



Pearson
Edexcel

A Level Chemistry



Specification

Pearson Edexcel Level 3 Advanced GCE in Chemistry (9CH0)

First teaching from September 2015

First certification from 2017

Issue 2



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This specification is Issue 2. Key changes are sidelined. We will inform centres of any changes to this issue. The latest issue can be found on the Edexcel website: www.edexcel.com

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From Pearson's Expert Panel for World Class Qualifications

May 2014

"The reform of the qualifications system in England is a profoundly important change to the education system. Teachers need to know that the new qualifications will assist them in helping their learners make progress in their lives.

When these changes were first proposed we were approached by Pearson to join an 'Expert Panel' that would advise them on the development of the new qualifications.

We were chosen, either because of our expertise in the UK education system, or because of our experience in reforming qualifications in other systems around the world as diverse as Singapore, Hong Kong, Australia and a number of countries across Europe.

We have guided Pearson through what we judge to be a rigorous qualification development process that has included:

- Extensive international comparability of subject content against the highest-performing jurisdictions in the world
- Benchmarking assessments against UK and overseas providers to ensure that they are at the right level of demand
- Establishing External Subject Advisory Groups, drawing on independent subject-specific expertise to challenge and validate our qualifications
- Subjecting the final qualifications to scrutiny against the DfE content and Ofqual accreditation criteria in advance of submission.

Importantly, we have worked to ensure that the content and learning is future oriented. The design has been guided by what is called an 'Efficacy Framework', meaning learner outcomes have been at the heart of this development throughout.

We understand that ultimately it is excellent teaching that is the key factor to a learner's success in education. As a result of our work as a panel we are confident that we have supported the development of qualifications that are outstanding for their coherence, thoroughness and attention to detail and can be regarded as representing world-class best practice."

Sir Michael Barber (Chair)

Chief Education Advisor, Pearson plc

Professor Lee Sing Kong

Director, National Institute of Education, Singapore

Bahram Bekhradnia

President, Higher Education Policy Institute

Professor Jonathan Osborne

Stanford University

Dame Sally Coates

Principal, Burlington Danes Academy

Professor Dr Ursula Renold

Federal Institute of Technology, Switzerland

Professor Robin Coningham

Pro-Vice Chancellor, University of Durham

Professor Bob Schwartz

Harvard Graduate School of Education

Dr Peter Hill

Former Chief Executive ACARA

All titles correct as at May 2014

Introduction

The Pearson Edexcel Level 3 Advanced GCE in Chemistry is designed for use in schools and colleges. It is part of a suite of GCE qualifications offered by Pearson.

Purpose of the specification

This specification sets out:

- the objectives of the qualification
- any other qualifications that a student must have completed before taking the qualification
- any prior knowledge and skills that the student is required to have before taking the qualification
- any other requirements that a student must have satisfied before they will be assessed or before the qualification will be awarded
- the knowledge and understanding that will be assessed as part of the qualification
- the method of assessment and any associated requirements relating to it
- the criteria against which a student's level of attainment will be measured (such as assessment criteria).

Rationale

The Pearson Edexcel Level 3 Advanced GCE in Chemistry meets the following purposes, which fulfil those defined by the Office of Qualifications and Examinations Regulation (Ofqual) for GCE qualifications in their *GCE Qualification Level Conditions and Requirements* document, published in April 2014.

The purposes of this qualification are to:

- define and assess achievement of the knowledge, skills and understanding that will be needed by students planning to progress to undergraduate study at UK higher education institutions, particularly (although not only) in the same subject area
- set out a robust and internationally comparable post-16 academic course of study to develop that knowledge, skills and understanding
- enable higher education institutions to identify accurately the level of attainment of students
- provide a basis for school and college accountability measures at age 18
- provide a benchmark of academic ability for employers.

Qualification aims and objectives

The aims and objectives of the Pearson Edexcel Level 3 Advanced GCE in Chemistry are to enable students to develop:

- essential knowledge and understanding of different areas of the subject and how they relate to each other
- a deep appreciation of the skills, knowledge and understanding of scientific methods
- competence and confidence in a variety of practical, mathematical and problem-solving skills
- their interest in and enthusiasm for the subject, including developing an interest in further study and careers associated with the subject
- an understanding of how society makes decisions about scientific issues and how the sciences contribute to the success of the economy and society.

The context for the development of this qualification

All our qualifications are designed to meet our World Class Qualification Principles^[1] and our ambition to put the student at the heart of everything we do.

We have developed and designed this qualification by:

- reviewing other curricula and qualifications to ensure that it is comparable with those taken in high-performing jurisdictions overseas
- consulting with key stakeholders on content and assessment, including subject associations, higher education academics, teachers and employers to ensure this qualification is suitable for a UK context
- reviewing the legacy qualification and building on its positive attributes.

This qualification has also been developed to meet criteria stipulated by Ofqual in their document *GCE Qualification Level Conditions and Requirements* and by the Department for Education (DfE) in their *GCE AS and A level regulatory requirements for biology, chemistry, physics and psychology* document, published in April 2014.

[1] Pearson's World Class Qualification principles ensure that our qualifications are:

- **demanding**, through internationally benchmarked standards, encouraging deep learning and measuring higher-order skills
- **rigorous**, through setting and maintaining standards over time, developing reliable and valid assessment tasks and processes, and generating confidence in end users of the knowledge, skills and competencies of certified students
- **inclusive**, through conceptualising learning as continuous, recognising that students develop at different rates and have different learning needs, and focusing on progression
- **empowering**, through promoting the development of transferable skills, see *Appendix 1*.

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Qualification at a glance

The Pearson Edexcel Level 3 Advanced GCE in Chemistry consists of three externally examined papers and the Science Practical Endorsement.

Students are expected to carry out the sixteen core practical experiments that are identified in the topics.

Students must complete all assessment in May/June in any single year.

Paper 1: Advanced Inorganic and Physical Chemistry

*Paper code: 9CH0/01

- Externally assessed
- Availability: May/June
- First assessment: 2017

**30% of the
total
qualification**

Overview of content

This paper will examine the following topics.

- Topic 1: Atomic Structure and the Periodic Table
- Topic 2: Bonding and Structure
- Topic 3: Redox I
- Topic 4: Inorganic Chemistry and the Periodic Table
- Topic 5: Formulae, Equations and Amounts of Substance
- Topic 8: Energetics I
- Topic 10: Equilibrium I
- Topic 11: Equilibrium II
- Topic 12: Acid-base Equilibria
- Topic 13: Energetics II
- Topic 14: Redox II
- Topic 15: Transition Metals

Overview of assessment

- Assessment is 1 hour 45 minutes.
- The paper consists of 90 marks.
- The paper may include multiple-choice, short open, open-response, calculations and extended writing questions.
- The paper will include questions that target mathematics at Level 2 or above (see *Appendix 6: Mathematical skills and exemplifications*). Overall, a minimum of 20% of the marks across the three papers will be awarded for mathematics at Level 2 or above.

*See *Appendix 3: Codes* for a description of this code and all other codes relevant to this qualification.

Paper 2: Advanced Organic and Physical Chemistry

*Paper code: 9CH0/02

- Externally assessed
- Availability: May/June
- First assessment: 2017

**30% of the
total
qualification**

Overview of content

This paper will examine the following topics.

- Topic 2: Bonding and Structure
- Topic 3: Redox I
- Topic 5: Formulae, Equations and Amounts of Substance
- Topic 6: Organic Chemistry I
- Topic 7: Modern Analytical Techniques I
- Topic 9: Kinetics I
- Topic 16: Kinetics II
- Topic 17: Organic Chemistry II
- Topic 18: Organic Chemistry III
- Topic 19: Modern Analytical Techniques II

Overview of assessment

- Assessment is 1 hour 45 minutes.
- The paper consists of 90 marks.
- The paper may include multiple-choice, short open, open-response, calculations and extended writing questions.
- The paper will include questions that target mathematics at Level 2 or above (see *Appendix 6: Mathematical skills and exemplifications*). Overall, a minimum of 20% of the marks across the three papers will be awarded for mathematics at Level 2 or above.

*See *Appendix 3: Codes* for a description of this code and all other codes relevant to this qualification.

Paper 3: General and Practical Principles in Chemistry

*Paper code: 9CH0/03

- Externally assessed
- Availability: May/June
- First assessment: 2017

**40% of the
total
qualification**

Overview of content

- Questions in this paper may draw on any of the topics in this specification.
- The paper will include synoptic questions that may draw on two or more different topics listed.
- The paper will include questions that assess conceptual and theoretical understanding of experimental methods (indirect practical skills) that will draw on students' experiences of the core practicals.

Overview of assessment

- Assessment is 2 hours 30 minutes.
- The paper consists of 120 marks.
- The paper may include short open, open-response, calculations and extended writing questions.
- The paper will include questions that target mathematics at Level 2 or above (see *Appendix 6: Mathematical skills and exemplifications*). Overall, a minimum of 20% of the marks across the three papers will be awarded for mathematics at Level 2 or above.
- Some questions will assess conceptual and theoretical understanding of experimental methods (see *Appendix 5: Working scientifically*).

*See *Appendix 3: Codes* for a description of this code and all other codes relevant to this qualification.

Science Practical Endorsement**

*Paper code: 9CH0/04

- Internally assessed and externally monitored by Pearson.
- Availability: May/June
- First assessment: 2017

Overview of content

The assessment of practical skills is a compulsory requirement of the course of study for A level chemistry. It will appear on all students' certificates as a separately reported result, alongside the overall grade for the qualification.

Students must carry out a minimum of 12 practical activities which, together, meet the requirements of *Appendices 5b (Practical skills identified for direct assessment and developed through teaching and learning)* and *5c (Use of apparatus and techniques)* from the prescribed subject content.

The practical activities prescribed in this specification (the "core practicals") provide opportunities for demonstrating competence in all the skills identified, together with the use of apparatus and techniques for each subject. However, students can also demonstrate these competencies in any additional practical activity undertaken throughout the course of study which covers the requirements of *Appendix 5c*.

Overview of assessment

Students' practical work will be assessed by teachers, using common practical assessment criteria (CPAC) that are consistent across exam boards. These criteria can be found on pages 48–49.

Students who demonstrate the required standard across all the requirements of the CPAC will receive a 'pass' grade.

Students may work in groups but teachers who award a pass to their students need to be confident of individual students' competence.

The correct application of CPAC to students' work will be monitored through a system of visits to centres. These visits will be coordinated across the exam boards by JCQ, to ensure that all centres are visited regularly, although not necessarily in each science subject.

*See *Appendix 3: Codes* for a description of this code and all other codes relevant to this qualification.

**Students will be assessed separately for the Science Practical Endorsement. The Endorsement will not contribute to the overall grade for this qualification, but the result will be recorded on the student's certificate.

Knowledge, skills and understanding

Content overview

Students will be expected to demonstrate and apply the knowledge, understanding and skills described in the content. They will also be expected to analyse, interpret and evaluate a range of scientific information, ideas and evidence using their knowledge, understanding and skills.

To demonstrate their knowledge, students should be able to undertake a range of activities, including the ability to recall, describe and define, as appropriate. To demonstrate their understanding, students should be able to explain ideas and to use their knowledge to apply, analyse, interpret and evaluate, as appropriate.

Core practicals will be assessed through examination.

There are opportunities for students to develop mathematical skills throughout the content. They are required to apply the skills to relevant chemistry contexts. Please see *Appendix 6: Mathematical skills and exemplifications* for further information.

Practical skills

Practical work is central to any study of chemistry. For this reason, the specification includes 16 core practical activities which form a thread linking theoretical knowledge and understanding to practical scenarios. In following this thread, students will build on practical skills learned at GCSE, becoming confident practical chemists, handling apparatus competently and safely. Using a variety of apparatus and techniques, they should be able to design and carry out both the core practical activities and their own investigations, collecting data which can be analysed and used to draw valid conclusions.

One important aspect of practical work is the ability to evaluate and manage potential risks. The variety of different practical techniques and scenarios in the core practical activities give students scope to consider risk management in different contexts.

Students should also consider the ethical issues presented by their work in the laboratory, which might include consideration for using minimum quantities of resources, such as through microscale procedures; the safe disposal of waste materials, especially from organic reactions; and appropriate consideration for other people involved in their own work or who is working nearby.

Also central to the development of practical skills is the ability to communicate information and ideas through the use of appropriate terminology and ICT. Being able to communicate clearly the findings of practical work is arguably as important as the collection of accurate data.

In carrying out practical activities, students will be expected to use their knowledge and understanding to pose scientific questions which can be investigated through experimental activities. Such activities will enable students to collect data, analyse it for correlations and causal relationships, and to develop solutions to the questions posed.

Questions within written examination papers will aim to assess the knowledge and understanding that students gain while carrying out practical activities, within the context of the 16 core practical activities, as well as in novel practical scenarios. The written papers will test the skills of students in planning practical work – both in familiar and unfamiliar applications – including risk management and the selection of apparatus, with reasons. As part of data handling, students will be expected to use significant figures appropriately, to process data and to plot graphs. In analysing outcomes and drawing valid conclusions, students should critically consider methods and data, including assessing measurement uncertainties and errors.

Examination papers will also provide the opportunity for students to evaluate the wider role of the scientific community in validating new knowledge and the ways in which society as a whole uses science to inform decision making. Within this, they could be asked to consider the implications and applications of chemistry in terms of associated benefits and risks. Students may also be asked to evaluate methodology, evidence and data and resolve conflicting evidence.

Success in questions that indirectly assess practical skills within written papers will come more naturally to those candidates who have a solid foundation of laboratory practice and who, having carried them out, have a thorough understanding of practical techniques. Therefore, where possible, teachers should consider adding additional experiments to the core practical activities. The 16 core practicals will provide the basis from which some of the Paper 3 examination questions will be drawn.

Teachers should note that the completion of the 16 core practical activities can also provide evidence of competence for the Science Practical Endorsement (please see page 45) and that evidence must be provided for the 12 practical techniques listed in *Appendix 5c* through a minimum of 12 core practical activities.

Topic 1: Atomic Structure and the Periodic Table

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include the use of hand-held spectrosopes to investigate spectra from flame tests.

Mathematical skills that could be developed in this topic include calculating a relative atomic mass from isotopic composition data, using simple probability to calculate the peak heights for the mass spectrum of chlorine molecules, using logarithms to compare successive ionisation energies for an element.

Within this topic, students can consider how models for the atom have developed over time, as new evidence has become available. They can also consider how data is used to investigate relationships, such as between the magnitude of ionisation energy and the structure of an atom.

Students should:

1. know the structure of an atom in terms of electrons, protons and neutrons
2. know the relative mass and relative charge of protons, neutrons and electrons
3. know what is meant by the terms 'atomic (proton) number' and 'mass number'
4. be able to determine the number of each type of sub-atomic particle in an atom, molecule or ion from the atomic (proton) number and mass number
5. understand the term 'isotopes'
6. be able to define the terms 'relative isotopic mass' and 'relative atomic mass', based on the ^{12}C scale
7. understand the terms 'relative molecular mass' and 'relative formula mass', including calculating these values from relative atomic masses
Definitions of these terms will not be expected.
The term 'relative formula mass' should be used for compounds with giant structures.
8. be able to analyse and interpret data from mass spectrometry to calculate relative atomic mass from relative abundance of isotopes and vice versa
9. be able to predict the mass spectra, including relative peak heights, for diatomic molecules, including chlorine
10. understand how mass spectrometry can be used to determine the relative molecular mass of a molecule
Limited to the m/z value for the molecular ion, M^+ , giving the relative molecular mass of the molecule.
11. be able to define the terms 'first ionisation energy' and 'successive ionisation energies'
12. understand how ionisation energies are influenced by the number of protons, the electron shielding and the electron sub-shell from which the electron is removed
13. understand reasons for the general increase in first ionisation energy across a period
14. understand reasons for the decrease in first ionisation energy down a group

Students should:

15. understand how ideas about electronic configuration developed from:
 - i the fact that atomic emission spectra provide evidence for the existence of quantum shells
 - ii the fact that successive ionisation energies provide evidence for the existence of quantum shells and the group to which the element belongs
 - iii the fact that the first ionisation energy of successive elements provides evidence for electron sub-shells
16. know the number of electrons that can fill the first four quantum shells
17. know that an orbital is a region within an atom that can hold up to two electrons with opposite spins
18. know the shape of an *s*-orbital and a *p*-orbital
19. know the number of electrons that occupy *s*, *p* and *d*-subshells
20. know that electrons fill subshells singly, before pairing up, and that two electrons in the same orbital must have opposite spins
21. be able to predict the electronic configurations, using 1s notation and electrons-in-boxes notation, of:
 - i atoms, given the atomic number, *Z*, up to *Z* = 36
 - ii ions, given the atomic number, *Z*, and the ionic charge, for *s* and *p* block ions only, up to *Z* = 36
22. know that elements can be classified as *s*, *p* and *d*-block elements
23. understand that electronic configuration determines the chemical properties of an element
24. understand periodicity in terms of a repeating pattern across different periods
25. understand reasons for the trends in the following properties of the elements from periods 2 and 3 of the Periodic Table:
 - i the melting and boiling temperatures of the elements, based on given data, in terms of structure and bonding
 - ii ionisation energy based on given data or recall of the plots of ionisation energy versus atomic number
26. be able to illustrate periodicity using data, including electronic configurations, atomic radii, melting and boiling temperatures and first ionisation energies

Topic 2: Bonding and Structure

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include investigating the migration of ions, for example in a U-tube of copper(II) chromate, seeing the effect of a charged rod on a flow of water.

Mathematical skills that could be developed in this topic include representing shapes of molecules with suitable sketches, plotting data to investigate trends in boiling temperatures of alkanes.

Within this topic, students can consider the strengths and weaknesses of the models used to describe different types of bonding. As part of their study of electron-pair repulsion theory, students can see how chemists can make generalisations and use them to make predictions.

Students should:

Topic 2A: Bonding

1. know that ionic bonding is the strong electrostatic attraction between oppositely charged ions
2. understand the effects that ionic radius and ionic charge have on the strength of ionic bonding
3. understand the formation of ions in terms of electron loss or gain
4. be able to draw electronic configuration diagrams of cations and anions using dot-and-cross diagrams
5. understand reasons for the trends in ionic radii down a group and for a set of isoelectronic ions, e.g. N^{3-} to Al^{3+}
6. understand that the physical properties of ionic compounds and the migration of ions provide evidence for the existence of ions
7. know that a covalent bond is the strong electrostatic attraction between two nuclei and the shared pair of electrons between them
8. be able to draw dot-and-cross diagrams to show electrons in covalent substances, including:
 - i molecules with single, double and triple bonds
 - ii species exhibiting dative covalent (coordinate) bonding, including Al_2Cl_6 and ammonium ion
9. understand the relationship between bond lengths and bond strengths for covalent bonds
10. understand that the shape of a simple molecule or ion is determined by the repulsion between the electron pairs that surround a central atom
11. understand reasons for the shapes of, and bond angles in, simple molecules and ions with up to six outer pairs of electrons (any combination of bonding pairs and lone pairs)
Examples should include $BeCl_2$, BCl_3 , CH_4 , NH_3 , NH_4^+ , H_2O , CO_2 , $PCl_5(g)$ and $SF_6(g)$ and related molecules and ions; as well as simple organic molecules in this specification.

Students should:	
12.	be able to predict the shapes of, and bond angles in, simple molecules and ions analogous to those specified above using electron-pair repulsion theory
13.	know that electronegativity is the ability of an atom to attract the bonding electrons in a covalent bond
14.	know that ionic and covalent bonding are the extremes of a continuum of bonding type and that electronegativity differences lead to bond polarity in bonds and molecules
15.	understand that molecules with polar bonds may not be polar molecules and be able to predict whether or not a given molecule is likely to be polar
16.	understand the nature of intermolecular forces resulting from the following interactions: - i London forces (instantaneous dipole – induced dipole) - ii permanent dipoles - iii hydrogen bonds
17.	understand the interactions in molecules, such as H ₂ O, liquid NH ₃ and liquid HF, which give rise to hydrogen bonding
18.	understand the following anomalous properties of water resulting from hydrogen bonding: - i its relatively high melting temperature and boiling temperature - ii the density of ice compared to that of water
19.	be able to predict the presence of hydrogen bonding in molecules analogous to those mentioned above
20.	understand, in terms of intermolecular forces, physical properties shown by materials, including: - i the trends in boiling temperatures of alkanes with increasing chain length - ii the effect of branching in the carbon chain on the boiling 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
21.	understand factors that influence the choice of solvents, including: - i water, to dissolve some ionic compounds, in terms of the hydration of the ions - ii water, to dissolve simple alcohols, in terms of hydrogen bonding - iii water, as a poor solvent for compounds (to include polar molecules such as halogenoalkanes), in terms of inability to form hydrogen bonds - iv non-aqueous solvents, for compounds that have similar intermolecular forces to those in the solvent
22.	know that metallic bonding is the strong electrostatic attraction between metal ions and the delocalised electrons

Students should:

Topic 2B: Structure

23. know that giant lattices are present in:
 - i ionic solids (giant ionic lattices)
 - ii covalently bonded solids, such as diamond, graphite and silicon(IV) oxide (giant covalent lattices)
 - iii solid metals (giant metallic lattices)
24. know that the structure of covalently bonded substances such as iodine, I₂, and ice, H₂O, is simple molecular
25. know the different structures formed by carbon atoms, including graphite, diamond and graphene
26. be able to predict the type of structure and bonding present in a substance from numerical data and/or other information
27. be able to predict the physical properties of a substance, including melting and boiling temperature, electrical conductivity and solubility in water, in terms of:
 - i the types of particle present (atoms, molecules, ions, electrons)
 - ii the structure of the substance
 - iii the type of bonding and the presence of intermolecular forces, where relevant

Topic 3: Redox I

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include simple test tube reactions to investigate redox systems.

Mathematical skills that could be developed in this topic include using an algebraic method to work out the oxidation number of an element within a complex species, balancing equations for redox reactions by combining ionic half-equations.

Within this topic, students can consider how the concept of oxidation number provides a more considered route for the process of balancing chemical equations.

Students should:

1. know what is meant by the term 'oxidation number'
2. be able to calculate the oxidation number of elements in compounds and ions
The use of oxidation numbers in peroxides and metal hydrides is expected.
3. understand oxidation and reduction in terms of electron transfer and changes in oxidation number, applied to reactions of *s*- and *p*-block elements
4. understand oxidation and reduction in terms of electron loss or electron gain
5. know that oxidising agents gain electrons
6. know that reducing agents lose electrons
7. understand that a disproportionation reaction involves an element in a single species being simultaneously oxidised and reduced
8. know that oxidation number is a useful concept in terms of the classification of reactions as redox and as disproportionation
9. be able to indicate the oxidation number of an element in a compound or ion, using a Roman numeral
10. be able to write formulae given oxidation numbers
11. understand that metals, in general, form positive ions by loss of electrons with an increase in oxidation number
12. understand that non-metals, in general, form negative ions by gain of electrons with a decrease in oxidation number
13. be able to write ionic half-equations and use them to construct full ionic equations

Topic 4: Inorganic Chemistry and the Periodic Table

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include reacting Group 2 elements with water, heating nitrates and carbonates of Group 1 and 2 elements, investigating flame colours of s-block elements, preparing iodine from seaweed, investigating displacement reactions in the halogens, reacting Group 1 halides with concentrated sulfuric acid.

Mathematical skills that could be developed in this topic include manipulating data on the solubility of hydroxides.

Within this topic, students can consider how data can be used to make predictions based on patterns and relationships, for example by predicting properties of Group 7 elements.

Students should:

Topic 4A: The elements of Groups 1 and 2

1. understand reasons for the trend in ionisation energy down Group 2
2. understand reasons for the trend in reactivity of the Group 2 elements down the group
3. know the reactions of the elements Mg to Ba in Group 2 with oxygen, chlorine and water
4. know the reactions of the oxides of Group 2 elements with water and dilute acid, and their hydroxides with dilute acid
5. know the trends in solubility of the hydroxides and sulfates of Group 2 elements
6. understand reasons for the trends in thermal stability of the nitrates and the carbonates of the elements in Groups 1 and 2 in terms of the size and charge of the cations involved
7. understand the formation of characteristic flame colours by Group 1 and 2 compounds in terms of electron transitions
Students will be expected to know the flame colours for Groups 1 and 2 compounds.
8. understand experimental procedures to show:
 - i patterns in thermal decomposition of Group 1 and 2 nitrates and carbonates
 - ii flame colours in compounds of Group 1 and 2 elements

Students should:

Topic 4B: The elements of Group 7 (halogens)

9. understand reasons for the trends in melting and boiling temperatures, physical state at room temperature, and electronegativity for Group 7 elements
10. understand reasons for the trend in reactivity of Group 7 elements down the group
11. understand the trend in reactivity of Group 7 elements in terms of the redox reactions of Cl_2 , Br_2 and I_2 with halide ions in aqueous solution, followed by the addition of an organic solvent
12. understand, in terms of changes in oxidation number, the following reactions of the halogens:
 - i oxidation reactions with Group 1 and 2 metals
 - ii the disproportionation reaction of chlorine with water and the use of chlorine in water treatment
 - iii the disproportionation reaction of chlorine with cold, dilute aqueous sodium hydroxide to form bleach
 - iv the disproportionation reaction of chlorine with hot alkali
 - v reactions analogous to those specified above
13. understand the following reactions:
 - i solid Group 1 halides with concentrated sulfuric acid, to illustrate the trend in reducing ability of the hydrogen halides
 - ii precipitation reactions of the aqueous anions Cl^- , Br^- and I^- with aqueous silver nitrate solution, followed by aqueous ammonia solution
 - iii hydrogen halides with ammonia and with water (to produce acids)
14. be able to make predictions about fluorine and astatine and their compounds, in terms of knowledge of trends in halogen chemistry

Topic 4C: Analysis of inorganic compounds

15. know reactions, including ionic equations where appropriate, for identifying:
 - i carbonate ions, CO_3^{2-} , and hydrogencarbonate ions, HCO_3^- , using an aqueous acid to form carbon dioxide
 - ii sulfate ions, SO_4^{2-} , using acidified barium chloride solution
 - iii ammonium ions, NH_4^+ , using sodium hydroxide solution and warming to form ammonia

Tests for halide ions and for the ions of Group 1 and 2 metals are also required, but are covered elsewhere in this Topic.

Topic 5: Formulae, Equations and Amounts of Substance

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include determining a simple empirical formula such as MgO or CuO, determining the number of moles of water of crystallisation in a salt such as Epsom salts, performing a wide range of titrations involving different indicators, preparing salts.

Mathematical skills that could be developed in this topic include converting between units such as cm^3 and dm^3 , using standard form with the Avogadro constant, rearranging formulae for calculating moles in solids and in solutions, calculating atom economy, dealing with percentage errors.

Within this topic, students first encounter core practicals and can consider ideas of measurement uncertainty, evaluating their results in terms of systematic and random errors. They can also consider how the concept of atom economy is useful to help chemists make decisions so that reactions can be made more efficient in terms of resources.

Students should:

1. know that the mole (mol) is the unit for amount of a substance
2. be able to use the Avogadro constant, L , ($6.02 \times 10^{23} \text{ mol}^{-1}$) in calculations
3. know that the molar mass of a substance is the mass per mole of the substance in g mol^{-1}
4. know what is meant by the terms 'empirical formula' and 'molecular formula'
5. be able to use experimental data to calculate
 - i. empirical formulae
 - ii. molecular formulae including the use of $pV = nRT$ for gases and volatile liquids

Calculations of empirical formula may involve composition by mass or percentage composition by mass data.
6. be able to write balanced full and ionic equations, including state symbols, for chemical reactions
7. be able to calculate amounts of substances (in mol) in reactions involving mass, volume of gas, volume of solution and concentration
These calculations may involve reactants and/or products.
8. be able to calculate reacting masses from chemical equations, and vice versa, using the concepts of amount of substance and molar mass
9. be able to calculate reacting volumes of gases from chemical equations, and vice versa, using the concepts of amount of substance
10. be able to calculate reacting volumes of gases from chemical equations, and vice versa, using the concepts of molar volume of gases

CORE PRACTICAL 1: Measure the molar volume of a gas

11. be able to calculate solution concentrations, in mol dm^{-3} and g dm^{-3} , including simple acid-base titrations using a range of acids, alkalis and indicators
The use of both phenolphthalein and methyl orange as indicators will be expected.

Students should:

CORE PRACTICAL 2: Prepare a standard solution from a solid acid and use it to find the concentration of a solution of sodium hydroxide

CORE PRACTICAL 3: Find the concentration of a solution of hydrochloric acid

12. be able to:
 - i calculate measurement uncertainties and measurement errors in experimental results
 - ii comment on sources of error in experimental procedures
13. understand how to minimise the percentage error and percentage uncertainty in experiments involving measurements
14. be able to calculate percentage yields and percentage atom economies using chemical equations and experimental results
$$\text{Atom economy of a reaction} = \frac{\text{molar mass of the desired product}}{\text{sum of the molar masses of all products}} \times 100\%$$
15. be able to relate ionic and full equations, with state symbols, to observations from simple test tube reactions, to include:
 - i displacement reactions
 - ii reactions of acids
 - iii precipitation reactions
16. understand risks and hazards in practical procedures and suggest appropriate precautions where necessary

Topic 6: Organic Chemistry I

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include cracking of artificial crude oil, extracting limonene from orange peel, dehydrating an alcohol to an alkene, preparing a simple halogenoalkane such as 1-bromobutane, simple test tube reactions for different functional groups.

Mathematical skills that could be developed in this topic include calculating the yield of a reaction or an atom economy.

Within this topic, students can consider how the polymer industry provides useful solutions for many modern applications, but poses questions about sustainability of resources and the feasibility of recycling. They will also encounter practical organic chemistry, showing them how chemists work safely with potentially hazardous chemicals by managing risks.

Students should:

Topic 6A: Introduction to organic chemistry

1. know that a hydrocarbon is a compound of hydrogen and carbon only
2. be able to represent organic molecules using empirical formulae, molecular formulae, general formulae, structural formulae, displayed formulae and skeletal formulae
3. know what is meant by the terms 'homologous series' and 'functional group'
4. be able to name compounds relevant to this specification using the rules of International Union of Pure and Applied Chemistry (IUPAC) nomenclature
Students will be expected to know prefixes for compounds up to C₁₀
5. be able to classify reactions as addition, elimination, substitution, oxidation, reduction, hydrolysis or polymerisation
6. understand the term 'structural isomerism' and determine the possible structural, displayed and skeletal formulae of an organic molecule, given its molecular formula
7. understand the term 'stereoisomerism', as illustrated by *E/Z* isomerism (including *cis-trans* isomerism where two of the substituent groups are the same)

Topic 6B: Alkanes

8. know the general formula for alkanes
9. know that alkanes and cycloalkanes are saturated hydrocarbons
10. understand that alkane fuels are obtained from the fractional distillation, cracking and reforming of crude oil
Reforming is described as the processing of straight-chain hydrocarbons into branched-chain alkanes and cyclic hydrocarbons for efficient combustion.
11. know that pollutants, including carbon monoxide, oxides of nitrogen and sulfur, carbon particulates and unburned hydrocarbons, are formed during the combustion of alkane fuels

Students should:

12. understand the problems arising from pollutants from the combustion of fuels, limited to the toxicity of carbon monoxide and the acidity of oxides of nitrogen and sulfur
13. understand how the use of a catalytic converter solves some problems caused by pollutants
14. understand the use of alternative fuels, including biodiesel and alcohols derived from renewable sources such as plants, in terms of a comparison with non-renewable fossil fuels
15. know that a radical:
 - i is a species with an unpaired electron and is represented in mechanisms by a single dot
 - ii is formed by homolytic fission of a covalent bond and results in the formation of radicals
16. understand the reactions of alkanes with:
 - i oxygen in air (combustion)
 - ii halogens, in terms of the mechanism of radical substitution through initiation, propagation and termination steps

The use of curly half-arrows is not expected in this mechanism.
17. understand the limitations of the use of radical substitution reactions in the synthesis of organic molecules, in terms of further substitution reactions and the formation of a mixture of products

Topic 6C: Alkenes

18. know the general formula for alkenes
19. know that alkenes and cycloalkenes are unsaturated hydrocarbons
20. understand the bonding in alkenes in terms of σ - and π - bonds
21. know what is meant by the term 'electrophile'
22. understand the addition reactions of alkenes with:
 - i hydrogen, in the presence of a nickel catalyst, to form an alkane
Knowledge of the application of this reaction to the manufacture of margarine by catalytic hydrogenation of unsaturated vegetable oils is expected.
 - ii halogens to produce dihalogenoalkanes
 - iii hydrogen halides to produce halogenoalkanes
 - iv steam, in the presence of an acid catalyst, to produce alcohols
 - v potassium manganate(VII), in acid conditions, to oxidise the double bond and produce a diol
23. understand that heterolytic bond fission of a covalent bond results in the formation of ions

Students should:

24. understand the mechanism of the electrophilic addition reactions between alkenes and:

- i halogens
- ii hydrogen halides, including addition to unsymmetrical alkenes
- iii other given binary compounds

Use of the curly arrow notation is expected – curly arrows should start from either a bond or from a lone pair of electrons.

Knowledge of the relative stability of primary, secondary and tertiary carbocation intermediates is expected.

25. know the qualitative test for a C=C double bond using bromine or bromine water

26. know that alkenes form polymers through addition polymerisation

Be able to identify the repeat unit of an addition polymer given the monomer, and vice versa.

27. know that waste polymers can be separated into specific types of polymer for:

- i recycling
- ii incineration to release energy
- iii use as a feedstock for cracking

28. understand, in terms of the use of energy and resources over the life cycle of polymer products, that chemists can contribute to the more sustainable use of materials

29. understand how chemists limit the problems caused by polymer disposal by:

- i developing biodegradable polymers
- ii removing toxic waste gases caused by incineration of plastics

Topic 6D: Halogenoalkanes

30. know that halogenoalkanes can be classified as primary, secondary or tertiary

31. understand what is meant by the term 'nucleophile'

32. understand the reactions of halogenoalkanes with:

- i aqueous potassium hydroxide to produce alcohols (where the hydroxide ion acts as a nucleophile)
- ii aqueous silver nitrate in ethanol (where water acts as a nucleophile)
- iii potassium cyanide to produce nitriles (where the cyanide ion acts as a nucleophile)
Students should know this as an example of increasing the length of the carbon chain.
- iv ammonia to produce primary amines (where the ammonia molecule acts as a nucleophile)
- v ethanolic potassium hydroxide to produce alkenes (where the hydroxide ion acts as a base)

Students should:

33. understand that experimental observations and data can be used to compare the relative rates of hydrolysis of:
- i primary, secondary and tertiary halogenoalkanes
 - ii chloro-, bromo-, and iodoalkanes
- using aqueous silver nitrate in ethanol

CORE PRACTICAL 4: Investigation of the rates of hydrolysis of some halogenoalkanes

34. know the trend in reactivity of primary, secondary and tertiary halogenoalkanes
35. understand, in terms of bond enthalpy, the trend in reactivity of chloro-, bromo-, and iodoalkanes
36. understand the mechanisms of the nucleophilic substitution reactions between primary halogenoalkanes and:
- i aqueous potassium hydroxide
 - ii ammonia

Topic 6E: Alcohols

37. know that alcohols can be classified as primary, secondary or tertiary
38. understand the reactions of alcohols with:
- i oxygen in air (combustion)
 - ii halogenating agents:
 - PCl_5 to produce chloroalkanes
 - 50% concentrated sulfuric acid and potassium bromide to produce bromoalkanes
 - red phosphorus and iodine to produce iodoalkanes
 - iii potassium dichromate(VI) in dilute sulfuric acid to oxidise primary alcohols to aldehydes (including a test for the aldehyde using Benedict's/Fehling's solution) and carboxylic acids, and secondary alcohols to ketones
In equations, the oxidising agent can be represented as [O].
 - iv concentrated phosphoric acid to form alkenes by elimination
Descriptions of the mechanisms of these reactions are not expected.
39. understand the following techniques used in the preparation and purification of a liquid organic compound:
- i heating under reflux
 - ii extraction with a solvent in a separating funnel
 - iii distillation
 - iv drying with an anhydrous salt
 - v boiling temperature determination

CORE PRACTICAL 5: The oxidation of ethanol

CORE PRACTICAL 6: Chlorination of 2-methylpropan-2-ol using concentrated hydrochloric acid

Topic 7: Modern Analytical Techniques I

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Hands-on practical work is limited in this topic, although many universities allow students to visit and learn about instrumentation first hand.

Mathematical skills that could be developed in this topic include analysing fragmentation patterns in mass spectra.

Within this topic, students can consider how different instrumental methods can provide evidence for analysis. They can see how accurate and sensitive methods of analysis can be applied to the study of chemical changes, but also to detect drugs such as in blood or urine testing in sport.

Students should:

Topic 7A: Mass spectrometry

1. be able to use data from a mass spectrometer to:
 - i determine the relative molecular mass of an organic compound from the molecular ion peak
 - ii suggest possible structures of a simple organic compound from the m/z of the molecular ion and fragmentation patterns

Topic 7B: Infrared (IR) spectroscopy

2. be able to use data from infrared spectra to deduce functional groups present in organic compounds and to predict infrared absorptions, given wavenumber data, due to familiar functional groups, including:
 - i C-H stretching absorption in alkanes, alkenes and aldehydes
 - ii C=C stretching absorption in alkenes
 - iii O-H stretching absorption in alcohols
 - iv C=O stretching absorption in aldehydes and ketones
 - v C=O stretching absorption and the broad O-H stretching absorption in carboxylic acids
 - vi N-H stretching absorption in amines

CORE PRACTICAL 7: Analysis of some inorganic and organic unknowns

Topic 8: Energetics I

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include a wide variety of calorimetry experiments involving displacement and neutralisation reactions, investigating the enthalpy of combustion of a homologous series of alcohols.

Mathematical skills that could be developed in this topic include plotting and extrapolating graphs of temperature rise against time for displacement reactions, calculating enthalpy changes in J and in kJ mol^{-1} , using algebra to solve Hess's law problems, calculating enthalpy changes using bond enthalpies.

Within this topic, students can consider how the use of Hess's Law can facilitate the study of energy changes in reactions which are not directly measureable. They can also consider the value of a general chemical concept, such as mean bond enthalpy, and why the use of a simplification such as this has some benefits, as well as some short-comings.

Students should:

1. know that standard conditions are 100 kPa and a specified temperature, usually 298 K
2. know that the enthalpy change is the heat energy change measured at constant pressure
3. be able to construct and interpret enthalpy level diagrams showing an enthalpy change, including appropriate signs for exothermic and endothermic reactions
Activation energy is not shown in enthalpy level diagrams but it is shown in reaction profile diagrams.
4. be able to define standard enthalpy change of:
 - i reaction
 - ii formation
 - iii combustion
 - iv neutralisation
5. understand experiments to measure enthalpy changes in terms of:
 - i processing results using the expression:
 $\text{energy transferred} = \text{mass} \times \text{specific heat capacity} \times \text{temperature change}$
 $(Q = mc\Delta T)$
 - ii evaluating sources of error and assumptions made in the experiments
Students will need to consider experiments where:
 - substances are mixed in an insulated container and the temperature change is measured
 - enthalpy of combustion is measured, such as using a series of alcohols in a spirit burner
 - the enthalpy change cannot be measured directly.
6. be able to calculate enthalpy changes in kJ mol^{-1} from given experimental results
Both a sign and units are expected in the final answer.

Students should:
7. be able to construct enthalpy cycles using Hess's Law
8. be able to calculate enthalpy changes from data using Hess's Law
CORE PRACTICAL 8: To determine the enthalpy change of a reaction using Hess's Law
9. know what is meant by the terms 'bond enthalpy' and 'mean bond enthalpy'
10. be able to calculate an enthalpy change of reaction using mean bond enthalpies and explain the limitations of this method of calculation
11. be able to calculate mean bond enthalpies from enthalpy changes of reaction

Topic 9: Kinetics I

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include investigating a variety of factors that influence the rates of reaction between, for example, marble chips and hydrochloric acid, or sodium thiosulfate and hydrochloric acid, investigating catalysis using hydrogen peroxide.

Mathematical skills that could be developed in this topic include calculating rates from reaction time, plotting graphs and having an appreciation of the nature of the graph for a Maxwell-Boltzmann distribution.

Within this topic, students can consider how 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 changing variables on the rate of a chemical reaction.

Students should:

1. understand, in terms of collision theory, the effect of a change in concentration, temperature, pressure and surface area on the rate of a chemical reaction
2. understand that reactions only take place when collisions take place with sufficient energy, known as activation energy
3. be able to calculate the rate of a reaction from:
 - i data showing the time taken for reaction
 - ii the gradient of a suitable graph, by drawing a tangent, either for initial rate, or at a time, t
4. understand qualitatively, in terms of the Maxwell-Boltzmann distribution of molecular energies, how changes in temperature affect the rate of a reaction
5. understand the role of catalysts in providing alternative reaction routes of lower activation energy
6. be able to draw the reaction profiles for uncatalysed and catalysed reactions
7. be able to interpret the action of a catalyst in terms of a qualitative understanding of the Maxwell-Boltzmann distribution of molecular energies
8. understand the use of a solid (heterogeneous) catalyst for industrial reactions, in the gas phase, in terms of providing a surface for the reaction
9. understand the economic benefits of the use of catalysts in industrial reactions

Topic 10: Equilibrium I

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include investigating equilibrium systems, such as iron(III) – thiocyanate, or the effect of temperature on the equilibrium between $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ and $[\text{CoCl}_4]^{2-}$

Mathematical skills that could be developed in this topic include deriving an algebraic expression for the equilibrium constant.

Within this topic, students can consider how an appreciation of equilibrium processes, coupled with kinetics, can lead chemists to redevelop manufacturing processes to make them more efficient.

Students should:

1. know that many reactions are readily reversible and that they can reach a state of dynamic equilibrium in which:
 - i the rate of the forward reaction is equal to the rate of the backward reaction
 - ii the concentrations of reactants and products remain constant
2. be able to predict and justify the qualitative effect of a change in temperature, concentration or pressure on a homogeneous system in equilibrium
3. evaluate data to explain the necessity, for many industrial processes, to reach a compromise between the yield and the rate of reaction
4. be able to deduce an expression for K_c , for homogeneous and heterogeneous systems, in terms of equilibrium concentrations

Topic 11: Equilibrium II

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include determining the value for an equilibrium constant for a simple esterification reaction.

Mathematical skills that could be developed in this topic include constructing expressions for K_c and K_p and calculating values with relevant units, estimating the change to the value of an equilibrium constant when a variable changes.

Within this topic, students can consider how chemists can use the concept of equilibria to predict quantitatively the direction and extent of chemical change.

Students should:

1. be able to deduce an expression for K_p , for homogeneous and heterogeneous systems, in terms of equilibrium partial pressures in atm
2. be able to calculate a value, with units where appropriate, for the equilibrium constant (K_c and K_p) for homogeneous and heterogeneous reactions, from experimental data
3. know the effect of changing temperature on the equilibrium constant (K_c and K_p), for both exothermic and endothermic reactions
4. understand that the effect of temperature on the position of equilibrium is explained using a change in the value of the equilibrium constant
5. understand that the value of the equilibrium constant is not affected by changes in concentration or pressure or by the addition of a catalyst

Topic 12: Acid-base Equilibria

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include a series of pH titrations to determine titration curves, calculating an ionisation constant for a pH indicator, making up and investigating the properties of buffer solutions and using a pH meter.

Mathematical skills that could be developed in this topic include the use of logarithms and exponentials for converting from concentration to pH and *vice versa*, rearranging K_a expressions into expressions suitable for calculating pH of a buffer solution, plotting and interpreting titration curves.

Within this topic, students can consider how the historical development of theories explaining acid and base behaviour show that scientific ideas change as a result of new evidence and fresh thinking. They can also relate their study of buffer solutions to a range of applications in living cells, medicines, foods and the natural environment.

Students should:

1. know that a Brønsted–Lowry acid is a proton donor and a Brønsted–Lowry base is a proton acceptor
2. know that acid-base reactions involve the transfer of protons
3. be able to identify Brønsted–Lowry conjugate acid-base pairs
4. be able to define the term 'pH'
5. be able to calculate pH from hydrogen ion concentration
6. be able to calculate the concentration of hydrogen ions, in mol dm^{-3} , in a solution from its pH, using the expression $[\text{H}^+] = 10^{-\text{pH}}$
7. understand the difference between a strong acid and a weak acid in terms of degree of dissociation
8. be able to calculate the pH of a strong acid
9. be able to deduce the expression for the acid dissociation constant, K_a , for a weak acid and carry out relevant calculations
10. be able to calculate the pH of a weak acid making relevant assumptions
11. be able to define the ionic product of water, K_w
12. be able to calculate the pH of a strong base from its concentration, using K_w
13. be able to define the terms 'pK_a' and 'pK_w'
14. be able to analyse data 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
15. be able to calculate K_a for a weak acid from experimental data given the pH of a solution containing a known mass of acid

Students should:	
16.	be able to draw and interpret titration curves using all combinations of strong and weak monobasic acids and bases
17.	be able to select a suitable indicator, using a titration curve and appropriate data
18.	know what is meant by the term 'buffer solution'
19.	understand the action of a buffer solution
20.	be able to calculate the pH of a buffer solution given appropriate data
21.	be able to calculate the concentrations of solutions required to prepare a buffer solution of a given pH
22.	understand how to use a weak acid–strong base titration curve to: - i demonstrate buffer action - ii determine K_a from the pH at the point where half the acid is neutralised
23.	understand why there is a difference in enthalpy changes of neutralisation values for strong and weak acids
24.	understand the roles of carbonic acid molecules and hydrogencarbonate ions in controlling the pH of blood
CORE PRACTICAL 9: Finding the K_a value for a weak acid	

Topic 13: Energetics II

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include measuring enthalpy change of solution, investigating enthalpy and entropy changes in reactions such as neutralisations.

Mathematical skills that could be developed in this topic include calculating the missing value from a Born-Haber cycle using algebraic expressions, using natural logarithms when calculating an equilibrium constant from ΔG .

Within this topic, students can consider how chemists evaluate theoretical models by comparing the real and ideal properties of chemicals, for example in the study of theoretical and experimental lattice energies. The study of entropy shows students how chemists use formal, abstract thinking to answer fundamental questions about the stability of chemicals and the direction of chemical change.

Students should:

Topic 13A: Lattice energy

1. be able to define lattice energy as the energy change when one mole of an ionic solid is formed from its gaseous ions
2. be able to define the terms:
 - i enthalpy change of atomisation, $\Delta_{\text{at}}H$
 - ii electron affinity
3. be able to construct Born-Haber cycles and carry out related calculations
4. know that lattice energy provides a measure of ionic bond strength
5. understand that a comparison of the experimental lattice energy value (from a Born-Haber cycle) with the theoretical value (obtained from electrostatic theory) in a particular compound indicates the degree of covalent bonding
6. understand the meaning of polarisation as applied to ions
7. know that the polarising power of a cation depends on its radius and charge
8. know that the polarisability of an anion depends on its radius and charge
9. be able to define the terms 'enthalpy change of solution, $\Delta_{\text{sol}}H'$, and 'enthalpy change of hydration, $\Delta_{\text{hyd}}H'$
10. be able to use energy cycles and energy level diagrams to carry out calculations involving enthalpy change of solution, enthalpy change of hydration and lattice energy
11. understand the effect of ionic charge and ionic radius on the values of:
 - i lattice energy
 - ii enthalpy change of hydration

Students should:

Topic 13B: Entropy

12. understand that, since some endothermic reactions can occur at room temperature, enthalpy changes alone do not control whether reactions occur

13. know that entropy is a measure of the disorder of a system and that the natural direction of change is increasing total entropy (positive entropy change)

14. understand why entropy changes occur during:

- i changes of state
- ii dissolving of a solid ionic lattice
- iii reactions in which there is a change in the number of moles from reactants to products

Students should be able to discuss typical reactions in terms of disorder and enthalpy change, including:

- *dissolving ammonium nitrate crystals in water*
- *reacting ethanoic acid with ammonium carbonate*
- *burning magnesium ribbon in air*
- *mixing solid barium hydroxide, $\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}$, with solid ammonium chloride.*

15. understand that the total entropy change in any reaction is the entropy change in the system added to the entropy change in the surroundings, shown by the expression:

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

16. be able to calculate the entropy change for the system, ΔS_{system} , in a reaction, given the entropies of the reactants and products

17. be able to calculate the entropy change in the surroundings, and hence ΔS_{total} , using the expression:

$$\Delta S_{\text{surroundings}} = -\frac{\Delta H}{T}$$

18. know that the balance between the entropy change and the enthalpy change determines the feasibility of a reaction and is represented by the equation

$$\Delta G = \Delta H - T\Delta S_{\text{system}}$$

19. be able to use the equation $\Delta G = \Delta H - T\Delta S_{\text{system}}$ to:

- i predict whether a reaction is feasible
- ii determine the temperature at which a reaction is feasible

20. be able to use the equation $\Delta G = -RT \ln K$ to show that reactions which are feasible in terms of ΔG have large values for the equilibrium constant and vice versa

21. understand why a reaction for which the ΔG value is negative may not occur in practice

22. know that reactions that are thermodynamically feasible may be inhibited by kinetic factors

Topic 14: Redox II

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include investigating redox systems (especially within transition metals), setting up a variety of electrochemical cells, investigating disproportionation in copper(I) salts, performing redox titrations using potassium manganate(VII) or iodine-thiosulfate. Mathematical skills that could be developed in this topic include calculating redox potentials, balancing redox equations from half cells, calculations involving redox titrations.

Within this topic, students can consider how ideas developed in different contexts within chemistry can be shown to be related to a major explanatory principle. Here, 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. Students can also consider how chemists continue to search for alternative sources of energy, through the development of fuel cells.

Students should:

1. understand the terms 'oxidation' and 'reduction' in terms of electron transfer, applied to *s*-, *p*- and *d*-block elements
2. understand the terms 'oxidation' and 'reduction' in terms of changes in oxidation number, applied to *s*-, *p*- and *d*-block elements
3. know what is meant by the term 'standard electrode potential', $E^\ominus$
4. know that the standard electrode potential, $E^\ominus$, refers to conditions of:
 - i 298 K temperature
 - ii 100 kPa pressure of gases
 - iii 1.00 mol dm⁻³ concentration of ions
5. know the features of the standard hydrogen electrode and understand why a reference electrode is necessary
6. understand that different methods are used to measure standard electrode potentials of:
 - i metals or non-metals in contact with their ions in aqueous solution
 - ii ions of the same element with different oxidation numbers

CORE PRACTICAL 10: Investigating some electrochemical cells

7. be able to calculate a standard emf, $E^\ominus_{\text{cell}}$, by combining two standard electrode potentials
8. be able to write cell diagrams using the conventional representation of half-cells
9. understand the importance of the conditions when measuring the electrode potential, E
10. be able to predict the thermodynamic feasibility of a reaction using standard electrode potentials

Students should:	
11.	understand that $E^{\ominus}_{\text{cell}}$ is directly proportional to the total entropy change and to $\ln K$ for a reaction
12.	understand the limitations of predictions made using standard electrode potentials, in terms of kinetic inhibition and departure from standard conditions
13.	know that standard electrode potentials can be listed as an electrochemical series
14.	understand how disproportionation reactions relate to standard electrode potentials
15.	understand the application of electrode potentials to storage cells
16.	understand that the energy released on the reaction of a fuel with oxygen is utilised in a fuel cell to generate a voltage <i>Knowledge that methanol and other hydrogen-rich fuels are used in fuel cells is expected.</i>
17.	know the electrode reactions that occur in a hydrogen-oxygen fuel cell <i>Knowledge of hydrogen-oxygen fuel cells with both acidic and alkaline electrolytes is expected.</i>
18.	be able to carry out both structured and non-structured titration calculations including $\text{Fe}^{2+}/\text{MnO}_4^-$, and $\text{I}_2/\text{S}_2\text{O}_3^{2-}$
19.	understand the methods used in redox titrations
CORE PRACTICAL 11: Redox titration	

Topic 15: Transition Metals

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include the stepwise reduction of vanadium(V) to vanadium(II), investigating the reactions of copper(II) ions or chromium(III) ions, using sodium hydroxide and ammonia solution to identify transition metal ions, investigating autocatalysis, preparing a complex transition metal salt.

Mathematical skills that could be developed in this topic include investigating the geometry of different transition metal complexes.

Within this topic, students can consider the model for the filling of electron orbitals encountered in Topic 1, and see how limitations in that model indicate the need for more sophisticated explanations. They can also appreciate that catalyst research is a frontier area, and one which provides an opportunity to show how the scientific community reports and validates new knowledge.

Students should:

Topic 15A: Principles of transition metal chemistry

1. be able to deduce the electronic configurations of atoms and ions of the *d*-block elements of period 4 (Sc–Zn), given the atomic number and charge (if any)
2. know that transition metals are *d*-block elements that form one or more stable ions with incompletely-filled *d*-orbitals
3. understand why transition metals show variable oxidation number
4. know what is meant by the term 'ligand'
5. understand that dative (coordinate) bonding is involved in the formation of complex ions
6. know that a complex ion is a central metal ion surrounded by ligands
7. know that transition metals form coloured ions in solution
8. understand that the colour of aqueous ions, and other complex ions, results from the splitting of the energy levels of the *d*-orbitals by ligands
9. understand why there is a lack of colour in some aqueous ions and other complex ions
10. understand that colour changes in transition metal ions may arise as a result of changes in:
 - i oxidation number
 - ii ligand
 - iii coordination number
11. understand the meaning of the term 'coordination number'
12. understand why H_2O , OH^- and NH_3 act as monodentate ligands
13. understand why complexes with six-fold coordination have an octahedral shape, such as those formed by metal ions with H_2O , OH^- and NH_3 as ligands

Students should:

14. know that transition metal ions may form tetrahedral complexes with relatively large ligands such as Cl^-
15. know that square planar complexes are also formed by transition metal ions and that *cis*-platin is an example of such a complex
16. understand why *cis*-platin used in cancer treatment is supplied as a single isomer and not in a mixture with the *trans* form
17. be able to identify bidentate ligands, such as $\text{NH}_2\text{CH}_2\text{CH}_2\text{NH}_2$ and multidentate ligands, such as EDTA^{4-}
18. know that haemoglobin is an iron(II) complex containing a multidentate ligand
The structure of the haem group will not be assessed.
19. know that a ligand exchange reaction occurs when an oxygen molecule bound to haemoglobin is replaced by a carbon monoxide molecule

Topic 15B: Reactions of transition metal elements

20. know the colours of the oxidation states of vanadium (+5, +4, +3 and +2) in its compounds
21. understand redox reactions for the interconversion of the oxidation states of vanadium (+5, +4, +3 and +2), in terms of the relevant E° values
22. understand, in terms of the relevant E° values, that the dichromate(VI) ion, $\text{Cr}_2\text{O}_7^{2-}$:
 - i can be reduced to Cr^{3+} and Cr^{2+} ions using zinc in acidic conditions
 - ii can be produced by the oxidation of Cr^{3+} ions using hydrogen peroxide in alkaline conditions (followed by acidification)
23. know that the dichromate(VI) ion, $\text{Cr}_2\text{O}_7^{2-}$, can be converted into chromate(VI) ions as a result of the equilibrium

$$2\text{CrO}_4^{2-} + 2\text{H}^+ \rightleftharpoons \text{Cr}_2\text{O}_7^{2-} + \text{H}_2\text{O}$$
24. be able to record observations and write suitable equations for the reactions of $\text{Cr}^{3+}(\text{aq})$, $\text{Fe}^{2+}(\text{aq})$, $\text{Fe}^{3+}(\text{aq})$, $\text{Co}^{2+}(\text{aq})$ and $\text{Cu}^{2+}(\text{aq})$ with aqueous sodium hydroxide and aqueous ammonia, including in excess
25. be able to write ionic equations to show the difference between ligand exchange and amphoteric behaviour for the reactions in (24) above
26. understand that ligand exchange, and an accompanying colour change, occurs in the formation of:
 - i $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ from $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ via $\text{Cu}(\text{OH})_2(\text{H}_2\text{O})_4$
 - ii $[\text{CuCl}_4]^{2-}$ from $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$
 - iii $[\text{CoCl}_4]^{2-}$ from $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$
27. understand that the substitution of small, uncharged ligands (such as H_2O) by larger, charged ligands (such as Cl^-) can lead to a change in coordination number
28. understand, in terms of the large positive increase in ΔS_{system} , that the substitution of a monodentate ligand by a bidentate or multidentate ligand leads to a more stable complex ion

Students should:	
29. know that transition metals and their compounds can act as heterogeneous and homogeneous catalysts	
30. know that a heterogeneous catalyst is in a different phase from the reactants and that the reaction occurs at the surface of the catalyst	
31. understand, in terms of oxidation number, how V_2O_5 acts as a catalyst in the contact process	
32. understand how a catalytic converter decreases carbon monoxide and nitrogen monoxide emissions from internal combustion engines by:	
i adsorption of CO and NO molecules onto the surface of the catalyst	
ii weakening of bonds and chemical reaction	
iii desorption of CO_2 and N_2 product molecules from the surface of the catalyst	
33. know that a homogeneous catalyst is in the same phase as the reactants and appreciate that the catalysed reaction will proceed via an intermediate species	
34. understand the role of Fe^{2+} ions in catalysing the reaction between I^- and $S_2O_8^{2-}$ ions	
35. know the role of Mn^{2+} ions in autocatalysing the reaction between MnO_4^- and $C_2O_4^{2-}$ ions	
CORE PRACTICAL 12: The preparation of a transition metal complex	

Topic 16: Kinetics II

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include investigating different methods for tracking rates of reaction by gas collection or change in mass or colour change, investigating clock reactions such as Harcourt-Essen, using a simple rates experiment to calculate an activation energy.

Mathematical skills that could be developed in this topic include plotting and justifying the shapes of rate-concentration and concentration-time graphs, calculating half-life of a reaction, calculating activation energy from a suitable graph, rearranging the Arrhenius equation in the form $y = mx + c$.

Within this topic, students can consider different methods used to measure reaction rates and collect valid data. Through the analysis of this data, and a knowledge of rate equations, they can see how chemists are able to propose models to describe the mechanisms of chemical reactions.

Students should:

1. understand the terms:
 - i rate of reaction
 - ii rate equation
 - iii order with respect to a substance in a rate equation
 - iv overall order of reaction
 - v rate constant
 - vi half-life
 - vii rate-determining step
 - viii activation energy
 - ix heterogeneous and homogenous catalyst
2. be able to determine and use rate equations of the form:
 $\text{rate} = k[A]^m[B]^n$, where m and n are 0, 1 or 2
3. be able to select and justify a suitable experimental technique to obtain rate data for a given reaction, including:
 - i titration
 - ii colorimetry
 - iii mass change
 - iv volume of gas evolved
 - v other suitable technique(s) for a given reaction
4. understand experiments that can be used to investigate reaction rates by:
 - i an initial-rate method, carrying out separate experiments where different initial concentrations of one reagent are used
A 'clock reaction' is an acceptable approximation of this method
 - ii a continuous monitoring method to generate data to enable concentration-time or volume-time graphs to be plotted

Students should:

5. be able to calculate the rate of reaction and the half-life of a first-order reaction using data from a concentration-time or a volume-time graph
6. be able to deduce the order (0, 1 or 2) with respect to a substance in a rate equation using data from:
 - i a concentration-time graph
 - ii a rate-concentration graph
7. be able to deduce the order (0, 1 or 2) with respect to a substance in a rate equation using data from an initial-rate method
8. understand how to:
 - i obtain data to calculate the order with respect to the reactants (and the hydrogen ion) in the acid-catalysed iodination of propanone
 - ii use these data to make predictions about species involved in the rate-determining step
 - iii deduce a possible mechanism for the reaction
9. be able to deduce a rate-determining step from a rate equation and vice versa
10. be able to deduce a reaction mechanism, using knowledge from a rate equation and the stoichiometric equation for a reaction
11. understand that knowledge of the rate equations for the hydrolysis of halogenoalkanes can be used to provide evidence for S_N1 or S_N2 mechanisms for tertiary and primary halogenoalkane hydrolysis
12. be able to use graphical methods to find the activation energy for a reaction from experimental data
The Arrhenius equation will be given if needed.

CORE PRACTICAL 13a and 13b: Rates of reaction

Following the rate of the iodine-propanone reaction by a titrimetric method and investigating a 'clock reaction' (Harcourt-Esson, iodine clock)

CORE PRACTICAL 14: Finding the activation energy of a reaction

Topic 17: Organic Chemistry II

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include investigating the reactions of different functional groups, identifying a carbonyl compound by preparing and finding the melting point of its 2,4-DNPH derivative, preparing and hydrolysing esters.

Mathematical skills that could be developed in this topic include representing chiral molecules with appropriate diagrams, calculating percentage yields and experimental errors.

Within this topic, students can consider how organic synthesis can produce a variety of important materials, such as esters for solvents, flavourings and perfumes. They will also continue their study of reaction mechanisms, and see the ways in which different mechanisms act as a pattern to describe a range of organic reactions.

Students should:

Topic 17A: Chirality

1. know that optical isomerism is a result of chirality in molecules with a single chiral centre
2. understand that optical isomerism results from chiral centre(s) in a molecule with asymmetric carbon atom(s) and that optical isomers are object and non-superimposable mirror images
3. know that optical activity is 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
4. understand the nature of a racemic mixture
5. be able to use data on optical activity of reactants and products as evidence for S_N1 and S_N2 mechanisms

Topic 17B: Carbonyl compounds

6. be able to identify the aldehyde and ketone functional groups
7. understand that aldehydes and ketones:
 - i do not form intermolecular hydrogen bonds and this affects their physical properties
 - ii can form hydrogen bonds with water and this affects their solubility

Students should:

8. understand the reactions of carbonyl compounds with:
 - i Fehling's or Benedict's solution, Tollens' reagent and acidified dichromate(VI) ions
In equations, the oxidising agent can be represented as [O]
 - ii lithium tetrahydridoaluminate (lithium aluminium hydride) in dry ether
In equations, the reducing agent can be represented as [H]
 - iii HCN, in the presence of KCN, as a nucleophilic addition reaction, using curly arrows, relevant lone pairs, dipoles and evidence of optical activity to show the mechanism
 - iv 2,4-dinitrophenylhydrazine (2,4-DNPH), as a qualitative test for the presence of a carbonyl group and to identify a carbonyl compound given data for the melting temperatures of derivatives
The equation for this reaction is not required
 - v iodine in the presence of alkali

Topic 17C: Carboxylic acids

9. be able to identify the carboxylic acid functional group
10. understand that hydrogen bonding affects the physical properties of carboxylic acids, in relation to their boiling temperatures and solubility
11. understand that carboxylic acids can be prepared by the oxidation of alcohols or aldehydes, and the hydrolysis of nitriles
12. understand the reactions of carboxylic acids with:
 - i lithium tetrahydridoaluminate (lithium aluminium hydride) in dry ether
 - ii bases to produce salts
 - iii phosphorus(V) chloride (phosphorus pentachloride)
 - iv alcohols in the presence of an acid catalyst
13. be able to identify the acyl chloride and ester functional groups
14. understand the reactions of acyl chlorides with:
 - i water
 - ii alcohols
 - iii concentrated ammonia
 - iv amines
15. understand the hydrolysis reactions of esters, in acidic and alkaline solution
16. understand how polyesters are formed by condensation polymerisation reactions

Topic 18: Organic Chemistry III

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include investigating the reactions of different functional groups, preparing an aromatic ester such as methyl benzoate, making nylon, purifying an organic solid.

Mathematical skills that could be developed in this topic include calculating the resonance stability of benzene from thermodynamic data, calculating percentage yields.

Within this topic, students can consider how the model for benzene structure has developed in response to new evidence. By this stage, their continuing practical experience should enable them to use techniques to carry out reactions and purify products efficiently and safely.

Students should:

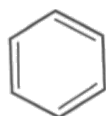
Topic 18A: Arenes - benzene

1. understand that the bonding in benzene has been represented using the Kekulé and the delocalised model, the latter in terms of overlap of p -orbitals to form π -bonds
2. understand that evidence for the delocalised model of the bonding in benzene is provided by data from enthalpy changes of hydrogenation and carbon-carbon bond lengths

Students may represent the structure of benzene as:



or



as appropriate in equations and mechanisms.

3. understand why benzene is resistant to bromination, compared with alkenes, in terms of delocalisation of π -bonds in benzene and the localised electron density of the π -bond in alkenes
4. understand the reactions of benzene with:
 - i oxygen in air (combustion with a smoky flame)
 - ii bromine, in the presence of a catalyst
 - iii a mixture of concentrated nitric and sulfuric acids
 - iv halogenoalkanes and acyl chlorides with aluminium chloride as catalyst (Friedel-Crafts reaction)
5. understand the mechanism of the electrophilic substitution reactions of benzene (halogenation, nitration and Friedel-Crafts reactions), including the generation of the electrophile
6. understand the reaction of phenol with bromine water
7. understand reasons for the relative ease of bromination of phenol, compared to benzene

Students should:

Topic 18B: Amines, amides, amino acids and proteins

8. be able to identify:
 - i the amine and amide functional groups
 - ii molecules that are amino acids
9. understand the reactions of primary aliphatic amines, using butylamine as an example, with:
 - i water to form an alkaline solution
 - ii acids to form salts
 - iii ethanoyl chloride
 - iv halogenoalkanes
 - v copper(II) ions to form complex ions
10. understand reasons for the difference in basicity of ammonia, primary aliphatic and primary aromatic amines given suitable data
11. understand, in terms of reagents and general reaction conditions, the preparation of primary aliphatic amines:
 - i from halogenoalkanes
 - ii by the reduction of nitriles
12. know that aromatic nitro-compounds can be reduced, using tin and concentrated hydrochloric acid, to form amines
13. understand that amides can be prepared from acyl chlorides
14. know that the formation of a polyamide is a condensation polymerisation reaction
15. be able to draw the structural formulae of the repeat units of condensation polymers formed by reactions between:
 - i dicarboxylic acids and diols
 - ii dicarboxylic acids and diamines
 - iii amino acids
16. understand the properties of 2-amino acids, including:
 - i acidity and basicity in solution, as a result of the formation of zwitterions
 - ii effect of aqueous solutions on plane-polarised monochromatic light
17. understand that the peptide bond in proteins:
 - i is formed when amino acids combine, by condensation polymerisation
 - ii can be hydrolysed to form the constituent amino acids, which can be separated by chromatography

CORE PRACTICAL 15: Analysis of some inorganic and organic unknowns

Students should:

Topic 18C: Organic Synthesis

18. be able to deduce the empirical formulae, molecular formulae and structural formulae of compounds from data obtained from combustion analysis, elemental percentage composition, characteristic reactions of functional groups, infrared spectra, mass spectra and nuclear magnetic resonance
19. be able to plan reaction schemes, of up to four steps, to form both familiar and unfamiliar compounds
20. understand methods of increasing the length of the carbon chain in a molecule by the use of magnesium to form Grignard reagents and the reactions of the latter with carbon dioxide and with carbonyl compounds in dry ether
21. be able to select and justify suitable practical procedures for carrying out reactions involving compounds with functional groups included in the specification, including identifying appropriate control measures to reduce risk, based on data about hazards
22. understand the following techniques used in the preparation and purification of organic compounds:
 - i refluxing
 - ii purification by washing
 - iii solvent extraction
 - iv recrystallisation
 - v drying
 - vi distillation, including steam distillation
 - vii melting temperature determination
 - viii boiling temperature determination

CORE PRACTICAL 16: The preparation of aspirin

Topic 19: Modern Analytical Techniques II

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include using chromatography to identify unknowns such as metals in a 'silver' coin or amino acids in a protein.

Mathematical skills that could be developed in this topic include calculating R_f values, interpreting a variety of different spectra, calculating relative molecular masses, using the $(n+1)$ rule for proton NMR.

Within this topic, students can consider a wider range of instrumental methods used for analysis, such as NMR; and see how this technique is used in medicine through MRI scans. They can also see a wide range of applications that rely on a combination of different analytical techniques.

Students should:

Topic 19A: Mass Spectrometry

1. be able to use data from mass spectra to:
 - i suggest possible structures of a simple organic compound given relative molecular masses, accurate to four decimal places
 - ii calculate the accurate relative molecular mass of a compound, given relative atomic masses to four decimal places, and therefore identify a compound

Topic 19B: Nuclear magnetic resonance (NMR)

2. understand that ^{13}C NMR spectroscopy provides information about the positions of ^{13}C atoms in a molecule
3. be able to use data from ^{13}C NMR spectroscopy to:
 - i predict the different environments for carbon atoms present in a molecule, given values of chemical shift, δ
 - ii justify the number of peaks present in a ^{13}C NMR spectrum because of carbon atoms in different environments
4. understand that high resolution proton NMR provides information about the positions of ^1H atoms in a molecule
5. be able to use data from high resolution ^1H NMR spectroscopy to:
 - i predict the different types of proton present in a molecule, given values of chemical shift, δ
 - ii relate relative peak areas, or ratio numbers of protons, to the relative numbers of ^1H atoms in different environments
 - iii deduce the splitting patterns of adjacent, non-equivalent protons using the $(n+1)$ rule and hence suggest the possible structures for a molecule
 - iv predict the chemical shifts and splitting patterns of the ^1H atoms in a given molecule

Students should:	
Topic 19C: Chromatography	
6.	know that chromatography separates components of a mixture between a mobile phase and a stationary phase
7.	be able to calculate R_f values from one-way chromatograms
8.	know that high performance liquid chromatography, HPLC, and gas chromatography, GC: - i are types of column chromatography - ii separate substances because of different retention times in the column - iii may be used in conjunction with mass spectrometry, in applications such as forensics or drugs testing in sport

Science Practical Endorsement

Overview

The assessment of practical skills is a compulsory requirement of the course of study for A level qualifications in biology, chemistry and physics. It will appear on all students' certificates as a separately reported result, alongside the overall grade for the qualification. The arrangements for the assessment of practical skills will be common to all awarding organisations. These arrangements include:

- A minimum of 12 practical activities to be carried out by each student which, together, meet the requirements of *Appendices 5b* (Practical skills identified for direct assessment and developed through teaching and learning) and *5c* (Use of apparatus and techniques) from the prescribed subject content, published by the Department for Education. The required practical activities will be defined by each awarding organisation.
- Teachers will assess students against Common Practical Assessment Criteria (CPAC) issued by the awarding organisations. The CPAC are based on the requirements of *Appendices 5b* and *5c* of the subject content requirements published by the Department for Education, and define the minimum standard required for the achievement of a pass.
- Each student will keep an appropriate record of their practical work, including their assessed practical activities
- Students who demonstrate the required standard across all the requirements of the CPAC will receive a 'pass' grade
- There will be no separate assessment of practical skills for AS qualifications.
- Students will answer questions in the AS and A level examination papers that assess the requirements of *Appendix 5a* (Practical skills identified for indirect assessment and developed through teaching and learning) from the prescribed subject content, published by the Department for Education. These questions may draw on, or range beyond, the practical activities included in the specification.

Setting practical work

Teaching and learning

Teachers should ensure that the core practicals listed in the subject content are incorporated into teaching and learning and that students carry them out. This is to support development of competency for the practical endorsement and also because students will be indirectly assessed on their practical skills in the examinations. Teachers should consider setting additional practical work to support teaching and learning.

Teachers must devise and retain a teaching plan that shows when practicals will be covered in teaching and learning.

Students should attempt all 16 practicals given in the qualification content.

Conditions for assessing practical work

Authenticity

Students and teachers must sign the practical competency authentication sheet (see *Appendix 4*).

Collaboration

Students may work in pairs on some practicals where appropriate, provided they are able to produce individual evidence to meet the competency statements.

Feedback

Teachers may help students to understand instructions and may provide feedback to support development of the competencies. Teachers should be confident that students have developed their skills and thus students should be able to demonstrate the competencies independently by the end of the course.

Resources

Students must have access to the equipment needed to carry out the core practicals. Students must also have access to IT and internet facilities.

Supervision

Teachers must ensure that students are supervised appropriately.

Evidence of practical work

Evidence should be collected of practical work that is sufficient to show that the competencies have been achieved. Evidence may take a variety of forms.

The practical activities prescribed in the specification provide opportunities for demonstrating competence in all the skills identified, together with the use of apparatus and techniques for each subject. However, students can also demonstrate these competencies in any additional practical activity undertaken throughout the course of study which covers the requirements of *Appendix 5c*.

Observations and notes by teachers

Teachers should observe sufficient student practicals to ensure that competencies have been achieved.

Student records

Students should keep notes of their practical work sufficient to show evidence of the practical competencies on making and recording observations and researching, referencing and reporting.

Assessing practical work

Teachers should make a judgement of student practical competence using the Common Practical Assessment Criteria on the following pages. Teachers should include any comments on the practical competency authentication sheet (see *Appendix 4*) to justify the decision made.

In order to achieve a pass, students will need to:

- develop these competencies by carrying out a minimum of 12 practical activities, which allow acquisition of the techniques outlined in the requirements of the specification
- consistently and routinely exhibit the competencies listed in the CPAC before the completion of the A-level course
- keep an appropriate record of their practical work, including their assessed practical activities
- be able to demonstrate and/or record independent evidence of their competency, including evidence of independent application of investigative approaches and methods to practical work.

Common Practical Assessment Criteria

Teachers must assess student practicals against the following competencies.

Criteria for the assessment of GCE Science practical competency for biology, chemistry and physics	
Competency	The criteria for a pass In order to be awarded a Pass a learner must, by the end of the practical science assessment, consistently and routinely meet the criteria in respect of each competency listed below. A learner may demonstrate the competencies in any practical activity undertaken as part of that assessment throughout the course of study. Learners may undertake practical activities in groups. However, the evidence generated by each learner must demonstrate that he or she independently meets the criteria outlined below in respect of each competency. Such evidence: (a) will comprise both the learner's performance during each practical activity and his or her contemporaneous record of the work that he or she has undertaken during that activity, and (b) must include evidence of independent application of investigative approaches and methods to practical work.
1. Follows written procedures	a) Correctly follows written instructions to carry out the experimental techniques or procedures.
2. Applies investigative approaches and methods when using instruments and equipment	a) Correctly uses appropriate instrumentation, apparatus and materials (including ICT) to carry out investigative activities, experimental techniques and procedures with minimal assistance or prompting. b) Carries out techniques or procedures methodically, in sequence and in combination, identifying practical issues and making adjustments when necessary. c) Identifies and controls significant quantitative variables where applicable, and plans approaches to take account of variables that cannot readily be controlled. d) Selects appropriate equipment and measurement strategies in order to ensure suitably accurate results.

Criteria for the assessment of GCE Science practical competency for biology, chemistry and physics	
3. Safely uses a range of practical equipment and materials	a) Identifies hazards and assesses risks associated with these hazards, making safety adjustments as necessary, when carrying out experimental techniques and procedures in the lab or field. b) Uses appropriate safety equipment and approaches to minimise risks with minimal prompting.
4. Makes and records observations	a) Makes accurate observations relevant to the experimental or investigative procedure. b) Obtains accurate, precise and sufficient data for experimental and investigative procedures and records this methodically using appropriate units and conventions.
5. Researches, references and reports	a) Uses appropriate software and/or tools to process data, carry out research and report findings. b) Cites sources of information demonstrating that research has taken place, supporting planning and conclusions.

Marking and standardisation

The practical work is assessed by teachers. Pearson will support teachers in making judgements against the criteria for assessment.

In coordination with other exam boards, Pearson will monitor how schools provide students with opportunities to develop and demonstrate the required practical skills and how they mark the assessments.

Every school will be monitored at least once in a two-year period in respect of at least one of the A level science subjects. These monitoring visits will be coordinated by JCQ, who will undertake communications with centres to facilitate the allocation of exam board monitoring visits.

In common with other exam boards, Pearson will require centres to provide a statement confirming they have taken reasonable steps to secure that students:

- undertook the minimum number of practical activities, and
- made a contemporaneous record of their work.

If a school fails to provide a statement, or provides a false statement, this will be treated as malpractice and/or maladministration.

Students will only get a certificate for the practical assessment if they achieve at least a grade E in the examined part of the qualification.

Students who do not pass the practical assessment will have a 'Not Classified' outcome included on their certificate unless they were exempt from the assessment because of a disability.

Malpractice

Candidate malpractice

Candidate malpractice refers to any act by a candidate that compromises or seeks to compromise the process of assessment or which undermines the integrity of the qualifications or the validity of results/certificates.

Candidate malpractice in controlled assessments discovered before the candidate has signed the declaration of authentication form does not need to be reported to Pearson.

Candidate malpractice found in controlled assessments after the declaration of authenticity has been signed, and in examinations **must** be reported to Pearson on a *JCQ M1 Form* (available at www.jcq.org.uk/exams-office/malpractice). The completed form can be emailed to pqsmalpractice@pearson.com or posted to Investigations Team, Pearson, 190 High Holborn, London, WC1V 7BH. Please provide as much information and supporting documentation as possible. Note that the final decision regarding appropriate sanctions lies with Pearson.

Failure to report candidate malpractice constitutes staff or centre malpractice.

Staff/centre malpractice

Staff and centre malpractice includes both deliberate malpractice and maladministration of our qualifications. As with candidate malpractice, staff and centre malpractice is any act that compromises or seeks to compromise the process of assessment or undermines the integrity of the qualifications or the validity of results/certificates.

All cases of suspected staff malpractice and maladministration **must** be reported immediately, before any investigation is undertaken by the centre, to Pearson on a *JCQ M2(a) Form* (available at www.jcq.org.uk/exams-office/malpractice). The form, supporting documentation and as much information as possible can be emailed to pqsmalpractice@pearson.com or posted to Investigations Team, Pearson, 190 High Holborn, London, WC1V 7BH. Note that the final decision regarding appropriate sanctions lies with Pearson.

Failure to report malpractice itself constitutes malpractice.

More-detailed guidance on malpractice can be found in the latest version of the document *JCQ General and Vocational Qualifications Suspected Malpractice in Examinations and Assessments*, available at www.jcq.org.uk/exams-office/malpractice.

Assessment

Assessment summary

Students must complete all assessment in May/June in any single year.

Paper 1: Advanced Inorganic and Physical Chemistry

***Paper code: 9CH0/01**

- Questions draw on content from Topics 1, 2, 3, 4, 5, 8, 10 and Topics 11–15.
- Questions are broken down into a number of parts.
- Availability: May/June
- First assessment: 2017
- The assessment is 1 hour 45 minutes.
- The assessment consists of 90 marks.

30% of the total qualification

Paper 2: Advanced Organic and Physical Chemistry

***Paper code: 9CH0/02**

- Questions draw on content from Topics 2, 3, 5, 6, 7, 9 and Topics 16–19.
- Questions are broken down into a number of parts.
- Availability: May/June
- First assessment: 2017
- The assessment is 1 hour 45 minutes.
- The assessment consists of 90 marks.

30% of the total qualification

Paper 3: General and Practical Principles in Chemistry

***Paper code: 9CH0/03**

- Questions draw on content from Topics 1–19.
- Questions are broken down into a number of parts.
- Availability: May/June
- First assessment: 2017
- The assessment is 2 hours 30 minutes.
- The assessment consists of 120 marks.

40% of the total qualification

Science Practical Endorsement**

*Paper code: 9CH0/04

- Internally assessed and externally moderated by Pearson.
- Availability: May/June
- First assessment: 2017
- The practical endorsement is teacher assessed against the Common Practical Assessment criteria (CPAC).

The sample assessment materials can be found in the *Pearson Edexcel Level 3 Advanced GCE in Chemistry Sample Assessment Materials* document.

*See *Appendix 3: Codes* for a description of this code and all other codes relevant to this qualification.

**Students will be assessed separately for the Science Practical Endorsement. The Endorsement will not contribute to the overall grade for this qualification, but the result will be recorded on the student's certificate.

Assessment Objectives and weightings

Students must:		% in GCE
A01	Demonstrate knowledge and understanding of scientific ideas, processes, techniques and procedures	31–33
A02	Apply knowledge and understanding of scientific ideas, processes, techniques and procedures: • in a theoretical context • in a practical context • when handling qualitative data • when handling quantitative data	41–43
A03	Analyse, interpret and evaluate scientific information, ideas and evidence, including in relation to issues, to: • make judgements and reach conclusions • develop and refine practical design and procedures	25–27
Total		100%

Breakdown of Assessment Objectives

Paper	AO1	AO2	AO3	Total for all Assessment Objectives
Paper 1: Advanced Inorganic and Physical Chemistry	11–13%	12–14%	5–7%	30%
Paper 2: Advanced Organic and Physical Chemistry	11–13%	12–14%	5–7%	30%
Paper 3: General and Practical Principles in Chemistry	8–10%	16–18%	13–15%	40%
Total for this qualification	31–33%	41–43%	25–27%	100%

Entry and assessment information

Student entry

Details of how to enter students for the examinations for this qualification can be found in our *UK Information Manual*. A copy is made available to all examinations officers and is available on our website at: www.edexcel.com/iwantto/Pages/uk-information-manual.aspx

Forbidden combinations and discount code

Centres should be aware that students who enter for more than one GCE qualification with the same discount code will have only one of the grades they achieve counted for the purpose of the School and College Performance Tables – normally the better grade (please see *Appendix 3: Codes*).

Students should be advised that if they take two qualifications with the same discount code, colleges, universities and employers are very likely to take the view that they have achieved only one of the two GCEs. The same view may be taken if students take two GCE qualifications that have different discount codes but have significant overlap of content. Students or their advisers who have any doubts about their subject combinations should check with the institution to which they wish to progress before embarking on their programmes.

Access arrangements, reasonable adjustments and special consideration

Access arrangements

Access arrangements are agreed before an assessment. They allow students with special educational needs, disabilities or temporary injuries to:

- access the assessment
- show what they know and can do without changing the demands of the assessment.

The intention behind an access arrangement is to meet the particular needs of an individual student with a disability without affecting the integrity of the assessment. Access arrangements are the principal way in which awarding bodies comply with the duty under the Equality Act 2010 to make 'reasonable adjustments'.

Access arrangements should always be processed at the start of the course. Students will then know what is available and have the access arrangement(s) in place for assessment.

Reasonable adjustments

The Equality Act 2010 requires an awarding organisation to make reasonable adjustments where a person with a disability would be at a substantial disadvantage in undertaking an assessment. The awarding organisation is required to take reasonable steps to overcome that disadvantage.

A reasonable adjustment for a particular person may be unique to that individual and therefore might not be in the list of available access arrangements.

Whether an adjustment will be considered reasonable will depend on a number of factors, which will include:

- the needs of the student with the disability
- the effectiveness of the adjustment
- the cost of the adjustment; and
- the likely impact of the adjustment on the student with the disability and other students.

An adjustment will not be approved if it involves unreasonable costs to the awarding organisation, timeframes or affects the security or integrity of the assessment. This is because the adjustment is not 'reasonable'.

Special consideration

Special consideration is a post-examination adjustment to a student's mark or grade to reflect temporary injury, illness or other indisposition at the time of the examination/assessment, which has had, or is reasonably likely to have had, a material effect on a candidate's ability to take an assessment or demonstrate his or her level of attainment in an assessment.

Further information

Please see our website for further information about how to apply for access arrangements and special consideration.

For further information about access arrangements, reasonable adjustments and special consideration, please refer to the JCQ website: www.jcq.org.uk.

Equality Act 2010 and Pearson equality policy

Equality and fairness are central to our work. Our equality policy requires all students to have equal opportunity to access our qualifications and assessments, and our qualifications to be awarded in a way that is fair to every student.

We are committed to making sure that:

- students with a protected characteristic (as defined by the Equality Act 2010) are not, when they are undertaking one of our qualifications, disadvantaged in comparison to students who do not share that characteristic
- all students achieve the recognition they deserve for undertaking a qualification and that this achievement can be compared fairly to the achievement of their peers.

Teachers can find details on how to make adjustments for students with protected characteristics in the policy document *Access Arrangements, Reasonable Adjustments and Special Consideration*, which is on our website, www.edexcel.com/Policies.

Synoptic assessment

Synoptic assessment requires students to work across different parts of a qualification and to show their accumulated knowledge and understanding of a topic or subject area.

Synoptic assessment enables students to show their ability to combine their skills, knowledge and understanding with breadth and depth of the subject.

In this qualification, synoptic assessment can be found in *Paper 3: General and Practical Principles in Chemistry*.

Awarding and reporting

This qualification will be graded, awarded and certificated to comply with the requirements of the current *Code of Practice* published by the Office of Qualifications and Examinations Regulation (Ofqual).

This qualification will be graded and certificated on a six-grade scale from A* to E using the total subject mark. Individual papers are not graded.

The first certification opportunity for the Pearson Edexcel Level 3 Advanced GCE in Chemistry will be 2017.

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.

Language of assessment

Assessment of this qualification will be available in English.
All student work must be in English.

Other information

Student recruitment

Pearson follows the JCQ policy concerning recruitment to our qualifications in 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.

Prior learning and other requirements

There are no prior learning or other requirements for this qualification.

Students who would benefit most from studying this qualification are likely to have a Level 2 qualification such as a GCSE in Additional Science or Chemistry.

Progression

Students can progress from this qualification to:

- a range of different, relevant academic or vocational higher education qualifications
- employment in a relevant sector
- further training.

Relationship between Advanced Subsidiary GCE and Advanced GCE

The content for Advanced GCE in Chemistry includes all the content studied at Advanced Subsidiary GCE. The Advanced GCE in Chemistry builds on the knowledge, skills, and understanding achieved when studying the Advanced Subsidiary GCE in Chemistry.

Progression from Advanced Subsidiary GCE to Advanced GCE

Students who have achieved the Advanced Subsidiary GCE in Chemistry can progress to the Advanced GCE in Chemistry. They would have covered Topics 1–10 which are common to both qualifications but the additional Topics 11–19 will need to be covered; all the assessment for the Advanced GCE qualification must be taken at the end of the course.

Relationship between GCSE and Advanced GCE

Students cover Key Stage 4 fundamental core concepts in sciences at GCSE and continue to cover these concepts and additional subject material in the Advanced GCE at Key Stage 5.

Progression from GCSE to Advanced GCE

Students will draw on knowledge and understanding achieved in GCSE Additional Science or GCSE Chemistry to progress to an Advanced GCE in Chemistry qualification.

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Appendix 1: Transferable skills

The need for transferable skills

In recent years, higher education institutions and employers have consistently flagged the need for students to develop a range of transferable skills to enable them to respond with confidence to the demands of undergraduate study and the world of work.

The Organisation for Economic Co-operation and Development (OECD) defines skills, or competencies, as 'the bundle of knowledge, attributes and capacities that can be learned and that enable individuals to successfully and consistently perform an activity or task and can be built upon and extended through learning.'¹

To support the design of our qualifications, the Pearson Research Team selected and evaluated seven global 21st-century skills frameworks. Following on from this process, we identified the National Research Council's (NRC) framework as the most evidence-based and robust skills framework. We adapted the framework slightly to include the Program for International Student Assessment (PISA) ICT Literacy and Collaborative Problem Solving (CPS) Skills.

The adapted National Research Council's framework of skills involves:²

Cognitive skills

- **Non-routine problem solving** – expert thinking, metacognition, creativity.
- **Systems thinking** – decision making and reasoning.
- **Critical thinking** – definitions of critical thinking are broad and usually involve general cognitive skills such as analysing, synthesising and reasoning skills.
- **ICT literacy** – access, manage, integrate, evaluate, construct and communicate³.

Interpersonal skills

- **Communication** – active listening, oral communication, written communication, assertive communication and non-verbal communication.
- **Relationship-building skills** – teamwork, trust, intercultural sensitivity, service orientation, self-presentation, social influence, conflict resolution and negotiation.
- **Collaborative problem solving** – establishing and maintaining shared understanding, taking appropriate action, establishing and maintaining team organisation.

¹ OECD (2012), Better Skills, Better Jobs, Better Lives (2012): <http://skills.oecd.org/documents/OECDSkillsStrategyFINALENG.pdf>

² Koenig, J. A. (2011) Assessing 21st Century Skills: Summary of a Workshop, National Research Council

³ PISA (2011) The PISA Framework for Assessment of ICT Literacy, PISA

Intrapersonal skills

- **Adaptability** – ability and willingness to cope with the uncertain, handling work stress, adapting to different personalities, communication styles and cultures, and physical adaptability to various indoor and outdoor work environments.
- **Self-management and self-development** – ability to work remotely in virtual teams, work autonomously, be self-motivating and self-monitoring, willing and able to acquire new information and skills related to work.

Transferable skills enable young people to face the demands of further and higher education, as well as the demands of the workplace, and are important in the teaching and learning of this qualification. We will provide teaching and learning materials, developed with stakeholders, to support our qualifications.

Appendix 2: Level 3 Extended Project qualification

What is the Extended Project?

The Extended Project is a stand-alone qualification that can be taken alongside GCEs. It supports the development of 21st-century independent learning skills and helps to prepare students for their next step – whether that be university study or employment. The qualification:

- is recognised by universities for the skills it develops
- is worth half of an Advanced GCE qualification at grades to A*–E
- carries UCAS points for university entry.

The Extended Project encourages students to develop skills in the following areas: research, critical thinking, extended writing and project management. Students identify and agree a topic area of their choice (which may or may not be related to a GCE subject they are already studying), guided by their teacher.

Students can choose from one of four approaches to produce:

- a dissertation (for example an investigation based on predominately secondary research)
- an investigation/field study (for example a practical experiment)
- a performance (for example in music, drama or sport)
- an artefact (for example creating a sculpture in response to a client brief or solving an engineering problem).

The qualification is coursework based and students are assessed on the skills of managing, planning and evaluating their project. Students will research their topic, develop skills to review and evaluate the information, and then present the final outcome of their project.

Students: what they need to do

The Extended Project qualification requires students to:

- select a topic of interest for an in-depth study and negotiate the scope of the project with their teacher
- identify and draft an objective for their project (for example in the form of a question, hypothesis, challenge, outline of proposed performance, issue to be investigated or commission for a client) and provide a rationale for their choice
- produce a plan for how they will deliver their intended objective
- conduct research as required by the project brief, using appropriate techniques
- carry out the project using tools and techniques safely
- share the outcome of the project using appropriate communication methods, including a presentation.

Teachers: key information

- The Extended Project has 120 guided learning hours (GLH) consisting of:
 - a 40-GLH taught element that includes teaching the technical skills (for example research skills)
 - an 80-GLH guided element that includes mentoring students through the project work.
- Group work is acceptable, however it is important that each student provides evidence of their own contribution and produces their own report.
- 100% externally moderated.
- Four Assessment Objectives: manage, use resources, develop and realise, review.
- Can be run over 1, 1½ or 2 years.
- Can be submitted in January or June.

What is the Extended Project for chemistry?

How to link the Extended Project with chemistry

The Extended Project creates the opportunity for students to develop transferable skills for progression to higher education and to the workplace through the exploration of either an area of personal interest or a topic of interest from the chemistry qualification content.

For example, chemistry students could choose to carry out an investigation that would give them an opportunity to develop their skills in data collection, in the development and testing of hypotheses and in the application of mathematical models in data analysis.

Skills developed

Through the Extended Project students will develop skills in the following areas:

- independent research skills, including skills in primary research and the selection of appropriate methods for data collection
- extended reading and academic writing, including reading scientific literature and writing about trends or patterns in data sets
- planning/project management, including the refining of hypotheses to be tested in investigations
- data handling and evaluation, including the comparison of data from primary research with published data and exploration of the significance of results
- evaluation of arguments and processes, including arguments in favour of alternative interpretations of data and evaluation of experimental methodology
- critical thinking.

In the context of the Extended Project, critical thinking refers to the ability to identify and develop arguments for a point of view or hypothesis and to consider and respond to alternative arguments.

The Extended Project is an ideal vehicle to develop the skills identified in *Appendix 1*.

Using the Extended Project to support breadth and depth

There is no specified material that students are expected to study and, in the Extended Project, students are assessed on the quality of the work they produce and the skills they develop and demonstrate through completing this work. Students can use the Extended Project to demonstrate *extension* in one or more dimensions:

- **deepening understanding:** where a student explores a topic in greater depth than in the specification content
- **broadening skills:** the student learns a new skill. In a chemistry-based project, this might involve learning to assemble and manipulate an unfamiliar piece of apparatus or learning advanced data-handling techniques
- **widening perspectives:** the student's project spans different subjects. This might involve discussing historical, philosophical or ethical aspects of a chemistry-based topic or making links with other subject areas such as economics.

Choosing topics and narrowing down to a question

A dissertation, typically around 6000 words in length, involves addressing a research question through a literature review and argumentative discussion while an investigation/field study involves data collection and analysis, leading to a written report of around 5000 words.

For example, consider a student with an interest in alternatives to conventional fuels who decided to carry out an investigation to compare the strengths and weaknesses of two different types of biodiesel. The investigation involved secondary research to establish the theoretical background to the project, to explore the uses and properties of different biodiesels and to consider what techniques can be used to gather data. The student collected data using appropriately designed experiments. The student's own data were compared with published data, and the trends and patterns in data analysed, with consideration of the significance of the results obtained, and an attempt to interpret them in the light of the mathematical models that the student had learned about through research.

The student drew conclusions about the relative merits of the two biodiesels, basing these conclusions on their own research together with analysis of published data. Finally, the student's project ended with a review of the effectiveness of the investigation and an oral presentation of the main findings and arguments considered.

Chemistry-based dissertation projects can cover a wide variety of topics, as these examples illustrate:

- Should legislation be used to enforce the principles of green chemistry?
- Could nanochemistry revolutionise medicine?

Examples of chemistry-based investigations include:

- Are calorific values in diet foods accurate?
- Can changing the method of synthesis significantly alter the material properties of a polymer?
- Is there a correlation between the chemical composition of a chilli pepper and its taste?
- Is the use of oil-dispersants an effective way of tackling oil spills?

There is also scope for chemistry-based artefact Extended Projects. For example, a student might set out to design, make and test an item of apparatus such as a spectrometer. Extended Projects involving a performance can also be chemistry based. For example, a social issue relating to chemistry could be explored through drama.

Appendix 3: Codes

Type of code	Use of code	Code number
Discount codes	Every qualification eligible for performance tables is assigned a discount code indicating the subject area to which it belongs. Discount codes are published by DfE.	Please see the GOV.UK website*
Regulated Qualifications Framework (RQF) codes	Each qualification title is allocated an Ofqual Regulated Qualifications Framework (RQF) code. The RQF code is known as a Qualification Number (QN). This is the code that features in the DfE Section 96 and on the LARA as being eligible for 16–18 and 19+ funding, and is to be used for all qualification funding purposes. The QN will appear on the student's final certification documentation.	The QN for the qualification in this publication is: 601/5646/6
Subject codes	The subject code is used by centres to enter students for a qualification. Centres will need to use the entry codes only when claiming students' qualifications.	Advanced GCE – 9CH0
Paper code	These codes are provided for reference purposes. Students do not need to be entered for individual papers.	Paper 1: 9CH0/01 Paper 2: 9CH0/02 Paper 3: 9CH0/03 Science Practical Endorsement: 9CH0/04

*www.gov.uk/government/publications/key-stage-4-qualifications-discount-codes-and-point-scores

Appendix 4: Practical competency authentication sheet

For students to gain the Science Practical Endorsement, centres will need to:

- ensure that there is evidence that students have completed the necessary practical activities, meeting the requirements of *Appendix 5c*
- ensure that there is evidence that students have met the requirements of each of the CPAC statements, in accordance with the guidelines provided for achieving the 'pass' standard
- complete an authentication sheet for their students.

Centres will also need to have had a satisfactory monitoring visit, according to the guidelines for monitoring visits, as set down by the JCQ.

Evidence for meeting practical attendance and CPAC competency may be provided in a variety of formats using student lab books or practical portfolios; and registers or tracking spreadsheets.

A final version of the authentication statement will be made available to schools in time for the first submission of entries in 2017.

Appendix 5: Working scientifically

Appendices 5, 5a, 5b and 5c are taken from the document *GCE AS and A level regulatory requirements for biology, chemistry, physics and psychology* published by the DfE in April 2014. Working scientifically is achieved through practical activities.

Specifications in biology, chemistry and physics must encourage the development of the skills, knowledge and understanding in science through teaching and learning opportunities for regular hands-on practical work.

In order to develop the necessary skills, knowledge and understanding, students studying biology, chemistry and physics will be required to have carried out a minimum of 12 practical activities, which will contribute towards the Practical Endorsement. These skills, knowledge and understanding will also be assessed in written examinations in the context of these, and other, practical activities.

The skills can be split into those which can be assessed through written examinations (*Appendix 5a*); and those that will be assessed by teachers through appropriate practical activities (*Appendix 5b*).

The practical activities highlighted as the minimum requirement within specifications must cover the use of apparatus and practical techniques identified for each science (*Appendix 5c*).

Appendix 5a: Practical skills identified for indirect assessment and developed through teaching and learning

Question papers will assess the following abilities:

a) Independent thinking

- solve problems set in practical contexts
- apply scientific knowledge to practical contexts

b) Use and application of scientific methods and practices

- comment on experimental design and evaluate scientific methods
- present data in appropriate ways
- evaluate results and draw conclusions with reference to measurement uncertainties and errors
- identify variables including those that must be controlled

c) Numeracy and the application of mathematical concepts in a practical context

- plot and interpret graphs
- process and analyse data using appropriate mathematical skills as exemplified in the mathematical appendix for each science
- consider margins of error, accuracy and precision of data

d) Instruments and equipment

- know and understand how to use a wide range of experimental and practical instruments, equipment and techniques appropriate to the knowledge and understanding included in the specification

Appendix 5b: Practical skills identified for direct assessment and developed through teaching and learning

Practical work carried out throughout the course will enable students to develop the following skills.

a) Independent thinking

- apply investigative approaches and methods to practical work

b) Use and apply scientific methods and practices

- safely and correctly use a range of practical equipment and materials
- follow written instructions
- make and record observations
- keep appropriate records of experimental activities
- present information and data in a scientific way
- use appropriate software and tools to process data, carry out research and report findings

c) Research and referencing

- use online and offline research skills including websites, textbooks and other printed scientific sources of information
- correctly cite sources of information

d) Instruments and equipment

- use a wide range of experimental and practical instruments, equipment and techniques appropriate to the knowledge and understanding included in the specification

Appendix 5c: Use of apparatus and techniques

Use of apparatus and techniques – chemistry

Specifications for chemistry must give students opportunities to use relevant apparatus to develop and demonstrate these techniques.

All of the techniques listed below will be assessed through a minimum of 12 identified practical activities within each specification. These 'core' practicals must allow students to demonstrate all of the practical skills given in 5b.

Practical techniques to be gained by candidates

1. use appropriate apparatus to record a range of measurements (to include mass, time, volume of liquids and gases, temperature)
2. use water bath or electric heater or sand bath for heating
3. measure pH using pH charts, or pH meter, or pH probe on a data logger
4. use laboratory apparatus for a variety of experimental techniques, including:
 - titration, using burette and pipette
 - distillation and heating under reflux, including setting up glassware using retort stand and clamps
 - qualitative tests for ions and organic functional groups
 - filtration, including use of fluted filter paper, or filtration under reduced pressure
5. use volumetric flask, including accurate technique for making up a standard solution
6. use acid-base indicators in titrations of weak/strong acids with weak/strong alkalis
7. purify:
 - a solid product by recrystallization
 - a liquid product, including use of separating funnel
8. use melting point apparatus
9. use thin-layer or paper chromatography
10. set up electrochemical cells and measuring voltages
11. safely and carefully handle solids and liquids, including corrosive, irritant, flammable and toxic substances
12. measure rates of reaction by at least two different methods, for example:
 - an initial rate method such as a clock reaction
 - a continuous monitoring method

Appendix 5d: Mapping between Appendix 5c and core practicals (chemistry)

This qualification gives students opportunities to use relevant apparatus to develop practical skills and demonstrate competency in a range of practical techniques.

All of the techniques listed in *Appendix 5c* will be assessed through a series of core practical activities within this specification.

To achieve the Science Practical Endorsement, students need to show competence in the 12 practical techniques listed in *Appendix 5c: Use of apparatus and techniques*.

The following table shows how each core practical activity, listed in the content, maps to the required practical techniques in *Appendix 5c: Use of apparatus and techniques*.

Chemistry Core Practical	Practical technique in Appendix 5c											
	1	2	3	4	5	6	7	8	9	10	11	12
1: Measuring the molar volume of a gas	✓			✓							✓	
2: Preparation of a standard solution from a solid acid	✓			✓	✓	✓					✓	
3: Finding the concentration of a solution of hydrochloric acid	✓			✓	✓	✓					✓	
4: Investigation of the rates of hydrolysis of halogenoalkanes	✓	✓		✓							✓	
5: The oxidation of ethanol		✓		✓			✓				✓	
6: Chlorination of 2-methylpropan-2-ol with concentrated hydrochloric acid	✓			✓			✓	✓	✓		✓	
7: Analysis of some inorganic and organic unknowns		✓		✓							✓	
8: To determine the enthalpy change of a reaction using Hess's Law	✓			✓							✓	
9. Finding the K_a value for a weak acid			✓	✓							✓	
10. Investigating some electrochemical cells				✓						✓	✓	
11. Redox titration	✓			✓	✓						✓	
12. The preparation of a transition metal complex	✓			✓			✓		✓		✓	
13a and 13b: Following the rate of the iodine-propanone reaction by a titrimetric method and investigating a 'clock reaction' (Harcourt-Esson, iodine clock)	✓			✓		✓					✓	✓
14. Finding the activation energy of a reaction	✓			✓							✓	
15. Analysis of some inorganic and organic unknowns		✓		✓				✓			✓	
16. The preparation of aspirin	✓	✓		✓			✓	✓	✓		✓	

Appendix 6: Mathematical skills and exemplifications

The information in this appendix has been taken directly from the document *GCE AS and A level regulatory requirements for biology, chemistry, physics and psychology* published by the Department for Education in April 2014.

In order to be able to develop their skills, knowledge and understanding in science, students need to have been taught, and to have acquired competence in, the appropriate areas of mathematics relevant to the subject as indicated in the table of coverage below.

The assessment of quantitative skills will include at least 10% level 2 or above mathematical skills for biology and psychology, 20% for chemistry and 40% for physics. These skills will be applied in the context of the relevant science A Level.

All mathematical content must be assessed within the lifetime of the specification.

The following tables illustrate where these mathematical skills may be developed and could be assessed in each of the sciences. Those shown in bold type would only be tested in the full A Level course.

This list of examples is not exhaustive. These skills could be developed in other areas of specification content.

	Mathematical skills	Exemplification of mathematical skill in the context of A Level chemistry (assessment is not limited to the examples given below)
(i) B.0 – arithmetic and numerical computation		
B.0.0	Recognise and make use of appropriate units in calculation	Candidates may be tested on their ability to: • convert between units, e.g. cm^3 to dm^3 as part of volumetric calculations • give units for an equilibrium constant or a rate constant • understand that different units are used in similar topic areas, so that conversions may be necessary, e.g. entropy in $\text{J mol}^{-1} \text{K}^{-1}$ and enthalpy changes in kJ mol^{-1}
B.0.1	Recognise and use expressions in decimal and ordinary form	Candidates may be tested on their ability to: • use an appropriate number of decimal places in calculations, e.g. for pH • carry out calculations using numbers in standard and ordinary form, e.g. use of Avogadro's number • understand standard form when applied to areas such as (but not limited to) K_w • convert between numbers in standard and ordinary form • understand that significant figures need retaining when making conversions between standard and ordinary form, e.g. $0.0050 \text{ mol dm}^{-3}$ is equivalent to $5.0 \times 10^{-3} \text{ mol dm}^{-3}$
B.0.2	Use ratios, fractions and percentages	Candidates may be tested on their ability to: • calculate percentage yields • calculate the atom economy of a reaction • construct and/or balance equations using ratios

	Mathematical skills	Exemplification of mathematical skill in the context of A Level chemistry (assessment is not limited to the examples given below)
B.0.3	Make estimates of the results of calculations (without using a calculator).	Candidates may be tested on their ability to: • evaluate the effect of changing experimental parameters on measurable values, e.g. how the value of K_c would change with temperature given different specified conditions
B.0.4	Use calculators to find and use power, exponential and logarithmic functions	Candidates may be tested on their ability to: • carry out calculations using the Avogadro constant • carry out pH and pK_a calculations • make appropriate mathematical approximations in buffer calculations
(ii) B.1 – handling data		
B.1.1	Use an appropriate number of significant figures	Candidates may be tested on their ability to: • report calculations to an appropriate number of significant figures given raw data quoted to varying numbers of significant figures • understand that calculated results can only be reported to the limits of the least accurate measurement
B.1.2	Find arithmetic means	Candidates may be tested on their ability to: • calculate weighted means, e.g. calculation of an atomic mass based on supplied isotopic abundances • select appropriate titration data (i.e. identification of outliers) in order to calculate mean titres
B.1.3	Identify uncertainties in measurements and use simple techniques to determine uncertainty when data are combined	Candidates may be tested on their ability to: • determine uncertainty when two burette readings are used to calculate a titre value

	Mathematical skills	Exemplification of mathematical skill in the context of A Level chemistry (assessment is not limited to the examples given below)
(iii) B.2 – algebra		
B.2.1	Understand and use the symbols: =, <, <<, >>, >, ∞ , $\sim$, equilibrium sign	No exemplification required.
B.2.2	Change the subject of an equation	Candidates may be tested on their ability to: carry out structured and unstructured mole calculations, e.g. calculate a rate constant k from a rate equation
B.2.3	Substitute numerical values into algebraic equations using appropriate units for physical quantities	Candidates may be tested on their ability to: - carry out structured and unstructured mole calculations carry out rate calculations calculate the value of an equilibrium constant K_c
B.2.4	Solve algebraic equations	Candidates may be tested on their ability to: - carry out Hess's law calculations calculate a rate constant k from a rate equation
B.2.5	Use logarithms in relation to quantities that range over several orders of magnitude	Students may be tested on their ability to: carry out pH and pK_a calculations
(iv) B.3 – graphs		
B.3.1	Translate information between graphical, numerical and algebraic forms	Candidates may be tested on their ability to: - interpret and analyse spectra determine the order of a reaction from a graph derive rate expression from a graph
B.3.2	Plot two variables from experimental or other data	Candidates may be tested on their ability to: plot concentration–time graphs from collected or supplied data and draw an appropriate best-fit curve

	Mathematical skills	Exemplification of mathematical skill in the context of A Level chemistry (assessment is not limited to the examples given below)
B.3.3	Determine the slope and intercept of a linear graph	Candidates may be tested on their ability to: • calculate the rate constant of a zero-order reaction by determination of the gradient of a concentration–time graph
B.3.4	Calculate rate of change from a graph showing a linear relationship	Candidates may be tested on their ability to: • calculate the rate constant of a zero-order reaction by determination of the gradient of a concentration–time graph
B.3.5	Draw and use the slope of a tangent to a curve as a measure of rate of change	Candidates may be tested on their ability to: • determine the order of a reaction using the initial rates method
(v) B.4 – geometry and trigonometry		
B.4.1	Appreciate angles and shapes in regular 2D and 3D structures.	Candidates may be tested on their ability to: • predict/identify shapes of and bond angles in molecules with and without a lone pair(s), for example NH₃, CH₄, H₂O etc
B.4.2	Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects	Candidates may be tested on their ability to: • draw different forms of isomers • identify chiral centres from a 2D or 3D representation
B.4.3	Understand the symmetry of 2D and 3D shapes	Candidates may be tested on their ability to: • describe the types of stereoisomerism shown by molecules/complexes • identify chiral centres from a 2D or 3D representation

Appendix 7: Command words used in examination papers

The following table lists the command words used in the external assessments.

Command word	Definition
Add/Label	Requires the addition or labelling to a stimulus material given in the question, for example labelling a diagram or adding units to a table.
Assess	Give careful consideration to all the factors or events that apply and identify which are the most important or relevant. Make a judgement on the importance of something, and come to a conclusion where needed.
Calculate	Obtain a numerical answer, showing relevant working. If the answer has a unit, this must be included.
Comment on	Requires the synthesis of a number of variables from data/information to form a judgement.
Compare and contrast	Looking for the similarities and differences of two (or more) things. Should not require the drawing of a conclusion. Answer must relate to both (or all) things mentioned in the question. The answer must include at least one similarity and one difference.
Complete	Requires the completion of a table/diagram.
Criticise	Inspect a set of data, an experimental plan or a scientific statement and consider the elements. Look at the merits and faults of the information presented and back judgements made by giving evidence.
Deduce	Draw/reach conclusion(s) from the information provided.
Describe	To give an account of something. Statements in the response need to be developed as they are often linked but do not need to include a justification or reason.
Determine	The answer must have an element which is quantitative from the stimulus provided, or must show how the answer can be reached quantitatively. To gain maximum marks there must be a quantitative element to the answer.
Devise	Plan or invent a procedure from existing principles/ideas
Discuss	- Identify the issue/situation/problem/argument that is being assessed within the question. - Explore all aspects of an issue/situation/problem/argument. - Investigate the issue/situation etc by reasoning or argument.

Command word	Definition
Draw	Produce a diagram either using a ruler or using freehand.
Evaluate	Review information then bring it together to form a conclusion, drawing on evidence including strengths, weaknesses, alternative actions, relevant data or information. Come to a supported judgement of a subject's qualities and relation to its context.
Explain	An explanation requires a justification/exemplification of a point. The answer must contain some element of reasoning/justification, this can include mathematical explanations.
Give/State/Name	All of these command words are really synonyms. They generally all require recall of one or more pieces of information.
Give a reason/reasons	When a statement has been made and the requirement is only to give the reasons why.
Identify	Usually requires some key information to be selected from a given stimulus/resource.
Justify	Give evidence to prove (either the statement given in the question or an earlier answer)
Plot	Produce a graph by marking points accurately on a grid from data that is provided and then drawing a line of best fit through these points. A suitable scale and appropriately labelled axes must be included if these are not provided in the question.
Predict	Give an expected result.
Show that	Verify the statement given in the question.
Sketch	Produce a freehand drawing. For a graph this would need a line and labelled axis with important features indicated, the axis are not scaled.
State what is meant by	When the meaning of a term is expected but there are different ways of how these can be described.
Write	When the questions ask for an equation.

Appendix 8: Data Booklet

This appendix shows the data included in a Data Booklet that will be available on our website. Centres will be sent copies of the Data Booklet for the first examination series.

Centres can make additional fresh copies by printing the Data Booklet from our website. Candidates must use an unmarked copy of the Data Booklet in examinations.

Acknowledgement of source

The data used in the Data Booklet is derived from the *Nuffield Advanced Science, Revised Book of Data* (ISBN 058235448X), Nuffield Foundation.

Physical constants

Avogadro constant (L) $6.02 \times 10^{23} \text{ mol}^{-1}$

Elementary charge (e) $1.60 \times 10^{-19} \text{ C}$

Gas constant (R) $8.31 \text{ J mol}^{-1} \text{ K}^{-1}$

Molar volume of ideal gas:

at r.t.p. $24 \text{ dm}^3 \text{ mol}^{-1}$

Specific heat capacity of water $4.18 \text{ J g}^{-1} \text{ K}^{-1}$

Ionic product of water (K_w) $1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$

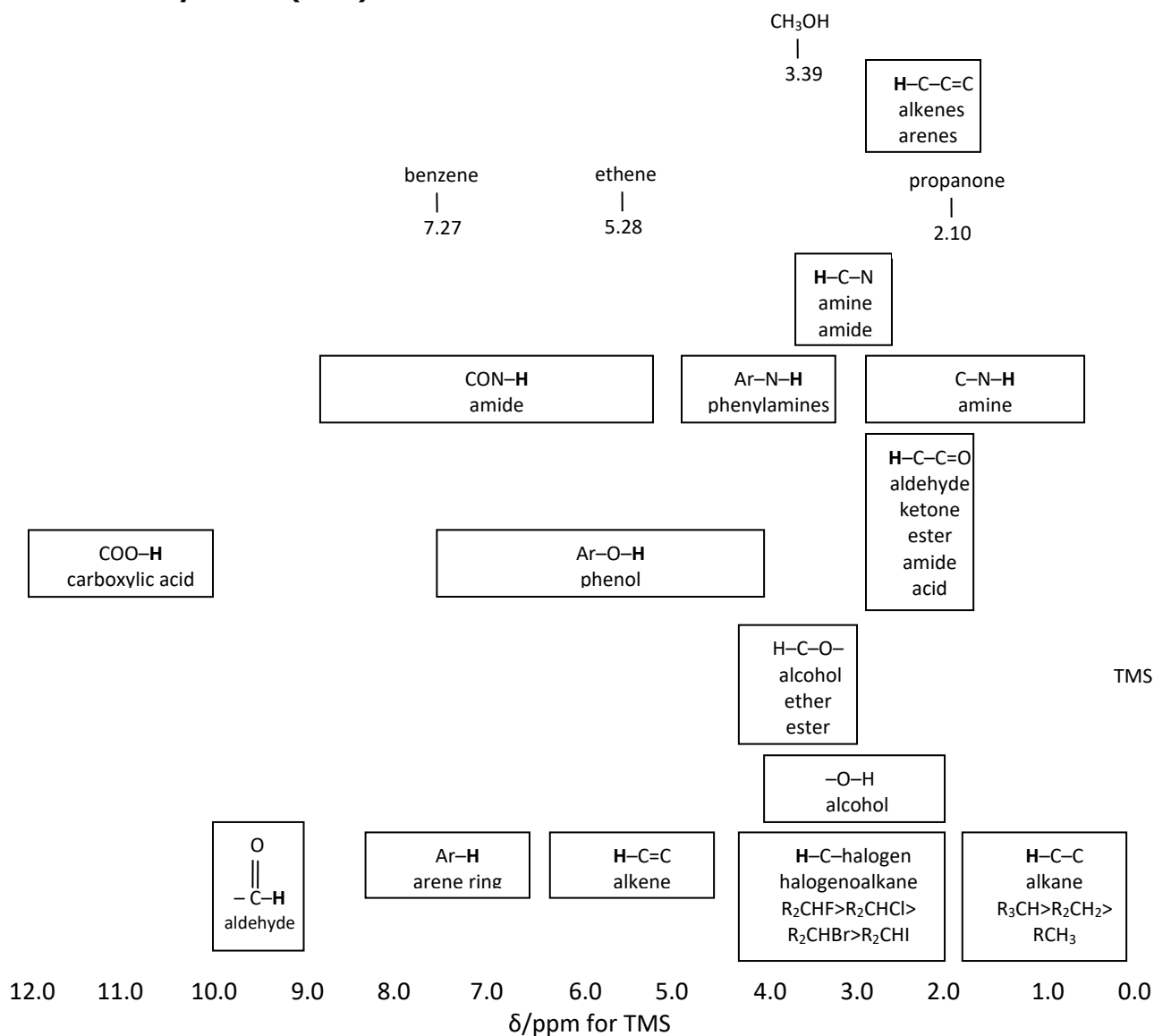
$1 \text{ dm}^3 = 1\,000 \text{ cm}^3 = 0.001 \text{ m}^3$

Infrared spectroscopy

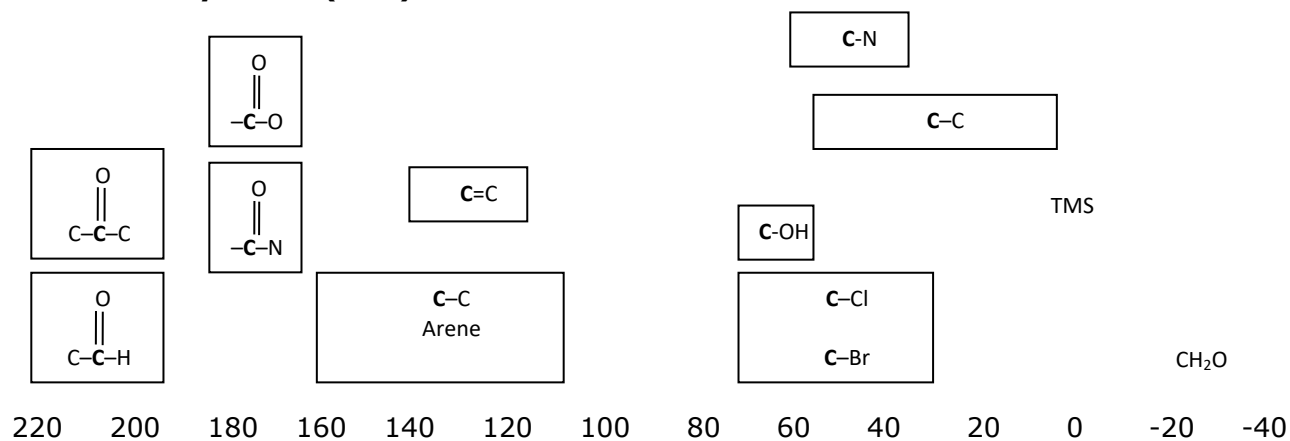
Correlation of infrared absorption wavenumbers with molecular structure

Group	Wavenumber range/cm ⁻¹
C-H stretching vibrations	
Alkane	2962-2853
Alkene	3095-3010
Alkyne	3300
Arene	3030
Aldehyde	2900-2820 and 2775-2700
C-H bending variations	
Alkane	1485-1365
Arene 5 adjacent hydrogen atoms	750 and 700
4 adjacent hydrogen atoms	750
3 adjacent hydrogen atoms	780
2 adjacent hydrogen atoms	830
1 adjacent hydrogen atom	880
N-H stretching vibrations	
Amine	3500-3300
Amide	3500-3140
O-H stretching vibrations	
Alcohols and phenols	3750-3200
Carboxylic acids	3300-2500
C=C stretching vibrations	
Isolated alkene	1669-1645
Arene	1600, 1580, 1500, 1450
C=O stretching vibrations	
Aldehydes, saturated alkyl	1740-1720
Ketones, alkyl	1720-1700
Ketones, aryl	1700-1680
Carboxylic acids, alkyl	1725-1700
Carboxylic acids, aryl	1700-1680
Carboxylic acid, anhydrides	1850-1800 and 1790-1740
Acyl halides, chlorides	1795
Acyl halides, bromides	1810
Esters, saturated	1750-1735
Amides	1700-1630
Triple bond stretching vibrations	
C≡N	2260-2215
C≡C	2260-2100

¹H nuclear magnetic resonance chemical shifts relative to tetramethylsilane (TMS)



¹³C nuclear magnetic resonance chemical shifts relative to tetramethylsilane (TMS)



Pauling electronegativities

Pauling electronegativity index

																	H 2.1						He
Li	Be											B	C	N	O	F	Ne						
1.0	1.5											2.0	2.5	3.0	3.5	4.0							
Na	Mg											Al	Si	P	S	Cl	Ar						
0.9	1.2											1.5	1.9	2.1	2.5	3.0							
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr						
0.8	1.0	1.3	1.5	1.6	1.6	1.5	1.8	1.8	1.8	1.9	1.6	1.6	2.0	2.0	2.4	2.8							
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe						
0.8	1.0	1.2	1.3	1.6	2.1	1.9	2.2	2.2	2.2	1.9	1.6	1.7	1.9	1.9	2.1	2.5							
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn						
0.7	0.9	1.1	1.3	1.5	2.3	1.9	2.2	2.2	2.2	2.5	2.0	1.6	1.8	1.9	2.0	2.2							

Relation in electronegativity difference, ΔN_e and ionic character $P/\%$

Electronegativity difference ΔN_e	0.1	0.3	0.5	0.7	1.0	1.3	1.5	1.7	2.0	2.5	3.0
Percentage ionic character $P/\%$	0.5	2	6	12	22	34	43	51	63	79	89

Indicators

		pK_{in} (at 298 K)	acid	pH range	alkaline
1	Thymol blue (acid)	1.7	red	1.2–2.8	yellow
2	Screened methyl orange	3.7	purple	3.2–4.2	green
3	Methyl orange	3.7	red	3.2–4.4	yellow
4	Bromophenol blue	4.0	yellow	2.8–4.6	blue
5	Bromocresol green	4.7	yellow	3.8–5.4	blue
6	Methyl red	5.1	red	4.2–6.3	yellow
7	Litmus		red	5.0–8.0	blue
8	Bromothymol blue	7.0	yellow	6.0–7.6	blue
9	Phenol red	7.9	yellow	6.8–8.4	red
10	Phenolphthalein (in ethanol)	9.3	colourless	8.2–10.0	red

Standard electrode potentials

E° Standard electrode potential of aqueous system at 298 K, that is, standard emf of electrochemical cell in the hydrogen half-cell forms the left-hand side electrode system.

	Right-hand electrode system	E°/V
1	$\text{Na}^+ + \text{e}^- \rightleftharpoons \text{Na}$	-2.71
2	$\text{Mg}^{2+} + 2\text{e}^- \rightleftharpoons \text{Mg}$	-2.37
3	$\text{Al}^{3+} + 3\text{e}^- \rightleftharpoons \text{Al}$	-1.66
4	$\text{V}^{2+} + 2\text{e}^- \rightleftharpoons \text{V}$	-1.18
5	$\text{Zn}^{2+} + 2\text{e}^- \rightleftharpoons \text{Zn}$	-0.76
6	$\text{Cr}^{3+} + 3\text{e}^- \rightleftharpoons \text{Cr}$	-0.74
7	$\text{Fe}^{2+} + 2\text{e}^- \rightleftharpoons \text{Fe}$	-0.44
8	$\text{Cr}^{3+} + \text{e}^- \rightleftharpoons \text{Cr}^{2+}$	-0.41
9	$\text{V}^{3+} + \text{e}^- \rightleftharpoons \text{V}^{2+}$	-0.26
10	$\text{Ni}^{2+} + 2\text{e}^- \rightleftharpoons \text{Ni}$	-0.25
11	$\text{H}^+ + \text{e}^- \rightleftharpoons \frac{1}{2}\text{H}_2$	0.00
12	$\frac{1}{2}\text{S}_4\text{O}_6^{2-} + \text{e}^- \rightleftharpoons \text{S}_2\text{O}_3^{2-}$	+0.09
13	$\text{Cu}^{2+} + \text{e}^- \rightleftharpoons \text{Cu}^+$	+0.15
14	$\text{Cu}^{2+} + 2\text{e}^- \rightleftharpoons \text{Cu}$	+0.34
15	$\text{VO}^{2+} + 2\text{H}^+ + \text{e}^- \rightleftharpoons \text{V}^{3+} + \text{H}_2\text{O}$	+0.34
16	$\frac{1}{2}\text{O}_2 + \text{H}_2\text{O} + 2\text{e}^- \rightleftharpoons 2\text{OH}^-$	+0.40
17	$\text{S}_2\text{O}_3^{2-} + 6\text{H}^+ + 4\text{e}^- \rightleftharpoons 2\text{S} + 3\text{H}_2\text{O}$	+0.47
18	$\text{Cu}^+ + \text{e}^- \rightleftharpoons \text{Cu}$	+0.52
19	$\frac{1}{2}\text{I}_2 + \text{e}^- \rightleftharpoons \text{I}^-$	+0.54
20	$3\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{H}_2\text{O}_2$	+0.68
21	$\text{Fe}^{3+} + \text{e}^- \rightleftharpoons \text{Fe}^{2+}$	+0.77
22	$\text{Ag}^+ + \text{e}^- \rightleftharpoons \text{Ag}$	+0.80
23	$\text{NO}_3^- + 2\text{H}^+ + \text{e}^- \rightleftharpoons \text{NO}_2 + \text{H}_2\text{O}$	+0.80
24	$\text{ClO}^- + \text{H}_2\text{O} + 2\text{e}^- \rightleftharpoons \text{Cl}^- + 2\text{OH}^-$	+0.89
25	$\text{VO}_2^+ + 2\text{H}^+ + \text{e}^- \rightleftharpoons \text{VO}^{2+} + \text{H}_2\text{O}$	+1.00
26	$\frac{1}{2}\text{Br}_2 + \text{e}^- \rightleftharpoons \text{Br}^-$	+1.09
27	$\frac{1}{2}\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{H}_2\text{O}$	+1.23
28	$\frac{1}{2}\text{Cr}_2\text{O}_7^{2-} + 7\text{H}^+ + 3\text{e}^- \rightleftharpoons \text{Cr}^{3+} + \frac{7}{2}\text{H}_2\text{O}$	+1.33
29	$\frac{1}{2}\text{Cl}_2 + \text{e}^- \rightleftharpoons \text{Cl}^-$	+1.36
30	$\text{MnO}_4^- + 8\text{H}^+ + 5\text{e}^- \rightleftharpoons \text{Mn}^{2+} + 4\text{H}_2\text{O}$	+1.51
31	$\frac{1}{2}\text{H}_2\text{O}_2 + \text{H}^+ + \text{e}^- \rightleftharpoons \text{H}_2\text{O}$	+1.77

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