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INTERNATIONAL ADVANCED LEVEL

Chemistry

SPECIFICATION

Pearson Edexcel International Advanced Subsidiary in Chemistry (XCH01)

Pearson Edexcel International Advanced Level in Chemistry (YCH01)

For first teaching in September 2013
First examination January 2014
Issue 3

ALWAYS LEARNING PEARSON

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This specification is Issue 3. Key changes are sidelined. We will inform centres of any changes to this issue. The latest issue can be found on the Pearson website: qualifications.pearson.com

Acknowledgements

This specification has been produced by Pearson on the basis of consultation with teachers, examiners, consultants and other interested parties. Pearson would like to thank all those who contributed their time and expertise to the specification's development.

References to third party material made in this specification are made in good faith. Pearson does not endorse, approve or accept responsibility for the content of materials, which may be subject to change, or any opinions expressed therein. (Material may include textbooks, journals, magazines and other publications and websites.)

All information in this specification is correct at time of going to publication.

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About this specification

Pearson Edexcel International Advanced Level in Chemistry is designed for use in schools and colleges outside the United Kingdom. It is part of a suite of International Advanced Level qualifications offered by Pearson.

This qualification has been approved by Pearson Education Limited as meeting the criteria for Pearson's Self-regulated Framework.

Pearson's Self-regulated Framework is designed for qualifications that have been customised to meet the needs of a particular range of learners and stakeholders. These qualifications are not accredited or regulated by any UK regulatory body.

Structure: flexible, modular structure comprising six units.

Content: engaging and relevant to international customers.

Assessment: 100% external assessment, with January and June assessment opportunities.

Approach: practical activities embedded within each unit to reflect the nature of chemistry.

Specification updates

This specification is Issue 3 and is valid for the Pearson Edexcel International Advanced Subsidiary and International Advanced Level examination from 2014. If there are any significant changes to the specification Pearson will write to centres to let them know. Changes will also be posted on our website.

For more information please visit:
qualifications.pearson.com/en/qualifications/edexcel-international-advanced-levels.html

Using this specification

The specification content has been designed to give guidance to teachers and encourage effective delivery of the qualification. The following information will help you get the most out of the content and guidance.

The specification content enables motivating contemporary chemistry contexts to be included in the teaching and learning programme. It is designed to motivate both teachers and students, to encourage more students to study chemistry and to encourage teachers to update the content that they deliver.

Students will study aspects of chemistry that are often in the media and affect their lives. It is important that students have the necessary knowledge and understanding to explain many different aspects of contemporary chemistry. These areas include:

- climate change
- green chemistry
- pharmaceuticals
- chemistry research.

These contexts are given as examples within the units so they can be updated or expanded upon by teachers over the lifetime of this qualification.

The content of this specification includes the fundamental key concepts of chemistry needed for progression into higher education and employment. However, it has been streamlined to allow students enough time to study the units in depth. This ensures that the teaching and learning experience is enjoyable.

Depth and breadth of content: teachers should prepare students to respond to assessment questions. Teachers should use the full range of content and all the assessment objectives given in *Section B: Specification Overview.*

Qualification abbreviations

International Advanced Level – IAL

International Advanced Subsidiary – IAS

International Advanced Level 2 (the additional content required for an IAL) – IA2

Contents

Contents

A Specification at a glance

Unit overview

IAS Unit 1: The Core Principles of Chemistry	*Unit code WCH01	
■ Externally assessed ■ Availability: January and June ■ First assessment: January 2014	40% of the total IAS raw marks	20% of the total IAL raw marks
Content summary: This unit provides opportunities for students to develop the basic chemical skills of formulae writing, equation writing and calculating chemical quantities. The study of energetics in chemistry is of theoretical and practical importance. In this unit students learn to define, measure and calculate enthalpy changes. They will see how a study of enthalpy changes can help chemists to understand chemical bonding. The study of atomic structure introduces s, p and d orbitals and shows how a more detailed understanding of electron configurations can account for the arrangement of elements in the periodic table. The unit introduces the three types of strong chemical bonding (ionic, covalent and metallic). Organic chemistry is also introduced with students studying alkanes and alkenes.		
Assessment: Examination of 1 hour 30 minutes in two sections: ■ Section A: objective test questions ■ Section B: mixture of short-answer and extended answer questions.		

IAS Unit 2: Application of Core Principles of Chemistry	*Unit code WCH02	
■ Externally assessed ■ Availability: January and June ■ First assessment: January 2014	40% of the total IAS raw marks	20% of the total IAL raw marks
Content summary: This unit develops the treatment of chemical bonding by introducing intermediate types of bonding and by exploring the nature and effects of intermolecular forces. Study of the periodic table is extended to cover the chemistry of groups 2 and 7. Ideas about redox reactions are applied, in particular, to the reactions of halogens and their compounds. The unit develops a largely qualitative understanding of the ways in which chemists can control the rate, direction and extent of chemical change. Organic chemistry in this unit covers alcohols and halogenoalkanes. The treatment is extended to explore the mechanisms of selected examples. Students have to use formulae and balance equations and have an understanding of chemical quantities. Aspects of green chemistry and climate change are also studied.		
Assessment: Examination of 1 hour 30 minutes in three sections: ■ Section A: objective test questions ■ Section B: mixture of short-answer and extended answer questions ■ Section C: contemporary context questions.		

* *See Appendix 2* for description of this code and all other codes relevant to this qualification.

IAS	Unit 3: Chemistry Laboratory Skills I Alternative	*Unit code WCH03	
	■ Externally assessed ■ Availability: January and June ■ First assessment: January 2014	20% of the total IAS raw marks	10% of the total IAL raw marks

Content summary:

This unit contains a practical written examination that covers the content of Units 1 and 2. There is no specific content for this unit. The practical written examination covers the areas of physical, organic and inorganic chemistry and the following types of practicals:

- qualitative observations
- quantitative measurements
- preparations.

Assessment:

Examination of 1 hour 15 minutes with one section.

IA2	Unit 4: General Principles of Chemistry I – Rates, Equilibria and Further Organic Chemistry	*Unit code WCH04	
	■ Externally assessed ■ Availability: January and June ■ First assessment: January 2014	40% of the total IA2 raw marks	20% of the total IAL raw marks

Content summary:

In this unit students make a quantitative study of chemical kinetics and take further their study of organic reaction mechanisms. The topics of entropy and equilibria show how chemists are able to predict quantitatively the direction and extent of chemical change. The organic chemistry in this unit covers carbonyl compounds, plus carboxylic acids and their derivatives. Students are required to apply their knowledge gained in Units 1 and 2 to all aspects of this unit. This includes nomenclature, ideas of isomerism, bond polarity and bond enthalpy, reagents and reaction conditions, reaction types and mechanisms. Students are also expected to use formulae and balance equations and calculate chemical quantities.

Assessment:

Examination of 1 hour 40 minutes in three sections:

- Section A: objective test questions
- Section B: mixture of short-answer and extended answer questions
- Section C: data questions, with use of a data booklet.

* *See Appendix 2* for description of this code and all other codes relevant to this qualification.

IA2 Unit 5: General Principles of Chemistry II – Transition Metals and Organic Nitrogen Chemistry	*Unit code WCH05	
■ Externally assessed ■ Availability: January and June ■ First assessment: January 2014	40% of the total IA2 raw marks	20% of the total IAL raw marks
Content summary: In this unit the study of electrode potentials builds on the study of redox in Unit 2, including the concept of oxidation number and the use of redox half equations. Students will study further chemistry related to redox and transition metals. The further organic chemistry section of this unit focuses on arenes and organic nitrogen compounds such as amines, amides, amino acids and proteins. Students are expected to use the knowledge and understanding of organic chemistry that they have gained over the whole International Advanced Level in Chemistry when covering the organic synthesis section. This unit draws on all other units within the International Advanced Level in Chemistry and students are expected to use their prior knowledge when learning about these areas. Students will again encounter ideas of isomerism, bond polarity and bond enthalpy, reagents and reaction conditions, reaction types and mechanisms. Students are also expected to use formulae and balance equations and calculate chemical quantities.		
Assessment: Examination of 1 hour 40 minutes in three sections: ■ Section A: objective test questions ■ Section B: mixture of short-answer and extended answer questions ■ Section C: contemporary context questions.		

Students complete either Unit 6 or Unit 7.

IA2 Unit 6: Chemistry Laboratory Skills II Alternative	*Unit code WCH06	
■ Externally assessed ■ Availability: January and June ■ First assessment: January 2014	20% of the total IA2 raw marks	10% of the total IAL raw marks
Content summary: This unit contains a practical written examination that covers the content of Units 4 and 5. There is no specific content for this unit. The practical written examination covers the areas of physical, organic and inorganic chemistry and the following types of practicals: ■ qualitative observations ■ quantitative measurements ■ preparations.		
Assessment: Examination of 1 hour 15 minutes with one section.		

Students complete either Unit 6 or Unit 7.

IA2 Unit 7: Chemistry Practical Examination	*Unit code WCH07	
■ Externally assessed ■ Availability: January and June ■ First assessment: January 2017	20% of the total IA2 raw marks	10% of the total IAL raw marks
Content summary: This unit gives opportunities for students to be tested on their practical skills developed through their laboratory work in Units 1, 2, 4 and 5. Questions will be set on areas of laboratory chemistry that students will have covered throughout the course. These could include qualitative observations on inorganic anions, cations and organic functional groups. Students are required to make inferences from their observations and identify inorganic and organic unknowns. Students are also expected to interpret spectroscopic data on organic compounds. Students will have developed skills in quantitative physical chemistry and should be able to assemble and manipulate the apparatus used in titrations, rates of reaction and thermochemistry. The results of quantitative questions could be used to carry out calculations and draw graphs. Some of the techniques in organic chemistry could be examined, for example by asking students to determine the melting and boiling temperature of organic compounds.		
Assessment: Examination of 2 hours with one section.		

* *See Appendix 2* for description of this code and all other codes relevant to this qualification.

A Specification at a glance

B Specification overview

Summary of assessment requirements

Unit number and unit title	Level	Assessment information	Number of raw marks allocated in the unit
Unit 1: The Core Principles of Chemistry	IAS	Examination length: 1 hour and 30 minutes. Examination paper in two sections. Section A is an objective test section, and Section B contains a mixture of short-answer and extended answer questions. Section B will include questions on the analysis and evaluation of practical work. Quality of written communication will be assessed in Section B.	80
Unit 2: Application of Core Principles of Chemistry	IAS	Examination length: 1 hour and 30 minutes. Examination paper in three sections. Section A is an objective test section, and Section B contains a mixture of short-answer and extended answer questions. Section C will contain questions on contemporary contexts. This may contain stimulus materials on a scenario that students must read in order to answer the questions. Quality of written communication will be assessed in either Section B or C. Questions on the analysis and evaluation of practical work will also be included in either Section B or C.	80
Unit 3: Chemistry Laboratory Skills I Alternative	IAS	Examination length: 1 hour and 15 minutes. Examination paper contains one section. Quality of written communication will be assessed in this examination.	50
Unit 4: General Principles of Chemistry I – Rates, Equilibria and Further Organic Chemistry	IA2	Examination length: 1 hour and 40 minutes. Examination paper in three sections. Section A is an objective test section, and Section B contains a mixture of short-answer and extended answer questions. Section C will contain data questions and will require the use of a data booklet. The longer timing of the examination reflects the style of the Section C questions. Students will be able to show their full ability in Sections B and C as these contain areas where they will be stretched and challenged. They will be provided with data from a laboratory experiment and asked a series of questions on it. Quality of written communication will be assessed in this examination in either Section B or C.	90

Unit number and unit title	Level	Assessment information	Number of raw marks allocated in the unit
Unit 5: General Principles of Chemistry II – Transition Metals and Organic Nitrogen Chemistry	IA2	Examination length: 1 hour and 40 minutes. Examination paper in three sections. Section A is an objective test section, and Section B contains a mixture of short-answer and extended answer questions. Questions on the analysis and evaluation of practical work will also be included in Section B. Section C will contain questions on contemporary contexts. This may contain stimulus materials on a scenario that students must read in order to answer the questions. The longer timing of the examination reflects the style of the Section C questions. Students will be able to show their full ability in Sections B and C as these contain areas where they will be stretched and challenged. Quality of written communication will be assessed in this examination in either Section B or C.	90
Unit 6: Chemistry Laboratory Skills II Alternative	IA2	Examination length: 1 hour and 15 minutes. Examination paper contains one section. Quality of written communication will be assessed in this examination.	50
Unit 7: Chemistry Practical Examination	IA2	Examination length: 2 hours Examination paper contains one section. Quality of written communication will be assessed in this examination. Centres offering this unit must meet the chemistry practical examination requirements in *Appendix 6*.	50

Assessment objectives and weightings

		% in IAS	% in IA2	% in IAL
AO1	Knowledge and understanding of science and of *How Science Works*	38.4%	25%	31.7%
AO2	Application of knowledge and understanding of science and of *How Science Works*	38.4%	43%	40.7%
AO3	*How Science Works*	23.2%	32%	27.6%
		100%	100%	100%

Relationship of assessment objectives to units

Unit number	Assessment objective			
	AO1	**AO2**	**AO3**	**Total for AO1, AO2 and AO3**
Unit 1	10%	8%	2%	20%
Unit 2	8%	10%	2%	20%
Unit 3	1.2%	1.2%	7.6%	10%
Unit 4	5.3%	9.4%	5.3%	20%
Unit 5	6%	10.9%	3.1%	20%
Unit 6/7	1.2%	1.2%	7.6%	10%
Total for International Advanced Level	31.7%	40.7%	27.6%	100%

Qualification summary

Aims

The aims of the International Advanced Level in Chemistry enable students to develop:

- an interest in, and enthusiasm, for chemistry including developing an interest in further study and careers in chemistry
- an appreciation of how society makes decisions about scientific issues and how the sciences contribute to the success of the economy and society
- a deeper understanding of the skills, knowledge and understanding of *How Science Works*
- essential knowledge and understanding of different areas of the subject and how they relate to each other.

IAS/IA2 knowledge and understanding

The International Advanced Level qualifications in Chemistry require students to:

- recognise, recall and show understanding of scientific knowledge
- select, organise and communicate relevant information in a variety of forms
- analyse and evaluate scientific knowledge and processes
- apply scientific knowledge and processes to unfamiliar situations
- assess the validity, reliability and credibility of scientific information.

How Science Works

The International Advanced Level in Chemistry qualifications allows students to develop the skills, knowledge and understanding of *How Science Works*, a newly introduced section that builds on from the Key Stage 4 Programme of Study for science. These are described as follows:

- use theories, models and ideas to develop and modify scientific explanations
- use knowledge and understanding to pose scientific questions, define scientific problems and present scientific arguments and ideas
- use appropriate methodology, including ICT, to answer scientific questions and solve scientific problems
- carry out experimental and investigative activities, including appropriate risk management, in a range of contexts
- analyse and interpret data to provide evidence, recognising correlations and causal relationships
- evaluate methodology, evidence and data and resolve conflicting evidence
- appreciate the tentative nature of scientific knowledge
- communicate information and ideas in appropriate ways using appropriate terminology
- consider the applications and implications of science and appreciate their associated benefits and risks
- consider ethical issues in the treatment of humans, other organisms and the environment
- appreciate the role of the scientific community in validating new knowledge and ensuring integrity
- appreciate the ways in which society uses science to inform decision making.

These statements have been embedded within the specification and will be assessed in the external assessments, both at IAS and IA2. A more detailed mapping of where these statements are found within the units can be found in *Appendix 3*. This also contains a further expansion on the specification points which address these *How Science Works* statements.

Experimental and investigative skills

The International Advanced Level in Chemistry qualifications require students to develop a range of experimental and investigative skills. These are highlighted in the previous *How Science Works* section.

Core practicals that all students should carry out have been listed within the unit specification, at both IAS and IA2 level. Many of these will be standard International Advanced Level practicals. This ensures that all students cover a variety of different practicals and have developed their experimental and investigative skills. The examinations can contain questions of a more practical nature, such as analysis and evaluation of practical work.

With all laboratory practicals it is essential that centres carry out a detailed risk assessment before allowing students to carry out the practical. For further information on risk assessments and chemical hazards please refer to the CLEAPSS website: www.cleapss.org.uk

C Chemistry unit content

Course structure

- The Pearson Edexcel International Advanced Level in Chemistry comprises six units and contains an International Advanced Subsidiary subset of three IAS units.
- The International Advanced Subsidiary is the first half of the International Advanced Level course and consists of Units 1, 2 and 3. It may be awarded as a discrete qualification or contribute 50 per cent of the total International Advanced Level marks.
- The full International Advanced Level award consists of the three IAS units (Units 1, 2 and 3), plus three IA2 units (Units 4, 5 and **either 6 or 7**) which make up the other 50 per cent of the International Advanced Level. Students wishing to take the full International Advanced Level must, therefore, complete six units.
- The structure of this qualification allows teachers to construct a course of study that can be taught and assessed either as:
  - distinct modules of teaching and learning with related units of assessment taken at appropriate stages during the course; or
  - a linear course which is assessed in its entirety at the end.

Practical assessment option

Scientific subjects are, by their nature, experimental. It is therefore important that an assessment of a student's knowledge and understanding of chemistry should contain a practical component (see assessment objective AO3).

Centres' circumstances (e.g. the availability of resources) differ greatly, so two alternative ways of assessing the practical component are provided. **Centres can choose for their students to take either Unit 6: Chemistry Laboratory Skills II Alternative or Unit 7: Chemistry Practical Examination.**

Whichever practical assessment route is chosen, the following points should be noted:

- the same assessment objectives apply
- the same practical activities are carried out on the course
- the same practical skills are to be learned and developed.

1.1 Unit description

Chemical ideas

This unit provides opportunities for students to develop the basic chemical skills of formulae writing, equation writing and calculating chemical quantities.

The study of energetics in chemistry is of theoretical and practical importance. In this unit students learn to define, measure and calculate enthalpy changes. They will see how a study of enthalpy changes can help chemists to understand chemical bonding.

The study of atomic structure introduces s, p, and d orbitals and shows how a more detailed understanding of electron configurations can account for the arrangement of elements in the periodic table.

The unit introduces the three types of strong chemical bonding (ionic, covalent and metallic).

Organic chemistry is also introduced, with students studying alkanes and alkenes.

How chemists work

Practical work measuring energy changes helps students to understand the ideas of uncertainty in measurements and evaluate their results in terms of systematic and random errors.

The study of atomic structure gives some insight into the types of evidence which scientists use to study electrons in atoms. This leads to an appreciation of one of the central features of chemistry which is the explanation of the properties of elements and the patterns in the periodic table in terms of atomic structure.

The role of instrumentation in analytical chemistry is illustrated by mass spectrometry.

Students are introduced to some of the evidence which will help them to understand the different kinds of chemical bonding.

Chemists set up theoretical models and gain insights by comparing real and ideal properties of chemicals. This is illustrated in the unit by the ionic model and the comparison of lattice energies calculated from theory with those determined with the help of Born-Haber cycles.

Throughout the unit students see the importance of chemical data and learn to select data from databases and use it to look for patterns and calculate other quantities.

The introduction to organic chemistry shows how chemists work safely with potentially hazardous chemicals by managing risks.

Chemistry in action

The uses of mass spectrometry illustrate the importance of sensitive methods of analysis in areas such as space research, medical research and diagnosis, in detecting drugs in sport and in environmental monitoring.

In this unit students learn how chemical insights can help to make the use of polymeric and other materials more sustainable. This involves analysis of the uses of energy, raw materials and other resources at each stage of the life cycle of products.

Core practicals

The following specification points are core practicals within this unit that students should complete:

1.3j

1.3k

1.4f

These practicals may appear in the written examination for Unit 1.

Use of examples

Examples in practicals

Where 'e.g.' follows a type of experiment in the specification students are not expected to have carried out that specific experiment. However, they should be able to use data from that or similar experiments.

For instance in this unit, *1.4f ii Energetics*, the specification states:

simple enthalpy of combustion experiments using, e.g. a series of alcohols in a spirit burner.

Students should have carried out simple enthalpy of combustion reactions, but they may or may not have carried out these using alcohol in spirit burners.

In the unit test students could be given experimental data for this, or any other enthalpy of combustion reaction, and be expected to analyse and evaluate this data.

Examples in unit content

Where 'e.g.' follows a concept students are not expected to have been taught the particular example given in the specification. They should be able to illustrate their answer with an example of their choice.

For instance in this unit, *1.6.1f Ionic bonding*, the specification states:

recall trends in ionic radii down a group and for a set of isoelectronic ions, e.g. N^{3-} *to* Al^{3+}.

Students will be expected to recall the trends in ionic radii down a group, and for a set of isoelectronic ions, but they may or may not have done this from N^{3-} to Al^{3+}.

In the unit test students could be asked to recall the trends in ionic radii down a group. They could be asked this in reference to any group in the periodic table, either the one listed as an example or another group.

1.2 Assessment information

Unit 1 examination

The examination will be 1 hour 30 minutes and have 80 marks. It will contain two sections – A and B.

Section A is an objective test section which will aim to cover a large proportion of the specification for this unit.

Section B contains a mixture of short-answer and extended answer questions. This will include questions on the analysis and evaluation of practical work.

Students may use a calculator.

Quality of written communication will be assessed in this examination through questions which are labelled with an asterisk (*). When answering these questions students should consider spelling, punctuation and grammar of their response, as well as the clarity of expression.

1.3 Formulae, equations and amount of substance

Application of ideas from this topic will be applied to all other units.

Students will be assessed on their ability to:

a demonstrate an understanding of the terms *atom*, *element*, *ion*, *molecule*, *compound*, *empirical* and *molecular formulae*

b write balanced equations (full and ionic) for simple reactions, including the use of state symbols

c demonstrate an understanding of the terms *relative atomic mass*, *amount of substance*, *molar mass* and *parts per million (ppm)*, e.g. gases in the atmosphere, exhausts, water pollution

d calculate the amount of substance in a solution of known concentration (excluding titration calculations at this stage), e.g. use data from the concentrations of the various species in blood samples to perform calculations in mol dm^{-3}

e use chemical equations to calculate reacting masses and vice versa using the concepts of amount of substance and molar mass

f use chemical equations to calculate volumes of gases and vice versa using the concepts of amount of substance and molar volume of gases, e.g. calculation of the mass or volume of CO_2 produced by combustion of a hydrocarbon (given a molar volume for the gas)

g use chemical equations and experimental results to deduce percentage yields and atom economies in laboratory and industrial processes and understand why they are important

h demonstrate an understanding of, and be able to perform, calculations using the Avogadro constant

i analyse and evaluate the results obtained from finding a formula or confirming an equation by experiment, e.g. the reaction of lithium with water and deducing the equation from the amounts in moles of lithium and hydrogen j make a salt and calculate the percentage yield of product, e.g. preparation of a double salt (ammonium iron(II) sulfate from iron, ammonia and sulfuric acid)

k carry out and interpret the results of simple test tube reactions, such as displacements, reactions of acids, precipitations, to relate the observations to the state symbols used in equations and to practise writing full and ionic equations.

1.4 Energetics

Students will be assessed on their ability to:

a demonstrate an understanding of the term *enthalpy change*, ΔH

b construct simple enthalpy level diagrams showing the enthalpy change

c recall the sign of ΔH for exothermic and endothermic reactions, e.g. illustrated by the use of exo- and endothermic reactions in hot and cold packs

d recall the definition of standard enthalpy changes of reaction, formation, combustion, neutralisation and atomisation and use experimental data to calculate energy transferred in a reaction and hence the enthalpy change of the reaction. This will be limited to experiments where substances are mixed in an insulated container and combustion experiments

e recall Hess's Law and apply it to calculating enthalpy changes of reaction from data provided, selected from a table of data or obtained from experiments and understand why standard data is necessary to carry out calculations of this type

f evaluate the results obtained from experiments using the expression:

energy transferred in joules = mass × specific heat capacity × temperature change

and comment on sources of error and assumptions made in the experiments. The following types of experiments should be performed:

i experiments in which substances are mixed in an insulated container and the temperature rise measured

ii simple enthalpy of combustion experiments using, e.g. a series of alcohols in a spirit burner

iii plan and carry out an experiment where the enthalpy change cannot be measured directly, e.g. the enthalpy change for the decomposition of calcium carbonate using the enthalpy changes of reaction of calcium carbonate and calcium oxide with hydrochloric acid

g demonstrate an understanding of the terms *bond enthalpy* and *mean bond enthalpy*, and use bond enthalpies in Hess cycle calculations and recognise their limitations. Understand that bond enthalpy data gives some indication about which bond will break first in a reaction, how easy or difficult it is and therefore how rapidly a reaction will take place at room temperature.

1.5 Atomic structure and the periodic table

Students will be assessed on their ability to:

a recall the definitions of relative atomic mass, relative isotopic mass and relative molecular mass and understand that they are measured relative to 1/12th the mass of a ^{12}C atom

b demonstrate an understanding of the basic principles of a mass spectrometer and interpret data from a mass spectrometer to:

i deduce the isotopic composition of a sample of an element, e.g. polonium

ii deduce the relative atomic mass of an element

iii measure the relative molecular mass of a compound

c describe some uses of mass spectrometers, e.g. in radioactive dating, in space research, in sport to detect use of anabolic steroids, in the pharmaceutical industry to provide an identifier for compounds synthesised for possible identification as drugs

d recall and understand the definition of ionisation energies of gaseous atoms and that they are endothermic processes

e recall that ideas about electronic structure developed from:

i an understanding that successive ionisation energies provide evidence for the existence of quantum shells and the group to which the element belongs

ii an understanding that the first ionisation energy of successive elements provides evidence for electron sub-shells

f describe the shapes of electron density plots (or maps) for s and p orbitals

g predict the electronic structure and configuration of atoms of the elements from hydrogen to krypton inclusive using 1s …notation and electron-in-boxes notation (recall electrons populate orbits singly before pairing up)

h demonstrate an understanding that electronic structure determines the chemical properties of an element

i recall that the periodic table is divided into blocks, such as s, p and d

j represent data, in a graphical form, for elements 1 to 36 and use this to explain the meaning of the term *periodic property* k explain trends in the following properties of the element from periods 2 and 3 of the periodic table:

  i melting temperature of the elements based on given data using the structure and the bonding between the atoms or molecules of the element

  ii ionisation energy based on given data or recall of the shape of the plots of ionisation energy versus atomic number using ideas of electronic structure and the way that electron energy levels vary across the period.

1.6 Bonding

Students will be assessed on their ability to:

1 Ionic bonding

a recall and interpret evidence for the existence of ions, limited to physical properties of ionic compounds, electron density maps and the migration of ions, e.g. electrolysis of aqueous copper chromate(VI)

b describe the formation of ions in terms of electron loss or gain

c draw electron configuration diagrams of cations and anions using dots or crosses to represent electrons

d describe ionic crystals as giant lattices of ions

e describe ionic bonding as the result of strong net electrostatic attraction between ions

f recall trends in ionic radii down a group and for a set of isoelectronic ions, e.g. N^{3-} to Al^{3+}

g recall the stages involved in the formation of a solid ionic crystal from its elements and that this leads to a measure value for the lattice energy (students will not be expected to draw the full Born-Haber cycles)

h test the ionic model for ionic bonding of a particular compound by comparison of lattice energies obtained from the experimental values used in Born-Haber cycles, with provided values calculated from electrostatic theory

i explain the meaning of the term *polarisation* as applied to ions

j demonstrate an understanding that the polarising power of a cation depends on its radius and charge, and the polarisability of an anion depends on its size

k demonstrate an understanding that polarisation of anions by cations leads to some covalency in an ionic bond, based on evidence from the Born-Haber cycle

l use values calculated for standard heats of formation based on Born-Haber cycles to explain why particular ionic compounds exist, e.g. the relative stability of $MgCl_2$ over MgCl or $MgCl_3$ and NaCl over $NaCl_2$.

2 Covalent bonding

a demonstrate an understanding that covalent bonding is strong and arises from the electrostatic attraction between the nucleus and the electrons which are between the nuclei, based on the evidence:

i the physical properties of giant atomic structures

ii electron density maps for simple molecules

b draw electron configuration diagrams for simple covalently bonded molecules, including those with multiple bonds and dative covalent bonds, using dots or crosses to represent electrons.

3 Metallic bonding

a demonstrate an understanding that metals consist of giant lattices of metal ions in a sea of delocalised electrons

b describe metallic bonding as the strong attraction between metal ions and the sea of delocalised electrons

c use the models in 1.6.3a and 1.6.3b to interpret simple properties of metals, e.g. conductivity and melting temperatures.

1.7 Introductory organic chemistry

Related topics in Units 2, 4 and 5 will assume knowledge of this material.

Students will be assessed on their ability to:

1 Introduction

a demonstrate an understanding that there are series of organic compounds characterised by a general formula and one or more functional groups

b apply the rules of IUPAC nomenclature to compounds relevant to this specification and draw these compounds, as they are encountered in the specification, using structural, displayed and skeletal formulae

c appreciate the difference between hazard and risk

d demonstrate an understanding of the hazards associated with organic compounds and why it is necessary to carry out risk assessments when dealing with potentially hazardous materials. Suggest ways by which risks can be reduced and reactions can be carried out safely by:

i working on a smaller scale

ii taking specific precautions or using alternative techniques depending on the properties of the substances involved

iii carrying out the reaction using an alternative method that involves less hazardous substances.

2 Alkanes

a state the general formula of alkanes and understand that they are saturated hydrocarbons which contain single bonds only

b explain the existence of structural isomers using alkanes (up to C_5) as examples

c know that alkanes are used as fuels and obtained from the fractional distillation, cracking and reformation of crude oil

d discuss the reasons for developing alternative fuels in terms of sustainability and reducing emissions, including the emission of CO_2 and its relationship to climate change

e describe the reactions of alkanes in terms of combustion and substitution by chlorine showing the mechanism of free radical substitution in terms of initiation, propagation and termination and using curly half-arrows in the mechanism to show the formation of free radicals in the initiation step using a single dot to represent the unpaired electron.

3 Alkenes

a state the general formula of alkenes and understand that they are unsaturated hydrocarbons with a carbon-carbon double bond which consists of a σ and a π bond

b explain E-Z isomerism (geometric/cis-trans isomerism) in terms of restricted rotation around a C=C double bond and the nature of the substituents on the carbon atoms

c demonstrate an understanding of the E-Z naming system and why it is necessary to use this when the *cis*- and *trans*- naming system breaks down

d describe the addition reactions of alkenes, limited to:

- i the addition of hydrogen with a nickel catalyst to form an alkane
- ii the addition of halogens to produce di-substituted halogenoalkanes
- iii the addition of hydrogen halides to produce mono-substituted halogenoalkanes
- iv oxidation of the double bond by potassium manganate(VII) to produce a diol

e describe the mechanism (including diagrams), giving evidence where possible, of:

- i the electrophilic addition of bromine and hydrogen bromide to ethene
- ii the electrophilic addition of hydrogen bromide to propene

f describe the test for the presence of C=C using bromine water and understand that the product is the addition of OH and Br

g describe the addition polymerisation of alkenes and identify the repeat unit given the monomer, and vice versa

h interpret given information about the uses of energy and resources over the life cycle of polymer products to show how the use of renewable resources, recycling and energy recovery can contribute to the more sustainable use of materials.

2.1 Unit description

Chemical ideas

This unit develops the treatment of chemical bonding by introducing intermediate types of bonding and by exploring the nature and effects of intermolecular forces.

Study of the periodic table is extended to cover the chemistry of groups 2 and 7. Ideas about redox reactions are applied in particular to the reactions of halogens and their compounds.

The unit develops a largely qualitative understanding of the ways in which chemists can control the rate, direction and extent of chemical change.

Organic chemistry in this unit covers alcohols and halogenoalkanes. The treatment is extended to explore the mechanisms of selected examples.

Students have to use formulae and balance equations and have an understanding of chemical quantities.

How chemists work

Electron-pair repulsion theory shows how chemists can make generalisations and use them to make predictions.

Chemists rationalise a great deal of information about chemical changes by using theory to categorise reagents and types of chemical change. This is illustrated by the use of inorganic and organic examples in this unit.

The use of models in chemistry is illustrated by the way in which the Maxwell-Boltzmann distribution and collision theory can account for the effects of temperature on the rates of chemical reactions.

The unit shows how chemists can study chemical changes on an atomic scale and propose mechanisms to account for their observations.

Chemistry in action

This unit shows the contribution that chemistry can make to a more sustainable economy by redeveloping manufacturing processes to make them more efficient, less hazardous and less polluting.

Insight into the mechanisms of chemical reactions can help to account for the damaging effects of some chemicals on the natural environment.

The study of spectroscopy gives further examples of the importance of accurate and sensitive methods of analysis which can be applied to study chemical changes but also to detect drugs such as alcohol.

The unit deals with issues regarding the environment, such as climate change, the effect of greenhouse gases, carbon footprints and other aspects of green chemistry. It ensures that students understand the underlying chemistry and can investigate ways to combat these issues.

Core practicals

The following specification points are core practicals within this unit that students should complete:

2.4d

2.5c

2.7.1g

2.7.2b

2.7.2c

2.7.2d

2.8f

2.10.1d

2.10.2c

2.10.2e

These practicals may appear in the written examination for Unit 2.

Use of examples

Examples in practicals

Where 'e.g.' follows a type of experiment in the specification students are not expected to have carried out that specific experiment. However, they should be able to use data from that or similar experiments.

For instance in this unit, *2.7g ii Properties down group 2*, the specification states:

simple acid-base titrations using a range of indicators, acids and alkalis, to calculate solution concentrations in g dm^{-3} *and mol dm*$^{-3}$*, e.g. measuring the residual alkali present after skinning fruit with potassium hydroxide.*

Students will be expected to have carried out simple acid-base titrations, but they may or may not have done this to measure the residual alkali present after skinning fruit.

In the unit test students could be given experimental data for this or any other acid-base titration, and be expected to analyse and evaluate this data.

Examples in unit content

Where 'e.g.' follows a concept students are not expected to have been taught the particular example given in the specification. They should be able to illustrate their answer with an example of their choice.

For instance in this unit, *2.10.2f Halogenoalkanes*, the specification states:

discuss the uses of halogenoalkanes, e.g. as fire retardants and modern refrigerants.

Students will be expected to discuss the use of halogenoalkanes, but they may or may not have looked at their use as fire retardants or refrigerants.

In the unit test students could be asked to discuss some of the uses of halogenoalkanes. This could be those listed as examples or other uses.

2.2 Assessment information

Unit 2 examination

The examination will be 1 hour 30 minutes and have 80 marks. It will contain three sections – A, B and C.

Section A is an objective test section which will aim to cover a large proportion of the specification for this unit.

Section B contains a mixture of short-answer and extended answer questions. This will include questions on the analysis and evaluation of practical work.

Section C will contain extended answer questions on contemporary contexts. This may contain stimulus materials on a scenario that students must read in order to answer the questions. It will focus on the chemistry behind the contexts and will not be a comprehension exercise.

Students may use a calculator.

Quality of written communication will be assessed in this examination through questions which are labelled with an asterisk (*). When answering these questions students should consider spelling, punctuation and grammar of their response, as well as the clarity of expression.

Questions on the analysis and evaluation of practical work will also be included in either Section B or C.

2.3 Shapes of molecules and ions

Students will be assessed on their ability to:

a demonstrate an understanding of the use of electron-pair repulsion theory to interpret and predict the shapes of simple molecules and ions

b recall and explain the shapes of $BeCl_2$, BCl_3, CH_4, NH_3, NH_4^+, H_2O, CO_2, gaseous PCl_5 and SF_6 and the simple organic molecules listed in Units 1 and 2

c apply the electron-pair repulsion theory to predict the shapes of molecules and ions analogous to those in 2.3b

d demonstrate an understanding of the terms *bond length* and *bond angle* and predict approximate bond angles in simple molecules and ions

e discuss the different structures formed by carbon atoms, including graphite, diamond, fullerenes and carbon nanotubes, and the applications of these, e.g. the potential to use nanotubes as vehicles to carry drugs into cells.

2.4 Intermediate bonding and bond polarity

Students will be assessed on their ability to:

a explain the meaning of the term *electronegativity* as applied to atoms in a covalent bond

b recall that ionic and covalent bonding are the extremes of a continuum of bonding type and explain this in terms of electronegativity differences leading to bond polarity in bonds and molecules, and to ionic bonding if the electronegativity is large enough

c distinguish between polar bonds and polar molecules and be able to predict whether or not a given molecule is likely to be polar

d carry out experiments to determine the effect of an electrostatic force on jets of liquids and use the results to determine whether the molecules are polar or non-polar.

2.5 Intermolecular forces

Students will be assessed on their ability to:

a demonstrate an understanding of the nature of intermolecular forces resulting from interactions between permanent dipoles, instantaneous dipoles and induced dipoles (London forces) and from the formation of hydrogen bonds

b relate the physical properties of materials to the types of intermolecular force present, e.g.:

- i the trends in boiling and melting temperatures of alkanes with increasing chain length
- ii the effect of branching in the carbon chain on the boiling and melting temperatures of alkanes
- iii the relatively low volatility (higher boiling temperatures) of alcohols compared to alkanes with a similar number of electrons
- iv the trends in boiling temperatures of the hydrogen halides HF to HI

c carry out experiments to study the solubility of simple molecules in different solvents

d interpret given information about solvents and solubility to explain the choice of solvents in given contexts, discussing the factors that determine the solubility including:

- i the solubility of ionic compounds in water in terms of the hydration of the ions
- ii the water solubility of simple alcohols in terms of hydrogen bonding
- iii the insolubility of compounds that cannot form hydrogen bonds with water molecules, e.g. polar molecules such as halogenoalkanes
- iv the solubility in non-aqueous solvents of compounds which have similar intermolecular forces to those in the solvent.

2.6 Redox

Students will be assessed on their ability to:

a demonstrate an understanding of:

  i oxidation number — the rules for assigning oxidation numbers

  ii oxidation and reduction as electron transfer

  iii oxidation and reduction in terms of oxidation number changes

  iv how oxidation number is a useful concept in terms of the classification of reactions as redox and as disproportionation

b write ionic half-equations and use them to construct full ionic equations.

2.7 The periodic table — groups 2 and 7

Students will be assessed on their ability to:

1 Properties down group 2

a explain the trend in the first ionisation energy down group 2

b recall the reaction of the elements in group 2 with oxygen, chlorine and water

c recall the reactions of the oxides of group 2 elements with water and dilute acid, and their hydroxides with dilute acid

d recall the trends in solubility of the hydroxides and sulfates of group 2 elements

e recall the trends in thermal stability of the nitrates and the carbonates of the elements in groups 1 and 2 and explain these in terms of size and charge of the cations involved

f recall the characteristic flame colours formed by group 1 and 2 compounds and explain their origin in terms of electron transitions

g describe and carry out the following:

- i experiments to study the thermal decomposition of group 1 and 2 nitrates and carbonates
- ii flame tests on compounds of group 1 and 2
- iii simple acid-base titrations using a range of indicators, acids and alkalis, to calculate solution concentrations in g dm^{-3} and mol dm^{-3}, e.g. measuring the residual alkali present after skinning fruit with potassium hydroxide

h demonstrate an understanding of how to minimise the sources of measurement uncertainty in volumetric analysis and estimate the overall uncertainty in the calculated result.

2 Inorganic chemistry of group 7 (limited to chlorine, bromine and iodine)

a recall the characteristic physical properties of the elements limited to the appearance of solutions of the elements in water and hydrocarbon solvents

b describe and carry out the following chemical reactions of halogens:

i oxidation reactions with metal and non-metallic elements and ions such as iron(II) and iron(III) ions in solution

ii disproportionation reactions with cold and hot alkali, e.g. hot potassium hydroxide with iodine to produce potassium iodate(V)

c carry out an iodine/thiosulfate titration, including calculation of the results and evaluation of the procedures involved, e.g. determination of the purity of potassium iodate(V) by liberation of iodine and titration with standard sodium thiosulfate solution

d describe and carry out the following reactions:

i potassium halides with concentrated sulfuric acid, halogens and silver nitrate solution

ii silver halides with sunlight and their solubilities in aqueous ammonia solution

iii hydrogen halides with ammonia and with water (to produce acids)

e make predictions about fluorine and astatine and their compounds based on the trends in the physical and chemical properties of halogens.

2.8 Kinetics

Students will be assessed on their ability to:

a recall the factors that influence the rate of chemical reaction, including concentration, temperature, pressure, surface area and catalysts

b explain the changes in rate based on a qualitative understanding of collision theory

c use, in a qualitative way, the Maxwell-Boltzmann model of the distribution of molecular energies to relate changes of concentration and temperature to the alteration in the rate of a reaction

d demonstrate an understanding of the concept of activation energy and its qualitative relationship to the effect of temperature changes on the rate of reaction

e demonstrate an understanding of the role of catalysts in providing alternative reaction routes of lower activation energy and draw the reaction profile of a catalysed reaction including the energy level of the intermediate formed with the catalyst

f carry out simple experiments to demonstrate the factors that influence the rate of chemical reactions, e.g. the decomposition of hydrogen peroxide.

2.9 Chemical equilibria

Students will be assessed on their ability to:

a demonstrate an understanding that chemical equilibria are dynamic

b deduce the qualitative effects of changes of temperature, pressure and concentration on the position of equilibrium, e.g. extraction of methane from methane hydrate

c interpret the results of simple experiments to demonstrate the effect of a change of temperature, pressure and concentration on a system at equilibrium, e.g.

  i iodine(I) chloride reacting with chlorine to form iodine(III) chloride, or

  ii N_2O_4 $2NO_2$.

2.10 Organic chemistry

Related topics in Units 4 and 5 will assume knowledge of this material.

Students will be assessed on their ability to:

1 Alcohols

a give examples of, and recognise, molecules that contain the alcohol functional group

b demonstrate an understanding of the nomenclature and corresponding structural, displayed and skeletal formulae of alcohols, and classify them as primary, secondary or tertiary

c describe the following chemistry of alcohols:

i combustion

ii reaction with sodium

iii substitution reactions to form halogenoalkanes, including reaction with PCl_5 and its use as a qualitative test for the presence of the –OH group

iv oxidation using potassium dichromate(VI) in dilute sulfuric acid on primary alcohols to produce aldehydes and carboxylic acids and on secondary alcohols to produce ketones

d demonstrate an understanding of, and practise, the preparation of an organic liquid (reflux and distillation), e.g. oxidation of alcohols.

2 Halogeno alkanes

a demonstrate an understanding of the nomenclature and corresponding structural, displayed and skeletal formulae for halogenoalkanes, including the distinction between primary, secondary and tertiary structures

b interpret given data and observations comparing the reactions and reactivity of primary, secondary and tertiary compounds

c carry out the preparation of an halogenoalkane from an alcohol and explain why a metal halide and concentrated sulfuric acid should not be used when making a bromoalkane or an iodoalkane d describe the typical behaviour of halogenoalkanes. This will be limited to treatment with:

   i aqueous alkali, e.g. KOH (aq)

   ii alcoholic potassium hydroxide

   iii water containing dissolved silver nitrate

   iv alcoholic ammonia

e carry out the reactions described in 2.10.2d i, ii, iii

f discuss the uses of halogenoalkanes, e.g. as fire retardants and modern refrigerants.

2.11 Mechanisms

Students will be assessed on their ability to:

a classify reactions (including those in Unit 1) as addition, elimination, substitution, oxidation, reduction, hydrolysis or polymerisation

b demonstrate an understanding of the concept of a reaction mechanism and that bond breaking can be homolytic or heterolytic and that the resulting species are either free radicals, electrophiles or nucleophiles

c give definitions of the terms *free radical*, *electrophile* and *nucleophile*

d demonstrate an understanding of why it is helpful to classify reagents

e demonstrate an understanding of the link between bond polarity and the type of reaction mechanism a compound will undergo

f describe the mechanisms of the substitution reactions of halogenoalkanes and recall those in 1.7.2e and 1.7.3e

g demonstrate an understanding of how oxygen, O_2, and ozone, O_3, absorb UV radiation and explain the part played by emission of oxides of nitrogen, from aircraft, in the depletion of the ozone layer, including the free radical mechanism for the reaction and the fact that oxides act as catalysts.

2.12 Mass spectra and IR

Students will be assessed on their ability to:

a interpret fragment ion peaks in the mass spectra of simple organic compounds, e.g. the difference between propanal and propanone

b use infrared spectra, or data from infrared spectra, to deduce functional groups present in organic compounds and predict infrared absorptions, given wavenumber data, due to familiar functional groups. This will be limited to:

- i C–H stretching absorptions in alkanes, alkenes and aldehydes
- ii O–H stretching absorptions in alcohols and carboxylic acids
- iii N–H stretching absorption in amines
- iv C=O stretching absorptions in aldehydes and ketones
- v C–X stretching absorption in halogenoalkanes
- vi as an analytical tool to show the change in functional groups during the oxidation of an alcohol to a carbonyl

c demonstrate an understanding that only molecules which change their polarity as they vibrate can absorb infrared radiation

d demonstrate an understanding that H_2O, CO_2, CH_4 and NO molecules absorb IR radiation and are greenhouse gases, whilst O_2 and N_2 are not.

2.13 Green chemistry

Students will be assessed on their ability to:

a demonstrate an understanding that the processes in the chemical industry are being reinvented to make them more sustainable ('greener') by:

- i changing to renewable resources
- ii finding alternatives to very hazardous chemicals
- iii discovering catalysts for reactions with higher atom economies, e.g. the development of methods used to produce ethanoic acid based on catalysts of cobalt, rhodium and iridium
- iv making more efficient use of energy, e.g. the use of microwave energy to heat reactions in the pharmaceutical industry
- v reducing waste and preventing pollution of the environment

b discuss the relative effects of different greenhouse gases as absorbers of IR and hence on global warming

c discuss the difference between anthropogenic and natural climate change over hundreds of thousands of years

d demonstrate understanding of the terms *carbon neutrality* and *carbon footprint*

e apply the concept of carbon neutrality to different fuels, such as petrol, bio-ethanol and hydrogen

f discuss and explain, including the mechanisms for the reactions, the science community's reasons for recommending that CFCs are no longer used due to their damaging effect on the ozone layer.

3.1 Unit description

Introduction

This unit contains a practical written examination that covers the content of Units 1 and 2. There is no specific content for this unit.

Development of practical skills, knowledge and understanding

Students are expected to develop experimental skills, and a knowledge and understanding of the necessary techniques, by carrying out a range of practicals while they study Units 1 and 2.

This unit will assess students' knowledge and understanding of practical procedures and techniques that they develop.

To prepare them for the assessment of this unit centres should provide opportunities for students to carry out practical activities, collect and analyse data, and draw conclusions.

Students should carry out at least five practicals in class. By completing these practicals students will be able to:

- follow and interpret experimental instructions, covering the full range of laboratory exercises set throughout the course, with minimal help from the teacher
- always work with interest and enthusiasm in the laboratory completing most laboratory exercises in the time allocated
- manipulate apparatus, use chemicals, carry out all common laboratory procedures and use data logging (where appropriate) with the highest level of skill that may be reasonably expected at this level
- work sensibly and safely in the laboratory paying due regard to health and safety requirements without the need for reminders from the teacher
- gain accurate and consistent results in quantitative exercises, make most of the expected observations in qualitative exercises and obtain products in preparations of high yield and purity.

How chemists work

Students should be given the opportunity to develop their practical skills for *How Science Works* by completing a range of different practicals that require a variety of different techniques.

Students' laboratory reports on their practical work should use appropriate scientific, technical and mathematical language, conventions and symbols in order to meet the requirements of *How Science Works*.

3.2 Assessment information

Unit 3 examination

This unit contains a practical written examination that covers the content of Units 1 and 2.

The practical written examination covers the following types of practicals:

- qualitative observations
- quantitative measurements
- preparations.

The examination will last 1 hour 15 minutes and have 50 marks. It will contain one section.

Students may use a calculator.

The quality of written communication will be assessed in the practical written examination. When answering these questions students will be assessed on their ability to organise and present information, ideas, descriptions and arguments clearly and logically, include the use of grammar, punctuation and spelling.

Unit 4 General Principles of Chemistry I – Rates, Equilibria and Further Organic Chemistry

IA2 compulsory unit

Externally assessed

4.1 Unit description

Introduction

In this unit students make a quantitative study of chemical kinetics and take further their study of organic reaction mechanisms.

The topics of entropy and equilibria show how chemists are able to predict quantitatively the direction and extent of chemical change.

The organic chemistry in this unit covers carbonyl compounds, plus carboxylic acids and their derivatives.

Students are required to apply their knowledge gained in Units 1 and 2, to all aspects of this unit. This includes nomenclature, ideas of isomerism, bond polarity and bond enthalpy, reagents and reaction conditions, reaction types and mechanisms. Students are also expected to use formulae and balance equations and calculate chemical quantities.

How chemists work

Through practical work, students will learn about the methods used to measure reaction rates. They will collect data, analyse it and interpret the results. They then see how a knowledge of rate equations and other evidence can enable chemists to propose models to describe the mechanisms of reactions.

The study of entropy introduces students to the methods of thermodynamics and shows how chemists use formal, quantitative and abstract thinking to answer fundamental questions about the stability of chemicals and the direction of chemical change.

The unit tests the equilibrium law by showing the degree to which it can accurately predict changes during acid-base reactions, notably the changes to pH during titrations.

The historical development of theories explaining acids and bases shows how scientific ideas change as a result of new evidence and fresh thinking.

Chemistry in action

This unit shows how the principles of kinetics and thermodynamics can help to achieve optimal conditions for the manufacture of chemicals.

The study of buffer solutions shows the varied importance of equilibrium systems in living cells, in medicines, in foods and in the natural environment.

The two broad areas of application of chemistry are synthesis and analysis. In this unit synthesis is illustrated by reactions of carbonyl compounds (notably with cyanide ions) and the production of esters for use as solvents, flavourings and perfumes. The main analytical technique featured is nmr including coverage of magnetic resonance imaging.

Core practicals

The following specification points are core practicals within this unit that students should complete:

4.3c

4.3e

4.4g

4.8.2c

4.8.3d

4.8.4b

4.8.4c

These practicals may appear in the written examination for Unit 4.

Use of examples

Examples in practicals

Where 'e.g.' follows a type of experiment in the specification students are not expected to have carried out that specific experiment.

However they should be able to use data from that or similar experiments.

For instance in this unit, *4.3g How fast? – rates*, the specification states:

investigate the activation energy of a reaction, e.g. oxidation of iodide ions by iodate(V).

Students will be expected to have investigated the activation energy of a reaction, but they may or may not have done this by the oxidation of iodide ions by iodate(V).

In the unit test students could be given experimental data for this or any other reaction, and be expected to use this data to evaluate or estimate the activation energy.

Examples in unit content

Where 'e.g.' follows a concept students are not expected to have been taught the particular example given in the specification. They should be able to illustrate their answer with an example of their choice.

For instance in this unit, *4.7m Acid/base equilibria*, the specification states:

explain the importance of buffer solutions in biological environments, e.g. buffers in cells and in blood (H_2CO_3/HCO_3^-) and in foods to prevent deterioration due to pH change (caused by bacterial or fungal activity).

Students will be expected to explain the importance of buffer solutions in biological systems, but they may or may not have looked at buffers in cells and blood, or in food.

In the unit test students could be asked to illustrate the importance of buffer solutions with a biological example that they select themselves. This could be one listed as an example or it could be another example.

4.2 Assessment information

Unit 4 examination

The examination will be 1 hour 40 minutes and have 90 marks. It will contain three sections – A, B and C.

Section A is an objective test section which will aim to cover a large proportion of the specification for this unit.

Section B contains a mixture of short-answer and extended answer questions.

Section C will contain data questions and will require students to select the necessary data from the data booklet. They will be provided with data from a laboratory experiment and asked a series of questions on it. The longer timing of the examination reflects the style of the questions for Section C.

Students will be able to show their full ability in Sections B and C as these will contain areas where they will be stretched and challenged.

Students may use a calculator.

Quality of written communication will be assessed in this examination through questions which are labelled with an asterisk (*). When answering these questions students should consider spelling, punctuation and grammar of their response, as well as the clarity of expression.

4.3 How fast? – rates

Knowledge of the concepts introduced in Unit 2, *Topic 2.8: Kinetics* will be assumed and extended in this topic.

Students will be assessed on their ability to:

a demonstrate an understanding of the terms *rate of reaction*, *rate equation*, *order of reaction*, *rate constant*, *half-life*, *rate-determining step*, *activation energy*, *heterogeneous* and *homogenous catalyst*

b select and describe a suitable experimental technique to obtain rate data for a given reaction, e.g. colorimetry, mass change and volume of gas evolved

c investigate reactions which produce data that can be used to calculate the rate of the reaction, its half-life from concentration or volume against time graphs, e.g. a clock reaction

d present and interpret the results of kinetic measurements in graphical form, including concentration-time and rate-concentration graphs

e investigate the reaction of iodine with propanone in acid to obtain data for the order with respect to the reactants and the hydrogen ion and make predictions about molecules/ions involved in the rate-determining step and possible mechanism (details of the actual mechanism can be discussed at a later stage in this topic)

f deduce from experimental data for reactions with zero, first and second order kinetics:

- i half-life (the relationship between half-life and rate constant will be given if required)
- ii order of reaction
- iii rate equation
- iv rate-determining step related to reaction mechanisms
- v activation energy (by graphical methods only; the Arrhenius equation will be given if needed)

g investigate the activation energy of a reaction, e.g. oxidation of iodide ions by iodate(V) h apply a knowledge of the rate equations for the hydrolysis of halogenoalkanes to deduce the mechanisms for primary and tertiary halogenoalkane hydrolysis and to deduce the mechanism for the reaction between propanone and iodine

i demonstrate that the mechanisms proposed for the hydrolysis of halogenoalkanes are consistent with the experimentally determined orders of reactions, and that a proposed mechanism for the reaction between propanone and iodine is consistent with the data from the experiment in 4.3e

j use kinetic data as evidence for S_N1 or S_N2 mechanisms in the nucleophilic substitution reactions of halogenoalkanes.

4.4 How far? – entropy

Students will be assessed on their ability to:

a demonstrate an understanding that, since endothermic reactions can occur spontaneously at room temperature, enthalpy changes alone do not control whether reactions occur

b demonstrate an understanding of entropy in terms of the random dispersal of molecules and of energy quanta between molecules

c demonstrate an understanding that the entropy of a substance increases with temperature, that entropy increases as solid → liquid → gas and that perfect crystals at zero kelvin have zero entropy

d demonstrate an understanding that the standard entropy of a substance depends mainly on its physical state but also on its complexity

e demonstrate an understanding that reactions occur due to chance collisions, and that one possible ordered arrangement, e.g. in a crystalline solid, can be rearranged into many possible disordered arrangements, e.g. in a solution, so the probability of disorder is greater than order

f interpret the natural direction of change as being in the direction of increasing total entropy (positive entropy change), e.g. gases spread spontaneously through a room

g carry out experiments and relate the results to disorder and enthalpy changes including:

i dissolving a solid, e.g. adding ammonium nitrate crystals to water

ii gas evolution, e.g. reacting ethanoic acid with ammonium carbonate

iii exothermic reaction producing a solid, e.g. burning magnesium ribbon in air

iv endothermic reaction of two solids, e.g. mixing solid barium hydroxide, $Ba(OH)_2.8H_2O$ with solid ammonium chloride

h demonstrate an understanding that the entropy change in any reaction is made up of the entropy change in the system added to the entropy change in the surroundings, summarised by the expression:

$\Delta S_{total} = \Delta S_{system} + \Delta S_{surroundings}$

i calculate the entropy change in the system for a reaction, ΔS_{system}, given entropy data

j use the expression $\Delta S_{surroundings} = -\Delta H/T$ to calculate the entropy change in the surroundings and hence ΔS_{total}

k demonstrate an understanding that the feasibility of a reaction depends on the balance between ΔS_{system} and $\Delta S_{surroundings}$, and that at higher temperatures the magnitude of $\Delta S_{surroundings}$ decreases and its contribution to ΔS_{total} is less. Reactions can occur as long as ΔS_{total} is positive even if one of the other entropy changes is negative

l demonstrate an understanding of and distinguish between the concepts of thermodynamic stability and kinetic inertness

m calculate ΔS_{system} and $\Delta S_{surroundings}$ for the reactions in 4.4g to show that endothermic reactions can occur spontaneously at room temperature

n define the term *enthalpy of hydration* of an ion and use it and lattice energy to calculate the enthalpy of solution of an ionic compound

o demonstrate an understanding of the factors that affect the values of enthalpy of hydration and the lattice energy of an ionic compound

p use entropy and enthalpy of solution values to predict the solubility of ionic compounds.

4.5 Equilibria

Knowledge of the concepts introduced in Unit 2, *Topic 2.9: Chemical equilibria* will be assumed and extended in this topic.

Students will be assessed on their ability to:

a demonstrate an understanding of the term *dynamic equilibrium* as applied to states of matter, solutions and chemical reactions

b recall that many important industrial reactions are reversible

c use practical data to establish the idea that a relationship exists between the equilibrium concentrations of reactants and products which produces the equilibrium constant for a particular reaction, e.g. data on the hydrogen-iodine equilibrium

d calculate a value for the equilibrium constant for a reaction based on data from experiment, e.g. the reaction of ethanol and ethanoic acid (this can be used as an example of the use of ICT to present and analyse data), the equilibrium Fe^{2+}(aq) + Ag^{+} (aq) • Fe^{3+}(aq) + Ag(s) or the distribution of ammonia or iodine between two immiscible solvents

e construct expressions for K_c and K_p for homogeneous and heterogeneous systems, in terms of equilibrium concentrations or equilibrium partial pressures, perform simple calculations on K_c and K_p and work out the units of the equilibrium constants

f demonstrate an understanding that when ΔS_{total} increases the magnitude of the equilibrium constant increases since ΔS_{total} = RIn*K*

g apply knowledge of the value of equilibrium constants to predict the extent to which a reaction takes place

h relate the effect of a change in temperature on the value of ΔS_{total}.

4.6 Application of rates and equilibrium

Students will be assessed on their ability to:

a demonstrate an understanding of how, if at all, and why a change in temperature, pressure or the presence of a catalyst affects the equilibrium constant and the equilibrium composition and recall the effects of changes of temperature and pressure on rate, e.g. the thermal decomposition of ammonium chloride, or the effect of temperature and pressure changes in the system $2NO_2 \rightleftharpoons N_2O_4$

b use information on enthalpy change and entropy to justify the conditions used to obtain economic yields in industrial processes, and understand that in reality industrial processes cannot be in equilibrium since the products are removed, e.g. in the Haber process temperature affects the equilibrium yield and rate whereas pressure affects only the equilibrium yield (knowledge of industrial conditions are not required)

c demonstrate an understanding of the steps taken in industry to maximise the atom economy of the process, e.g. recycling unreacted reagents or using an alternative reaction

d demonstrate an understanding of the importance of being able to control reactions, through knowledge of equilibrium constants and entropy changes, the importance of controlling reactions to produce adequate yields under safe, economically viable conditions and why some reactions ‘go’ and some will never occur.

4.7 Acid/base equilibria

Students will be assessed on their ability to:

a demonstrate an understanding that the theory about acidity developed in the 19th and 20th centuries from a substance with a sour taste to a substance which produces an excess of hydrogen ions in solution (Arrhenius theory) to the Brønsted-Lowry theory

b demonstrate an understanding that a Brønsted–Lowry acid is a proton donor and a base a proton acceptor and that acid-base equilibria involve transfer of protons

c demonstrate an understanding of the Brønsted–Lowry theory of acid-base behaviour, and use it to identify conjugate acid-base pairs

d define the terms pH, K_a and K_w, pK_a and pK_w, and be able to carry out calculations relating the pH of strong acids and bases to their concentrations in mol dm^{-3}

e demonstrate an understanding that weak acids and bases are only slightly dissociated in aqueous solution, and apply the equilibrium law to deduce the expressions for the equilibrium constants K_a and K_w

f analyse the results obtained from the following experiments:

  i measuring the pH of a variety of substances, e.g. equimolar solutions of strong and weak acids, strong and weak bases and salts

  ii comparing the pH of a strong acid and a weak acid after dilution 10, 100 and 1000 times

g analyse and evaluate the results obtained from experiments to determine K_a for a weak acid by measuring the pH of a solution containing a known mass of acid, and discuss the assumptions made in this calculation

h calculate the pH of a solution of a weak acid based on data for concentration and K_a, and discuss the assumptions made in this calculation

i measure the pH change during titrations and draw titration curves using different combinations of strong and weak monobasic acids and bases

j use data about indicators, together with titration curves, to select a suitable indicator and the use of titrations in analysis k explain the action of buffer solutions and carry out calculations on the pH of buffer solutions, e.g. making buffer solutions and comparing the effect of adding acid or alkali on the pH of the buffer

l use titration curves to show the buffer action and to determine K_a from the pH at the point where half the acid is neutralised

m explain the importance of buffer solutions in biological environments, e.g. buffers in cells and in blood (H_2CO_3/HCO_3^-) and in foods to prevent deterioration due to pH change (caused by bacterial or fungal activity).

4.8 Further organic chemistry

Related topics in Unit 5 will assume knowledge of this material.

Students will be assessed on their ability to:

1 Chirality

a recall the meaning of structural and E-Z isomerism (geometric/cis-trans isomerism)

b demonstrate an understanding of the existence of optical isomerism resulting from chiral centre(s) in a molecule with asymmetric carbon atom(s) and understand optical isomers as object and non-superimposable mirror images

c recall optical activity as the ability of a single optical isomer to rotate the plane of polarisation of plane-polarised monochromatic light in molecules containing a single chiral centre and understand the nature of a racemic mixture

d use data on optical activity of reactants and products as evidence for proposed mechanisms, as in S_N1 and S_N2 and addition to carbonyl compounds.

2 Carbonyl compounds

a give examples of molecules that contain the aldehyde or ketone functional group

b explain the physical properties of aldehydes and ketones relating this to the lack of hydrogen bonding between molecules and their solubility in water in terms of hydrogen bonding with the water

c describe and carry out, where appropriate, the reactions of carbonyl compounds. This will be limited to:

i oxidation with Fehling's or Benedict's solution, Tollens' reagent and acidified dichromate(VI) ions

ii reduction with lithium tetrahydridoaluminate (lithium aluminium hydride) in dry ether

iii nucleophilic addition of HCN in the presence of KCN, using curly arrows, relevant lone pairs, dipoles and evidence of optical activity to show the mechanism

iv the reaction with 2,4-dinitrophenylhydrazine and its use to detect the presence of a carbonyl group and to identify a carbonyl compound given data of the melting temperatures of derivatives

v iodine in the presence of alkali.

3 Carboxylic acids

a give some examples of molecules that contain the carboxylic acid functional group

b explain the physical properties of carboxylic acids in relation to their boiling temperatures and solubility due to hydrogen bonding

c describe the preparation of carboxylic acids to include oxidation of alcohols and carbonyl compounds and the hydrolysis of nitriles

d describe and carry out, where appropriate, the reactions of carboxylic acids. This will be limited to:

- i reduction with lithium tetrahydridoaluminate (lithium aluminium hydride) in dry ether (ethoxyethane)
- ii neutralisation to produce salts, e.g. to determine the amount of citric acid in fruit
- iii phosphorus(V) chloride (phosphorus pentachloride)
- iv reactions with alcohols in the presence of an acid catalyst, e.g. the preparation of ethyl ethanoate as a solvent or as pineapple flavouring.

4 Carboxylic acid derivatives

a demonstrate an understanding that these include acyl chlorides and esters and recognise their respective functional groups, giving examples of molecules containing these functional groups

b describe and carry out, where appropriate, the reactions of acyl chlorides limited to their reaction with:

i water

ii alcohols

iii concentrated ammonia

iv amines

c describe and carry out, where appropriate, the reactions of esters. This will be limited to:

i their hydrolysis with an acid

ii their hydrolysis with a base, e.g. to form soaps

iii their reaction with alcohols and acids to explain the process of trans-esterification and recall how it is applied to the manufacture of bio-diesel (as a potentially greener fuel) and low-fat spreads (replacing the hydrogenation of vegetable oils to produce margarine)

d demonstrate an understanding of the importance of the formation of polyesters and describe their formation by condensation polymerisation of ethane-1,2-diol and benzene 1,4-dicarboxylic acid.

4.9 Spectroscopy and chromatography

Knowledge of the concepts introduced in Unit 2, *Topic 2.12: Mass Spectra* and *IR* will be assumed and extended in this topic.

Students will be assessed on their ability to:

a explain the effect of different types of radiation on molecules and how the principles of this are used in chemical analysis and in reactions, limited to:

- i infrared in analysis
- ii microwaves for heating
- iii radio waves in nmr
- iv ultraviolet in initiation of reactions

b explain the use of high resolution nmr spectra to identify the structure of a molecule:

- i based on the different types of proton present from chemical shift values
- ii by using the spin-spin coupling pattern to identify the number of protons adjacent to a given proton
- iii the effect of radio waves on proton spin in nmr, limited to ^1H nuclei
- iv the use of magnetic resonance imaging as a non-invasive technique, e.g. scanning for brain disorders, or the use of nmr to check the purity of a compound in the pharmaceutical industry

c demonstrate an understanding of the use of IR spectra to follow the progress of a reaction involving change of functional groups, e.g. in the chemical industry to determine the extent of the reaction

d interpret simple mass spectra to suggest possible structures of a simple compound from the *m/e* of the molecular ion and fragmentation patterns

e describe the principles of gas chromatography and HPLC as used as methods of separation of mixtures, prior to further analysis (theory of R_f values not required), and also to determine if substances are present in industrial chemical processes.

Unit 5 General Principles of Chemistry II – Transition Metals and Organic Nitrogen Chemistry

IA2 compulsory unit

Externally assessed

5.1 Unit description

Introduction

In this unit the study of electrode potentials builds on the study of redox in Unit 2, including the concept of oxidation number and the use of redox half equations.

Students will study further chemistry related to redox and transition metals.

The organic chemistry section of this unit focuses on arenes and organic nitrogen compounds such as amines, amides, amino acids and proteins. Students are expected to use the knowledge and understanding of organic chemistry that they have gained over the whole International Advanced Level in Chemistry when covering the organic synthesis section.

This unit draws on all other units within the International Advanced Level in Chemistry and students are expected to use their prior knowledge when learning about these areas. Students will again encounter ideas of isomerism, bond polarity and bond enthalpy, reagents and reaction conditions, reaction types and mechanisms. Students are also expected to use formulae and balance equations, and calculate chemical quantities.

How chemists work

The study of chemical cells provides an opportunity to illustrate the impact on scientific thinking when it emerges that ideas developed in different contexts can be shown to be related to a major explanatory principle. In this unit, cell emfs and equilibrium constants are shown to be related to the fundamental criterion for the feasibility of a chemical reaction: the total entropy change.

The explanatory power of the energy-level model for electronic structures is further illustrated by showing how it can help to account for the existence and properties of transition metals. In this context there are opportunities to show the limitations of the models used at this level and to indicate the need for more sophisticated explanations.

Study of the structure of benzene is another example that shows how scientific models develop in response to new evidence. This links to further investigations of the models that chemists use to describe the mechanisms of organic reactions.

The study of catalysts touches on a 'frontier' area for current chemical research and development which is of theoretical and practical importance. This provides an opportunity to show how the scientific community reports and validates new knowledge.

Students have further opportunities to carry out quantitative analysis, to interpret complex data and assess the outcomes in terms of the principles of valid measurement. The topic of organic synthesis illustrates a selection of the techniques that chemists have developed to carry out reactions and purify products efficiently and safely.

Core practicals

The following specification points are core practicals within this unit that students should complete:

5.3.1d

5.3.1g

5.3.2g

5.3.2j

5.4.1d

5.4.1e

5.4.2b

5.4.2d

5.4.2i

5.4.3f

These practicals may appear in the written examination for Unit 5.

Use of examples

Examples in practicals

Where 'e.g.' follows a type of experiment in the specification students are not expected to have carried out that specific experiment. However they should be able to use data from that or similar experiments.

For instance in this unit, *5.3.1h i Application of redox equilibria*, the specification states:

demonstrate an understanding of the procedures of the redox titrations below (i and ii) and carry out a redox titration with one:

i *potassium manganate(VII), e.g. the estimation of iron in iron tablets*.

Students will be expected to have carried out a redox titration with potassium manganate(VII), but they may or may not have done this to estimate the amount of iron in iron tablets.

In the unit test students could be given experimental data for a potassium manganate(VII) titration, in any context, and be expected to analyse and evaluate this data.

Examples in unit content

Where 'e.g.' follows a concept students are not expected to have been taught the particular example given in the specification. They should be able to illustrate their answer with an example of their choice.

For instance in this unit*, 5.4.2h Organic nitrogen compounds:*

amines, amides, amino acids and proteins, the specification states:

comment on the physical properties of polyamides and the solubility in water of the addition polymer poly(ethenol) in terms of hydrogen bonding, e.g. soluble laundry bags or liquid detergent capsules (liquitabs).

Students will be expected to comment on the physical properties of polyamides and the solubility of poly(ethenol) in terms of hydrogen bonding, but they may or may not have looked at soluble laundry bags or liquitabs.

In the unit test students could be asked to comment on the physical properties of this polyamide and the solubility of the addition polymer in terms of hydrogen bonding. This could be in the context of soluble laundry bags, or in another completely different context.

5.2 Assessment information

Unit 5 examination

The examination will be 1 hour 40 minutes and have 90 marks. It will contain three sections – A, B and C.

Section A is an objective test section which will aim to cover a large proportion of the specification for this unit.

Section B contains a mixture of short-answer and extended answer questions. Questions on the analysis and evaluation of practical work will also be included in Section B.

Section C will contain extended answer questions on contemporary contexts. This may contain stimulus materials on a scenario that students must read in order to answer the questions. It will focus on the chemistry behind the contexts and will not be a comprehension exercise. The longer timing of the examination reflects the style of the questions for Section C.

Students will be able to show their full ability in Sections B and C as these will contain areas where they will be stretched and challenged.

Students may use a calculator.

The quality of written communication will be assessed in the context of this unit through questions which are labelled with an asterisk (*). When answering these questions students should consider spelling, punctuation and grammar of their response, as well as the clarity of expression.

5.3 Redox and the chemistry of the transition metals

Students will be assessed on their ability to:

1 Application of redox equilibria

a demonstrate an understanding of the terms *oxidation number*, *redox*, *half-reactions* and use these to interpret reactions involving electron transfer

b relate changes in oxidation number to reaction stoichiometry

c recall the definition of standard electrode potential and standard hydrogen electrode and understand the need for a reference electrode

d set up some simple cells and calculate values of $E_{cell}^{\ominus}$ from standard electrode potential values and use them to predict the thermodynamic feasibility and extent of reactions

e demonstrate an understanding that $E_{cell}^{\ominus}$ is directly proportional to the total entropy change and to ln$K$ for a reaction

f demonstrate an understanding of why the predictions in 5.3.1d may not be borne out in practice due to kinetic effects and non-standard conditions

g carry out and evaluate the results of an experiment involving the use of standard electrode potentials to predict the feasibility of a reaction, e.g. interchange of the oxidation states of vanadium or manganese

h demonstrate an understanding of the procedures of the redox titrations below (i and ii) and carry out a redox titration with one:

i potassium manganate(VII), e.g. the estimation of iron in iron tablets

ii sodium thiosulfate and iodine, e.g. estimation of percentage of copper in an alloy

i discuss the uncertainty of measurements and their implications for the validity of the final results

j discuss the use of hydrogen and alcohol fuel cells as energy sources, including the source of the hydrogen and alcohol, e.g. used in space exploration, in electric cars

k demonstrate an understanding of the principles of modern breathalysers based on an ethanol fuel cell and compare this to methods based on the use of IR and to the reduction of chromium compounds.

2 Transition metals and their chemistry

a describe transition metals as those elements which form one or more stable ions which have incompletely filled d orbitals

b derive the electronic configuration of the atoms of the d-block elements (Sc to Zn) and their simple ions from their atomic number

c discuss the evidence for the electronic configurations of the elements Sc to Zn based on successive ionisation energies

d recall that transition elements in general:

- i show variable oxidation number in their compounds, e.g. redox reactions of vanadium
- ii form coloured ions in solution
- iii form complex ions involving monodentate and bidentate ligands
- iv can act as catalysts both as the elements and as their compounds

e recall the shapes of complex ions limited to linear $[CuCl_2]^-$, planar $[Pt(NH_3)_2Cl_2]$, tetrahedral $[CrCl_4]^-$ and octahedral $[Cr(NH_3)_6]^{3+}$, $[Cu(H_2O)_6]^{2+}$ and other aqua complexes

f use the chemistries of chromium and copper to illustrate and explain some properties of transition metals as follows:

- i the formation of a range of compounds in which they are present in different oxidation states
- ii the presence of dative covalent bonding in complex ions, including the aqua-ions
- iii the colour or lack of colour of aqueous ions and other complex ions, resulting from the splitting of the energy levels of the d orbitals by ligands
- iv simple ligand exchange reactions
- v relate relative stability of complex ions to the entropy changes of ligand exchange reactions involving polydentate ligands (qualitatively only), e.g. EDTA
- vi relate disproportionation reactions to standard electrode potentials and hence to $E_{cell}^{\ominus}$

g carry out experiments to:

  i investigate ligand exchange in copper complexes

  ii study the redox chemistry of chromium in oxidation states Cr(VI), Cr(III) and Cr(II)

  iii prepare a sample of a complex, e.g. chromium(II) ethanoate

h recall that transition metals and their compounds are important as catalysts and that their activity may be associated with variable oxidation states of the elements or surface activity, e.g. catalytic converters in car exhausts

i explain why the development of new catalysts is a priority area for chemical research today and, in this context, explain how the scientific community reports and validates new discoveries and explanations, e.g. the development of new catalysts for making ethanoic acid from methanol and carbon monoxide with a high atom economy (green chemistry)

j carry out and interpret the reactions of transition metal ions with aqueous sodium hydroxide and aqueous ammonia, both in excess, limited to reactions with aqueous solutions of Cr(III), Mn(II), Fe(II), Fe(III), Ni(II), Cu(II), Zn(II)

k write ionic equations to show the difference between amphoteric behaviour and ligand exchange in the reactions in 5.3.2g

l discuss the uses of transition metals and/or their compounds, e.g. in polychromic sun glasses, chemotherapy drugs.

5.4 Organic chemistry – arenes, nitrogen compounds and synthesis

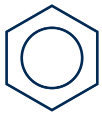
Knowledge of the common uses of organic compounds mentioned in this topic is expected.

Students will be assessed on their ability to:

1 Arenes: benzene

a use thermochemical, x-ray diffraction and infrared data as evidence for the structure and stability of the benzene ring

Students may represent the structure of benzene as



or

as appropriate in equations and mechanisms

b describe the following reactions of benzene, limited to:

i combustion to form a smoky flame

treatment with:

ii bromine

iii concentrated nitric and sulfuric acids

iv fuming sulfuric acid

v halogenoalkanes and acyl chlorides with aluminium chloride as catalyst (Friedel-Crafts reaction)

vi addition reactions with hydrogen

c describe the mechanism of the electrophilic substitution reactions of benzene in halogenation, nitration and Friedel-Crafts reactions including the formation of the electrophile

d carry out the reactions in 5.4.1b where appropriate (using methylbenzene or methoxybenzene)

e carry out the reaction of phenol with bromine water and dilute nitric acid and use these results to illustrate the activation of the benzene ring.

2 Organic nitrogen compounds: amines, amides, amino acids and proteins

a give examples of:

- i molecules that contain amine and amide functional groups
- ii amino acids

b describe and carry out, where appropriate (using butylamine and phenylamine), reactions to investigate the typical behaviour of primary amines. This will be limited to:

- i characteristic smell
- ii miscibility with water as a result of hydrogen bonding and the alkaline nature of the resulting solution
- iii formation of salts
- iv complex ion formation with copper(II) ions
- v treatment with ethanoyl chloride and halogenoalkanes, e.g. making paracetamol

c describe the reduction of aromatic nitro-compounds using tin and concentrated hydrochloric acid to form amines

d describe and carry out, where appropriate, the reaction of aromatic amines with nitrous acid to form benzenediazonium ions followed by a coupling reaction with phenol to form a dye

e recall the synthesis of amides using acyl chlorides

f describe:

- i condensation polymerisation for the formation of polyesters such as terylene and polyamides such as nylon and Kevlar
- ii addition polymerisation including poly(propenamide) and poly(ethenol)

g draw the structural formulae of the repeat units of the polymers in 5.4.2f

h comment on the physical properties of polyamides and the solubility in water of the addition polymer poly(ethenol) in terms of hydrogen bonding, e.g. soluble laundry bags or liquid detergent capsules (liquitabs)

- i describe and carry out, where appropriate, experiments to investigate the characteristic behaviour of amino acids. This is limited to:
  - i acidity and basicity and the formation of zwitterions
  - ii separation and identification by chromatography
  - iii effect of aqueous solutions on plane-polarised monochromatic light
  - iv formation of peptide groups in proteins by condensation polymerisation
  - v reaction with ninhydrin.

3 Organic synthesis

- a give examples to illustrate the importance of organic synthesis in research for the production of useful products
- b explain why sensitive methods of chemical analysis are important when planning and monitoring organic syntheses
- c deduce the empirical formulae, molecular formulae and structural formulae from data drawn from combustion analysis, elemental percentage composition, characteristic reactions of functional groups, infrared spectra, mass spectra and nuclear magnetic resonance
- d use knowledge of organic chemistry contained in this specifications to solve problems such as:
  - i predicting the properties of unfamiliar compounds containing one or more of the functional groups included in the specification, and explain these predictions
  - ii planning reaction schemes of up to four steps, recalling familiar reactions and using unfamiliar reactions given sufficient information
  - iii selecting suitable practical procedures for carrying out reactions involving compounds with functional groups included in the specification
  - iv identifying appropriate control measures to reduce risk during a synthesis based upon data of hazards
  - v understanding why, in the synthesis of stereo-specific drugs, it is important to understand the mechanism of the reaction and how this can help to plan the synthesis
- e explain why the pharmaceutical industry has adopted combinatorial chemistry in drug research, including passing reactants over reagents on polymer supports

f describe and carry out, where appropriate, the preparation of a compound, e.g. cholesteryl benzoate (a liquid crystal) and of methyl 3-nitrobenzoate, requiring some of the following techniques:

- i refluxing
- ii purification by washing, e.g. with water and sodium carbonate solution
- iii solvent extraction
- iv recrystallisation
- v drying
- vi distillation
- vii steam distillation
- viii melting temperature determination
- ix boiling temperature determination.

6.1 Unit description

Introduction

This unit contains a practical written examination that covers the content of Units 4 and 5. There is no specific content for this unit.

Students complete either Unit 6 or Unit 7.

Development of practical skills, knowledge and understanding

Students are expected to develop experimental skills, and a knowledge and understanding of the necessary techniques, by carrying out a range of practicals while they study Units 4 and 5.

This unit will assess students' knowledge and understanding of practical procedures and techniques that they develop.

To prepare them for the assessment of this unit centres should provide opportunities for students to carry out practical activities, collect and analyse data, and draw conclusions.

By completing these practicals students will be able to:

- follow and interpret experimental instructions, covering the full range of laboratory exercises set throughout the course, with minimal help from the teacher
- always work with interest and enthusiasm in the laboratory completing most laboratory exercises in the time allocated
- manipulate apparatus, use chemicals, carry out all common laboratory procedures and use data logging (where appropriate) with the highest level of skill that may be reasonably expected at this level
- work sensibly and safely in the laboratory paying due regard to health and safety requirements without the need for reminders from the teacher
- gain accurate and consistent results in quantitative exercises, make most of the expected observations in qualitative exercises and obtain products in preparations of high yield and purity.

These practical activities should cover a range of different topic areas and require the use of a variety of practical techniques.

How chemists work

Students should be given the opportunity to develop their practical skills for *How Science Works* by completing a range of different practicals that require a variety of different techniques.

Students' laboratory reports on their practical work should use appropriate scientific, technical and mathematical language, conventions and symbols in order to meet the requirements of *How Science Works*.

6.2 Assessment information

Unit 6 examination

This unit contains a practical written examination that covers the content of Units 4 and 5.

The practical written examination covers the following types of practicals:

- qualitative observations
- quantitative measurements
- preparations.

The examination will last 1 hour 15 minutes and have 50 raw marks. It will contain one section.

Students may use a calculator.

The quality of written communication will be assessed in the practical written examination. When answering these questions students will be assessed on their ability to organise and present information, ideas, descriptions and arguments clearly and logically, including the use of grammar, punctuation and spelling.

7.1 Unit description

Introduction

This unit contains a practical examination that draws on all the prior knowledge, understanding and skills developed when carrying out practical work throughout the course.

Students complete either Unit 6 or Unit 7.

Development of practical skills, knowledge and understanding

Students are expected to develop experimental skills, and a knowledge and understanding of the necessary techniques, by carrying out a range of practicals throughout the course.

This unit will assess students' knowledge and understanding of practical procedures and techniques.

To prepare them for the assessment of this unit, centres should provide opportunities for students to carry out practical activities, collect and analyse data, and draw conclusions.

By completing these practicals students will be able to:

- follow and interpret experimental instructions, covering the full range of laboratory exercises set throughout the course, with minimal help from the teacher
- always work with interest and enthusiasm in the laboratory completing most laboratory exercises in the time allocated
- manipulate apparatus, use chemicals, carry out all common laboratory procedures and use data logging (where appropriate) with the highest level of skill that may be reasonably expected at this level
- work sensibly and safely in the laboratory paying due regard to health and safety requirements without the need for reminders from the teacher
- gain accurate and consistent results in quantitative exercises, make most of the expected observations in qualitative exercises and obtain products in preparations of high yield and purity.

These practical activities should cover a range of different topic areas and require the use of a variety of practical techniques.

How chemists work

Students should be given the opportunity to develop their practical skills for *How Science Works* by completing a range of different practicals that require a variety of different techniques.

Students' laboratory reports on their practical work should use appropriate scientific, technical and mathematical language, conventions and symbols in order to meet the requirements of *How Science Works*.

7.2 Assessment information

Unit 7 examination

This unit contains a practical examination that assesses the experimental skills, and a knowledge and understanding of the necessary techniques that students have gained throughout the course.

The practical examination covers some or all of the following areas of practical work:

- qualitative observations on inorganic anions, cations and organic functional groups
- quantitative measurements
- organic techniques.

The examination will last 2 hours and have 50 raw marks.

It will contain one section.

Students may use a calculator.

The quality of written communication will be assessed in the practical examination. When answering these questions students will be assessed on their ability to organise and present information, ideas, descriptions and arguments clearly and logically, including the use of grammar, punctuation and spelling.

Centres offering this unit must meet the chemistry practical examination requirements in *Appendix 6*.

D Assessment and additional information

Assessment information

Assessment requirements

For a summary of assessment requirements and assessment objectives, see *Section B: Specification overview*.

Entering candidates for the examinations for this qualification

Details of how to enter candidates for the examinations for this qualification can be found in the International Information Manual, copies of which are sent to all examinations officers. The information can also be found at qualifications.pearson.com

Resitting of units

There is one resit opportunity allowed for each unit prior to claiming certification for the qualification. The best available result for each contributing unit will count towards the final grade. After certification, all unit results may be reused to count towards a new award. Students may re-enter for certification only if they have retaken at least one unit. Results of units are held in the Pearson unit bank and have a shelf life limited only by the shelf life of this specification. Please see the following page for further information: qualifications.pearson.com/IAL-entry-certification-procedures

Awarding and reporting

The IAS qualification will be graded and certificated on a five-grade scale from A to E. The full International Advanced Level will be graded on a six-point scale A* to E. Individual unit results will be reported.

A pass in an International Advanced Subsidiary subject is indicated by one of the five grades A, B, C, D, E of which grade A is the highest and grade E the lowest. A pass in an International Advanced Level subject is indicated by one of the six grades A*, A, B, C, D, E of which grade A* is the highest and grade E the lowest. To be awarded an A* students will need to achieve an A on the full International Advanced Level qualification and an A* aggregate of the IA2 units. Students whose level of achievement is below the minimum judged by Pearson to be of sufficient standard to be recorded on a certificate will receive an unclassified U result.

Performance descriptions

Performance descriptions give the minimum acceptable level for a grade. See *Appendix 1* for the performance descriptions for this subject.

Unit results

The minimum uniform marks required for each grade for each unit:

Unit 1

Unit grade	A	B	C	D	E
Maximum uniform mark = 120	**96**	**84**	**72**	**60**	**48**

Students who do not achieve the standard required for a grade E will receive a uniform mark in the range 0–47.

Unit 2

Unit grade	A	B	C	D	E
Maximum uniform mark = 120	**96**	**84**	**72**	**60**	**48**

Students who do not achieve the standard required for a grade E will receive a uniform mark in the range 0–47.

Unit 3

Unit grade	A	B	C	D	E
Maximum uniform mark = 60	**48**	**42**	**36**	**30**	**24**

Students who do not achieve the standard required for a grade E will receive a uniform mark in the range 0–23.

Unit 4

Unit grade	A	B	C	D	E
Maximum uniform mark = 120	**96**	**84**	**72**	**60**	**48**

Students who do not achieve the standard required for a grade E will receive a uniform mark in the range 0–47.

Unit 5

Unit grade	A	B	C	D	E
Maximum uniform mark = 120	**96**	**84**	**72**	**60**	**48**

Students who do not achieve the standard required for a grade E will receive a uniform mark in the range 0–47.

Unit 6/7

Unit grade	A	B	C	D	E
Maximum uniform mark = 60	**48**	**42**	**36**	**30**	**24**

Students who do not achieve the standard required for a grade E will receive a uniform mark in the range 0–23.

Qualification results

The minimum uniform marks required for each grade:

International Advanced Subsidiary cash-in code XCH01

Qualification grade	A	B	C	D	E
Maximum uniform mark = 300	**240**	**210**	**180**	**150**	**120**

Students who do not achieve the standard required for a grade E will receive a uniform mark in the range 0–119.

International Advanced Level cash-in code YCH01

Qualification grade	A	B	C	D	E
Maximum uniform mark = 600	**480**	**420**	**360**	**300**	**240**

Students who do not achieve the standard required for a grade E will receive a uniform mark in the range 0–239.

To be awarded an A* students will need to achieve an A on the full International Advanced Level qualification and an A* aggregate of the IA2 units.

Language of assessment	Assessment of this specification will be available in English only. Assessment materials will be published in English only and all work submitted for examination must be produced in English.
Quality of written communication	Students will be assessed on their ability to: ■ write legibly, with accurate use of spelling, grammar and punctuation in order to make the meaning clear ■ organise relevant information clearly and coherently, using specialist vocabulary when appropriate. In IAL Chemistry the quality of written communication will cover all of these, with students selecting the most relevant way of communicating their information, to a particular context. Quality of written communication will be assessed in all units.
Synoptic assessment	In synoptic assessment there should be a concentration on the quality of assessment to ensure that it encourages the development of the holestic understanding of the subject. Synopticity requires students to connect knowledge, understanding and skills acquired in different parts of the International Advanced Level course. Synoptic assessment in the context of chemistry requires students to apply knowledge and understanding gained from other units to solve a problem. For example, problems related to organic chemistry in Unit 5 require all of the knowledge and understanding the students have developed throughout the other IAS and IA2 topics. In the Unit 4 and 5 examinations at IA2 there will be three sections. Sections B and C will contain extended answer questions where students can demonstrate the scientific knowledge they have developed over the whole IAL in Chemistry. These sections will address the synoptic assessment of the IAL in Chemistry. In addition there will be specific questions in Section C of the examinations which will address synopticity. In Unit 4 students will have to answer data questions, using knowledge and understanding gained from the IAS units and Unit 4. In Unit 5 students will have to answer contextualised questions on the areas of Unit 5, drawing on their knowledge and understanding gained throughout the whole IAL in Chemistry.

Additional information

Malpractice	For up-to-date information on malpractice, please refer to the latest Joint Council for Qualifications (JCQ) Suspected Malpractice in Examinations and Assessments: Policies and Procedures document, available on the JCQ website: www.jcq.org.uk
Access arrangements and special requirements	Pearson's policy on access arrangements and special considerations for GCE, GCSE, IAL and Entry Level is designed to ensure equal access to qualifications for all students (in compliance with the Equality Act 2010) without compromising the assessment of skills, knowledge, understanding or competence. Please see the JCQ website (www.jcq.org.uk) for their policy on access arrangements, reasonable adjustments and special considerations. Please see our website (qualifications.pearson.com) for: ■ the forms to submit for requests for access arrangements and special considerations ■ dates for submissions of the forms.
Equality Act 2010	Please see our website (qualifications.pearson.com) for information on the Equality Act 2010.
Prior learning and progression	**Prior learning** There no prior learning or other requirements for this qualification. **Progression** This qualification supports progression into further education, training or employment.
Combinations of entry	Only units achieved from this qualification may contribute to the certification of the International Advanced Subsidiary in Chemistry or the International Advanced Level in Chemistry.
Student recruitment	Pearson's access policy concerning recruitment to our qualifications is that: ■ they must be available to anyone who is capable of reaching the required standard ■ they must be free from barriers that restrict access and progression ■ equal opportunities exist for all students.

E Support, training and resources

Support

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F Appendices

Appendix 1 Performance descriptions

Introduction

Performance descriptions describe the learning outcomes and levels of attainment likely to be demonstrated by a representative candidate performing at the A/B and E/U boundaries for IAS and IA2.

In practice most candidates will show uneven profiles across the attainments listed, with strengths in some areas compensating in the award process for weaknesses or omissions elsewhere. Performance descriptions illustrate expectations at the A/B and E/U boundaries of the IAS and IA2 as a whole; they have not been written at unit level.

Grade A/B and E/U boundaries should be set using professional judgement. The judgement should reflect the quality of candidates' work, informed by the available technical and statistical evidence. Performance descriptions are designed to assist examiners in exercising their professional judgement. They should be interpreted and applied in the context of individual specifications and their associated units. However, performance descriptions are not designed to define the content of specifications and units.

IAS performance descriptors for Chemistry

	Assessment objective 1	Assessment objective 2	Assessment objective 3
Assessment objectives	**Knowledge and understanding of science and of *How Science Works*** Candidates should be able to: ■ recognise, recall and show understanding of scientific knowledge ■ select, organise and communicate relevant information in a variety of forms.	**Application of knowledge and understanding of science and of *How Science Works*** Candidates should be able to: ■ analyse and evaluate scientific knowledge and processes ■ apply scientific knowledge and processes to unfamiliar situations including those related to issues ■ assess the validity, reliability and credibility of scientific information.	***How Science Works*** Candidates should be able to: ■ demonstrate and describe ethical, safe and skilful practical techniques and processes, selecting appropriate qualitative and quantitative methods ■ make, record and communicate reliable and valid observations and measurements with appropriate precision and accuracy ■ analyse, interpret, explain and evaluate the methodology, results and impact of their own and others' experimental and investigative activities in a variety of ways.
A/B boundary performance descriptions	Candidates characteristically: a) demonstrate knowledge and understanding of most principles, concepts and facts from the IAS specification b) select relevant information from the IAS specification c) organise and present information clearly in appropriate forms using scientific terminology d) write equations for most straightforward reactions using scientific terminology.	Candidates characteristically: a) apply principles and concepts in familiar and new contexts involving only a few steps in the argument b) describe significant trends and patterns shown by data presented in tabular or graphical form; interpret phenomena with few errors; and present arguments and evaluations clearly c) comment critically on statements, conclusions or data d) carry out accurately most structured calculations specified for IAS e) use a range of chemical equations f) translate successfully data presented as prose, diagrams, drawings, tables or graphs from one form to another.	Candidates characteristically: a) devise and plan experimental and investigative activities, selecting appropriate techniques b) demonstrate safe and skilful practical techniques c) make observations and measurements with appropriate precision and record these methodically d) interpret, explain, evaluate and communicate the results of their own and others' experimental and investigative activities, in appropriate contexts.

	Assessment objective 1	Assessment objective 2	Assessment objective 3
E/U boundary performance descriptions	Candidates characteristically: a) demonstrate knowledge and understanding of some principles and facts from the IAS specification b) select some relevant information from the IAS specification c) present information using basic terminology from the IAS specification d) write equations for some straightforward reactions.	Candidates characteristically: a) apply a given principle to material presented in familiar or closely related contexts involving only a few steps in the argument b) describe some trends or patterns shown by data presented in tabular or graphical form c) identify, when directed, inconsistencies in conclusions or data d) carry out some steps within calculations e) use simple chemical equations f) translate data successfully from one form to another, in some contexts.	Candidates characteristically: a) devise and plan some aspects of experimental and investigative activities b) demonstrate safe practical techniques c) make observations and measurements and record them d) interpret, explain and communicate some aspects of the results of their own and others' experimental and investigative activities, in appropriate contexts.

IA2 performance descriptors for Chemistry

	Assessment objective 1	Assessment objective 2	Assessment objective 3
Assessment objectives	**Knowledge and understanding of science and of *How Science Works*** Candidates should be able to: ■ recognise, recall and show understanding of scientific knowledge ■ select, organise and communicate relevant information in a variety of forms.	**Application of knowledge and understanding of science and of *How Science Works*** Candidates should be able to: ■ analyse and evaluate scientific knowledge and processes ■ apply scientific knowledge and processes to unfamiliar situations including those related to issues ■ assess the validity, reliability and credibility of scientific information.	***How Science Works*** Candidates should be able to: ■ demonstrate and describe ethical, safe and skilful practical techniques and processes, selecting appropriate qualitative and quantitative methods ■ make, record and communicate reliable and valid observations and measurements with appropriate precision and accuracy ■ analyse, interpret, explain and evaluate the methodology, results and impact of their own and others' experimental and investigative activities in a variety of ways.
A/B boundary performance descriptions	Candidates characteristically: a) demonstrate detailed knowledge and understanding of most principles, concepts and facts from the IA2 specification b) select relevant information from the IA2 specification c) organise and present information clearly in appropriate forms using scientific terminology d) write equations for most chemical reactions.	Candidates characteristically: a) apply principles and concepts in familiar and new contexts involving several steps in the argument b) describe significant trends and patterns shown by complex data presented in tabular or graphical form; interpret phenomena with few errors; and present arguments and evaluations clearly c) evaluate critically any statements, conclusions or data d) carry out accurately complex calculations specified for International Advanced level e) use chemical equations in a range of contexts f) translate successfully data presented as prose, diagrams, drawings, tables or graphs from one form to another g) select a wide range of facts, principles and concepts from both IAS and IA2 specifications h) link together appropriate facts principles and concepts from different areas of the specification.	Candidates characteristically: a) devise and plan experimental and investigative activities, selecting appropriate techniques b) demonstrate safe and skilful practical techniques c) make observations and measurements with appropriate precision and record these methodically d) interpret, explain, evaluate and communicate the results of their own and others' experimental and investigative activities, in appropriate contexts.

	Assessment objective 1	Assessment objective 2	Assessment objective 3
E/U boundary performance descriptions	Candidates characteristically: a) demonstrate knowledge and understanding of some principles, concepts and facts from the IA2 specification b) select some relevant information from the IA2 specification c) present information using basic terminology from the IA2 specification d) write equations for some chemical reactions.	Candidates characteristically: a) apply given principles or concepts in familiar and new contexts involving a few steps in the argument b) describe, and provide a limited explanation of, trends or patterns shown by complex data presented in tabular or graphical form c) identify, when directed, inconsistencies in conclusions or data d) carry out some steps within calculations e) use some chemical equations f) translate data successfully from one form to another, in some contexts g) select some facts, principles and concepts from both IAS and IA2 specifications h) put together some facts, principles and concepts from different areas of the specification.	Candidates characteristically: a) devise and plan some aspects of experimental and investigative activities b) demonstrate safe practical techniques c) make observations and measurements and record them d) interpret, explain and communicate some of the results of their own and others' experimental and investigative activities, in appropriate contexts.

Appendix 2 Codes

Type of code	Use of code	Code number
Unit codes	Each unit is assigned a unit code. This unit code is used as an entry code to indicate that a student wishes to take the assessment for that unit. Centres will need to use the entry codes only when entering students for their examination.	Unit 1 – WCH01 Unit 2 – WCH02 Unit 3 – WCH03 Unit 4 – WCH04 Unit 5 – WCH05 Unit 6 – WCH06 Unit 7 – WCH07
Cash-in codes	The cash-in code is used as an entry code to aggregate the student's unit scores to obtain the overall grade for the qualification. Centres will need to use the entry codes only when entering students for their qualification.	IAS – XCH01 IAL – YCH01
Entry codes	The entry codes are used to: 1 enter a student for the assessment of a unit 2 aggregate the student's unit scores to obtain the overall grade for the qualification.	Please refer to the *Pearson Information Manual*, available on our website (qualifications.pearson.com).

Appendix 3 How Science Works — mapping and expansion on specification content

How Science Works — mapping

How Science Works reference	Specification reference			
	Unit 1	Unit 2	Unit 4	Unit 5
1 Use theories, models and ideas to develop and modify scientific explanations	1.4d 1.4e 1.4g 1.5e 1.5f 1.5g 1.5k 1.6.1a 1.6.1h 1.6.1l 1.6.3b 1.7.2e 1.7.3b 1.7.3e	2.3c 2.4a 2.4b 2.4c 2.4d 2.5b 2.5d 2.6a all of 2.7 2.8b 2.8c 2.8d 2.8e 2.11a 2.11b 2.11c 2.11d 2.11e 2.11f	4.3h 4.3j all of 4.4 4.5c 4.5f 4.5g 4.5h all of 4.6 4.7a 4.7b 4.7c 4.7e	5.3.1c 5.3.1d 5.3.1e 5.3.1f 5.3.2c 5.4.1a
2 Use knowledge and understanding to pose scientific questions, define scientific problems, and present scientific arguments and ideas	1.7.2c 1.7.2d 1.7.2e 1.7.3b 1.7.3h	2.11g 2.12d 2.13b	4.6a 4.6b 4.6c 4.6d 4.7g	5.3.2g 5.4.2h 5.4.3a 5.4.3d
3 Use appropriate methodology, including ICT, to answer scientific questions and solve scientific problems	1.4d 1.4f 1.5b 1.7.2c 1.7.2d 1.7.3h	2.11g	4.3c 4.3d 4.3e 4.8.1d	5.4.3a 5.4.3d
4 Carry out experimental and investigative activities, including appropriate risk management, in a range of contexts	General laboratory work			

How Science Works reference	Specification reference			
	Unit 1	Unit 2	Unit 4	Unit 5
5 Analyse and interpret data to provide evidence, recognising correlations and causal relationships	1.3j 1.4f 1.7.1c	all of 2.7 2.11g	2.7 2.11g 4.5c 4.8.1d	5.3.1l 5.4.3b 5.4.3c
6 Evaluate methodology, evidence and data and resolve conflicting evidence	1.3i 1.7.3h			1.3i 1.7.3h
7 Appreciate the tentative nature of scientific knowledge	1.5e 1.5f	2.4a 2.4b 2.4c 2.4d		5.3.1d 5.3.1e 5.3.1f 5.3.2c 5.4.1a
8 Communicate information and ideas in appropriate ways using appropriate terminology	1.7.2c 1.7.2d 1.7.3h	2.11g all of 2.13	4.6a 4.6b 4.6c 4.6d	5.3.1i 5.3.2h
9 Consider the applications and implications of science and appreciate their associated benefits and risks	1.7.1c 1.7.1d 1.7.3d 1.7.3h	2.3e 2.9c 2.10.2f all of 2.13	4.6a 4.6b 4.6c 4.6d 4.7m all of 4.9	5.3.1j 5.3.1k 5.3.2h 5.3.2k 5.4.3a 5.4.3d
10 Consider ethical issues in the treatment of humans, other organisms and the environment		2.3e 2.11g all of 2.13	4.6a 4.6b 4.6c 4.6d all of 4.9	5.3.2l
11 Appreciate the role of the scientific community in validating new knowledge and ensuring integrity	1.7.3h	all of 2.13	all of 4.9	5.3.2h 5.4.3b 5.4.3c
12 Appreciate the ways in which society uses science to inform decision making	1.3c 1.7.2c 1.7.2d 1.7.3h	2.7.1h 2.11g all of 2.13	4.6a 4.6b 4.6c 4.6d all of 4.9	5.3.1i

How Science Works — expansion of specification content

The following notes show how the ideas involved with *How Science Works* can be developed from the specification content. In many cases this will involve a change in approach to a topic rather than the introduction of unfamiliar content.

Unit 1: The Core Principles of Chemistry

Topic 1.3 – Formulae, equations and amounts of substance	
Throughout the unit students see the importance of chemical data and learn to select data from databases and use it to look for patterns and calculate other quantities.	
1.3c	Students should appreciate that mol dm^{-3} is not a very useful unit when dealing with very small concentrations and alternatives provide a better understanding for comparative purposes. Students could also consider examples of the labelling of contents of food by supermarkets and discuss whether they have scientific and mathematical validity, e.g. the use of pie charts. **HSW 12**
1.3i	Quantitative exercises of this type provide an opportunity to introduce evaluation of methodology such as limitations of techniques, accuracy of measurement, types of errors and uncertainty of the final result and the idea that it is impossible to get a 100 per cent accurate result in experiments of this type and the implications this may have for testing for drugs etc. **HSW 6**
1.3j	These exercises are designed to get students to interpret information generated at a macroscopic level, to suggest what is happening at a molecular level and to use this to write different types of equation. Much of this could be used to introduce the ideas of microscale chemistry. **HSW 5**
Topic 1.4 – Energetics	
Practical work to measure energy changes helps students to understand the ideas of uncertainty in measurements and evaluate their results in terms of systematic and random errors.	
1.4d	Students need to consider why it is necessary to have a standard set of conditions when quoting thermochemical data and the idea that only energy changes can be measured and, consequently, some fixed points are needed (such as the standard heat of formation of elements being defined as 0 J mol^{-1}). Examples might include the energy generated by burning different fuels. **HSW 1, HSW 3**
1.4e	Hess's law is an example of a mathematical model that can be used to bring together data and allow it to be used to calculate energy changes that cannot be measured directly such as standard heat of formation of hydrocarbon fuels. **HSW 1**

1.4f	Students should consider the assumptions made in calculations based on data from thermochemical experiments and their validity. Students could be asked to plan and carry out an investigation to find an energy change that cannot be measured directly such as the hydration of magnesium sulfate. **HSW 4** These exercises are designed to allow students to carry out a range of different data collecting techniques. Experiments of this type can be used to discuss alternative techniques to produce more accurate results but also show that repeating an experiment leads to reliability rather than improved accuracy. **HSW 3, HSW 5**
1.4g	Students could use bond data as a tool to provide ideas about possible mechanisms for reactions such as free radical substitution, structures of compounds and energy changes for reactions. They should realise the limitations of using mean bond energy data by comparing actual data from experiments to theoretical data based on bond energy. **HSW 1**
Topic 1.5 – Atomic structure and the periodic table	
The role of instrumentation in analytical chemistry is illustrated by mass spectrometry. *The study of atomic structure gives some insight into the types of evidence which scientists use to study electrons in atoms. This leads to an appreciation of one of the central features of chemistry which is the explanation of the properties of elements and of the patterns in the periodic table in terms of atomic structure.*	
1.5b	Students could consider the use of the mass spectrometer by the pharmaceutical industry to produce data concerning molecular mass. **HSW 3**
1.5e	Looking at electronic structure can provide an opportunity to discuss the historical development of a model and the way that evidence is used to generate a chemical model that is then modified as more data becomes available. **HSW 1, HSW 7**
1.5f	Students should consider why a more sophisticated model is needed to explain the properties of electrons in atoms and the way atoms join together. **HSW 1, HSW 7**
1.5g	Students could discuss the idea that trying to remember the electronic structure of every element is difficult so chemists devised a way to rationalise the information about the electronic structure of each atom into a pattern that could help to predict the electronic structure of other atoms. Students need to realise that the idea helps chemists decide on the minimum energy arrangement of a particular number of electrons around a nucleus and that this has limitations. **HSW 1**
1.5k	Use the model of bonding theory to explain the properties of the elements. **HSW 1**

Topic 1.6 – Bonding	
Students are introduced to some of the evidence which will help them to understand the different kinds of chemical bonding. *Chemists set up theoretical models and gain insights by comparing real and ideal properties of chemicals. This is illustrated in the unit by the ionic model and the comparison of lattice energies calculated from theory with those determined with the help of Born-Haber cycles.*	
1.6.1a and 1.6.1l	Students could discuss the evidence for complete electron transfer or electron sharing based on electron density maps. **HSW 1**
1.6.1h	Compare theoretical data based on the assumption of complete electron transfer data with that from practical measurement of lattice energy based on Born-Haber cycles. **HSW 1**
1.6.3b	Use of the model of metallic bonding to explain properties of metals. **HSW 1**
Topic 1.7 – Introductory organic chemistry	
The introduction to organic chemistry shows how chemists work safely with potentially hazardous chemicals by managing risks.	
1.7.1c and 1.7.1d	Students should be encouraged in their laboratory work to appreciate the difference between hazard and risk. They should appreciate that the total elimination of risk is almost impossible if society is to function normally and that laboratories are generally very safe environments compared with the risks of everyday life such as taking a car ride. Students could be encouraged to look at comparative risks associated with the use of applied pesticides compared with those from natural pesticides generated by nature. Students should understand the reasoning behind the steps that can be taken to minimise risk so that laboratory reactions can be carried out in safety. **HSW 5, HSW 9**
1.7.2c and 1.7.2d	Students could use the internet to research data concerning alternative fuels and compare the relative environmental impact in terms of reducing emissions and sustainability. The data could then be presented using ICT. An example might include the use of hydrogen as a fuel in motor cycles. Questions such as the carbon neutrality of hydrogen could be considered taking into account the energy used to produce the hydrogen, the problems associated with refuelling, the fact that the emissions are greenhouse gases and the myth that hydrogen is dangerous because it is 'explosive' could be exposed. **HSW 8, HSW 2, HSW 3, HSW 12**
1.7.2e	If linked with 1.4g several potential mechanisms could be offered and tested using bond energy and could provide evidence for the probable mechanism. This is an example of the use of a model to help chemists explain and classify reactions. **HSW 1, HSW 2**

1.7.3b	The introduction of the need for the E-Z nomenclature could be developed by looking at examples of structures that cannot be classified using the cis-trans convention. This needs to be in the context of why it is necessary to be able to distinguish between E-Z isomers (geometric). An example might include the colours in tomatoes. **HSW 1, HSW 2**
1.7.3di	Students describe the addition reactions of alkenes, limited to the addition of hydrogen with a nickel catalyst to form an alkane. **HSW 9**
1.7.3e	This is an example of the collection of data to be used to support an hypothesis that develops into a model that helps our understanding of reactions at a molecular level. **HSW 1**
1.7.3h	Data on polymers could be collected to investigate their overall environmental impact and introduce the idea of carbon footprint and what can be done to reduce the impact on the environment. **HSW 2, HSW 3, HSW 6, HSW 8, HSW 9, HSW 11, HSW 12**

Unit 2: Application of Core Principles of Chemistry

Topics 2.3, 2.4 and 2.5 – Shapes of molecules and ions, intermediate bonding and bond polarity, intermolecular forces	
Electron-pair repulsion theory shows how chemists can make generalisations and use them to make predictions.	
2.3c	Students use the electron-pair repulsion theory to predict the shapes of unfamiliar molecules. **HSW 1**
2.3e	The work on nanochemistry could include colloid chemistry and the increased reactivity of nanoparticles compared to larger ones. Also in the cosmetics industry the use of nano-sized particles in creams etc so that they can be more easily absorbed through the skin, as in moisturisers, and particles that are smaller than the wavelength of light and are therefore too small to see, and can be used in sunscreen creams but are transparent to light rather than opaque. This could raise issues about risks to and implications for humans. **HSW 9, HSW 10**
2.4a and 2.4d	This topic raises the issue of the bonding model as applied to actual compounds and can lead students to consider the limitations of the model and the need to consider other ideas to explain observed phenomena. **HSW 1, HSW 7**
2.5b and 2.5d	Use of the bonding models to explain observed phenomena. **HSW 1**

Topics 2.6 and 2.7 – Redox, the periodic table – groups 2 and 7	
Chemists rationalise a great deal of information about chemical changes by using theory to categorise reagents and types of chemical change. This is illustrated by the use of inorganic and organic examples in this unit.	
2.6a	Students use the concept of oxidation number to classify reactions and to help their understanding of changes at the atomic level. **HSW 1**
2.7	This topic on the periodic table can be used to illustrate the ways in which chemists collate data, search for patterns, reduce the need to remember every single reaction of every compound and predict the chemistry of unfamiliar compounds such as those of astatine. **HSW 1, HSW 5**
2.7.1h and 2.7.2c	Using the technique of volumetric analysis provides an opportunity for students to evaluate their own methodology to include the limitations of the apparatus, accuracy of measurement, types of errors and uncertainty of the final result. The difference between reliability and uncertainty could be explored, including the idea that repeating an experiment with the same apparatus will not improve the accuracy, only the reliability and the need to appreciate that an uncertainty in a final result can have implications for how the information may be used. **HSW 5 with potential for HSW 12**
Topics 2.8 and 2.9 – Kinetics, chemical equilibria	
The use of models in chemistry is illustrated by the way in which the Maxwell-Boltzmann distribution and collision theory can account for the effects of temperature on the rates of chemical reactions.	
2.8b	The collision theory provides a model that students can apply to help their understanding of how reactions happen at the molecular level and explain the effect of changing conditions on the rate of a reaction. **HSW 1**
2.8c	The Maxwell-Boltzmann curves provides students with a mathematical model that allows them to understand and predict the effect of changing conditions on the rate of a reaction. **HSW 1**
2.8d and 2.8e	Use of the concept of activation energy to explain changes in rate of reactions. **HSW 1**
2.9c	The equilibrium model and the effect of changes on the position of equilibrium can be applied to industrial situations. This can lead into discussions of atom economy and the ways in which industrial chemists and chemical engineers manipulate the conditions in a reaction to maximize yield and minimise waste of raw materials. Examples might include recycling of unreacted gases and finding new catalysts that work at lower temperatures. **HSW 9**

Topics 2.10, 2.11 and 2.12 – Organic chemistry, mechanisms, mass spectra and IR	
The unit shows how chemists study chemical changes on an atomic scale and propose mechanisms to account for their observations.	
2.10.2f	Discussion of the use of fire retardants and a consideration of the benefits against the risks involved with the use of halogenoalkanes. **HSW 9**
2.11a to 2.11e	The work on mechanisms provides an example of the advantages of classifying reactions and models and will help students' understanding of what is happening at the molecular level. **HSW 1**
2.11f	Students can apply the model to deepen their understanding of how reactions proceed at the molecular level including substitution in halogenoalkanes. **HSW 1**
2.11g	Consideration of the depletion of the ozone layer, NO emissions from cars and the problem of exhaust NO from high flying aircraft could be used as a starting point for discussions on how understanding the mechanism of a reaction can help scientists to propose solutions to environmental problems such as the role catalytic converters in cars can play in the reducing of NO emissions. Students should understand the difference between greenhouse gases and those associated with the ozone layer depletion but also that some are the same. **HSW 2, HSW 3, HSW 5, HSW 8, HSW 10, HSW 12**
2.12d and 2.13b	The model of polarity allows chemists to understand why some gases present problems in terms of global warming while others do not. **HSW 2**
Topics 2.13 – Green chemistry	
2.13	This topic provides an opportunity to bring together areas where chemists are involved in attempting to solve environmental problems by the application of theories and new technologies and are helping the public to understand the implications of the decisions that they make. This includes efforts by industry such as: ■ consideration of renewable resources ■ making industrial processes more environmentally friendly ■ using more efficient energy sources for reactions ■ reducing waste. Students should consider the concept of carbon neutrality and explore the need to consider all stages of a process. Students should identify examples of the way scientific information has helped society to change. **HSW 9, HSW 10, HSW 11, HSW 12**

Unit 4: General Principles of Chemistry I – Rates, Equilibria and Further Organic Chemistry

Topics 4.3 – How fast? – rates	
Through practical work, students will learn about the methods used to measure reaction rates. They will collect data, analyse it and interpret the results. They can then see how a knowledge of rate equations, and other evidence, can enable chemists to propose models to describe the mechanisms of reactions.	
4.3c and 4.3d	Practical investigations in kinetics can help improve students' skills in presenting and interpretation of data. **HSW 3**
4.3d and 4.3e	This investigation can be used to bring together all the basic ideas associated with kinetics and introduce ideas of how the data can be used to help understand reactions at the molecular level. **HSW 3**
4.3h, 4.3i and 4.3j	This looks at how knowledge of rate equations, and other evidence, can enable chemists to propose models to describe the mechanisms of reactions. **HSW 1, HSW 2**
Topics 4.4 – How far? – entropy	
Topic 4.4	The study of entropy introduces students to the methods of thermodynamics and shows how chemists use formal, quantitative and abstract thinking to answer fundamental questions about the stability of chemicals and the direction of chemical change. **HSW 1**
Topics 4.5, 4.6 and 4.7 – Equilibria, application of rates and equilibrium, acid/base equilibria	
This unit tests the equilibrium law by showing the degree to which it can accurately predict changes during acid-base reactions, notably the changes to pH during titrations. *The historical development of theories explaining acids and bases shows how scientific ideas change as a result of new evidence and fresh thinking.*	
4.5c	Students could be encouraged to analyse data from theory or experiments to establish equilibrium relationships. They should appreciate that the relationships are empirical and apply only to the system under consideration. **HSW 1, HSW 5**
4.5f and 4.5h	These sections link thermodynamic theories with equilibrium situations and allows students to obtain a deeper understanding of the reasons for observed effects of changes of conditions on equilibrium. **HSW 1**
4.6a to 4.6d	This topic applies the material in topics 4.3, 4.4 and 4.5 of this unit to industrial situations and begins to look at the way industry can use models/theories, including kinetics, equilibrium and thermodynamic data, in the search for better yields at a lower cost to the environment. **HSW 1, HSW 2, HSW 8, HSW 9, HSW 10, HSW 12**

4.7a to 4.7c	Students could look at how our understanding of acid and bases has developed over the last 150 years as knowledge has increased and new theories of atomic behaviour have been formulated. **HSW 1**
4.7e	Students can use the model of ionic dissociation to explain acid/base behaviour. **HSW 1**
4.7g	Determination of Ka from pH and concentration data provides a good example of when it is appropriate to make approximations in chemistry and when it is not. **HSW 2**
4.7m	This can be used as an example of how chemists can help society to understand and minimise risk. **HSW 9**
Topics 4.8 – Further organic chemistry	
4.8.1d	Analysis of data for optical activity — i.e. production of a racemic mixture or a single enantiomorph could be used to provide evidence for proposed mechanisms. **HSW 3, HSW 5**
Topics 4.9 – Spectroscopy and chromatography	
Topic 4.9	This considers how chemists use the interaction of various types of radiation with molecules, including the use of: ▪ IR by the chemical industry as a non-invasive technique to follow the extent of a reaction ▪ microwaves to provide a heat source in a closed system that can allow reactions to proceed at a temperature double that of the highest boiling point component thus reducing the time for a reaction by orders of magnitude, saving time and energy ▪ nmr spectroscopy in medicine and industry. It also includes the use of HPLC as a method of rapid separation of liquid mixtures prior to further analysis. **HSW 9, HSW 10, HSW 11, HSW 12**

Unit 5: General Principles of Chemistry II – Transition Metals and Organic Nitrogen Chemistry

Topics 5.3 – Redox and the chemistry of the transition metals	
The study of chemical cells provides an opportunity to illustrate the impact on scientific thinking when it emerges that ideas developed in different contexts can be shown to be related to a major explanatory principle. In this unit, cell emfs and equilibrium constants are shown to be related to the fundamental criterion for the feasibility of a chemical reaction: the total entropy change.	
5.3.1c	Students need to understand that electrode potentials are relative and therefore some reference point is needed to classify the data. Hence the need for a standard reference electrode. **HSW 1**

5.3.1d to 5.3.1f	Students apply the model to predict the direction of possible change and then link this to other theories to get a more complete picture of why reactions do or do not actually occur. **HSW 1, HSW 7**
5.3.1i	Using the technique of volumetric analysis provides an opportunity for students to evaluate their own methodology to include limitations of the apparatus, accuracy of measurement, types of errors and uncertainty of the final result. The difference between reliability and uncertainty could be explored, including the idea that repeating an experiment with the same apparatus will not improve the accuracy, only the reliability and the need to appreciate that an uncertainty in a final result can have implications for how the information may be used. **HSW 5 with potential for HSW 8, HSW 12**
5.3.1j and 5.3.1k	These are some applications of electrode potential to the solution of problems. **HSW 9 with potential for HSW 6**
The explanatory power of the energy-level model for electronic structures is further illustrated by showing how it can help to account for the existence and properties of transition metals. In this context there are opportunities to show the limitations of the models used at this level and to indicate the need for more sophisticated explanations.	
5.3.2c	The energy-level model can be used to provide evidence for the proposed electronic structures of d-block elements by consideration of plots of the first, second and third ionisation energies, particularly those of chromium and copper where evidence for the presence of half-full and full shells in the elements shows up clearly. **HSW 1, HSW 7**
5.3.2h	Students can use the energy-level model and ideas of bonding to explain the catalytic behavior of the elements and their compounds. **HSW 2**
5.3.2i	This encourages students to explore the development of new catalysts as a priority area for chemical research today. This could be used to explain how the scientific community reports and validates new discoveries and explanations, e.g. the development of new catalysts for making ethanoic acid from methanol and carbon monoxide with a high atom economy. **HSW 8, HSW 9, HSW 11**
5.3.2l	This is an example of the application of the properties of transition metals and their compounds and their impact on society, with the associated risk and benefits in the case of chemotherapy drugs. **HSW 9**

Topics 5.4 – Further organic chemistry	
The topic of organic synthesis illustrates a selection of the techniques that chemists have developed to carry out reactions and purify products efficiently and safely.	
5.4.1a	The development of theories concerning the structure of benzene provides evidence for the way theories develop as new knowledge becomes available. **HSW 1, HSW 7**
5.4.2h	This is an example of the development of polymers with specific properties and the ways in which effects on the environment can be minimised by application of the theories of bonding and structure. **HSW 2**
5.4.3a and 5.4.3d	Students need to appreciate the importance of organic synthesis in the production of new materials and the way that the pharmaceutical industry makes tens of thousands of new compounds a year which are then tested for biological activity. **HSW 2, HSW 3, HSW 9**
5.4.3b and 5.4.3c	This could be used to develop ideas associated with the need to know exactly the shape of a molecule and the way the production process proceeds in the context of stereo-specific drugs. **HSW 5, HSW 6, HSW 11**
5.4.3d i ii	This is an example of how knowledge of organic chemistry can be applied to the properties of new compounds, development of synthesis routes, selection of procedures and the identification of associated risks. **HSW 2**
5.4.3f	Students need to be familiar with basic laboratory techniques. **HSW 4**

Appendix 4 Mathematical requirements mapping

Reference	Coverage of mathematical requirements
Arithmetical and numerical computation	
a recognise and use expressions in decimal and standard form	All calculations involving concentrations in solution, all calculations involving enthalpy changes, acid base calculations and most involving rate
b use ratios, fractions and percentages	All mole calculations and accuracy discussions
c make estimates of the results of calculations (without using a calculator)	Not explicit but encourage students to look at their answers and estimate if the order of magnitude is correct
d use calculators to find and use power, exponential and logarithmic functions	Activation energy calculations, kinetics calculations and all acid/base calculations
Handling Data	
a use an appropriate number of significant figures	A vital element of all quantitative work particularly the practical aspects
b find arithmetic means	Volumetric analysis
Algebra	
a understand and use the symbols: $=, <, <<, >>, >, \mu, \sim$	Use as appropriate mainly $= <, >$
b change the subject of an equation	All mole calculations and most equilibrium and acid/base calculations
c substitute numerical values into algebraic equations using appropriate units for physical quantities	Enthalpy calculations, kinetics calculations, equilibrium calculations
d solve simple algebraic equations	Equilibrium calculations
e use logarithms in relation to quantities which range over several orders of magnitude	pH, pK_a, pK_w, K_p, successive ionisation energy
Graphs	
a translate information between graphical, numerical and algebraic forms	Kinetics and enthalpy practical data
b plot two variables from experimental or other data	Almost all experiments where data is collected
c understand that $y = mx + c$ represents a linear relationship	Kinetics

Reference	Coverage of mathematical requirements
d determine the slope and intercept of a linear graph	Kinetics
e calculate rate of change from a graph showing a linear relationship	Kinetics
f draw and use the slope of a tangent to a curve as a measure of rate of change	Kinetics
Geometry	
a appreciate angles and shapes in regular 2D and 3D structures	Molecular shape descriptions
b visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects	Solid shape descriptions
c understand the symmetry of 2D and 3D shapes	E-Z isomerism

The periodic table of elements

Key

relative atomic mass
atomic symbol
name
atomic (proton) number

1 (1)	2 (2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	3 (13)	4 (14)	5 (15)	6 (16)	7 (17)	0 (8) (18)
							1.0 **H** hydrogen 1										4.0 **He** helium 2
6.9 **Li** lithium 3	9.0 **Be** beryllium 4											10.8 **B** boron 5	12.0 **C** carbon 6	14.0 **N** nitrogen 7	16.0 **O** oxygen 8	19.0 **F** fluorine 9	20.2 **Ne** neon 10
23.0 **Na** sodium 11	24.3 **Mg** magnesium 12											27.0 **Al** aluminium 13	28.1 **Si** silicon 14	31.0 **P** phosphorus 15	32.1 **S** sulfur 16	35.5 **Cl** chlorine 17	39.9 **Ar** argon 18
39.1 **K** potassium 19	40.1 **Ca** calcium 20	45.0 **Sc** scandium 21	47.9 **Ti** titanium 22	50.9 **V** vanadium 23	52.0 **Cr** chromium 24	54.9 **Mn** manganese 25	55.8 **Fe** iron 26	58.9 **Co** cobalt 27	58.7 **Ni** nickel 28	63.5 **Cu** copper 29	65.4 **Zn** zinc 30	69.7 **Ga** gallium 31	72.6 **Ge** germanium 32	74.9 **As** arsenic 33	79.0 **Se** selenium 34	79.9 **Br** bromine 35	83.8 **Kr** krypton 36
85.5 **Rb** rubidium 37	87.6 **Sr** strontium 38	88.9 **Y** yttrium 39	91.2 **Zr** zirconium 40	92.9 **Nb** niobium 41	95.9 **Mo** molybdenum 42	[98] **Tc** technetium 43	101.1 **Ru** ruthenium 44	102.9 **Rh** rhodium 45	106.4 **Pd** palladium 46	107.9 **Ag** silver 47	112.4 **Cd** cadmium 48	114.8 **In** indium 49	118.7 **Sn** tin 50	121.8 **Sb** antimony 51	127.6 **Te** tellurium 52	126.9 **I** iodine 53	131.3 **Xe** xenon 54
132.9 **Cs** caesium 55	137.3 **Ba** barium 56	138.9 **La*** lanthanum 57	178.5 **Hf** hafnium 72	180.9 **Ta** tantalum 73	183.8 **W** tungsten 74	186.2 **Re** rhenium 75	190.2 **Os** osmium 76	192.2 **Ir** iridium 77	195.1 **Pt** platinum 78	197.0 **Au** gold 79	200.6 **Hg** mercury 80	204.4 **Tl** thallium 81	207.2 **Pb** lead 82	209.0 **Bi** bismuth 83	[209] **Po** polonium 84	[210] **At** astatine 85	[222] **Rn** radon 86
[223] **Fr** francium 87	[226] **Ra** radium 88	[227] **Ac*** actinium 89	[261] **Rf** rutherfordium 104	[262] **Db** dubnium 105	[266] **Sg** seaborgium 106	[264] **Bh** bohrium 107	[277] **Hs** hassium 108	[268] **Mt** meitnerium 109	[271] **Ds** darmstadtium 110	[272] **Rg** roentgenium 111							

Elements with atomic numbers 112-116 have been reported but not fully authenticated

* Lanthanide series	140 **Ce** cerium 58	141 **Pr** praseodymium 59	144 **Nd** neodymium 60	[147] **Pm** promethium 61	150 **Sm** samarium 62	152 **Eu** europium 63	157 **Gd** gadolinium 64	159 **Tb** terbium 65	163 **Dy** dysprosium 66	165 **Ho** holmium 67	167 **Er** erbium 68	169 **Tm** thulium 69	173 **Yb** ytterbium 70	175 **Lu** lutetium 71
* Actinide series	232 **Th** thorium 90	[231] **Pa** protactinium 91	238 **U** uranium 92	[237] **Np** neptunium 93	[242] **Pu** plutonium 94	[243] **Am** americium 95	[247] **Cm** curium 96	[245] **Bk** berkelium 97	[251] **Cf** californium 98	[254] **Es** einsteinium 99	[253] **Fm** fermium 100	[256] **Md** mendelevium 101	[254] **No** nobelium 102	[257] **Lr** lawrencium 103

Appendix 5 The periodic table of the elements

Appendix 6 Requirements for chemistry practical examination

Centres offering *Unit 7: Chemistry Practical Examination* will need to be able to fulfil the requirements outlined in this appendix.

It is the responsibility of the centre to carry out a full risk assessment before any practical examination takes place.

The detailed requirements for the practical examination will be specified in the *IAL Chemistry Practical Examination Confidential Instructions* document, which will be sent to centres well in advance of the date of the examination.

Laboratories

To conduct the practical examination, centres must have a suitably equipped laboratory:

- the laboratory temperature must be maintained at a comfortable level. The levels of lighting and ventilation should be suitable for the practical examination
- laboratories must have adequate bench space for each candidate and must be equipped with running water, electric lighting, gas supply and fume cupboards. An adequate supply of distilled or deionised water is essential
- candidates must be able to work safely in the laboratory. They must be supplied with safety equipment, including laboratory overalls, eye protection and plastic gloves as appropriate.

Centres are required to supply their own materials, including preparing their own solutions, for use in the practical examination. Therefore, an area of complete security where materials can be prepared and stored is essential.

It is assumed that candidates have access to the normal range of chemicals and apparatus used for the International Advanced Level Chemistry course. It should be noted that not all of the materials listed below will be needed in any one practical examination.

General bench reagents

- Concentrated sulfuric acid
- Concentrated hydrochloric acid
- Concentrated aqueous ammonia
- Dilute sulfuric acid; concentration approximately 1.0 mol dm^{-3}
- Dilute hydrochloric acid; concentration approximately 2.0 mol dm^{-3}
- Dilute nitric acid; concentration approximately 2.0 mol dm^{-3}
- Dilute sodium hydroxide; concentration approximately 1.0 mol dm^{-3}
- Dilute aqueous ammonia; concentration approximately 2.0 mol dm^{-3}

- Aqueous silver nitrate; concentration approximately 0.05 mol dm^{-3}
- Aqueous barium chloride; concentration approximately 0.20 mol dm^{-3}
- Distilled or deionised water
- Universal indicator solution

Other reagents

- Bromine water
- Sodium chlorate(I)
- Iodine
- Sodium carbonate
- Sodium hydrogencarbonate
- Limewater
- Hydrogen peroxide
- Potassium dichromate(VI)
- Potassium manganate(VII)
- 2,4-dinitrophenylhydrazine
- Phosphorus(V) chloride
- Sodium
- Zinc
- Iron filings
- Starch

Volumetric reagents

- Potassium manganate(VII)
- Sodium thiosulfate
- Iron(II) sulfate
- Iron(II) ammonium sulfate
- Ethanedioic acid
- Succinic acid
- Sulfamic acid
- Potassium iodate

Inorganic compounds

- Sodium and potassium chloride, bromide, iodide, carbonate, sulfate
- Magnesium and calcium carbonate
- Magnesium sulfate
- Ammonium chloride, ammonium sulfate
- Sodium nitrate, potassium nitrate
- Chromium(III), manganese(II), iron(II), nickel(II), copper(II) and zinc(II) sulfates
- Iron(III) chloride

Organic compounds

- Alkanes: hexane
- Alkenes: cyclohexene
- Alcohols: ethanol, propan-1-ol, propan-2-ol, 2-methylpropan-2-ol, butan-1-ol
- Carboxylic acids: ethanoic, propanoic, stearic, palmitic acid
- Carbonyl compounds: propanal, propanone, butanone
- Halogenoalkanes: 2-bromobutane, 1-iodobutane
- Esters: ethyl ethanoate, methyl propanoate, phenyl benzoate

Chemicals should be in stoppered containers labelled with the name, but not necessarily the concentration of the chemical. The appropriate hazard warning should be attached to the chemical container.

Laboratory equipment

- A supply of clean test tubes and boiling tubes in a test-tube rack
- Stoppers for test tubes and boiling tubes
- Test-tube and boiling-tube holders
- Watch glass
- Small evaporating basin
- 10 cm^3 and 25 cm^3 or 50 cm^3 measuring cylinders
- 100 cm^3 and 250 cm^3 beakers
- Tongs
- Spatula
- Mortar and pestle
- Glass stirring rod

- Dropping pipettes
- Bunsen burner
- Heat-proof mat
- Tripod and gauze
- Wooden splints

Volumetric apparatus

- 50.0 cm^3 burette with stand, white tile and small funnel for filling burette
- 25.0 cm^3 pipette with safety filler
- 250 cm^3 volumetric flask with stopper
- 250 cm^3 conical flasks
- Wash bottle

Other equipment

- Plastic cup for enthalpy experiments
- Beaker to hold plastic cup for enthalpy experiments
- 0–50 °C and 0–100 °C, or similar range, thermometers
- Timer
- pH meter and electrodes
- Capillary tubes
- Ignition tube
- Stand and clamp
- Laboratory overall
- Safety goggles
- Plastic gloves
- Access to balance weighing to at least 0.01 g

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