GCE A LEVEL

eduqas
Part of WJEC

# WJEC Eduqas GCE A LEVEL in CHEMISTRY

ACCREDITED BY OFQUAL


# SPECIFICATION

Teaching from 2015
For award from 2017

Version 2 January 2019

wjec cbac

This Ofqual regulated qualification is not available for candidates in maintained schools and colleges in Wales.

# SUMMARY OF AMENDMENTS

| Version | Description | Page number |
|---|---|---|
| 2 | ‘Arrangements for non-exam assessment' section has been amended to clarify requirements. | 44 – 46 |
| | 'Making entries' section has been amended to clarify resit rules and carry forward of NEA endorsement grade. | 47 |

# WJEC Eduqas GCE A LEVEL in CHEMISTRY

## For teaching from 2015
## For award from 2017

# A LEVEL Chemistry

## SUMMARY OF ASSESSMENT

**Component 1: Physical and Inorganic Chemistry**
Written examination: **2 hours 30 minutes (120 marks)**
**40% of qualification**

Section A: short answer questions – 15 marks

Section B: structured and extended answer questions set in a range of theoretical, practical and other contexts – 105 marks

Questions based on the knowledge and understanding outlined in the **Physical and Inorganic Chemistry** and **Core Ideas, Principles and Concepts** sections

**Component 2: Organic Chemistry and Analysis**
Written examination: **2 hours 30 minutes (120 marks)**
**40% of qualification**

Section A: short answer questions – 15 marks

Section B: structured and extended answer questions set in a range of theoretical, practical and other contexts – 105 marks

Questions based on the knowledge and understanding outlined in the **Organic Chemistry and Analysis** and **Core Ideas, Principles and Concepts** sections

**Component 3: Chemistry in Practice**
Written examination: **1 hour 15 minutes (60 marks)**
**20% of qualification**

Structured and extended answer questions with an emphasis on practical contexts and applications

Questions based on content from **Core Ideas, Principles and Concepts; Physical and Inorganic Chemistry** and **Organic Chemistry and Analysis**

**Practical endorsement**
Non-exam assessment

Assessment of practical competency

Reported separately and not contributing to final grade

This linear qualification will be available in the months of May and June of each year. It will be awarded for the first time in summer 2017.

**Qualification Accreditation Number: 601/5645/4**

# A LEVEL CHEMISTRY

# 1 INTRODUCTION

## 1.1 Aims and objectives

The WJEC Eduqas A level in Chemistry provides a broad, coherent, satisfying and worthwhile course of study. It encourages learners to develop confidence in, and a positive attitude towards, chemistry and to recognise its importance in their own lives and to society.

Studying this A level in Chemistry encourages learners to:

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

The specification lends itself to a variety of teaching and learning styles and offers learners of all abilities an enjoyable and positive learning experience.

Practical work is an intrinsic part of chemistry, and is greatly valued by higher education. It is imperative that practical skills are developed throughout the course and that an investigative approach is promoted wherever possible.

## 1.2 Prior learning and progression

Any requirements set for entry to a course following this specification are at the discretion of centres. It is reasonable to assume that many learners will have achieved qualifications equivalent to Level 2 at KS4. Skills in Numeracy/Mathematics, Literacy/English and Information Communication Technology will provide a good basis for progression to this Level 3 qualification.

The specification builds on the knowledge, understanding and skills set out in the GCSE criteria/content for science. Most learners will have followed chemistry at GCSE and all are expected to demonstrate knowledge and understanding of standard content covered at that level.

Mathematical requirements are specified in Appendix C of this specification.

This specification provides the required foundation for the study of chemistry in higher education, including Chemistry at degree level and in related areas such as Medicine, Biochemistry and Chemical Engineering. It also develops a range of knowledge and skills essential for direct entry into employment in many chemistry-related fields. In addition, the specification provides a coherent, satisfying and worthwhile course of study for candidates who do not progress to further study or employment related to chemistry.

This specification is not age specific and, as such, provides opportunities for candidates to extend their life-long learning.

## 1.3 Equality and fair assessment

This specification may be followed by any learner, irrespective of gender, ethnic, religious or cultural background. It has been designed to avoid, where possible, features that could, without justification, make it more difficult for a learner to achieve because they have a particular protected characteristic.

The protected characteristics under the Equality Act 2010 are age, disability, gender reassignment, pregnancy and maternity, race, religion or belief, sex and sexual orientation.

The specification has been discussed with groups who represent the interests of a diverse range of learners, and the specification will be kept under review.

Reasonable adjustments are made for certain learners in order to enable them to access the assessments (e.g. candidates are allowed access to a Sign Language Interpreter, using British Sign Language). Information on reasonable adjustments is found in the following document from the Joint Council for Qualifications (JCQ): *Access Arrangements, Reasonable Adjustments and Special Consideration: General and Vocational Qualifications.*

This document is available on the JCQ website (www.jcq.org.uk). As a consequence of provision for reasonable adjustments, very few learners will have a complete barrier to any part of the assessment.

# 2 SUBJECT CONTENT

This section outlines the knowledge, understanding and skills to be developed by learners studying A level Chemistry. Learners should be prepared to apply the knowledge, understanding and skills specified in a range of theoretical, practical, industrial and environmental contexts. It is a requirement of all A level specifications that learners must demonstrate a holistic understanding of the links between different areas of content. In practice this means that questions set in any component may require learners to draw upon knowledge from other parts of the specification.

Each topic area includes an overview outlining the content and how it contributes to the wider aims of the specification. Knowledge of specific contexts and/or examples included in the overview will not be directly assessed.

Practical work is an intrinsic part of this specification. It is vitally important in developing a conceptual understanding of many topics and it enhances the experience and enjoyment of chemistry. The practical skills developed are also fundamentally important to learners going on to further study in chemistry and related subjects, and are transferable to many careers. This section includes **specified practical work** that **must** be undertaken by learners in order that they are suitably prepared for the written examinations. The completion of this practical work will develop the practical skills listed in Appendix A. The requirements of the practical endorsement are detailed in Section 3.2. Appendix B lists the specified practical tasks that facilitate development of each of the required practical techniques.

Individual topic areas include details of the mathematical skills to be developed through that content. Appendix C lists the mathematical requirements with exemplification in the context of A level Chemistry and some topic areas which provide opportunities for their development.

The specification provides wide-ranging opportunities to increase learners' awareness and understanding of How Science Works. Content should be introduced in such a way that it develops learners' ability to:

- use theories, models and ideas to develop scientific explanations
- use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas
- use appropriate methodology, including information and communication technology (ICT), to answer scientific questions and solve scientific problems
- carry out experimental and investigative activities, including appropriate risk management, in a range of contexts
- analyse and interpret data to provide evidence, recognising correlations and causal relationships
- evaluate methodology, evidence and data, and resolve conflicting evidence
- know that scientific knowledge and understanding develops over time

- communicate information and ideas in appropriate ways using appropriate terminology
- consider applications and implications of science and evaluate their associated benefits and risks
- consider ethical issues in the treatment of humans, other organisms and the environment
- evaluate the role of the scientific community in validating new knowledge and ensuring integrity
- evaluate the ways in which society uses science to inform decision making.

Individual topic areas include a list detailing which of these skills could be developed through that particular content and Appendix D shows a sample of coverage.

**Subject content is defined in three sections:**

- **Core Ideas, Principles and Concepts** (outlines the content required as the foundation on which deeper understanding is built in subsequent study)
  **Topic C1 The language of chemistry and structure of matter**
  **Topic C2 Chemical change**
  **Topic C3 Chemistry of carbon compounds**

- **Physical and Inorganic Chemistry**
  **Topic PI1 Electrochemistry**
  **Topic PI2 More complex patterns of the Periodic Table**
  **Topic PI3 Chemical kinetics**
  **Topic PI4 Energy changes**
  **Topic PI5 Equilibria**

- **Organic Chemistry and Analysis**
  **Topic OA1 Higher concepts in organic chemistry**
  **Topic OA2 Organic compounds containing oxygen**
  **Topic OA3 Organic compounds containing nitrogen**
  **Topic OA4 Organic synthesis and analysis**

## CORE IDEAS, PRINCIPLES AND CONCEPTS

**Topic C1 The language of chemistry and structure of matter**



### C1.1 Formulae and equations

**Overview**
The ability to represent reactions using chemical formulae and equations is an essential part of communicating knowledge and understanding in chemistry. This skill is of course required throughout the specification.

**Mathematical Skills**
Leaners will develop their ability to use ratios by writing chemical formulae and constructing balanced chemical equations.

**How Science Works**
There are opportunities here for learners to:
use theories, models and ideas to develop scientific explanations;
communicate information and ideas in appropriate ways using appropriate terminology.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) formulae of common compounds and common ions and how to write formulae for ionic compounds

(b) oxidation numbers of atoms in a compound or ion

(c) how to construct balanced chemical equations, including ionic equations, with appropriate use of state symbols

## C1.2 Basic ideas about atoms

**Overview**
The study of the structure of the atom is essential to understanding chemical reactions and radioactivity. There is an opportunity here to consider how the model of the atom has developed over time and how different models can be useful in explaining different observations.

**Mathematical Skills**
Learners will develop their ability to:
use ratios by solving problems on half-life of radioactive decay;
use expressions in decimal and standard form, use powers, change the subject of an equation and substitute values into an equation in frequency/energy calculations.

**How Science Works**
There are opportunities here for learners to:
use theories, models and ideas to develop scientific explanations;
know that scientific knowledge and understanding develops over time;
consider applications and implications of science and evaluate their associated benefits and risks;
consider ethical issues in the treatment of humans, other organisms and the environment.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) nature of radioactive decay and the resulting changes in atomic number and mass number (including positron emission and electron capture)

(b) behaviour of $\alpha$-, $\beta$- and $\gamma$-radiation in electric and magnetic fields and their relative penetrating power

(c) half-life of radioactive decay

(d) adverse consequences for living cells of exposure to radiation and use of radioisotopes in many contexts, including health, medicine, radio-dating, industry and analysis

(e) significance of standard molar ionisation energies of gaseous atoms and their variation from one element to another

(f) link between successive ionisation energy values and electronic structure

(g) shapes of *s*- and *p*-orbitals and order of *s*-, *p*- and *d*-orbital occupation for elements 1-36

(h) origin of emission and absorption spectra in terms of electron transitions between atomic energy levels

(i) atomic emission spectrum of the hydrogen atom

(j) relationship between energy and frequency ($E = hf$) and that between frequency and wavelength ($f = c/\lambda$)

(k) order of increasing energy of infrared, visible and ultraviolet light

(l) significance of the frequency of the convergence limit of the Lyman series and its relationship with the ionisation energy of the hydrogen atom

## C1.3 Chemical calculations

**Overview**
An understanding of the amount of substance is fundamental to all chemical reactions. The majority of calculations appearing here are relevant throughout the course.

**Mathematical Skills**
Learners will develop their ability to:
find arithmetic means by calculating relative atomic mass from mass spectrum data
use ratios and percentages by solving empirical formula problems and calculating atom economy and yield of a reaction;
recognise and make use of units in calculations involving amounts of substance;
use powers in calculations using the Avogadro constant;
change the subject of an equation and substitute values into an equation in calculations relating to acid-base titrations and ideal gases;
estimate approximate volume required to reach a titration end-point;
select appropriate data to calculate mean titres;
use an appropriate number of significant figures in all calculations;
identify uncertainty in acid-base titration data.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) relative mass terms (atomic, isotopic, formula, molecular)

(b) principles of the mass spectrometer and its use in determining relative atomic mass and relative abundance of isotopes

(c) simple mass spectra, for example, that of chlorine gas

(d) how empirical and molecular formulae can be determined from given data

(e) relationship between the Avogadro constant, the mole and molar mass

(f) relationship between grams and moles

(g) concept of concentration and its expression in terms of grams or moles per unit volume (including solubility)

(h) molar volume and correction due to changes in temperature and pressure

(i) ideal gas equation ($pV = nRT$)

(j) concept of stoichiometry and its use in calculating reacting quantities, including in acid-base titrations

(k) concepts of atom economy and percentage yield

(l) how to estimate the percentage error in a measurement and use this to express numeric answers to the appropriate number of significant figures

## C1.4 Bonding

**Overview**
An understanding of bonding is fundamental in explaining why chemical reactions happen. This topic considers the electronic changes that take place in the formation of stable structures. These ideas will be referred to throughout the specification.

**Mathematical Skills**
Leaners will develop their ability to predict bond angles and shapes of molecules and to represent these shapes in 2D and 3D.

**How Science Works**
There are opportunities here for learners to:
use theories, models and ideas to develop scientific explanations;
communicate information and ideas in appropriate ways using appropriate terminology.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) ionic bonding in terms of ion formation and the interaction between positive and negative ions in an ionic crystal

(b) covalent bonding, including coordinate bonding, in terms of the sharing of electrons and the balance of forces of attraction and repulsion within the molecule

(c) intermediate character of many bonds between purely ionic and purely covalent

(d) concepts of electronegativity and bond polarity

(e) forces between molecules being much weaker than covalent (and ionic) bonds

(f) permanent and temporary dipoles and their relative effects on physical properties, such as boiling temperature and solubility

(g) hydrogen bonding and its effect on physical properties, such as boiling temperature and solubility

(h) VSEPR principle and its use in predicting the shapes of simple molecules and ions

(i) bond angles associated with linear, trigonal planar, tetrahedral and octahedral molecules and ions

## C1.5 Solid structures

### Overview
This section relates the structures and properties of different types of solids to the bonding present within them. A thorough understanding of the differences between atoms, ions and molecules and of the difference between interactions within and between molecules is essential. A broader understanding could be developed by looking at the structures and properties of novel materials such as smart materials and 'bucky ball' structures.

### How Science Works
There are opportunities here for learners to:
use theories, models and ideas to develop scientific explanations;
communicate information and ideas in appropriate ways using appropriate terminology;
evaluate the role of the scientific community in validating new knowledge and ensuring integrity.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) crystal structures of sodium chloride and caesium chloride

(b) structures of diamond and graphite

(c) structures of iodine and ice

(d) 'electron sea' model for bonding in metals

(e) relationship between physical properties (for example, melting temperature, solubility, hardness and electrical conductance) and structure and bonding in ionic compounds, giant molecular substances, simple molecular substances and metals

## C1.6 The Periodic Table

**Overview**
The location of the elements in the Periodic Table can be explained by their atomic structure, which in turn can be utilised to explain trends and patterns down groups and across periods. Consideration should be given to the fact that the modern form of the Periodic Table developed over time with separate advances made by several scientists. There are ample opportunities here to carry out a range of practical work, including qualitative and quantitative problem-solving tasks. Recall of reactions studied at GCSE is assumed prior knowledge, e.g., Group 1 metals with water and Group 2 metals with dilute acids.

**Mathematical Skills**
Learners will develop their ability to change the subject of an equation and substitute values into an equation in calculations relating to gravimetric analysis.

**How Science Works**
There are opportunities here for learners to:
use theories, models and ideas to develop scientific explanations;
use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas;
carry out experimental and investigative activities;
know that scientific knowledge and understanding develops over time.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) elements being arranged according to atomic number in the Periodic Table

(b) electronic structures of the elements relate to their position in the *s*-, *p*- and *d*-blocks of the Periodic Table

(c) oxidation and reduction in terms of electron transfer in reactions of *s*-, *p*- and *d*-block elements/compounds/ions

(d) general trends in ionisation energy, melting temperature and electronegativity across periods and down groups

(e) reactions of Group 2 elements with oxygen and water/steam

(f) reactions of the aqueous cations $Mg^{2+}$, $Ca^{2+}$ and $Ba^{2+}$ with $OH^-$, $CO_3^{2-}$ and $SO_4^{2-}$ ions

(g) characteristic flame colours shown by compounds of Li, Na, K, Ca, Sr and Ba (Mg compounds show no colour)

(h) trend in general reactivity of Group 1 and Group 2 metals

(i) trend in thermal stability of the Group 2 carbonates and hydroxides

(j) trends in solubility of Group 2 hydroxides and sulfates

(k) basic character of the oxides and hydroxides of Group 1 and Group 2 metals

(l) trend in volatility of Group 7 elements (halogens)

(m) reactions of the halogens with metals

(n) trend in reactivity of the halogens in terms of relative oxidising power

(o) reaction between aqueous $Ag^+$ and halide ions followed by dilute aqueous $NH_3$

(p) displacement reactions of halogens in terms of redox

(q) use of chlorine and fluoride ions in water treatment and the related health and ethical issues

(r) soluble salt formation and crystallisation, insoluble salt formation by precipitation and simple gravimetric analysis

**SPECIFIED PRACTICAL WORK**

- Gravimetric analysis, for example, by precipitation of a Group 2 metal carbonate or a metal chloride
- Identification of unknown solutions by qualitative analysis

**Topic C2 Chemical change**

**C2.1 Simple equilibria and acid-base reactions**
**C2.2 Thermochemistry**
**C2.3 Rates of reaction**
**C2.4 The wider impact of chemistry**

## C2.1 Simple equilibria and acid-base reactions

**Overview**
The concept of equilibrium could be introduced in the context of industrial processes such as the Haber and contact processes and developed in more depth by consideration of the effects of ocean acidification on the carbonate/hydrogencarbonate system. Acid-base reactions provide extensive opportunities for quantitative practical work linking with key chemical calculations. Recall of the reactions of dilute acids with bases and carbonates is assumed prior knowledge.

**Mathematical Skills**
Learners will develop their ability to:
estimate results when evaluating the effect of changing temperature on the value of $K_c$;
change the subject of an equation and substitute values into an equation in calculations relating to acid-base titrations and equilibrium constant, $K_c$;
estimate approximate volume required to reach a titration end-point;
select appropriate data to calculate mean titres;
use an appropriate number of significant figures in all calculations;
identify uncertainty in acid-base titration data;
use a calculator to solve logarithmic functions in simple pH calculations.

**How Science Works**
There are opportunities here for learners to:
use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas;
use appropriate methodology, including information and communication technology, to answer scientific questions and solve scientific problems;
carry out experimental and investigative activities, including appropriate risk management, in a range of contexts.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) reversible reactions and dynamic equilibrium

(b) Le Chatelier's principle in deducing the effect of changes in temperature, concentration and pressure

(c) equilibrium constant ($K_c$) and calculations involving given equilibrium concentrations

(d) acids as donors of $H^+(aq)$ and bases as acceptors of $H^+(aq)$

(e) relationship between pH and $H^+(aq)$ ion concentration ($pH = -\log[H^+(aq)]$)

(f) acid-base titrations

(g) difference between strong acids and weak acids in terms of relative dissociation

## SPECIFIED PRACTICAL WORK

- Preparation of a soluble salt by titration
- Standardisation of an acid solution
- Back titration, for example, determination of the percentage of calcium carbonate in limestone
- Double titration, for example, analysis of a mixture of sodium hydroxide and sodium carbonate

## C2.2 Thermochemistry

**Overview**
A quantitative approach to the energy changes taking place during both chemical and physical processes is used to explain why some changes are exothermic and others endothermic. This is supported by a variety of practical work which offers opportunities for evaluation of methodology and data.

**Mathematical Skills**
Learners will develop their ability to:
change the subject of an equation, substitute values into an equation and solve algebraic equations in Hess's law calculations and in calculating enthalpy changes from experimental data;
translate information between graphical and numerical data and plot data from simple procedures to determine enthalpy changes.

**How Science Works**
There are opportunities here for learners to:
use appropriate methodology, including information and communication technology, to answer scientific questions and solve scientific problems;
carry out experimental and investigative activities, including appropriate risk management, in a range of contexts;
evaluate methodology, evidence and data, and resolve conflicting evidence.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) enthalpy change of reaction, enthalpy change of combustion and standard molar enthalpy change of formation, $\Delta_f H^\ominus$

(b) Hess's law and energy cycles

(c) concept of average bond enthalpies and how they are used to carry out simple calculations

(d) how to calculate enthalpy changes

(e) simple procedures to determine enthalpy changes

**SPECIFIED PRACTICAL WORK**

- Indirect determination of an enthalpy change of reaction, for example, for magnesium oxide and carbon dioxide to form magnesium carbonate
- Determination of an enthalpy change of combustion

## C2.3 Rates of reaction

**Overview**
Chemical reactions are monitored in various ways to determine rates of reaction. A particle approach is used to explain changes to rate during a reaction and changes occurring as a result of varying conditions. Practical work here presents the opportunity to plan a range of approaches and data collection methods and therefore good scope for evaluation.

**Mathematical Skills**
Learners will develop their ability to translate information between graphical and numerical data, plot data from simple procedures and find gradients in determining reaction rate.

**How Science Works**
There are opportunities here for learners to:
use theories, models and ideas to develop scientific explanations;
use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas;
use appropriate methodology, including information and communication technology, to answer scientific questions and solve scientific problems;
carry out experimental and investigative activities, including appropriate risk management, in a range of contexts;
analyse and interpret data to provide evidence, recognising correlations and causal relationships;
evaluate methodology, evidence and data, and resolve conflicting evidence.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) collision theory in explaining the effects of changing conditions on reaction rate

(b) how to calculate rates from experimental data and how to establish the relationship between reactant concentrations and rate

(c) concepts of energy profiles and activation energy

(d) rapid increase in rate with temperature in terms of changes in the Boltzmann energy distribution curve

(e) characteristics of a catalyst

(f) how catalysts increase reaction rates by providing alternative routes of lower activation energy

(g) how colorimetry can be used in studies of some reaction rates

(h) measurement of reaction rate by gas collection and precipitation methods and by an ‘iodine clock’ reaction

**SPECIFIED PRACTICAL WORK**

- Investigation of a rate of reaction by a gas collection method
- Study of an ‘iodine clock’ reaction

## C2.4 The wider impact of chemistry

### Overview
This is an opportunity to reflect on how an understanding of chemical principles can be used to inform judgements on the correct balance between exploiting the Earth's natural resources and ensuring that future generations will not be adversely affected by our decisions. Should we develop the technologies to extract shale gas reserves in order to satisfy energy needs or should low-carbon energy be the focus?

### How Science Works
There are opportunities here for learners to:
use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas;
analyse and interpret data to provide evidence, recognising correlations and causal relationships;
consider applications and implications of science and evaluate their associated benefits and risks;
consider ethical issues in the treatment of humans, other organisms and the environment;
evaluate the role of the scientific community in validating new knowledge and ensuring integrity.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) social, economic and environmental impact of chemical synthesis and the production of energy

(b) role of green chemistry in improving sustainability in all aspects of developments

**Topic C3 Chemistry of carbon compounds**

**C3.1 Organic compounds**
**C3.2 Hydrocarbons**
**C3.3 Halogenoalkanes**
**C3.4 Alcohols and carboxylic acids**
**C3.5 Instrumental analysis**

## C3.1 Organic compounds

**Overview**
This topic provides the foundation skills and knowledge, including the representation and naming of organic structures, required to study organic chemistry.

**Mathematical Skills**
Learners will develop their ability to represent 3D forms in 2D and 3D in exploring structural isomerism.

**How Science Works**
There are opportunities here for learners to:
use theories, models and ideas to develop scientific explanations;
communicate information and ideas in appropriate ways using appropriate terminology.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) how to represent simple organic compounds using shortened, displayed and skeletal formulae

(b) nomenclature rules relating to alkanes, alkenes, halogenoalkanes, alcohols and carboxylic acids

(c) effect of increasing chain length and the presence of functional groups on melting/boiling temperature and solubility

(d) concept of structural isomerism

(e) description of species as electrophiles, nucleophiles and radicals and bond fission as homolytic or heterolytic

## C3.2 Hydrocarbons

**Overview**
This topic considers saturated and unsaturated hydrocarbons derived from the petroleum industry and their respective uses as fuels and in making plastics. Particular attention is given to understanding the very different ways is which alkanes and alkenes react.

**Mathematical Skills**
Learners will develop their ability to understand the symmetry of 3D shapes in studying *E–Z* isomerism.

**How Science Works**
There are opportunities here for learners to:
communicate information and ideas in appropriate ways using appropriate terminology;
consider applications and implications of science and evaluate their associated benefits and risks;
consider ethical issues in the treatment of humans, other organisms and the environment
evaluate the ways in which society uses science to inform decision making.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) combustion reaction of alkanes and benefits and drawbacks relating to the use of fossil fuels, including formation of carbon dioxide, acidic gases and carbon monoxide

(b) C—C and C—H bonds in alkanes as σ-bonds

(c) mechanism of radical substitution, such as the photochlorination of alkanes

(d) difference in reactivity between alkanes and alkenes in terms of the C=C bond as a region of high electron density

(e) C=C bond in ethene and other alkenes as comprising π-bond and σ-bond

(f) *E–Z* isomerism in terms of restricted rotation about a carbon-carbon double bond

(g) mechanism of electrophilic addition, such as in the addition of $Br_2$ to ethene, as a characteristic reaction of alkenes

(h) bromine/bromine water and potassium manganate(VII) tests for alkenes

(i) orientation of the normal addition of HBr to propene in terms of the relative stabilities of the possible carbocations involved

(j) conditions required for the catalytic hydrogenation of ethene and relevance of this reaction

(k) nature of addition polymerisation and the economic importance of the polymers of alkenes and substituted alkenes

## C3.3 Halogenoalkanes

**Overview**
Nucleophilic substitution, including the factors that affect its rate, is considered here as the characteristic reaction of halogenoalkanes. This type of reaction is an important step in chemical synthesis and is carried out in the laboratory by refluxing. Important properties of halogenoalkanes are also discussed.

**How Science Works**
There are opportunities here for learners to:
carry out experimental and investigative activities, including appropriate risk assessments;
communicate information and ideas in appropriate ways using appropriate terminology;
consider applications and implications of science and evaluate their associated benefits and risks;
consider ethical issues in the treatment of humans, other organisms and the environment
evaluate the ways in which society uses science to inform decision making.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) elimination reaction of halogenoalkanes forming alkenes, for example, HBr eliminated from 1-bromopropane to form propene

(b) mechanism of nucleophilic substitution, such as in reaction between $OH^-$(aq) and primary halogenoalkanes

(c) effect of bond polarity and bond enthalpy on the ease of substitution of halogenoalkanes

(d) hydrolysis/$Ag^+$(aq) test for halogenoalkanes

(e) halogenoalkanes as solvents, anaesthetics and refrigerants, and tight regulation of their use due to toxicity or adverse environmental effects

(f) adverse environmental effects of CFCs and the relevance of the relative bond strengths of C–H, C–F and C–Cl in determining their impact in the upper atmosphere

(g) how to carry out a reflux (for example, for nucleophilic substitution reaction of halogenoalkanes with hydroxide ions)

**SPECIFIED PRACTICAL WORK**

- Nucleophilic substitution reaction, for example, 1-bromobutane with aqueous sodium hydroxide

## C3.4 Alcohols and carboxylic acids

**Overview**
Reactions of two groups of oxygen-containing compounds are considered here, including the oxidation of an alcohol to a carboxylic acid and the reaction of one with the other to form an ester. Each of these reactions can be carried out in the laboratory. This is the first opportunity to use a distillation apparatus.

**How Science Works**
There are opportunities here for learners to carry out experimental and investigative activities, including appropriate risk assessments.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) industrial preparation of ethanol from ethene

(b) preparation of ethanol and other alcohols by fermentation followed by distillation, and issues relating to the use of biofuels

(c) dehydration reactions of alcohols

(d) classification of alcohols as primary, secondary and tertiary

(e) oxidation of primary alcohols to aldehydes/carboxylic acids and secondary alcohols to ketones

(f) dichromate(VI) test for primary/secondary alcohols and sodium hydrogencarbonate test for carboxylic acids

(g) reactions of carboxylic acids with bases, carbonates and hydrogencarbonates forming salts

(h) esterification reaction that occurs when a carboxylic acid reacts with an alcohol

(i) separation by distillation

**SPECIFIED PRACTICAL WORK**

- Preparation of an ester and separation by distillation

## C3.5 Instrumental analysis

**Overview**
An introduction to the spectroscopic techniques that have replaced chemical tests in many applications in recent years, e.g. in the drivers' breathalyser test. The focus here should be on data interpretation in order to identify a compound's key characteristics and to draw conclusions together in finding its structure.

**Mathematical Skills**
Learners will develop their ability to translate information between graphical and numerical forms while analysing and interpreting spectra.

**How Science Works**
There are opportunities here for learners to:
use appropriate methodology, including information and communication technology (ICT) to answer scientific questions and solve scientific problems
analyse and interpret data to provide evidence, recognising correlations and causal relationships.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) use of mass spectra in identification of chemical structure

(b) use of IR spectra in identification of chemical structure

(c) use of $^{13}C$ and low resolution $^{1}H$ NMR spectra in identification of chemical structure

## PHYSICAL AND INORGANIC CHEMISTRY

**Topic PI1 Electrochemistry**

**PI1.1 Redox and standard electrode potential**
**PI1.2 Redox reactions**

### PI1.1 Redox and standard electrode potential

**Overview**

This topic develops the links between position in the Periodic Table, reactivity and redox reactions. There are opportunities here to consider developments in cell technologies and the corrosion of metals, including iron, and its economic impact.

**Mathematical Skills**
Learners will develop their ability to solve algebraic equations in calculating cell values for cell EMF.

**How Science Works**
There are opportunities here for learners to:
use theories, models and ideas to develop scientific explanations;
use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas
carry out experimental and investigative activities, including appropriate risk assessments;
communicate information and ideas in appropriate ways using appropriate terminology;
consider applications and implications of science and evaluate their associated benefits and risks;
evaluate the role of the scientific community in validating new knowledge and ensuring integrity.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) redox reactions in terms of electron transfer

(b) how to represent redox systems in terms of ion/electron half-equations and as half-cells in cell diagrams

(c) concept of standard electrode potential and role of the standard hydrogen electrode

(d) how simple electrochemical cells are formed by combining electrodes (metal/metal ion electrodes and electrodes based on different oxidation states of the same element)

(e) concept of cell EMF and its significance in terms of the feasibility of reactions

(f) principles of the hydrogen fuel cell and its benefits and drawbacks

**SPECIFIED PRACTICAL WORK**

- Construction of electrochemical cells and measurement of $E_{cell}$

## PI1.2 Redox reactions

### Overview

Further development of the understanding of redox reactions encompassing theoretical and practical aspects of titrimetric analysis. Many of these reactions are self-indicating as a result of involving *d*-block compounds. They are very useful in analysis in many environmental and industrial contexts.

**Mathematical Skills**
Learners will develop their ability to:
recognise and make use of units in calculations involving amounts of substance;
change the subject of an equation, substitute values into an equation and solve algebraic equations in calculations relating to redox titrations;
estimate approximate volume required to reach a titration end-point;
select appropriate data to calculate mean titres;
use an appropriate number of significant figures in all calculations;
identify uncertainty in redox titration data.

**How Science Works**
There are opportunities here for learners to:
use appropriate methodology, including information and communication technology (ICT) to answer scientific questions and solve scientific problems
carry out experimental and investigative activities, including appropriate risk assessments;
communicate information and ideas in appropriate ways using appropriate terminology.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) how to construct ion/electron half-equations, for example, for the reduction of acidified $Cr_2O_7^{2-}$ to $Cr^{3+}$ and acidified $MnO_4^-$ to $Mn^{2+}$ and the oxidation of $S_2O_3^{2-}$ to $S_4O_6^{2-}$

(b) how to combine half-equations to give a stoichiometric redox equation

(c) redox reaction between $Cu^{2+}$ and $I^-$ and the determination of the liberated iodine with $S_2O_3^{2-}$

(d) how to carry out a redox titration

**SPECIFIED PRACTICAL WORK**

- Simple redox titration
- Estimation of copper in copper(II) salts

**Topic PI2 More complex patterns of the Periodic Table**

**PI2.1 Chemistry of the *p*-block**
**PI2.2 Chemistry of the *d*-block transition metals**

## PI2.1 Chemistry of the *p*-block

### Overview

This topic develops a deeper understanding of the role of electronic configuration in trends in reactivity – from non-metallic behaviour at the top of groups to metallic behaviour at the bottom. The amphoteric nature of some elements can be seen in simple test tube reactions and are useful in exercises to identify unknown compounds.

### How Science Works

There are opportunities here for learners to:
use theories, models and ideas to develop scientific explanations;
carry out experimental and investigative activities, including appropriate risk assessments;
communicate information and ideas in appropriate ways using appropriate terminology;
consider applications and implications of science and evaluate their associated benefits and risks.

### Learners should be able to demonstrate and apply their knowledge and understanding of

(a) amphoteric behaviour of *p*-block elements as demonstrated by the reactions of $Al^{3+}$/Al and $Pb^{2+}$/Pb

(b) increasing stability of the inert pair cations on descent of Groups 3, 4 and 5

(c) how some Group 3 elements can form compounds with fewer than eight electrons in their valence shells and some elements of Groups 5, 6 and 7 can form compounds with more than eight

(d) structure and bonding in $Al_2Cl_6$ and formation of donor-acceptor compounds such as $NH_3.BF_3$

(e) bonding and structure in hexagonal and cubic boron nitride and how these relate to their properties and uses

(f) change in relative stability of oxidation states II and IV down Group 4 as shown by reactions of CO as a reducing agent with oxides and Pb(IV) as an oxidising agent in the reaction of $PbO_2$ with concentrated hydrochloric acid

(g) nature, physical properties and acid-base properties of $CO_2$ and PbO

(h) change in the types of bonding down Group 4 as shown by the chlorides $CCl_4$, $SiCl_4$ and $PbCl_2$ and their reactions with water

(i) reactions of $Pb^{2+}$(aq) with aqueous NaOH, $Cl^-$ and $I^-$

(j) reactions of $Cl_2$ with both cold and warm aqueous NaOH and the various disproportionation reactions involved

(k) bleaching and bactericidal action of $Cl_2$ and chlorate(I) ($ClO^-$) resulting from their oxidising power

(l) differences in behaviour of NaCl, NaBr and NaI with concentrated sulfuric acid (formation and subsequent reactions of HX)

## PI2.2 Chemistry of the *d*-block transition metals

### Overview

A study of the defining properties of transition metals and their compounds focusing on understanding the origin of colour in their complexes and their catalytic activity which is so important in industrial processes.

**Mathematical Skills**
Learners will develop their ability to predict bond angles in octahedral and tetrahedral complexes and to represent these shapes in 3D.

**How Science Works**
There are opportunities here for learners to:
use theories, models and ideas to develop scientific explanations;
communicate information and ideas in appropriate ways using appropriate terminology;
consider applications and implications of science and evaluate their associated benefits and risks.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) how the *d*-block elements attain various oxidation states in their compounds

(b) the most important oxidation states of Cr, Mn, Fe, Co and Cu and the colours of aqueous solutions of compounds containing $Cr^{3+}$, $CrO_4^{2-}$, $Cr_2O_7^{2-}$, $MnO_4^{-}$, $Co^{2+}$, $Fe^{2+}$, $Fe^{3+}$ and $Cu^{2+}$

(c) bonding in tetrahedral and octahedral complexes

(d) origin of colour in transition metal complexes, as exemplified by octahedral 6-coordinate species such as $[Cu(H_2O)_6]^{2+}$ and $[Fe(H_2O)_6]^{3+}$, in terms of the splitting of d-orbitals

(e) idea of ligand exchange and how this can lead to a change in coordination number as exemplified by the reactions of $[Cu(H_2O)_6]^{2+}$ and $[Co(H_2O)_6]^{2+}$ with concentrated HCl

(f) colours and formulae of the approximately octahedral complex ions $[Cu(H_2O)_6]^{2+}$, $[Cu(NH_3)_4(H_2O)_2]^{2+}$ and $[Co(H_2O)_6]^{2+}$ and the approximately tetrahedral ions $[CuCl_4]^{2-}$ and $[CoCl_4]^{2-}$

(g) catalytic properties of many transition metals and their compounds; heterogeneous catalysis as a result of surface adsorption and homogeneous catalysis as a result of variable oxidation state

(h) nickel and iron as the catalysts used in the hydrogenation of alkenes and the Haber process respectively

(i) vanadium(V) oxide as the catalyst used in the contact process and manganese(IV) oxide as an effective catalyst for the decomposition of hydrogen peroxide

(j) reactions of $Cr^{3+}$, $Fe^{2+}$, $Fe^{3+}$ and $Cu^{2+}$ with excess aqueous $OH^-$

## Topic PI3 Chemical kinetics

**Overview**

This topic develops a quantitative approach to measurement of reaction rates and an understanding of the use of rate information in the wider context of reaction mechanism.

**Mathematical Skills**
Learners will develop their ability to:
make use of appropriate units and decimal and standard form;
use ratios to establish reaction order from experimental results;
change the subject of an equation, substitute values into an equation and solve algebraic equations in using the general rate equation;
translate information between graphical, numerical and algebraic forms, plot variables from experimental data, use the slope of a straight line and the tangent of a curve in rate calculations;
determine the slope and intercept of a linear graph and use logarithms in problems based on the Arrhenius equation.

**How Science Works**
There are opportunities here for learners to:
use theories, models and ideas to develop scientific explanations;
use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas
use appropriate methodology, including information and communication technology (ICT) to answer scientific questions and solve scientific problems
carry out experimental and investigative activities, including appropriate risk assessments;
analyse and interpret data to provide evidence, recognising correlations and causal relationships;
evaluate methodology, evidence and data, and resolve conflicting evidence;
communicate information and ideas in appropriate ways using appropriate terminology.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) principles underlying the measurement of reaction rate by sampling and quenching

(b) how reaction order is found from experimental results

(c) the general rate equation and how it is used

(d) concept of a rate determining step

(e) link between reaction kinetics and mechanism

(f) the Arrhenius equation to show the effect of changing temperature and the use of a catalyst on the rate constant, and to find the activation energy and frequency factor of a reaction

**SPECIFIED PRACTICAL WORK**

- Determination of the order of a reaction, for example, the oxidation of iodide ions by hydrogen peroxide in acid solution

**Topic PI4 Energy changes**

**PI4.1 Enthalpy changes for solids and solutions**
**PI4.2 Entropy and feasibility of reactions**

## PI4.1 Enthalpy changes for solids and solutions

### Overview

A more quantitative approach to the enthalpy changes involved in the formation of ionic compounds and in dissolving them in water. It leads on to asking why endothermic changes occur, e.g. why is ammonium chloride soluble?

**Mathematical Skills**
Learners will develop their ability to:
substitute values into an equation and solve algebraic equations in calculations relating to solubility and Born-Haber cycles;
translate information between graphical, numerical and algebraic forms in constructing and using Born-Haber cycles.

**How Science Works**
There are opportunities here for learners to:
use theories, models and ideas to develop scientific explanations;
communicate information and ideas in appropriate ways using appropriate terminology.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) enthalpy changes of atomisation, lattice formation and breaking, hydration and solution

(b) how solubility of ionic compounds in water (enthalpy change of solution) depends on the balance between the enthalpy change of lattice breaking and the hydration enthalpies of the ions

(c) processes involved in the formation of simple ionic compounds as described in a Born-Haber cycle

(d) exothermicity or endothermicity of $\Delta_f H^{\Theta}$ as a qualitative indicator of a compound's stability

## PI4.2 Entropy and feasibility of reactions

### Overview

This topic introduces entropy. It leads to an appreciation that both enthalpy and entropy influence the spontaneity of a reaction and that it is the value of the Gibbs free energy change that is required to predict whether or not a reaction occurs at a given temperature.

**Mathematical Skills**
Learners will develop their ability to:
recognise and make use of appropriate units in calculating entropy and Gibbs energy;
substitute values into an equation using appropriate units in calculating entropy and Gibbs energy;
change the subject of an equation and solve algebraic equations in applying the Gibbs equation.

**How Science Works**
There are opportunities here for learners to:
use theories, models and ideas to develop scientific explanations;
use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) entropy, $S$, of a system as a measure of the freedom possessed by particles within it and the increase in entropy towards a maximum for all natural changes

(b) particles in a solid having much less freedom than those in a gas and that, other factors being equal, entropy increasing in the sequence $S$(gas) > $S$(liquid) > $S$(solid)

(c) how to calculate an entropy change from absolute entropy values, $\Delta S = S_{\text{final}} - S_{\text{initial}}$

(d) concept of Gibbs free energy change and how it is calculated using the relationship, $\Delta G = \Delta H - T\Delta S$

(e) spontaneous reactions having a negative value for $\Delta G$ and how the effect of entropy change explains the spontaneous occurrence of endothermic processes

**Topic PI5 Equilibria**

**PI5.1 Equilibrium constants**
**PI5.2 Acid-base equilibria**

## PI5.1 Equilibrium constants

### Overview

This topic introduces the quantitative approach to equilibria and gives the opportunity to use equilibrium constants to understand the manipulation of equilibrium positions in reactions occurring in industrial processes.

**Mathematical Skills**
Learners will develop their ability to:
recognise and make use of appropriate units in calculating values of $K_p$ and $K_c$;
change the subject of an equation, substitute values into an equation and solve algebraic equations in calculating values of $K_p$ and $K_c$.

**How Science Works**
There are opportunities here for learners to:
use theories, models and ideas to develop scientific explanations;
carry out experimental and investigative activities, including appropriate risk assessments;
analyse and interpret data to provide evidence, recognising correlations and causal relationships;
communicate information and ideas in appropriate ways using appropriate terminology.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) effect of temperature on $K_p$ and $K_c$ for exothermic and endothermic reactions

(b) how to calculate values of $K_p$ and $K_c$ and quantities present at equilibrium from given data

(c) significance of the magnitude of an equilibrium constant and how this relates to the position of equilibrium

**SPECIFIED PRACTICAL WORK**

- Determination of an equilibrium constant, for example, for the equilibrium established when ethanol reacts with ethanoic acid

## PI5.2 Acid-base equilibria

### Overview

This topic features the quantitative application of the principles of equilibria to acids and bases developing an understanding of the difference between strong and weak acids (and bases). Reactions involving living systems are pH dependent and buffer solutions of the required pH can be made by varying the concentrations of their components.

**Mathematical Skills**
Learners will develop their ability to:
use expressions in decimal and standard form and use calculators to use power and logarithmic functions in simple pH calculations and in more complex calculations relating to strong and weak acids and strong bases;
change the subject of an equation, substitute values into an equation and solve algebraic equations in simple and complex pH calculations.

**How Science Works**
There are opportunities here for learners to:
use theories, models and ideas to develop scientific explanations;
use appropriate methodology, including information and communication technology (ICT) to answer scientific questions and solve scientific problems
carry out experimental and investigative activities, including appropriate risk assessments;
analyse and interpret data to provide evidence, recognising correlations and causal relationships;
communicate information and ideas in appropriate ways using appropriate terminology;
consider applications and implications of science and evaluate their associated benefits and risks.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) Lowry-Bronsted theory of acids and bases

(b) differences in behaviour between strong and weak acids and bases in terms of the acid dissociation constant, $K_a$

(c) significance of the ionic product of water, $K_w$

(d) how to use pH, $K_w$, $K_a$ and p$K_a$ in calculations involving strong and weak acids and pH and $K_w$ in calculations involving strong bases

(e) shapes of the titration curves for strong acid/strong base, strong acid/weak base, weak acid/strong base and weak acid/weak base systems

(f) mode of action of buffer solutions and how to use pH, $K_w$, $K_a$ and p$K_a$ in appropriate calculations

(g) importance of buffer solutions in living systems and industrial processes

(h) concept of hydrolysis of salts of a strong acid/strong base, a strong acid/weak base and a weak acid/strong base

(i) how suitable indicators are selected for acid-base titrations

**SPECIFIED PRACTICAL WORK**

- Titration using a pH probe, for example, titration of a weak acid against a weak base

## ORGANIC CHEMISTRY AND ANALYSIS

**Topic OA1 Higher concepts in organic chemistry**

**OA1.1 Stereoisomerism**
**OA1.2 Aromaticity**

### OA1.1 Stereoisomerism

**Overview**

Optical isomerism is introduced as a second type of stereoisomerism, which gives the opportunity to explore 3D models in comparing isomers. The orientation of atoms about a chiral centre is critically important in the activity of biochemical compounds.

**Mathematical Skills**
Learners will develop their ability to visualise and represent 2D and 3D forms and understand the symmetry of 2D and 3D shapes in the study of *E*–*Z* isomerism and optical isomerism.

**How Science Works**
There are opportunities here for learners to:
use theories, models and ideas to develop scientific explanations;
use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas
analyse and interpret data to provide evidence, recognising correlations and causal relationships;
communicate information and ideas in appropriate ways using appropriate terminology;
consider applications and implications of science and evaluate their associated benefits and risks;
consider ethical issues in the treatment of humans, other organisms and the environment
evaluate the role of the scientific community in validating new knowledge and ensuring integrity
evaluate the ways in which society uses science to inform decision making.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) how stereoisomerism is distinct from structural isomerism and that stereoisomerism encompasses *E*–*Z* isomerism and optical isomerism

(b) the terms chiral centre, enantiomer, optical activity and racemic mixture

(c) optical isomerism in terms of an asymmetric carbon atom

(d) effect of an enantiomer on plane-polarised light

## OA1.2 Aromaticity

### Overview

This topic introduces the delocalisation of electrons leading to the energetically more stable aromatic structure found in benzene and similar compounds. Substitution by electrophiles is the characteristic reaction of benzene as this energy advantage is maintained.

**How Science Works**
There are opportunities here for learners to:
use theories, models and ideas to develop scientific explanations;
use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas
carry out experimental and investigative activities, including appropriate risk assessments;
evaluate methodology, evidence and data, and resolve conflicting evidence;
know that scientific knowledge and understanding develops over time;
communicate information and ideas in appropriate ways using appropriate terminology.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) structure of and bonding in benzene and other arenes

(b) resistance to addition reactions shown by aromatic compounds such as benzene

(c) mechanism of electrophilic substitution, such as in the nitration, halogenation and Friedel-Crafts alkylation of benzene, as the characteristic reaction of arenes

(d) interaction between benzene and substituent groups, as exemplified by the increase in C—Cl bond strength in chlorobenzene when compared with a chloroalkane

**Topic OA2 Organic compounds containing oxygen**

**OA2.1 Alcohols and phenols**
**OA2.2 Aldehydes and ketones**
**OA2.3 Carboxylic acids and their derivatives**

## OA2.1 Alcohols and phenols

### Overview

This topic builds upon the previous introduction of alcohols and includes phenols.

**How Science Works**
There are opportunities here for learners to:
use theories, models and ideas to develop scientific explanations;
carry out experimental and investigative activities, including appropriate risk assessments;
analyse and interpret data to provide evidence, recognising correlations and causal relationships;
communicate information and ideas in appropriate ways using appropriate terminology.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) methods of forming primary and secondary alcohols from halogenoalkanes and carbonyl compounds

(b) reactions of primary and secondary alcohols with hydrogen halides and ethanoyl chloride and carboxylic acids

(c) acidity of phenol and its reactions with bromine and ethanoyl chloride

(d) $FeCl_3$(aq) test for phenols

## OA2.2 Aldehydes and ketones

**Overview**

This topic introduces the preparation and reactions of aldehydes and ketones. Oxygen-containing compounds often undergo oxidation and reduction reactions and aldehydes are easily reduced and oxidised. There are ample opportunities to carry out a range of practical tests and preparations.

**How Science Works**
There are opportunities here for learners to:
use appropriate methodology, including information and communication technology (ICT) to answer scientific questions and solve scientific problems;
carry out experimental and investigative activities, including appropriate risk assessments;
analyse and interpret data to provide evidence, recognising correlations and causal relationships.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) formation of aldehydes and ketones by the oxidation of primary and secondary alcohols respectively

(b) how aldehydes and ketones may be distinguished by their relative ease of oxidation using Tollens' reagent and Fehling's reagent

(c) reduction of aldehydes and ketones using $NaBH_4$

(d) mechanism of nucleophilic addition, such as in the addition of HCN to ethanal and propanone, as a characteristic reaction of aldehydes and ketones

(e) reaction of aldehydes and ketones with 2,4-dinitrophenylhydrazine and its use as a test for a carbonyl group and in identifying specific aldehydes and ketones

(f) triiodomethane (iodoform) test and its use in identifying $CH_3CO$— groups or their precursors

**SPECIFIED PRACTICAL WORK**

- Identification of aldehydes/ketones by their reaction with 2,4-dinitrophenylhydrazine

## OA2.3 Carboxylic acids and their derivatives

### Overview

The relative acidity of various organic compounds is compared. Carboxylic acids undergo the same reactions as mineral acids as well as a range of further reactions to produce derivatives of synthetic importance.

### How Science Works

There are opportunities here for learners to:
use appropriate methodology, including information and communication technology (ICT) to answer scientific questions and solve scientific problems;
carry out experimental and investigative activities, including appropriate risk assessments;
analyse and interpret data to provide evidence, recognising correlations and causal relationships;
evaluate methodology, evidence and data, and resolve conflicting evidence.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) order of relative acidity of carboxylic acids, phenols, alcohols and water and how these can be demonstrated

(b) formation of carboxylic acids by the oxidation of alcohols and aldehydes

(c) reduction of carboxylic acids using $LiAlH_4$

(d) formation of aromatic carboxylic acids by the oxidation of methyl side-chains

(e) decarboxylation of carboxylic acids

(f) conversion of carboxylic acids to esters and acid chlorides and the hydrolysis of these compounds

(g) conversion of carboxylic acids to amides and nitriles

(h) formation of nitriles from halogenoalkanes and hydroxynitriles from aldehydes and ketones

(i) hydrolysis of nitriles and amides

(j) reduction of nitriles using $LiAlH_4$

**Topic OA3 Organic compounds containing nitrogen**

**OA3.1 Amines**
**OA3.2 Amino acids, peptides and proteins**

## OA3.1 Amines

### Overview

This topic includes the preparation and reactions of amines and explains their basicity. Amines are important starting materials for many synthetic routes, including in the dye industry.

**How Science Works**
There are opportunities here for learners to:
use theories, models and ideas to develop scientific explanations;
use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas
carry out experimental and investigative activities, including appropriate risk assessments;
communicate information and ideas in appropriate ways using appropriate terminology.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) formation of primary aliphatic amines from halogenoalkanes and nitriles

(b) formation of aromatic amines from nitrobenzenes

(c) basicity of amines

(d) ethanoylation of primary amines using ethanoyl chloride

(e) reaction of primary amines (aliphatic and aromatic) with cold nitric(III) acid

(f) coupling of benzenediazonium salts with phenols and aromatic amines

(g) role of the —N=N— chromophore in azo dyes

(h) origin of colour in terms of the wavelengths of visible light absorbed

## OA3.2 Amino acids, peptides and proteins

### Overview

Amino acids, peptides and proteins are naturally-occurring nitrogen compounds and are the basis of living organisms. The importance of protein structure in understanding enzyme activity is considered. This is a good opportunity to link amino acid structure to optical isomerism.

**How Science Works**
There are opportunities here for learners to:
use theories, models and ideas to develop scientific explanations;
use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas;
communicate information and ideas in appropriate ways using appropriate terminology.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) general formula and classification of $\alpha$-amino acids

(b) amphoteric and zwitterionic nature of amino acids and the effect on melting temperature and solubility

(c) combination of $\alpha$-amino acids to form dipeptides

(d) formation of polypeptides and proteins

(e) basic principles of primary, secondary and tertiary protein structure

(f) essential role of proteins in living systems, for example, as enzymes

## Topic OA4 Organic synthesis and analysis

### Overview

This topic provides the opportunity to draw together theoretical knowledge of organic chemistry and practical skills to carry out a range of preparations and other practical tasks. The industrial importance of condensation polymers is emphasised. It is also an opportunity for analysis and interpretation of more complex spectroscopic data and chemical tests to identify unknown compounds.

**Mathematical Skills**
Learners will develop their ability to translate information between graphical and numerical forms while analysing and interpreting spectra.

**How Science Works**
There are opportunities here for learners to:
use appropriate methodology, including information and communication technology (ICT) to answer scientific questions and solve scientific problems
carry out experimental and investigative activities, including appropriate risk assessments;
analyse and interpret data to provide evidence, recognising correlations and causal relationships;
evaluate methodology, evidence and data, and resolve conflicting evidence;
communicate information and ideas in appropriate ways using appropriate terminology;
consider applications and implications of science and evaluate their associated benefits and risks;
consider ethical issues in the treatment of humans, other organisms and the environment
evaluate the role of the scientific community in validating new knowledge and ensuring integrity
evaluate the ways in which society uses science to inform decision making.

**Learners should be able to demonstrate and apply their knowledge and understanding of**

(a) synthesis of organic compounds by a sequence of reactions

(b) principles underlying the techniques of manipulation, separation and purification used in organic chemistry

(c) distinction between condensation polymerisation and addition polymerisation

(d) how polyesters and polyamides are formed

(e) use of melting temperature as a determination of purity

(f) use of high resolution $^{1}H$ NMR spectra (alongside the other spectral data specified in C3.5) in the elucidation of structure of organic molecules

(g) use of chromatographic data from TLC/paper chromatography, GC and HPLC to find the composition of mixtures

## SPECIFIED PRACTICAL WORK

- Synthesis of a liquid organic product, including separation using a separating funnel
- Synthesis of a solid organic product, including recrystallisation and determination of melting temperature
- Two-step synthesis, including purification and determination of melting temperature of product
- Planning a sequence of tests to identify organic compounds from a given list
- Paper chromatography separation, including two-way separation

# 3 ASSESSMENT

## 3.1 Assessment objectives and weightings

Below are the assessment objectives for this specification. Learners must:

**AO1**
Demonstrate knowledge and understanding of scientific ideas, processes, techniques and procedures

**AO2**
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

**AO3**
Analyse, interpret and evaluate scientific information, ideas and evidence, including in relation to issues, to:
- make judgements and reach conclusions (including in relation to issues);
- develop and refine practical design and procedures.

The table below shows the weighting of each assessment objective for each component and for the qualification as a whole.

| | **AO1** | **AO2** | **AO3** |
|---|---|---|---|
| **Component 1** | 12 % | 18 % | 10 % |
| **Component 2** | 12 % | 18 % | 10 % |
| **Component 3** | 6.7 % | 6.7 % | 6.7 % |
| **Overall weighting** | 30.7 % | 42.7 % | 26.7 % |

For each series:

- The weighting for the assessment of mathematical skills will be a minimum of 20 %.
- The weighting for the indirect assessment of practical skills will be a minimum of 15 %.

The ability to select, organise and communicate information and ideas coherently using appropriate scientific conventions and vocabulary will be tested across the assessment objectives.

# 3.2 Arrangements for non-exam assessment

**PRACTICAL ENDORSEMENT**

The assessment of practical skills is a compulsory requirement of the course of study for A level qualifications in Chemistry. It will appear on all learners' 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 will include:

- A minimum of 12 practical activities to be carried out by each learner which, together, meet the requirements of Appendix A part (b) (Practical skills identified for direct assessment and developed through teaching and learning) and Appendix A part (c) (Use of apparatus and techniques) from the prescribed subject content, published by the Department for Education.

- Teachers will assess learners against Common Practical Assessment Criteria (CPAC) issued by the awarding organisations. The CPAC (see pages 47 and 48) are based on the requirements of Appendix A parts (b) and (c) of the subject content requirements published by the Department for Education, and define the minimum standard required for the achievement of a pass.

- Each learner will keep an appropriate record of their assessed practical activities.

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

- The practical activities prescribed in this specification (the specified practicals) provide opportunities for demonstrating competence in all the skills identified, together with the use of apparatus and techniques for each subject. However, learners can also demonstrate these competences in any additional practical activity undertaken throughout the course of study which covers the requirements of Appendix A part (c).

- There will be no separate assessment of practical skills for AS qualifications.

- Learners will answer questions in the AS and A level examination papers that assess the requirements of Appendix A part (a) (Practical skills identified for indirect assessment and developed through teaching and learning) from the prescribed subject content, published by the Department for Education.

| Criteria for the assessment of practical competency in A level Chemistry (CPAC) | |
|---|---|
| **Competency** | **Practical Mastery:**<br><br>In order to achieve a **pass,** learners will need to have met the following expectations.<br><br>Learners will be expected to develop these competencies through the acquisition of the technical skills specified in Appendix A part (c). Learners can demonstrate these competencies in any practical activity undertaken throughout the course of study. The practical activities prescribed in the subject specification, which cover the requirements of Appendix A part (c), will provide opportunities for demonstrating competence in all the skills identified together with the use of apparatus and practical techniques for each subject.<br><br>Learners may work in groups but must be able to demonstrate and record independent evidence of their competency. This must include evidence of independent application of investigative approaches and methods to practical work.<br><br>Teachers who award a pass to their learners need to be confident that the learner consistently and routinely exhibits the competencies listed below before completion of the A level course. |
| 1. Follows written procedures | Correctly follows written instructions to carry out the experimental techniques or procedures. |
| 2. Applies investigative approaches and methods when using instruments and equipment | Correctly uses appropriate instrumentation, apparatus and materials (including ICT) to carry out investigative activities, experimental techniques and procedures with minimal assistance or prompting.<br><br>Carries out techniques or procedures methodically, in sequence and in combination, identifying practical issues and making adjustments when necessary.<br><br>Identifies and controls significant quantitative variables where applicable, and plans approaches to take account of variables that cannot readily be controlled.<br><br>Selects appropriate equipment and measurement strategies in order to ensure suitably accurate results. |

| | | |
|---|---|---|
| 3. | Safely uses a range of practical equipment and materials | 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.<br><br>Uses appropriate safety equipment and approaches to minimise risks with minimal prompting. |
| 4. | Makes and records observations | Makes accurate observations relevant to the experimental or investigative procedure.<br><br>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 | Uses appropriate software and/or tools to process data, carry out research and report findings.<br><br>Cites sources of information are cited demonstrating that research has taken place, supporting planning and conclusions. |

**Marking and Standardisation**
The practical work is assessed by teachers. WJEC Eduqas will support teachers in making judgements against the criteria for assessment.

In co-ordination with other exam boards, WJEC Eduqas will monitor how centres provide learners with opportunities to develop and demonstrate the required practical skills and how they mark the assessments.

Every centre will be monitored at least once in a two-year period in respect of at least one of the A level science subjects.

In common with other exam boards, WJEC Eduqas will require centres to provide a statement annually confirming they have taken reasonable steps to ensure that learners:

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

If a centre fails to provide a statement, or provides a false statement, this will be treated as malpractice and/or maladministration. Learners will only get a certificate for the practical endorsement if they achieve at least a grade E in the examined part of the qualification.

Practical endorsement results for each learner need to be submitted by centres to WJEC Eduqas by 15 May each year.

# 4 TECHNICAL INFORMATION

## 4.1 Making entries

This is a linear qualification in which all assessments must be taken at the end of the course. Assessment opportunities will be available in the months of May and June from 2017 until the end of the life of this specification.

A qualification may be taken more than once. Candidates must resit all examination components in the same series.

The endorsement grade for NEA may be carried forward for the life of the specification, even if it was awarded by a different awarding body. If a candidate resits an NEA component (rather than carrying forward the previous NEA endorsement grade), it is the new grade that will be used, even if this is 'Not Classified'.

Where a candidate has certificated on two or more previous occasions, the most recent NEA endorsement grade is carried forward, even if this is 'Not Classified'.

The entry code appears below.

WJEC Eduqas A level Chemistry: A410QS

The current edition of our *Entry Procedures and Coding Information* gives up-to-date entry procedures.

## 4.2 Grading, awarding and reporting

A level qualifications are reported as a grade from A* to E. Results not attaining the minimum standard for the award will be reported as U (unclassified).

# APPENDIX A

## WORKING SCIENTIFICALLY

The practical skills can be split into those which can be assessed indirectly through written examinations (Part (a)) and those that will be assessed directly by teachers through appropriate practical activities (Part (b)).

### Part (a) – Practical skills identified for indirect assessment and developed through teaching and learning

Question papers will assess learners' abilities to:

**Independent thinking**

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

**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

**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 (see Appendix C)
- consider margins of error, accuracy and precision of data

**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

**Part (b) - Practical skills identified for direct assessment and developed through teaching and learning**

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

**Independent thinking**

- apply investigative approaches and methods to practical work

**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

**Research and referencing**

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

**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

**Part (c) – Use of apparatus and techniques**

The practical work specified in the subject content section has been chosen to facilitate learners in developing the skills and acquiring the techniques listed below.

**Practical techniques to be gained by learners**

- use appropriate apparatus to record a range of measurements (to include mass, time, volume of liquids and gases, temperature)

- use water bath or electric heater or sand bath for heating

- measure pH using pH charts, or pH meter, or pH probe on a data logger

- 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

- use volumetric flask, including accurate technique for making up a standard solution

- use acid-base indicators in titrations of weak/strong acids with weak/strong alkalis

- purify:
    - a solid product by recrystallisation
    - a liquid product, including use of separating funnel

- use melting point apparatus

- use thin-layer or paper chromatography

- set up electrochemical cells and measure voltages

- safely and carefully handle solids and liquids, including corrosive, irritant, flammable and toxic substances

- 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 B

## DEVELOPMENT OF PRACTICAL TECHNIQUES

| | Technique | Specified practical work | |
|---|---|---|---|
| | | Topic reference | Description |
| 1 | Use appropriate apparatus to record a range of quantitative measurements (to include mass, time, volume of liquids and gases, temperature) | C1.6 | Gravimetric analysis |
| | | C2.1 | Preparation of a soluble salt by titration |
| | | C2.1 | Standardisation of an acid solution |
| | | C2.1 | Back titration |
| | | C2.1 | Double titration |
| | | C2.2 | Indirect determination of an enthalpy change of reaction |
| | | C2.2 | Determination of an enthalpy change of combustion |
| | | C2.3 | Investigation of a rate of reaction by a gas collection method |
| | | C2.3 | Study of an 'iodine clock' reaction |
| | | PI1.2 | Simple redox titration |
| | | PI1.2 | Estimation of copper in copper(II) salts |
| | | PI3 | Determination of the order of a reaction |
| | | PI5.1 | Determination of an equilibrium constant |
| 2 | Use water bath or electric heater or sand bath for heating | C3.3 | Nucleophilic substitution reaction |
| | | C3.4 | Preparation of an ester and separation of the product by distillation |
| | | OA4 | Synthesis of a liquid organic product, including separation using a separating funnel |
| | | OA4 | Synthesis of a solid organic product, including recrystallization and determination of melting temperature |
| | | OA4 | Two-step synthesis, including purification and determination of melting temperature |
| 3 | Measure pH using pH charts, or pH meter, or pH probe on a data logger | PI5.2 | Titration using a pH probe |

| | | | |
|---|---|---|---|
| 4 | Use laboratory apparatus for a variety of experimental techniques including:<br><br>titration, using burette and pipette<br><br>distillation and heating under reflux, including setting up glassware using retort stand and clamps<br><br>qualitative tests for ions and organic functional groups<br><br>filtration, including use of fluted filter paper, or filtration under reduced pressure | C2.1 | Preparation of a soluble salt by titration |
| | | C2.1 | Standardisation of an acid solution |
| | | C2.1 | Back titration |
| | | C2.1 | Double titration |
| | | C3.3 | Nucleophilic substitution reaction |
| | | C3.4 | Preparation of an ester and separation by distillation |
| | | PI1.2 | Simple redox titration |
| | | PI1.2 | Estimation of copper in copper(II) salts |
| | | PI5.1 | Determination of an equilibrium constant |
| | | PI5.2 | Titration using a pH probe |
| | | OA4 | Synthesis of a liquid organic product, including separation using a separating funnel |
| | | OA4 | Synthesis of a solid organic product, including recrystallisation and determination of melting temperature |
| | | OA4 | Two-step synthesis, including purification and determination of melting temperature |
| | | C1.6 | Identification of unknown solutions by qualitative analysis |
| | | OA4 | Planning a sequence of tests to identify organic compounds from a given list |
| | | OA2.2 | Identification of aldehydes/ketones by their reaction with 2,4-dinitrophenylhydrazine |
| | | OA4 | Synthesis of a solid organic product, including recrystallisation and determination of melting temperature |
| | | OA4 | Two-step synthesis, including purification and determination of melting temperature |
| 5 | Use volumetric flask, including accurate technique for making up a standard solution | C2.1 | Preparation of a soluble salt by titration |
| | | C2.1 | Standardisation of an acid solution |
| | | C2.1 | Back titration |
| | | C2.1 | Double titration |
| | | PI1.2 | Simple redox titration |
| | | PI1.2 | Estimation of copper in copper(II) salts |
| 6 | Use acid-base indicators in titrations of weak/strong acids with weak/strong alkalis | C2.1 | Preparation of a soluble salt by titration |
| | | C2.1 | Standardisation of an acid solution |
| | | C2.1 | Back titration |
| | | C2.1 | Double titration |
| 7 | Purify:<br>A solid product by recrystallisation<br>A liquid product, including use of separating funnel | OA4 | Synthesis of a liquid organic product, including separation using a separating funnel |
| | | OA4 | Synthesis of a solid organic product, including recrystallisation and determination of melting temperature |
| | | OA4 | Two-step synthesis, including purification and determination of melting temperature |

| | | | |
|---|---|---|---|
| 8 | Use melting point apparatus | OA2.2 | Identification of aldehydes/ketones by their reaction with 2,4-dinitrophenylhydrazine |
| | | OA4 | Synthesis of a solid organic product, including recrystallisation and determination of melting temperature |
| | | OA4 | Two-step synthesis, including purification and determination of melting temperature |
| 9 | Use thin-layer or paper chromatography | OA4 | Paper chromatography separation, including two-way separation |
| 10 | Set up electrochemical cells and measure voltages | PI1.1 | Construction of electrochemical cells and measurement of $E_{cell}$ |
| 11 | Safely and carefully handle solids and liquids, including corrosive, irritant, flammable and toxic substances | C2.1 | Preparation of a soluble salt by titration |
| | | C2.1 | Standardisation of an acid solution |
| | | C2.1 | Back titration |
| | | C2.1 | Double titration |
| | | C2.2 | Indirect determination of an enthalpy change of reaction |
| | | C2.2 | Determination of an enthalpy change of combustion |
| | | C3.3 | Nucleophilic substitution reaction |
| | | PI1.2 | Simple redox titration |
| | | PI1.2 | Estimation of copper in copper(II) salts |
| | | OA2.2 | Identification of aldehydes/ketones by their reaction with 2,4-dinitrophenylhydrazine |
| | | OA4 | Planning a sequence of tests to identify organic compounds from a given list |
| 12 | Measure rate of reactions by at least two different methods, for example:<br>An initial rate method such as a clock reaction<br>A continuous monitoring method | C2.3 | Investigation of a rate of reaction by a gas collection method |
| | | C2.3 | Study of an ‘iodine clock’ reaction |
| | | PI3 | Determination of the order of a reaction |

# APPENDIX C

## MATHEMATICAL REQUIREMENTS AND EXEMPLIFICATION

| **Mathematical skills** | **Exemplification of mathematical skill in the context of A level Chemistry (assessment is not limited to the examples given below)** | **Topic areas providing opportunities to develop skill** |
|---|---|---|
| **Arithmetic and numerical computation** | | |
| Recognise and make use of appropriate units in calculation | Learners may be tested on their ability to:<br>• convert between units e.g. $cm^3$ to $dm^3$ as part of volumetric calculations<br>• give units for an equilibrium constant or a rate constant<br>• understand that different units are used in similar topic areas, so that conversions may be necessary e.g. entropy in J $mol^{-1}$ $K^{-1}$ and enthalpy changes in kJ $mol^{-1}$ | C1.2(j)<br>C1.3(e)(f)(g)(h)(i)(j)<br>PI3(a)(b)(c)<br>PI4.2(c)(d)<br>PI5.1(b) |
| Recognise and use expressions in decimal and ordinary form | Learners may be tested on their ability to:<br>• use an appropriate number of decimal places in calculations e.g. for pH<br>• carry out calculations using numbers in standard and ordinary form e.g. use of Avogadro's number<br>• understand standard form when applied to areas such as (but not limited to) $K_w$<br>• convert between numbers in standard and ordinary form<br>• understand that significant figures need retaining when making conversions between standard and ordinary form e.g. 0.0050 mol $dm^{-3}$ is equivalent to $5.0 \times 10^{-3}$ mol $dm^{-3}$ | C1.2(j)<br>PI3(a)(b)(c)<br>PI5.2(d) |
| Use ratios, fractions and percentages | Learners may be tested on their ability to:<br>• calculate percentage yields<br>• calculate the atom economy of a reaction<br>• construct and/or balance equations using ratios | C1.1(a)(c)<br>C1.2(c)<br>C1.3(d)<br>PI3(b) |

| | | |
|---|---|---|
| Estimate results | Learners may be tested on their ability to:<br>• 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 | C2.1(c)<br>PI1.2(d) |
| Use calculators to find and use power, exponential and logarithmic functions | Learners may be tested on their ability to:<br>• carry out calculations using the Avogadro constant<br>• carry out pH and p$K_a$ calculations<br>• carry out calculations using the Arrhenius equation<br>• make appropriate mathematical approximations in buffer calculations | C1.2(j)<br>C1.3(e)<br>C2.1(e)<br>PI3(f)<br>PI5.2(d)(f) |

| **Handling data** | | |
|---|---|---|
| Use an appropriate number of significant figures | Learners may be tested on their ability to:<br>• report calculations to an appropriate number of significant figures given raw data quoted to varying numbers of significant figures<br>• understand that calculated results can only be reported to the limits of the least accurate measurement | C1.3(e)(f)(g)(h)(i)(j)<br>C2.1(f)<br>C2.2(e)<br>C2.3(h)<br>PI1.2(d) |
| Find arithmetic means | Learners may be tested on their ability to:<br>• calculate weighted means e.g. calculation of an atomic mass based on supplied isotopic abundances<br>• select appropriate titration data (i.e. identification of outliers) in order to calculate mean titres | C1.3(b)(j)<br>PI1.2(d) |
| Identify uncertainties in measurements and use simple techniques to determine uncertainty when data are combined | Learners may be tested on their ability to:<br>• determine uncertainty when two burette readings are used to calculate a titre value | C1.3(l)<br>C2.1(f)<br>C2.2(e)<br>C2.3(h)<br>PI1.2(d) |

| **Algebra** | | |
|---|---|---|
| Understand and use the symbols: =, <, <<, >>, >, ∝, ~, equilibrium sign | No exemplification required | |
| Change the subject of an equation | Learners may be tested on their ability to:<br>• carry out structured and unstructured mole calculations<br>• use the ideal gas equation<br>• calculate a rate constant *k* from a rate equation<br>• carry out calculations using the Arrhenius equation | C1.2(j)<br>C1.3(e)(f)(g)(h)(i)(j)<br>C1.6(r)<br>C2.1(f)<br>C2.2(b)(c)(d)<br>PI1.2(d)<br>PI3(c)<br>PI3(f)<br>PI4.2(d)<br>PI5.1(b)<br>PI5.2(d)(f) |
| Substitute numerical values into algebraic equations using appropriate units for physical quantities | Learners may be tested on their ability to:<br>• carry out structured and unstructured mole calculations<br>• use the ideal gas equation<br>• carry out rate calculations<br>• calculate the value of an equilibrium constant $K_C$ | C1.2(j)<br>C1.3(e)(f)(g)(h)(i)(j)<br>C1.6(r)<br>C2.1(f)<br>C2.2(b)(c)(d)(e)<br>PI1.2(d)<br>PI3(c)<br>PI3(f)<br>PI4.1(b)(c)<br>PI4.2(c)(d)<br>PI5.1(b)<br>PI5.2(d)(f) |
| Solve algebraic equations | Learners may be tested on their ability to:<br>• carry out Hess's law calculations<br>• calculate a rate constant *k* from a rate equation<br>• carry out calculations using the Arrhenius equation | C2.2(b)(c)(d)<br>PI1.1(e)<br>PI1.2(d)<br>PI3(c)<br>PI3(f)<br>PI4.1(b)(c)<br>PI4.2(d)<br>PI5.1(b)<br>PI5.2(d)(f) |
| Use logarithms in relation to quantities that range over several orders of magnitude | Learners may be tested on their ability to:<br>• carry out pH and $pK_a$ calculations<br>• carry out calculations using the Arrhenius equation | C2.1(e)<br>PI3(f)<br>PI5.2(d)(f) |

| | | |
|---|---|---|
| **Graphs** | | |
| Translate information between graphical, numerical and algebraic forms | Learners may be tested on their ability to:<br>• interpret and analyse spectra<br>• determine the order of a reaction from a graph<br>• derive rate expression from a graph<br>• carry out calculations using the Arrhenius equation | C2.2(e)<br>C2.3(b)(g)(h)<br>C3.5(a)(b)(c)<br>PI3(a)(c)<br>PI3(f)<br>PI4.1(c)<br>OA4(f) |
| Plot two variables from experimental or other data | Learners may be tested on their ability to:<br>• plot concentration–time graphs and draw an appropriate best-fit curve | C2.2(e)<br>C2.3(b)(g)(h)<br>PI3(a)(c) |
| Determine the slope and intercept of a linear graph | Learners may be tested on their ability to:<br>• calculate the rate constant of a zero-order reaction<br>• carry out calculations using the Arrhenius equation | C2.3(h)<br>PI3(a)(c)<br>PI3(f) |
| Calculate rate of change from a graph showing a linear relationship | Learners may be tested on their ability to:<br>• calculate the rate constant of a zero-order reaction | PI3(a)(c) |
| Draw and use the slope of a tangent to a curve as a measure of rate of change | Learners may be tested on their ability to:<br>• determine the order of a reaction using the initial rates method | PI3(a)(c) |
| **Geometry and trigonometry** | | |
| Use angles and shapes in regular 2D and 3D structures | Learners may be tested on their ability to:<br>• predict/identify shapes of and bond angles in molecules with and without a lone pair(s) for example $NH_3$, $CH_4$, $H_2O$ etc. | C1.4(h)(i)<br>PI2.2(f) |
| Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects | Learners may be tested on their ability to:<br>• draw different forms of isomers<br>• identify chiral centres from a 2D or 3D representation | C1.4(h)(i)<br>C3.1(d)<br>OA1.1(a)(b) |
| Understand the symmetry of 2D and 3D shapes | Learners may be tested on their ability to:<br>• describe the types of stereoisomerism shown by molecules/complexes<br>• identify chiral centres from a 2D or 3D representation | C3.2(f)<br>OA1.1(a)(b) |

# APPENDIX D

## HOW SCIENCE WORKS

| How Science Works skill | Sample of topic areas providing opportunities to develop skill |
|---|---|
| use theories, models and ideas to develop scientific explanations | C1.1(c)<br>C1.2(f)<br>C1.4<br>C1.5<br>C2.3(a)<br>PI2.2(d)<br>PI4.2(e)<br>PI5.2(b)<br>OA1.2(a)(b)<br>OA2.1(c)<br>OA3.1(c)<br>OA3.2(b) |
| use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas | C1.6(d)<br>C2.1(b)<br>C2.3(a)<br>PI3(d)<br>PI4.2(e) |
| use appropriate methodology, including information and communication technology (ICT), to answer scientific questions and solve scientific problems | C2.1(f)<br>C2.2(e)<br>C2.3(h)<br>PI1.2(d)<br>PI3(a) |
| carry out experimental and investigative activities, including appropriate risk management, in a range of contexts | C1.6(r)<br>C2.1(f)<br>C2.2(e)<br>C2.3(h)<br>C3.3(g)<br>C3.4(i)<br>PI1.2(d)<br>OA1.2(c)<br>OA2.2(e)<br>OA2.3(f)<br>OA4(a) |
| analyse and interpret data to provide evidence, recognising correlations and causal relationships | C2.3(h)<br>C2.4(a)<br>C3.5<br>PI3(b)<br>OA2.2(e)<br>OA4(f) |

| | |
|---|---|
| evaluate methodology, evidence and data, and resolve conflicting evidence | C2.2(e)<br>C2.3(h)<br>PI3(a) |
| know that scientific knowledge and understanding develops over time | C1.2(f)<br>C1.6(a) |
| communicate information and ideas in appropriate ways using appropriate terminology | C1.1(c)<br>C1.4<br>C1.5<br>C3.1(a)(b)<br>PI2.1(h)<br>PI2.2(g)<br>OA1.1(a)(b)<br>OA2.1(c)<br>OA3.1(c) |
| consider applications and implications of science and evaluate their associated benefits and risks | C1.2(d)<br>C2.4(a)<br>C3.2(a)<br>C3.3(e)(f)<br>PI1.1(f)<br>PI2.2(g)<br>PI5.2(g) |
| consider ethical issues in the treatment of humans, other organisms and the environment | C1.2(d)<br>C2.4(a)<br>C3.2(a)<br>C3.3(e)(f) |
| evaluate the role of the scientific community in validating new knowledge and ensuring integrity | C1.5(e)<br>C2.4(a)<br>PI1.1(f)<br>PI2.2(g) |
| evaluate the ways in which society uses science to inform decision making | C3.2(a)<br>C3.3(e)(f) |