

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