

# Unit 1: Structure, Bonding and Introduction to Organic Chemistry

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**IAS compulsory unit**

**Externally assessed**

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## Unit description

### Introduction

This unit gives students opportunities to develop the basic chemical skills of writing formulae and equations, and calculating chemical quantities.

The study of atomic structure includes a description of *s*, *p*, and *d* orbitals and shows how electronic configurations can account for the arrangement of elements in the Periodic Table. This leads to an appreciation of one of the central features of chemistry: the explanation of the properties of elements and the patterns in the Periodic Table in terms of atomic structure.

An understanding of the electronic structure of atoms leads to an appreciation of the three types of strong chemical bonding: ionic, covalent and metallic. Following from this, shapes of molecules can then be considered.

The basic principles of organic chemistry are covered and students study alkanes and alkenes, and will begin to develop a mechanistic approach to organic chemistry.

### Chemistry in action

The study of atomic structure gives some insight into the methods that scientists use to study the structure of atoms. This leads to the introduction of the mass spectrometer and its importance in sensitive methods of analysis in areas such as space research, medical research and diagnosis, in detecting drugs in sport and in environmental monitoring.

Chemists set up theoretical models and gain insight by comparing real and theoretical properties of chemicals. This is illustrated in the unit by considering the evidence for the different kinds of chemical bonding.

Electron-pair repulsion theory is also used to show how chemists can develop theories and use them to make predictions.

Students start to use the conventions for mechanisms in organic chemistry as a way to represent the movement of electrons in reactions.

**Practical skills**

Students can start with simple test-tube reactions to illustrate a range of chemical equations. They can then build up to carrying out practical work that can be used to find reaction quantities, covered in the first core practical on molar volume.

Simple practical work can be used to investigate the properties of substances with different types of bonding.

The introduction to organic chemistry shows how chemists work safely with hazardous chemicals by managing risks. A number of possible practicals can be used to explore the chemistry of alkenes.

**Mathematical skills**

There are opportunities for the development of mathematical skills in this unit. This includes converting between units such as  $\text{cm}^3$  and  $\text{dm}^3$ , using standard form with the Avogadro constant, rearranging formulae for calculating moles in solids and in solutions and the ideal gas equation, calculating atom economy, dealing with percentage errors, calculating a relative atomic mass from isotopic composition data, using simple probability to calculate the peak heights for the mass spectrum of molecules such as chlorine, using logarithms to compare successive ionisation energies for an element, representing shapes of molecules with suitable sketches, plotting data to investigate trends in boiling temperatures of alkanes and calculating the yield of a reaction. (Please see *Appendix 6: Mathematical skills and exemplifications* for more detail.)

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**Assessment information**

- First assessment: January 2019.
  - The assessment is 1 hour and 30 minutes.
  - The assessment is out of 80 marks.
  - Students must answer all questions.
  - This paper has two sections:
    - Section A: multiple choice questions
    - Section B: mixture of short-open, open-response and calculation questions.
  - This paper will include a minimum of 18 marks that target mathematics at Level 2 or above.
  - Students will be expected to apply their knowledge and understanding of experimental methods in familiar and unfamiliar contexts.
  - Calculators may be used in the examination (see *Appendix 8: Use of calculators*).
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# Topic 1: Formulae, Equations and Amount of Substance

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

**Students will be assessed on their ability to:**

<b>1.1</b>	know the terms 'atom', 'element', 'ion', 'molecule', 'compound', 'empirical formula' and 'molecular formula'
<b>1.2</b>	know that the mole (mol) is the unit for the amount of a substance and be able to perform calculations using the Avogadro constant $L$ ( $6.02 \times 10^{23} \text{ mol}^{-1}$ )
<b>1.3</b>	write balanced full and ionic equations, including state symbols, for chemical reactions
<b>1.4</b>	<p>understand the terms:</p> <ul style="list-style-type: none"> <li>i 'relative atomic mass' based on the <math>^{12}\text{C}</math> scale</li> <li>ii 'relative molecular mass' and 'relative formula mass', including calculating these values from relative atomic masses</li> </ul> <p><i>The term 'relative formula mass' should be used for compounds with giant structures.</i></p> <ul style="list-style-type: none"> <li>iii 'molar mass' as the mass per mole of a substance in <math>\text{g mol}^{-1}</math></li> <li>iv parts per million (ppm), including gases in the atmosphere</li> </ul>
<b>1.5</b>	<p>calculate the concentration of a solution in <math>\text{mol dm}^{-3}</math> and <math>\text{g dm}^{-3}</math></p> <p><i>Titration calculations are not required at this stage.</i></p>
<b>1.6</b>	be able to use experimental data to calculate empirical and molecular formulae
<b>1.7</b>	be able to use chemical equations to calculate reacting masses and vice versa, using the concepts of amount of substance and molar mass
<b>1.8</b>	<p>be able to use chemical equations to calculate volumes of gases and vice versa, using:</p> <ul style="list-style-type: none"> <li>i the concepts of amount of substance</li> <li>ii the molar volume of gases</li> <li>iii the expression <math>pV = nRT</math> for gases and volatile liquids</li> </ul>
<b>1.9</b>	<p>be able to calculate percentage yields and percentage atom economies (by mass) in laboratory and industrial processes, using chemical equations and experimental results</p> <p>Atom economy = <math>\frac{\text{molar mass of the desired product}}{\text{sum of the molar masses of all products}} \times 100\%</math></p>
<b>1.10</b>	be able to determine a formula or confirm an equation by experiment, including evaluation of the data
<b>1.11</b>	<p><b>CORE PRACTICAL 1</b></p> <p><b>Measurement of the molar volume of a gas.</b></p>
<b>1.12</b>	<p>be able to relate ionic and full equations, with state symbols, to observations from simple test-tube experiments, to include:</p> <ul style="list-style-type: none"> <li>i displacement reactions</li> <li>ii typical reactions of acids</li> <li>iii precipitation reactions</li> </ul>

	<p><b>Further suggested practicals:</b></p> <ul style="list-style-type: none"> <li>i preparation of a salt and calculating the percentage yield of product, including the preparation of a double salt, such as ammonium iron(II) sulfate from iron, ammonia and sulfuric acid</li> <li>ii determine a chemical formula by experiment, such as the formula of copper(II) oxide by reduction</li> <li>iii determine a chemical equation by experiment, such as the reaction between lithium and water, or the reaction between magnesium and an acid</li> <li>iv carry out and interpret the results of simple test-tube reactions, as outlined in 1.12</li> </ul>
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## Topic 2: Atomic Structure and the Periodic Table

Students will be assessed on their ability to:

<b>2.1</b>	know the structure of an atom in terms of electrons, protons and neutrons
<b>2.2</b>	know the relative mass and charge of protons, neutrons and electrons
<b>2.3</b>	know what is meant by the terms 'atomic (proton) number' and 'mass number'
<b>2.4</b>	be able to use the atomic number and the mass number to determine the number of each type of subatomic particle in an atom or ion
<b>2.5</b>	understand the term 'isotope'
<b>2.6</b>	<p>understand the basic principles of a mass spectrometer and be able to analyse and interpret mass spectra to:</p> <ul style="list-style-type: none"> <li>i deduce the isotopic composition of a sample of an element</li> <li>ii calculate the relative atomic mass of an element from relative abundances of isotopes and vice versa</li> <li>iii determine the relative molecular mass of a molecule, and hence identify molecules in a sample</li> <li>iv understand that ions in a mass spectrometer may have a 2+ charge</li> </ul>
<b>2.7</b>	be able to predict mass spectra, including relative peak heights, for diatomic molecules, including chlorine, given the isotopic abundances
<b>2.8</b>	be able to define first, second and third ionisation energies and understand that all ionisation energies are endothermic
<b>2.9</b>	know that an orbital is a region within an atom that can hold up to two electrons with opposite spins
<b>2.10</b>	understand how ionisation energies are influenced by the number of protons in the nucleus, the electron shielding and the sub-shell from which the electron is removed
<b>2.11</b>	<p>know that ideas about electronic structure developed from:</p> <ul style="list-style-type: none"> <li>i an understanding that successive ionisation energies provide evidence for the existence of quantum shells and the group to which the element belongs</li> <li>ii an understanding that the first ionisation energy of successive elements provides evidence for electron sub-shells</li> </ul>
<b>2.12</b>	be able to describe the shapes of <i>s</i> and <i>p</i> orbitals
<b>2.13</b>	<p>know that orbitals in sub-shells:</p> <ul style="list-style-type: none"> <li>i each take a single electron before pairing up</li> <li>ii pair up with two electrons of opposite spin</li> </ul>
<b>2.14</b>	be able to predict the electronic configuration of atoms of the elements from hydrogen to krypton inclusive and their ions, using <i>s</i> , <i>p</i> , <i>d</i> notation and electron-in-boxes notation
<b>2.15</b>	understand that electronic configuration determines the chemical properties of an element
<b>2.16</b>	know that the Periodic Table is divided into blocks, such as <i>s</i> , <i>p</i> and <i>d</i> , and know the number of electrons that can occupy <i>s</i> , <i>p</i> and <i>d</i> sub-shells in the first four quantum shells

<b>2.17</b>	be able to represent data, in a graphical form (including the use of logarithms of first ionisation energies on a graph) for elements 1 to 36 and hence explain the meaning of the term 'periodic property'
<b>2.18</b>	<p>be able to explain:</p> <ul style="list-style-type: none"> <li>i the trends in melting and boiling temperatures of the elements of Periods 2 and 3 of the Periodic Table in terms of the structure of the element and the bonding between its atoms or molecules</li> <li>ii the general increase and the specific trends in ionisation energy of the elements across Periods 2 and 3 of the Periodic Table</li> <li>iii the decrease in first ionisation energy down a group</li> </ul>

## Topic 3: Bonding and Structure

### 3A: Ionic bonding

Students will be assessed on their ability to:

<b>3.1</b>	know and be able to interpret evidence for the existence of ions, limited to physical properties of ionic compounds, electron density maps and the migration of ions
<b>3.2</b>	be able to describe the formation of ions in terms of loss or gain of electrons
<b>3.3</b>	be able to draw dot-and-cross diagrams to show electrons in cations and anions
<b>3.4</b>	be able to describe ionic crystals as giant lattices of ions
<b>3.5</b>	know that ionic bonding is the result of strong net electrostatic attraction between ions
<b>3.6</b>	understand the effects of ionic radius and ionic charge on the strength of ionic bonding
<b>3.7</b>	understand reasons for the trends in ionic radii down a group in the Periodic Table, and for a set of isoelectronic ions, including $\text{N}^{3-}$ to $\text{Al}^{3+}$
<b>3.8</b>	understand the meaning of the term 'polarisation' as applied to ions
<b>3.9</b>	understand that the polarising power of a cation depends on its radius and charge, and the polarisability of an anion also depends on its radius and charge
	<b>Further suggested practical</b> The migration of ions in a U-tube using copper(II) chromate solution or on a microscope slide using potassium manganate(VII) crystals

### 3B: Covalent bonding

Students will be assessed on their ability to:

<b>3.10</b>	understand that covalent bonding is the strong electrostatic attraction between two nuclei and the shared pair of electrons between them, based on the evidence: i the physical properties of giant atomic structures ii electron density maps for simple molecules
<b>3.11</b>	be able to draw dot-and-cross diagrams to show electrons in covalent substances, including: i molecules with single, double and triple bonds ii species with dative covalent (coordinate) bonds, including $\text{Al}_2\text{Cl}_6$ and the ammonium ion
<b>3.12</b>	be able to describe the different structures formed by giant lattices of carbon atoms, including graphite, diamond and graphene, and discuss the applications of each
<b>3.13</b>	understand the meaning of the term 'electronegativity' as applied to atoms in a covalent bond

<b>3.14</b>	know that ionic and covalent bonding are the extremes of a continuum of bonding type and be able to explain this in terms of electronegativity differences, leading to bond polarity in bonds and molecules, and to ionic bonding if the electronegativity is large enough
<b>3.15</b>	be able to distinguish between polar bonds and polar molecules and predict whether or not a given molecule is likely to be polar
	<b>Further suggested practical</b> Determine the effect of an electrostatic force on jets of liquids (water, ethanol and cyclohexane) and use the results to determine whether the molecules are polar or non-polar

### 3C: Shapes of molecules

**Students will be assessed on their ability to:**

<b>3.16</b>	understand the principles of the electron-pair repulsion theory, used to interpret and predict the shapes of simple molecules and ions
<b>3.17</b>	understand the terms 'bond length' and 'bond angle'
<b>3.18</b>	know and be able to explain the shapes of, and bond angles in, $\text{BeCl}_2$ , $\text{BCl}_3$ , $\text{CH}_4$ , $\text{NH}_3$ , $\text{NH}_4^+$ , $\text{H}_2\text{O}$ , $\text{CO}_2$ , gaseous $\text{PCl}_5$ , $\text{SF}_6$ and $\text{C}_2\text{H}_4$
<b>3.19</b>	be able to apply the electron-pair repulsion theory to predict the shapes of, and bond angles in, molecules and ions analogous to those in 3.18

### 3D: Metallic bonding

**Students will be assessed on their ability to:**

<b>3.20</b>	understand that metals consist of giant lattices of metal ions in a sea of delocalised electrons
<b>3.21</b>	know that metallic bonding is the strong electrostatic attraction between metal ions and the delocalised electrons
<b>3.22</b>	be able to use the models in 3.20 and 3.21 to interpret simple properties of metals, including electrical conductivity and high melting temperature



## Topic 4: Introductory Organic Chemistry and Alkanes

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

### 4A: Introduction

Students will be assessed on their ability to:

<b>4.1</b>	understand the difference between hazard and risk
<b>4.2</b>	understand the hazards associated with organic compounds and why it is necessary to carry out risk assessments when dealing with potentially hazardous materials
<b>4.3</b>	be able to suggest ways in which risks can be reduced and reactions carried out safely, for example: i working on a smaller scale ii taking precautions specific to the hazard iii using an alternative method that involves less hazardous substances
<b>4.4</b>	understand the concepts of homologous series and functional group
<b>4.5</b>	be able to apply the rules of International Union of Pure and Applied Chemistry (IUPAC) nomenclature to: i name compounds relevant to this specification ii draw these compounds, as they are encountered in the specification, using structural, displayed and skeletal formulae <i>Students will be expected to know prefixes for compounds up to C<sub>10</sub></i>
<b>4.6</b>	be able to classify reactions as addition, substitution, oxidation, reduction or polymerisation
<b>4.7</b>	understand that bond breaking can be: i homolytic, to produce free radicals ii heterolytic, to produce ions
<b>4.8</b>	know definitions of the terms 'free radical' and 'electrophile'

## 4B: Alkanes

Students will be assessed on their ability to:

<b>4.9</b>	know the general formula of alkanes and cycloalkanes, and understand that they are hydrocarbons (compounds of carbon and hydrogen only) which are saturated (contain single bonds only)
<b>4.10</b>	understand the term 'structural isomerism' and be able to draw the structural isomers of organic molecules, given their molecular formula
<b>4.11</b>	be able to draw and name the structural isomers of alkanes and cycloalkanes with up to six carbon atoms
<b>4.12</b>	know that alkanes are used as fuels and obtained from the fractional distillation, cracking and reforming of crude oil, and be able to write equations for these reactions
<b>4.13</b>	know that pollutants, including carbon monoxide, oxides of nitrogen and sulfur, carbon particulates and unburned hydrocarbons, are emitted during the combustion of alkane fuels
<b>4.14</b>	understand the problems arising from pollutants from the combustion of alkane fuels, limited to the toxicity of carbon monoxide and why it is toxic, and the acidity of oxides of nitrogen and sulfur
<b>4.15</b>	be able to discuss the reasons for developing alternative fuels in terms of sustainability and reducing emissions, including the emission of CO <sub>2</sub> and its relationship to climate change
<b>4.16</b>	be able to apply the concept of carbon neutrality to different fuels, such as petrol, bioethanol and hydrogen
<b>4.17</b>	understand the reactions of alkanes with: i oxygen in the air (combustion) ii halogens
<b>4.18</b>	understand the mechanism of the free radical substitution reaction between an alkane and a halogen: i using free radicals, which are species with an unpaired electron, represented by a single dot ii showing the initiation step of the mechanism, with curly half-arrows for free radical formation iii showing the propagation and termination steps of the mechanism iv having limited use in synthesis because of further substitution reactions
	<b>Further suggested practical</b>  Cracking alkanes by thermal decomposition, including liquid paraffin using aluminium oxide as a catalyst

## Topic 5: Alkenes

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

### Students will be assessed on their ability to:

<b>5.1</b>	know the general formula of alkenes and understand that alkenes and cycloalkenes are hydrocarbons which are unsaturated (have a carbon-carbon double bond which consists of a $\sigma$ bond and a $\pi$ bond)
<b>5.2</b>	be able to explain geometric isomerism in terms of restricted rotation around a C=C double bond and the nature of the substituents on the carbon atoms
<b>5.3</b>	understand the <i>E-Z</i> naming system for geometric isomers and why it is necessary to use this when the <i>cis-</i> and <i>trans-</i> naming system breaks down
<b>5.4</b>	be able to describe the reactions of alkenes, limited to: <ul style="list-style-type: none"> <li>i the addition of hydrogen, using a nickel catalyst, to form an alkane</li> <li>ii the addition of halogens to produce a di-substituted halogenoalkane</li> <li>iii the addition of hydrogen halides to produce mono-substituted halogenoalkanes</li> <li>iv the addition of steam, in the presence of an acid catalyst, to produce alcohols</li> <li>v oxidation of the double bond by acidified potassium manganate(VII) to produce a diol</li> </ul>
<b>5.5</b>	know the qualitative test for a C=C double bond using bromine or bromine water
<b>5.6</b>	be able to describe the mechanism (including diagrams), giving evidence where possible, of: <ul style="list-style-type: none"> <li>i the electrophilic addition of bromine and hydrogen bromide to ethene</li> <li>ii the electrophilic addition of hydrogen bromide to propene</li> </ul> <p><i>Use of the curly arrow notation is expected – the curly arrows should start from either a bond or from a lone pair of electrons.</i></p> <p><i>Knowledge of the relative stability of primary, secondary and tertiary carbocation intermediates is expected.</i></p>
<b>5.7</b>	be able to describe the addition polymerisation of alkenes and draw the repeat unit given the monomer, and vice versa
<b>5.8</b>	understand how chemists limit the problems caused by polymer disposal by: <ul style="list-style-type: none"> <li>i developing biodegradable polymers</li> <li>ii removing toxic waste gases produced by the incineration of polymers</li> </ul>
	<p><b>Further suggested practicals:</b></p> <ul style="list-style-type: none"> <li>i investigating the difference in reactivity of alkanes and alkenes, including combustion, reaction with bromine water, reaction with acidified potassium manganate(VII)</li> <li>ii preparation of cyclohexene from cyclohexanol</li> <li>iii preparation of limonene from orange peel by steam distillation</li> <li>iv preparation of Perspex® from methyl 2-methylpropenoate</li> </ul>

# Unit 2: Energetics, Group Chemistry, Halogenoalkanes and Alcohols

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**IAS compulsory unit**

**Externally assessed**

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## Unit description

### Introduction

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

Study of the Periodic Table is extended to cover the chemistry of Groups 1, 2 and 7, where ideas about redox reactions are applied to the reactions of halogens and their compounds.

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

The unit also develops an understanding – mostly at a qualitative level – of the ways in which chemists can control the rate, direction and extent of chemical change in reactions.

The organic chemistry in this unit covers halogenoalkanes and alcohols, and explores the mechanisms of selected reactions.

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

### Chemistry in action

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

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

The study of rates and equilibria shows the contribution that chemistry can make to a more sustainable economy by redeveloping manufacturing processes to make them more efficient, less hazardous and less polluting.

## Practical skills

Again, students can begin their practical work for this unit with simple reactions, in polystyrene cups, to investigate energy changes in chemical reactions. This leads to the first core practical in this unit.

Inorganic chemistry and basic redox reactions can also be explored with simple test-tube reactions.

The techniques of volumetric analysis are introduced in this unit, with two core practicals to develop competence in this key skill.

The effect of temperature, concentration and surface area on the rate of a reaction can be explored through a variety of reactions, and also forms part of the first core practical in organic chemistry.

Further core practicals in organic chemistry are used to develop students' skills in using glassware and techniques such as reflux, use of a separating funnel and distillation.

The final core practical considers qualitative analysis for ions and organic functional groups.

## Mathematical skills

There are opportunities for the development of mathematical skills in this unit. This includes plotting and extrapolating graphs of temperature rise against time for displacement reactions, calculating enthalpy changes in J and kJ mol<sup>-1</sup>, using algebra to solve Hess's Law problems, calculating enthalpy changes using bond enthalpies and evaluating experimental results in terms of measurement uncertainties and systematic errors in the context of measuring energy changes and in titrations. Also, calculating oxidation numbers within a complex system, balancing equations for redox reactions by combining ionic half-equations, calculating rates from reaction time, plotting graphs and having an appreciation of the graph for a Maxwell-Boltzmann distribution, and deriving an algebraic expression for the equilibrium constant. Further mathematical skills can be developed in analysing mass and infrared spectra. (Please see *Appendix 6: Mathematical skills and exemplifications* for more details.)

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## Assessment information

- First assessment: June 2019.
  - The assessment is 1 hour and 30 minutes.
  - The assessment is out of 80 marks.
  - Students must answer all questions.
  - This paper has three sections:
    - Section A: multiple choice questions
    - Section B: mixture of short-open, open-response, calculations and extended-writing questions
    - Section C: contemporary context question.
  - This paper will contain questions that require information from the Data Booklet (see *Appendix 9*).
  - This paper will include a minimum of 18 marks that target mathematics at Level 2 or above.
  - Students will be expected to apply their knowledge and understanding of experimental methods in familiar and unfamiliar contexts.
  - This paper may contain some synoptic questions which require knowledge and understanding from Unit 1.
  - Calculators may be used in the examination (see *Appendix 8: Use of calculators*).
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## Topic 6: Energetics

Students will be assessed on their ability to:

<b>6.1</b>	know that the enthalpy change, $\Delta H$ , is the heat energy change measured at constant pressure and that standard conditions are 100 kPa and a specified temperature, usually 298 K
<b>6.2</b>	know that, by convention, exothermic reactions have a negative enthalpy change and endothermic reactions have a positive enthalpy change
<b>6.3</b>	be able to construct and interpret enthalpy level diagrams, showing exothermic and endothermic enthalpy changes
<b>6.4</b>	<p>know the definition of standard enthalpy change of:</p> <ul style="list-style-type: none"> <li>i reaction, <math>\Delta_r H</math></li> <li>ii formation, <math>\Delta_f H</math></li> <li>iii combustion, <math>\Delta_c H</math></li> <li>iv neutralisation, <math>\Delta_{\text{neut}} H</math></li> <li>v atomisation, <math>\Delta_{\text{at}} H</math></li> </ul>
<b>6.5</b>	<p>be able to use experimental data to calculate:</p> <ul style="list-style-type: none"> <li>i energy transferred in a reaction recalling and using the expression: energy transferred (J) = mass (g) <math>\times</math> specific heat capacity (<math>\text{J g}^{-1} \text{ }^\circ\text{C}^{-1}</math>) <math>\times</math> temperature change (<math>^\circ\text{C}</math>)</li> <li>ii enthalpy change of the reaction in <math>\text{kJ mol}^{-1}</math></li> </ul> <p><i>This will be limited to experiments where substances are mixed in an insulated container and combustion experiments using a suitable calorimeter.</i></p>
<b>6.6</b>	<p>know Hess's Law and be able to apply it to:</p> <ul style="list-style-type: none"> <li>i constructing enthalpy cycles</li> <li>ii calculating enthalpy changes of reaction using data provided, or data selected from a table or obtained from experiments</li> </ul>
<b>6.7</b>	<p><b>CORE PRACTICAL 2</b></p> <p><b>Determination of the enthalpy change of a reaction using Hess's Law.</b></p>
<b>6.8</b>	<p>be able to evaluate the results obtained from experiments and comment on sources of error and uncertainty and any assumptions made in the experiments</p> <p><i>Students will need to consider experiments where substances are mixed in an insulated container and combustion experiments using, for example, a spirit burner and be able to draw suitable graphs and use cooling curve corrections.</i></p>
<b>6.9</b>	understand the terms 'bond enthalpy' and 'mean bond enthalpy', and be able to use bond enthalpies to calculate enthalpy changes, understanding the limitations of this method
<b>6.10</b>	be able to calculate mean bond enthalpies from enthalpy changes of reaction
<b>6.11</b>	understand that bond enthalpy data gives some indication about which bond will break first in a reaction, how easy or difficult it is and therefore how rapidly a reaction will take place at room temperature

	<p><b>Further suggested practicals:</b></p> <ul style="list-style-type: none"> <li>i the enthalpy change for the decomposition of calcium carbonate using the enthalpy changes of reaction of calcium carbonate and calcium oxide with hydrochloric acid</li> <li>ii the enthalpy change of combustion of an alcohol</li> <li>iii the enthalpy change of the reaction between zinc and copper(II) sulfate solution</li> <li>iv the enthalpy of hydration of anhydrous copper(II) sulfate</li> </ul>
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## Topic 7: Intermolecular Forces

Students will be assessed on their ability to:

<b>7.1</b>	understand the nature of the following intermolecular forces: <ul style="list-style-type: none"><li>i London forces (instantaneous dipole-induced dipole)</li><li>ii permanent dipole-permanent dipole interactions</li><li>iii hydrogen bonds</li></ul>
<b>7.2</b>	understand the interactions in molecules, such as $\text{H}_2\text{O}$ , liquid $\text{NH}_3$ and liquid $\text{HF}$ , which give rise to hydrogen bonding
<b>7.3</b>	understand the following anomalous properties of water resulting from hydrogen bonding: <ul style="list-style-type: none"><li>i its high melting and boiling temperature when compared with similar molecules</li><li>ii the density of ice compared to that of water</li></ul>
<b>7.4</b>	be able to predict the presence of hydrogen bonding in molecules analogous to those mentioned in 7.2
<b>7.5</b>	understand, in terms of intermolecular forces, physical properties shown by substances, including: <ul style="list-style-type: none"><li>i the trends in boiling temperatures of alkanes with increasing chain length</li><li>ii the effect of branching in the carbon chain on the boiling temperatures of alkanes</li><li>iii the relatively low volatility (higher boiling temperatures) of alcohols compared to alkanes with a similar number of electrons</li><li>iv the trends in boiling temperatures of the hydrogen halides <math>\text{HF}</math> to <math>\text{HI}</math></li></ul>
<b>7.6</b>	understand factors that influence the choice of solvents, including: <ul style="list-style-type: none"><li>i water, to dissolve some ionic compounds, in terms of the hydration of the ions</li><li>ii water, to dissolve simple alcohols, in terms of hydrogen bonding</li><li>iii water, as a poor solvent for compounds (to include polar molecules such as halogenoalkane), in terms of inability to form hydrogen bonds</li><li>iv non-aqueous solvents, for compounds that have similar intermolecular forces to those in the solvent</li></ul>
	<b>Further suggested practicals:</b> <ul style="list-style-type: none"><li>i the solubility of simple molecules in different solvents</li><li>ii measuring the enthalpy change of vaporisation of water</li><li>iii measuring temperature changes when substances dissolve</li></ul>

## Topic 8: Redox Chemistry and Groups 1, 2 and 7

### 8A: Redox chemistry

Students will be assessed on their ability to:

<b>8.1</b>	know what is meant by the term 'oxidation number' and understand the rules for assigning oxidation numbers
<b>8.2</b>	be able to calculate the oxidation number of elements in compounds and ions, including in peroxides and metal hydrides
<b>8.3</b>	be able to indicate the oxidation number of an element in a compound or an ion, using a Roman numeral
<b>8.4</b>	be able to write formulae given oxidation numbers
<b>8.5</b>	understand oxidation and reduction in terms of electron transfer and changes in oxidation number, and the application of these ideas to reactions of s-block and p-block elements
<b>8.6</b>	know that oxidising agents gain electrons and reducing agents lose electrons
<b>8.7</b>	understand that a disproportionation reaction involves an element in a single species being simultaneously oxidised and reduced
<b>8.8</b>	know that oxidation number is a useful concept in terms of the classification of reactions as redox and as disproportionation
<b>8.9</b>	understand that metals, in general, form positive ions by loss of electrons with an increase in oxidation number whereas non-metals, in general, form negative ions by gain of electrons with a decrease in oxidation number
<b>8.10</b>	be able to write ionic half-equations and use them to construct full ionic equations

### 8B: The elements of Groups 1 and 2

Students will be assessed on their ability to:

<b>8.11</b>	understand reasons for the trend in ionisation energy down Groups 1 and 2
<b>8.12</b>	understand reasons for the trend in reactivity of the elements down Group 1 (Li to K) and Group 2 (Mg to Ba)
<b>8.13</b>	know the reactions of the elements of Group 1 (Li to K) and Group 2 (Mg to Ba) with oxygen, chlorine and water
<b>8.14</b>	know the reactions of: i    oxides of Group 1 and 2 elements with water and dilute acid ii   hydroxides of Group 1 and 2 elements with dilute acid
<b>8.15</b>	know the trends in solubility of the hydroxides and sulfates of Group 2 elements
<b>8.16</b>	understand the reasons for the trends in thermal stability of the nitrates and the carbonates of the elements in Groups 1 and 2 in terms of the size and charge of the cations involved

<b>8.17</b>	understand the formation of characteristic flame colours by Group 1 and 2 compounds in terms of electron transitions <i>Students will be expected to know the flame colours for Group 1 and 2 compounds.</i>
<b>8.18</b>	know experimental procedures to show: i patterns in the thermal decomposition of Group 1 and 2 nitrates and carbonates <i>Students will be expected to know tests for carbon dioxide and oxygen; and to recognise nitrogen dioxide by its colour and acidic pH.</i> ii flame colours in compounds of Group 1 and 2 elements
<b>8.19</b>	know reactions, including ionic equations where appropriate, for identifying: i carbonate ions, $\text{CO}_3^{2-}$ , and hydrogencarbonate ions, $\text{HCO}_3^-$ , using an aqueous acid to form carbon dioxide (and testing the gas with limewater) ii sulfate ions, $\text{SO}_4^{2-}$ , using acidified barium chloride solution iii ammonium ions, $\text{NH}_4^+$ , using sodium hydroxide solution and warming to form ammonia (and testing with litmus and HCl fumes)
<b>8.20</b>	be able to calculate solution concentrations, in $\text{mol dm}^{-3}$ and $\text{g dm}^{-3}$ , including simple acid-base titrations using the indicators methyl orange and phenolphthalein
<b>8.21</b>	<b>CORE PRACTICAL 3</b> <b>Finding the concentration of a solution of hydrochloric acid.</b>
<b>8.22</b>	understand how to minimise the sources of measurement uncertainty in volumetric analysis and estimate the overall uncertainty in the calculated result
<b>8.23</b>	<b>CORE PRACTICAL 4</b> <b>Preparation of a standard solution from a solid acid and use it to find the concentration of a solution of sodium hydroxide.</b>
	<b>Further suggested practicals:</b> i experiments to study the thermal decomposition of Group 1 and 2 nitrates and carbonates ii flame tests on compounds of Group 1 and 2 iii simple acid-base titrations using the indicators methyl orange and phenolphthalein to calculate solution concentrations in $\text{g dm}^{-3}$ and $\text{mol dm}^{-3}$ iv the solubility of calcium hydroxide by titration v determination of moles of water of crystallisation by titration

## 8C: Inorganic chemistry of Group 7 (limited to chlorine, bromine and iodine)

Students will be assessed on their ability to:

<b>8.24</b>	understand reasons for the trends for Group 7 elements in: <ul style="list-style-type: none"><li>i melting and boiling temperatures and physical state at room temperature</li><li>ii electronegativity</li><li>iii reactivity down the group</li></ul>
<b>8.25</b>	understand the trend in reactivity of Group 7 elements in terms of the redox reactions of $\text{Cl}_2$ , $\text{Br}_2$ and $\text{I}_2$ with halide ions in aqueous solution <i>Students are expected to know the colours of the elements in standard conditions, in aqueous solution and in a non-polar organic solvent.</i>
<b>8.26</b>	understand, in terms of changes in oxidation number, the following reactions of the halogens: <ul style="list-style-type: none"><li>i oxidation reactions with Group 1 and 2 metals</li><li>ii the disproportionation reaction of chlorine with water and the use of chlorine in water treatment</li><li>iii the disproportionation reaction of chlorine with cold, dilute aqueous sodium hydroxide to form bleach</li><li>iv the disproportionation reaction of chlorine with hot alkali</li><li>v reactions analogous to those specified above</li></ul>
<b>8.27</b>	understand the following reactions: <ul style="list-style-type: none"><li>i solid Group 1 halides with concentrated sulfuric acid, to illustrate the trend in reducing ability of the hydrogen halides</li><li>ii precipitation reactions of the aqueous anions <math>\text{Cl}^-</math>, <math>\text{Br}^-</math> and <math>\text{I}^-</math> with aqueous silver nitrate solution and nitric acid, and the solubility of the precipitates in aqueous ammonia solution</li><li>iii hydrogen halides with ammonia gas (to produce ammonium halides) and with water (to produce acids)</li></ul>
<b>8.28</b>	be able to make predictions about fluorine and astatine and their compounds, in terms of knowledge of trends in halogen chemistry
	<b>Further suggested practicals:</b> <ul style="list-style-type: none"><li>i reaction of solid potassium halides with concentrated sulfuric acid</li><li>ii precipitation reaction for halides and other anions</li></ul>

## Topic 9: Introduction to Kinetics and Equilibria

### 9A: Kinetics

Students will be assessed on their ability to:

9.1	understand, in terms of the collision theory, the effect of changes in concentration, temperature, pressure and surface area on the rate of a chemical reaction
9.2	understand that reactions take place only when collisions have sufficient energy, known as the activation energy
9.3	be able to calculate the rate of a reaction from: i the time taken for a reaction, using $\text{rate} = 1/\text{time}$ ii the gradient of suitable graph, by drawing a tangent, either for initial rate, or at a time, $t$
9.4	understand qualitatively, in terms of the Maxwell-Boltzmann distribution of molecular energies, how changes in temperature affect the rate of a reaction
9.5	understand the role of catalysts in providing alternative reaction routes of lower activation energy
9.6	be able to draw the reaction profiles for uncatalysed and catalysed reactions, including the energy level of the intermediate formed with the catalyst
9.7	understand the use of catalysts in industry to make processes more sustainable by using less energy and/or higher atom economy
9.8	be able to interpret the action of a catalyst in terms of a qualitative understanding of the Maxwell-Boltzmann distribution of molecular energies
	<b>Further suggested practical</b>  Experiments to demonstrate the factors that influence the rate of chemical reactions, including the decomposition of hydrogen peroxide, reaction of marble chips with acid, reaction of thiosulfate ions with acid

### 9B: Equilibria

Students will be assessed on their ability to:

9.9	know that many reactions are readily reversible and that they can reach a state of dynamic equilibrium in which: i the rate of the forward reaction is equal to the rate of the backward reaction ii the concentrations of the reactants and the products remain constant
9.10	be able to predict and justify the qualitative effects of changes of temperature, pressure and concentration on the position of equilibrium in a homogeneous system
9.11	evaluate data to explain the necessity, for many industrial processes, to reach a compromise between the yield and the rate of reaction

	<p><b>Further suggested practicals:</b></p> <p>Demonstrate the effect of a change of temperature, pressure and concentration on a system at equilibrium:</p> <ul style="list-style-type: none"> <li>i chlorine reacting with iodine to form iodine(I) chloride, which then reacts with chlorine to form iodine(III) chloride</li> <li>ii the equilibrium system between nitrogen dioxide (<math>\text{NO}_2</math>) and dinitrogen tetroxide (<math>\text{N}_2\text{O}_4</math>)</li> </ul>
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## Topic 10: Organic Chemistry: Halogenoalkanes, Alcohols and Spectra

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

### 10A: General principles

Students will be assessed on their ability to:

<b>10.1</b>	be able to classify reactions (including those in Unit 1) as addition, elimination, substitution, oxidation, reduction, hydrolysis or polymerisation
<b>10.2</b>	understand the concept of a reaction mechanism
<b>10.3</b>	understand that heterolytic bond breaking results in species that are electrophiles or nucleophiles
<b>10.4</b>	know the definition of the term 'nucleophile'
<b>10.5</b>	understand the link between bond polarity and the type of reaction mechanism a compound will undergo

### 10B: Halogenoalkanes

Students will be assessed on their ability to:

<b>10.6</b>	understand the nomenclature of halogenoalkanes and be able to draw their structural, displayed and skeletal formulae
<b>10.7</b>	understand the distinction between primary, secondary and tertiary halogenoalkanes
<b>10.8</b>	<p>understand the reactions of halogenoalkanes with:</p> <ul style="list-style-type: none"><li>i aqueous alkali, including KOH(aq) to produce alcohols (where the hydroxide ion acts as a nucleophile)</li><li>ii ethanolic potassium hydroxide to produce alkenes by an elimination reaction (where the hydroxide ion acts as a base)</li><li>iii aqueous silver nitrate in ethanol (where water acts as a nucleophile)</li><li>iv alcoholic ammonia under pressure to produce amines (where the ammonia acts as a nucleophile)</li><li>v alcoholic potassium cyanide to produce nitriles (where the cyanide ion acts as a nucleophile)</li></ul> <p><i>Students should know this is an example of increasing the length of the carbon chain.</i></p>
<b>10.9</b>	<p>understand the mechanisms of the nucleophilic substitution reactions between primary halogenoalkanes and:</p> <ul style="list-style-type: none"><li>i aqueous potassium hydroxide</li><li>ii ammonia</li></ul> <p><i>S<sub>N</sub>1 and S<sub>N</sub>2 substitution mechanisms will be tested in Unit 4.</i></p>

<b>10.10</b>	understand that experimental observations and data can be used to compare the relative rates of hydrolysis of:  i primary, secondary and tertiary structural isomers of a halogenoalkane ii primary chloro-, bromo- and iodoalkanes using aqueous silver nitrate in ethanol
<b>10.11</b>	<b>CORE PRACTICAL 5</b> <b>Investigation of the rates of hydrolysis of some halogenoalkanes.</b>
<b>10.12</b>	know the trend in reactivity of primary, secondary and tertiary halogenoalkanes
<b>10.13</b>	understand, in terms of bond enthalpy, the trend in reactivity of chloro-, bromo- and iodoalkanes
<b>10.14</b>	<b>CORE PRACTICAL 6</b> <b>Chlorination of 2-methylpropan-2-ol with concentrated hydrochloric acid.</b>
	<b>Further suggested practicals:</b>  i the use of silver nitrate solution to identify the halogen present in halogenoalkanes  ii preparation of 1-bromobutane from butan-1-ol, potassium bromide and sulfuric acid

## 10C: Alcohols

**Students will be assessed on their ability to:**

<b>10.15</b>	understand the nomenclature of alcohols and be able to draw their structural, displayed and skeletal formulae
<b>10.16</b>	understand the distinction between primary, secondary and tertiary alcohols
<b>10.17</b>	understand the reactions of alcohols with:  i oxygen in air (combustion)  ii halogenating agents <ul style="list-style-type: none"> <li>• <math>\text{PCl}_5</math> to produce chloroalkanes (including its use as a qualitative test for the presence of the <math>-\text{OH}</math> group)</li> <li>• 50% concentrated sulfuric acid and potassium bromide to produce bromoalkanes</li> <li>• red phosphorus and iodine to produce iodoalkanes</li> </ul> iii concentrated phosphoric acid to form alkenes by elimination  <i>Descriptions of the mechanisms of these reactions are not required.</i>



<b>10.18</b>	<p>understand that potassium dichromate(VI) in dilute sulfuric acid can oxidise:</p> <ul style="list-style-type: none"> <li>i primary alcohols to produce aldehydes (which give a positive result with Benedict's or Fehling's solution) if the product is distilled as it forms</li> <li>ii primary alcohols to produce carboxylic acids (which give a positive result with sodium carbonate or sodium hydrogencarbonate) if the reagents are heated under reflux</li> <li>iii secondary alcohols to produce ketones</li> </ul> <p><i>In equations, the oxidising agent can be represented by [O].</i></p>
<b>10.19</b>	<p>understand, the following techniques in the preparation and purification of a liquid organic compound:</p> <ul style="list-style-type: none"> <li>i heating under reflux</li> <li>ii extraction with a solvent using a separating funnel</li> <li>iii distillation</li> <li>iv drying with an anhydrous salt</li> <li>v boiling temperature determination</li> </ul>
<b>10.20</b>	<p><b>CORE PRACTICAL 7</b></p> <p><b>The oxidation of propan-1-ol to produce propanal and propanoic acid.</b></p>
	<p><b>Further suggested practical:</b></p> <p>Investigation of reactions of primary and secondary alcohols, including propan-1-ol and propan-2-ol</p>

## 10D: Mass spectra and IR

**Students will be assessed on their ability to:**

<b>10.21</b>	be able to interpret data from mass spectra to suggest possible structures of simple organic compounds using the $m/z$ of the molecular ion and fragmentation patterns
<b>10.22</b>	<p>be able to use infrared spectra, or data from infrared spectra, to deduce functional groups present in organic compounds, and predict infrared absorptions, given wavenumber data, due to familiar functional groups including:</p> <ul style="list-style-type: none"> <li>i C–H stretching absorptions in alkanes, alkenes and aldehydes</li> <li>ii C=C stretching absorption in alkenes</li> <li>iii O–H stretching absorptions in alcohols and carboxylic acids</li> <li>iv C=O stretching absorptions in aldehydes, ketones and carboxylic acids</li> <li>v C–X stretching absorption in halogenoalkanes</li> <li>vi N–H stretching absorption in amines</li> </ul>
<b>10.23</b>	<p><b>CORE PRACTICAL 8</b></p> <p><b>Analysis of some inorganic and organic unknowns.</b></p>

# Unit 3: Practical Skills in Chemistry I

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## IAS compulsory unit

## Externally assessed

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### Unit description

#### Introduction

This unit consists of a written practical examination, covering the skills and techniques developed during practical work in Units 1 and 2.

Although the unit content contains eight core practical activities, the examination will not be limited to recall of these core practicals but may include questions where students are expected to apply their knowledge to new practical situations.

Students should, therefore, develop their practical skills by completing a range of different practicals that require a variety of different techniques.

As students carry out practical activities, they should be encouraged to write laboratory reports using appropriate scientific, technical and mathematical language, conventions and symbols.

#### Development of practical skills, knowledge and understanding

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

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

To prepare for assessment of this unit, centres should give students opportunities to carry out practical activities, collect and analyse data, and draw conclusions. Students should – at the least – carry out the eight core practicals in class. By completing these practicals students will be able to:

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

## Assessment information

- First assessment: June 2019.
  - The assessment is 1 hour and 20 minutes.
  - The assessment is out of 50 marks.
  - Students must answer all questions.
  - This paper may include short-open, open-response and calculation questions.
  - This paper will include a minimum of 6 marks that target mathematics at Level 2 or above.
  - Students will be expected to apply their knowledge and understanding of practical skills to familiar and unfamiliar situations.
  - Calculators may be used in the examination (see *Appendix 8: Use of calculators*).
-

## **The question paper will assess the following abilities.**

### **Independent thinking in a practical context**

- Solve problems set in a practical context.
- Apply scientific knowledge to practical contexts.

### **Use and application of scientific methods and practices**

- Identify and state how to control variables to improve experimental validity.
- Present data in appropriate ways.
- Evaluate results and draw conclusions.
- Appreciate measurement uncertainties and errors.
- Comment on the method for an experiment.

### **Numeracy and the application of mathematical concepts in a practical context**

- Plot and interpret graphs.
- Process and analyse data using appropriate mathematical skills.
- Use appropriate numbers of significant figures based on the experimental data.
- Consider the accuracy and precision of data.

### **Use of apparatus and equipment**

- Recognise a range of laboratory apparatus and select appropriate apparatus for a particular scenario.
- Understand how to use a range of apparatus and techniques appropriate to the knowledge and understanding included in this specification.
- Consider the range and resolution of apparatus.
- Identify health and safety issues and discuss how these may be dealt with.

### **Questions may require students to:**

- recall and/or interpret observations relating to tests for ions and gases in Units 1 and 2
  - recall and/or interpret observations relating to tests for organic functional groups in Units 1 and 2
  - manipulate data and comment on experimental methods and techniques for a range of experiments involving measurements in Units 1 and 2, including molar mass calculations, titrations, thermochemical investigations and simple kinetics experiments
  - comment on experimental methods and techniques in the preparation of inorganic or organic compounds in Units 1 and 2.
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# Unit 4: Rates, Equilibria and Further Organic Chemistry

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## IA2 compulsory unit

## Externally assessed

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### Unit description

#### Introduction

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

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

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

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

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

#### Chemistry in action

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

The study of entropy links thermodynamics and equilibrium, and shows how chemists approach fundamental questions about the stability of chemicals and the direction of chemical change.

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

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

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

## Practical skills

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

Simple practical work can be used to investigate equilibrium systems.

Students can develop their skill at volumetric analysis, with a number of titration activities as part of their exploration of acid-base equilibria.

Although the organic section of the unit contains no core practical activities, students would be expected to encounter simple test-tube reactions for organic functional groups – such as the use of Benedict's or Tollens' reagents. There are also opportunities to undertake synthetic reactions, for example to make and purify an ester.

## Mathematical skills

There are opportunities for the development of mathematical skills in this unit. This includes plotting and justifying the shapes of rate-concentration and concentration-time graphs, calculating the half-life of a reaction, calculating the activation energy from a suitable graph and rearranging the Arrhenius equation. Also, calculating entropy changes, constructing Born-Haber cycles and calculating missing values, constructing expressions for  $K_c$  and  $K_p$  and calculating values with relevant units, estimating the change in value of an equilibrium constant when a variable changes, using logarithms and exponentials for converting from concentration to pH of a buffer solution, plotting and interpreting titration curves and representing chiral molecules with appropriate diagrams. There is also an opportunity for calculating  $R_f$  values and interpreting infrared spectra and using the  $(n + 1)$  rule for proton NMR. (Please see *Appendix 6: Mathematical skills and exemplifications* for further information.)

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## Assessment information

- First assessment: January 2020.
  - The assessment is 1 hour and 45 minutes.
  - The assessment is out of 90 marks.
  - Students must answer all questions.
  - This paper has three sections:
    - Section A: multiple choice questions
    - Section B: mixture of short-open, open-response, calculations and extended-writing questions
    - Section C: data or calculation question.
  - This paper will contain questions that require information from the Data Booklet (see *Appendix 9*).
  - This paper will include a minimum of 22 marks that target mathematics at Level 2 or above.
  - Students will be expected to apply their knowledge and understanding of experimental methods in familiar and unfamiliar contexts.
  - This paper may contain some synoptic questions which require knowledge and understanding from Units 1 and 2.
  - Calculators may be used in the examination (see *Appendix 8: Use of calculators*).
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## Topic 11: Kinetics

Knowledge of the concepts introduced in Unit 2, Topic 9A: Kinetics will be assumed and extended in this topic.

### Students will be assessed on their ability to:

<b>11.1</b>	understand the terms: <ul style="list-style-type: none"><li>i rate of reaction</li><li>ii rate equation, <math>\text{rate} = k[\text{A}]^m[\text{B}]^n</math> where <math>m</math> and <math>n</math> are 0, 1 or 2</li><li>iii order with respect to a substance in a rate equation</li><li>iv overall order of a reaction</li><li>v rate constant</li><li>vi half-life</li><li>vii rate-determining step</li><li>viii activation energy</li><li>ix heterogeneous and homogeneous catalyst</li></ul>
<b>11.2</b>	be able to calculate the half-life of a reaction, using data from a suitable graph, and identify a reaction with a constant half-life as being first order
<b>11.3</b>	be able to select and justify a suitable experimental technique to obtain rate data for a given reaction, including: <ul style="list-style-type: none"><li>i titration</li><li>ii colorimetry</li><li>iii mass change</li><li>iv volume of gas evolved</li><li>v other suitable technique(s) for a given reaction</li></ul>
<b>11.4</b>	understand experiments that can be used to investigate reaction rates by: <ul style="list-style-type: none"><li>i an initial-rate method, carrying out separate experiments where different initial concentrations of one reagent are used</li></ul> <p><i>A 'clock reaction' is an acceptable approximation of this method.</i></p> <ul style="list-style-type: none"><li>ii a continuous monitoring method to generate data to enable concentration-time or volume-time graphs to be plotted</li></ul>
<b>11.5</b>	be able to deduce the order (0, 1 or 2) with respect to a substance in a rate equation, using data from: <ul style="list-style-type: none"><li>i a concentration-time graph</li><li>ii a rate-concentration graph</li><li>iii an initial-rate method</li></ul>



<b>11.6</b>	<p>understand how to:</p> <ul style="list-style-type: none"> <li>i obtain data to calculate the order with respect to the reactants (and the hydrogen ion) in the acid-catalysed iodination of propanone</li> <li>ii use these data to make predictions about species involved in the rate-determining step</li> <li>iii deduce a possible mechanism for the reaction</li> </ul>
<b>11.7</b>	be able to deduce the rate-determining step from a rate equation and vice versa
<b>11.8</b>	be able to deduce a reaction mechanism, using knowledge of the rate equation and the stoichiometric equation for a reaction
<b>11.9</b>	understand that knowledge of the rate equations for the hydrolysis of halogenoalkanes can be used to provide evidence for $S_N1$ and $S_N2$ mechanisms for tertiary and primary halogenoalkane hydrolysis
<b>11.10</b>	<p>be able to use calculations and graphical methods to find the activation energy for a reaction from experimental data</p> <p><i>The Arrhenius equation will be given if needed.</i></p>
<b>11.11</b>	understand the use of a solid (heterogeneous) catalyst for industrial reactions, in the gas phase, in terms of providing a surface for the reaction
<b>11.12</b>	<p><b>CORE PRACTICALS 9a and 9b</b></p> <p><b>Following the rate of the iodine-propanone reaction by a titrimetric method and investigating a 'clock reaction' (Harcourt-Esson, iodine clock).</b></p>
<b>11.13</b>	<p><b>CORE PRACTICAL 10</b></p> <p><b>Finding the activation energy of a reaction.</b></p>
	<p><b>Further suggested practicals:</b></p> <ul style="list-style-type: none"> <li>i the reaction between marble chips and hydrochloric acid (change of mass or change in volume of gas)</li> <li>ii the reaction between magnesium and hydrochloric acid to determine the activation energy</li> <li>iii following the rate of the iodine-propanone reaction by a colorimetric method</li> <li>iv the catalysis by a cobalt(II) salt of potassium sodium tartrate and hydrogen peroxide</li> <li>v the action of the enzyme urease on urea and thiourea</li> </ul>

## Topic 12: Entropy and Energetics

### 12A: Entropy

Students will be assessed on their ability to:

<b>12.1</b>	understand that, since endothermic reactions can occur spontaneously at room temperature, enthalpy changes alone do not control whether reactions occur
<b>12.2</b>	understand entropy as a measure of disorder of a system in terms of the random dispersal of molecules and of energy quanta between molecules
<b>12.3</b>	understand that the entropy of a substance increases with temperature, that entropy increases as solid → liquid → gas and that perfect crystals at zero kelvin have zero entropy
<b>12.4</b>	be able to interpret the natural direction of change as being in the direction of increasing total entropy (positive entropy change), including gases spread spontaneously through a room
<b>12.5</b>	understand why entropy changes occur during: <ul style="list-style-type: none"> <li>i changes of state</li> <li>ii dissolving of a solid ionic lattice</li> <li>iii reactions in which there is a change in the number of moles from reactants to products</li> </ul>
<b>12.6</b>	understand that the total entropy change of any reaction is the sum of the entropy change of the system and the entropy change of the surroundings, summarised by the expression: $\Delta S_{\text{total}} = \Delta S_{\text{system}} + \Delta S_{\text{surroundings}}$
<b>12.7</b>	be able to calculate the entropy change of the system for a reaction, $\Delta S_{\text{system}}$ , given the entropies of the reactants and products
<b>12.8</b>	be able to calculate the entropy change in the surroundings, and hence $\Delta S_{\text{total}}$ , using the expression $\Delta S_{\text{surroundings}} = \frac{-\Delta H}{T}$
<b>12.9</b>	understand that the feasibility of a reaction depends on: <ul style="list-style-type: none"> <li>i the balance between <math>\Delta S_{\text{system}}</math> and <math>\Delta S_{\text{surroundings}}</math>, so that even endothermic reactions can occur spontaneously at room temperature</li> <li>ii temperature, as higher temperatures decrease the magnitude of <math>\Delta S_{\text{surroundings}}</math> so its contribution to <math>\Delta S_{\text{total}}</math> is less</li> </ul> <p><i>Students should be able to calculate the temperature at which a reaction is feasible.</i></p> <p><i>Students may also use <math>\Delta G = \Delta H - T\Delta S_{\text{system}}</math> in answers, although this approach is not a requirement of the specification.</i></p>
<b>12.10</b>	understand that reactions can occur as long as $\Delta S_{\text{total}}$ is positive even if one of the other entropy changes is negative
<b>12.11</b>	understand and distinguish between the concepts of thermodynamic stability and kinetic stability

	<p><b>Further suggested practicals:</b></p> <p>Investigate chemical reactions in terms of disorder and enthalpy change, including:</p> <ul style="list-style-type: none"> <li>i dissolving a solid, including adding ammonium nitrate crystals to water</li> <li>ii gas evolution, including reacting ethanoic acid with ammonium carbonate</li> <li>iii exothermic reaction producing a solid, including burning magnesium ribbon in air</li> <li>iv endothermic reaction of two solids, including mixing solid barium hydroxide, <math>\text{Ba(OH)}_2 \cdot 8\text{H}_2\text{O}</math> with solid ammonium chloride</li> </ul>
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## 12B: Lattice energy

**Students will be assessed on their ability to:**

<b>12.12</b>	<p>be able to define the terms:</p> <ul style="list-style-type: none"> <li>i standard enthalpy change of atomisation, <math>\Delta_{\text{at}}H</math></li> <li>ii electron affinity</li> <li>iii lattice energy (as the exothermic process for the formation of one mole of an ionic solid from its gaseous ions)</li> </ul>
<b>12.13</b>	be able to construct Born-Haber cycles and carry out related calculations
<b>12.14</b>	understand that a comparison of the experimental lattice energy value (from a Born-Haber cycle) with the theoretical value (obtained from electrostatic theory) in a particular compound indicates the degree of covalent bonding
<b>12.15</b>	understand that polarisation of anions by cations leads to some covalency in an ionic bond, based on evidence from the Born-Haber cycle
<b>12.16</b>	be able to define the terms 'enthalpy change of solution, $\Delta_{\text{sol}}H$ ' and 'enthalpy change of hydration, $\Delta_{\text{hyd}}H$ of an ion'
<b>12.17</b>	be able to use energy cycles and energy level diagrams to calculate the enthalpy change of solution of an ionic compound, using enthalpy change of hydration and lattice energy
<b>12.18</b>	understand the effect of ionic charge and ionic radius on the values of enthalpy change of hydration and the lattice energy of an ionic compound
<b>12.19</b>	be able to use entropy and enthalpy changes of solution values to predict the solubility of ionic compounds and discuss trends in the solubility of ionic compounds covered in Unit 2
	<p><b>Further suggested practical</b></p> <p>Calculate the enthalpy change when a variety of ionic solids are dissolved in water</p>

## Topic 13: Chemical Equilibria

Knowledge of the concepts introduced in Unit 2, Topic 9B Chemical Equilibria will be assumed and extended in this topic.

**Students will be assessed on their ability to:**

<b>13.1</b>	be able to deduce an expression for $K_c$ , for homogeneous and heterogeneous systems, in terms of equilibrium concentrations
<b>13.2</b>	be able to deduce an expression for $K_p$ for homogeneous and heterogeneous systems, in terms of equilibrium partial pressures in atm
<b>13.3</b>	be able to calculate a value, with units where appropriate, for the equilibrium constants ( $K_c$ and $K_p$ ) for homogeneous and heterogeneous reactions, from experimental data
<b>13.4</b>	understand how, if at all, a change in temperature, pressure or the presence of a catalyst affects the equilibrium composition in a homogeneous or heterogeneous system
<b>13.5</b>	understand that the value of the equilibrium constant is not affected by changes in concentration or pressure or by the addition of a catalyst
<b>13.6</b>	know the effect of changing the temperature on the equilibrium constant ( $K_c$ and $K_p$ ) for both exothermic and endothermic reactions
<b>13.7</b>	understand that the effect of temperature on the position of equilibrium is explained using a change in the value of the equilibrium constant
<b>13.8</b>	understand the effect of a change in temperature on: <ul style="list-style-type: none"> <li>i the value of <math>\Delta S_{\text{total}}</math></li> <li>ii the magnitude of the equilibrium constant, since <math>\Delta S_{\text{total}} = R \ln K</math></li> </ul>
<b>13.9</b>	be able to apply knowledge of the value of equilibrium constants to predict the extent to which a reaction takes place
	<b>Further suggested practicals:</b> <ul style="list-style-type: none"> <li>i the reaction of ethanol and ethanoic acid (this can be used as an example of the use of ICT to present and analyse data)</li> <li>ii the equilibrium <math>\text{Fe}^{2+}(\text{aq}) + \text{Ag}^+(\text{aq}) \rightleftharpoons \text{Fe}^{3+}(\text{aq}) + \text{Ag}(\text{s})</math></li> <li>iii the distribution of ammonia or iodine between two immiscible solvents</li> <li>iv the thermal decomposition of ammonium chloride</li> <li>v the effect of temperature and pressure changes in the system <math>2\text{NO}_2 \rightleftharpoons \text{N}_2\text{O}_4</math></li> </ul>

## Topic 14: Acid-base Equilibria

Knowledge of the concepts introduced in Unit 2, Topic 9B Chemical Equilibria will be assumed and extended in this topic.

**Students will be assessed on their ability to:**

<b>14.1</b>	understand that a Brønsted–Lowry acid is a proton donor and a Brønsted–Lowry base is a proton acceptor and that acid-base reactions involve proton transfer
<b>14.2</b>	be able to identify Brønsted–Lowry conjugate acid-base pairs
<b>14.3</b>	be able to define the term ‘pH’
<b>14.4</b>	be able to calculate pH from hydrogen ion concentration
<b>14.5</b>	be able to calculate the concentration of hydrogen ions in a solution, in mol dm <sup>-3</sup> , from its pH, using the expression $[H^+] = 10^{-pH}$
<b>14.6</b>	understand the difference between a strong acid and a weak acid in terms of the degree of dissociation
<b>14.7</b>	be able to calculate the pH of a strong acid
<b>14.8</b>	be able to deduce the expression for the acid dissociation constant, $K_a$ , for a weak acid
<b>14.9</b>	be able to calculate the pH of a weak acid from $K_a$ or $pK_a$ values, making relevant assumptions <i>Students will not be expected to solve quadratic equations.</i>
<b>14.10</b>	be able to define the ionic product of water, $K_w$
<b>14.11</b>	be able to calculate the pH of a strong base from its concentration, using $K_w$ or $pK_w$
<b>14.12</b>	be able to define the terms ‘ $pK_a$ ’ and ‘ $pK_w$ ’
<b>14.13</b>	be able to analyse data from the following experiments: i measuring the pH of a variety of substances, including equimolar solutions of strong and weak acids, strong and weak bases, and salts ii comparing the pH of a strong and weak acid after dilution 10, 100 and 1000 times
<b>14.14</b>	be able to calculate $K_a$ for a weak acid from experimental data given the pH of a solution containing a known mass of acid
<b>14.15</b>	be able to draw and interpret titration curves, using all combinations of strong and weak monoprotic and diprotic acids with bases, and apply these principles to diprotic acids and bases
<b>14.16</b>	be able to select a suitable indicator for a titration, using a titration curve and appropriate data
<b>14.17</b>	know what is meant by the term ‘buffer solution’
<b>14.18</b>	understand the action of a buffer solution
<b>14.19</b>	be able to calculate the pH of a buffer solution given appropriate data
<b>14.20</b>	be able to calculate the concentrations of solutions required to prepare a buffer solution of a given pH

<b>14.21</b>	<p>understand how to use a weak acid-strong base or strong acid-weak base titration curve to:</p> <ul style="list-style-type: none"> <li>i demonstrate buffer action</li> <li>ii determine <math>K_a</math> from the pH at the point where half the acid is neutralised/ equivalence point</li> </ul>
<b>14.22</b>	<p>understand the importance of buffer solutions in biological environments:</p> <ul style="list-style-type: none"> <li>i buffers in cells and in blood (<math>H_2CO_3/HCO_3^-</math>)</li> <li>ii in foods to prevent deterioration due to pH change (caused by bacterial or fungal activity)</li> </ul>
<b>14.23</b>	<p><b>CORE PRACTICAL 11</b></p> <p><b>Finding the <math>K_a</math> value for a weak acid.</b></p>
	<p><b>Further suggested practicals:</b></p> <ul style="list-style-type: none"> <li>i carry out the measuring of the pH of solutions mentioned in 14.13</li> <li>ii obtain data to draw titration curves mentioned in 14.15 (which gives an opportunity to use data loggers)</li> <li>iii analysis of vinegar</li> </ul>

## Topic 15: Organic Chemistry: Carbonyls, Carboxylic Acids and Chirality

### 15A: Chirality

Students will be assessed on their ability to:

<b>15.1</b>	know that optical isomerism is a result of chirality in molecules with a single chiral centre
<b>15.2</b>	understand that optical isomerism results from chiral centre(s) in a molecule with asymmetric carbon atom(s) and that optical isomers (enantiomers) are object and non-superimposable mirror images and be able to draw 3D diagrams of these optical isomers
<b>15.3</b>	know that optical activity is the ability of a single optical isomer to rotate the plane of polarisation of plane-polarised monochromatic light in molecules containing a single chiral centre
<b>15.4</b>	know what is meant by the term 'racemic mixture'
<b>15.5</b>	be able to use data on optical activity of reactants and products as evidence for $S_N1$ and $S_N2$ mechanisms and addition to carbonyl compounds

## 15B: Carbonyl compounds

Students will be assessed on their ability to:

<b>15.6</b>	understand the nomenclature of aldehydes and ketones and be able to draw their structural, displayed and skeletal formulae
<b>15.7</b>	understand that aldehydes and ketones: i do not form intermolecular hydrogen bonds and this affects their physical properties ii can form hydrogen bonds with water and this affects their solubility
<b>15.8</b>	understand the reactions of carbonyl compounds with: i Fehling's or Benedict's solution, Tollens' reagent and acidified dichromate(VI) ions <i>In equations, the oxidising agent can be represented as [O].</i> ii lithium tetrahydridoaluminate(III) (lithium aluminium hydride) in dry ether (ethoxyethane) <i>In equations, the reducing agent can be represented by [H].</i> iii HCN, in the presence of KCN, as a nucleophilic addition reaction, using curly arrows, relevant lone pairs, dipoles and evidence of optical activity to show the mechanism iv 2,4-dinitrophenylhydrazine (2,4-DNPH), as a qualitative test for the presence of a carbonyl group and to identify a carbonyl compound given data of the melting temperatures of derivatives <i>The equation for this reaction is not required.</i> v iodine in the presence of alkali (the iodoform test)
	<b>Further suggested practical:</b> Reactions of aldehydes and ketones given in 15.8 i, iv and v



## 15C: Carboxylic acids

Students will be assessed on their ability to:

<b>15.9</b>	understand the nomenclature of carboxylic acids and be able to draw their structural, displayed and skeletal formulae
<b>15.10</b>	understand that hydrogen bonding affects the physical properties of carboxylic acids, in relation to their boiling temperatures and solubility
<b>15.11</b>	understand that carboxylic acids can be prepared by the oxidation of alcohols or aldehydes and the hydrolysis of nitriles
<b>15.12</b>	understand the reactions of carboxylic acids with: i lithium tetrahydridoaluminate(III) (lithium aluminium hydride) in dry ether (ethoxyethane) ii bases to produce salts iii phosphorus(V) chloride (phosphorus pentachloride) iv alcohols in the presence of an acid catalyst
	<b>Further suggested practicals:</b> i solubility of a range of carboxylic acids, aldehydes and ketones ii preparation of carboxylic acids by the oxidation of alcohols and aldehydes iii reactions of carboxylic acids given in 15.12 ii, iii and iv

## 15D: Carboxylic acid derivatives

Students will be assessed on their ability to:

<b>15.13</b>	understand the nomenclature of acyl chlorides and esters and be able to draw their structural, displayed and skeletal formulae
<b>15.14</b>	understand the reactions of acyl chlorides with: i water ii alcohols iii concentrated ammonia iv amines
<b>15.15</b>	understand the hydrolysis reactions of esters, in acidic and alkaline solution
<b>15.16</b>	understand how polyesters, such as terylene, are formed by condensation polymerisation reactions.
	<b>Further suggested practicals:</b> i demonstration of the reactions of ethanoyl chloride given in 15.14 i, ii and iii ii the preparation of esters such as ethyl ethanoate as a solvent or a pineapple flavouring iii hydrolysis of an ester

## 15E: Spectroscopy and chromatography

Knowledge of the concepts introduced in Unit 2, Topic 10D: Mass spectra and IR will be assumed and extended in this topic

### Students will be assessed on their ability to:

<b>15.17</b>	be able to use data from mass spectra to: <ul style="list-style-type: none"><li>i suggest possible structures of a simple organic compound given accurate relative molecular masses</li><li>ii calculate the accurate relative molecular mass of a compound, given accurate relative atomic masses to four decimal places</li></ul>
<b>15.18</b>	understand that carbon-13, ( $^{13}\text{C}$ ) NMR spectroscopy provides information about the positions of $^{13}\text{C}$ atoms in a molecule
<b>15.19</b>	be able to use data from $^{13}\text{C}$ NMR spectroscopy to: <ul style="list-style-type: none"><li>i predict the different environments for carbon atoms present in a molecule, given values of chemical shift, <math>\delta</math></li><li>ii justify the number of peaks present in a <math>^{13}\text{C}</math> NMR spectrum in terms of the number of carbon atoms in different environments</li></ul>
<b>15.20</b>	be able to use both low and high resolution proton NMR spectroscopy to: <ul style="list-style-type: none"><li>i predict the different types of proton present in a molecule, given values of chemical shift, <math>\delta</math></li><li>ii relate relative peak areas, or ratio number of protons, to the relative numbers of <math>^1\text{H}</math> atoms in different environments</li><li>iii deduce the splitting patterns of adjacent, non-equivalent protons using the (n+1) rule and hence suggest the possible structures for a molecule</li><li>iv predict the chemical shifts and splitting patterns of the <math>^1\text{H}</math> atoms in a given molecule</li></ul>
<b>15.21</b>	know that chromatography separates components of a mixture using a mobile phase and a stationary phase
<b>15.22</b>	be able to calculate $R_f$ values from one-way chromatograms in paper and thin-layer chromatography (TLC) and understand reasons for differences in $R_f$ values
<b>15.23</b>	know that high-performance liquid chromatography, HPLC, and gas chromatography, GC, are types of column chromatography that separate substances because of different retention times in the column and may be used in conjunction with mass spectrometry, in applications such as forensics or drug testing in sport

# Unit 5: Transition Metals and Organic Nitrogen Chemistry

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## IA2 compulsory unit

## Externally assessed

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### Unit description

#### Introduction

In this unit, the study of electrode potentials builds on the study of redox in Unit 2, including the concept of oxidation number and the use of redox half equations. Students will study further chemistry related to redox, including transition metals.

The organic chemistry section of this unit focuses on arenes and organic nitrogen compounds such as amines, amides, amino acids and proteins. The organic synthesis section requires students to use the knowledge and understanding of organic chemistry that they have gained over the entire specification.

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

#### Chemistry in action

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

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

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

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

**Practical skills**

As in previous units, students can begin their practical work in this unit with some simple test-tube reactions, investigating the reactions of transition metal ions in solution. This may lead to an exploration of redox reactions and, therefore, to the core practical on electrochemical cells.

Skills in volumetric analysis can be consolidated through titrations for redox systems such as iodine-thiosulfate or manganate(VII) titrations.

An opportunity to explore preparative inorganic chemistry is provided in the core practical devoted to making a transition metal complex.

In organic chemistry, there are further functional groups to explore and the possibility of preparing an azo dye.

The final core practical is an organic synthesis and can be used to showcase a selection of the techniques that students have developed to carry out reactions and purify products efficiently and safely.

**Mathematical skills**

There are opportunities for the development of mathematical skills in this unit. This includes calculating redox potentials, balancing redox equations from half cells, calculating masses and concentrations from redox titrations, investigating the geometry of transition metal complexes, calculating the resonance stability of benzene from thermodynamic data and calculating percentage yields. (Please see *Appendix 6: Mathematical skills and exemplifications* for more detail.)

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## Assessment information

- First assessment: June 2020.
  - The assessment is 1 hour and 45 minutes.
  - The assessment is out of 90 marks.
  - Students must answer all questions.
  - This paper has three sections:
    - Section A: multiple choice questions
    - Section B: mixture of short-open, open-response, calculations and extended-writing questions
    - Section C: contemporary context question.
  - This paper will contain questions that require information from the Data Booklet (see *Appendix 9*).
  - This paper will include a minimum of 18 marks that target mathematics at Level 2 or above.
  - Students will be expected to apply their knowledge and understanding of experimental methods in familiar and unfamiliar contexts.
  - This paper may contain some synoptic questions which require knowledge and understanding from Units 1, 2 and 4.
  - Calculators may be used in the examination (see *Appendix 8: Use of calculators*).
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## Topic 16: Redox Equilibria

Students will be assessed on their ability to:

<b>16.1</b>	understand the terms 'oxidation' and 'reduction' in terms of electron transfer and changes in oxidation number, applied to <i>s</i> -, <i>p</i> - and <i>d</i> -block elements
<b>16.2</b>	know what is meant by the term 'standard electrode potential', $E^\ominus$
<b>16.3</b>	know that the standard electrode potential, $E^\ominus$ , is measured in conditions of: <ul style="list-style-type: none"> <li>i 298 K temperature</li> <li>ii 100 kPa pressure of gases</li> <li>iii 1.00 mol dm<sup>-3</sup> concentration of ions</li> </ul>
<b>16.4</b>	know the features of the standard hydrogen electrode and understand why a reference electrode is necessary
<b>16.5</b>	understand that different methods are used to measure standard electrode potentials of: <ul style="list-style-type: none"> <li>i metals or non-metals in contact with their ions in aqueous solution</li> <li>ii ions of the same element with different oxidation numbers</li> </ul>
<b>16.6</b>	<b>CORE PRACTICAL 12</b> <b>Investigating some electrochemical cells.</b>
<b>16.7</b>	be able to calculate a standard emf, $E^\ominus_{\text{cell}}$ , by combining two standard electrode potentials
<b>16.8</b>	be able to write cell diagrams using the conventional representation of half-cells
<b>16.9</b>	understand the importance of the conditions when measuring an electrode potential, $E$
<b>16.10</b>	be able to use standard electrode potentials to predict the thermodynamic feasibility of a reaction
<b>16.11</b>	understand that $E^\ominus_{\text{cell}}$ is directly proportional to the total entropy change and to $\ln K$ for a reaction
<b>16.12</b>	understand the limitations of predictions made using standard electrode potentials, in terms of kinetic stability of systems and departure from standard conditions
<b>16.13</b>	know that standard electrode potentials are sometimes referred to as standard reduction potentials and can be listed as an electrochemical series
<b>16.14</b>	understand how standard electrode potentials can be used to predict the thermodynamic feasibility of disproportionation reactions
<b>16.15</b>	be able to carry out both structured and unstructured titration calculations involving redox reactions, including iron(II) ions and potassium manganate(VII) and sodium thiosulfate and iodine
<b>16.16</b>	be able to discuss the uncertainty of measurements and their implications for the validity of the final results

<b>16.17</b>	<b>CORE PRACTICALS 13a and 13b</b> <b>Carry out redox titrations with both:</b> <b>i iron(II) ions and potassium manganate(VII)</b> <b>ii sodium thiosulfate and iodine</b>
<b>16.18</b>	understand that fuel cells use the energy released on the reaction of a fuel with oxygen to generate a voltage <i>Knowledge that methanol and other hydrogen-rich fuels are used in fuel cells is expected.</i>
<b>16.19</b>	know the electrode reactions that occur in a hydrogen-oxygen fuel cell <i>Knowledge of hydrogen-oxygen fuel cells with both acidic and alkaline electrolyte is expected.</i>
	<b>Further suggested practicals:</b> i investigate the percentage of copper in brass, using iodine-thiosulfate titration ii investigate the percentage of iron in iron tablets, using potassium manganate(VII) titration iii prepare crystals of potassium iodate(VII) and measure their purity

## Topic 17: Transition Metals and their Chemistry

Students will be assessed on their ability to:

<b>17.1</b>	know that transition metals are <i>d</i> -block elements that form one or more stable ions with incompletely-filled <i>d</i> -orbitals
<b>17.2</b>	be able to deduce the electronic configurations of atoms and ions of the <i>d</i> -block elements of Period 4 (Sc-Zn) given their atomic number and charge (if any)
<b>17.3</b>	understand why transition metals show variable oxidation number
<b>17.4</b>	know what is meant by the term 'ligand'
<b>17.5</b>	understand that dative (coordinate) covalent bonding is involved in the formation of complex ions
<b>17.6</b>	know that a complex ion is a central metal ion surrounded by ligands
<b>17.7</b>	know that aqueous solutions of transition metal ions are usually coloured
<b>17.8</b>	understand that the colour of aqueous ions, and other complex ions, is a consequence of the splitting of the energy levels of the <i>d</i> -orbitals by ligands
<b>17.9</b>	understand why there is a lack of colour in some aqueous ions and other complex ions
<b>17.10</b>	understand the meaning of the term 'coordination number'
<b>17.11</b>	understand that colour changes in transition metal ions may arise as a result of changes in: <ul style="list-style-type: none"> <li>i oxidation number of the ion</li> <li>ii ligand</li> <li>iii coordination number of the complex</li> </ul>
<b>17.12</b>	understand that H <sub>2</sub> O, OH <sup>-</sup> and NH <sub>3</sub> act as monodentate ligands
<b>17.13</b>	understand why complexes with six-fold coordination have an octahedral shape, such as those formed by metal ions with H <sub>2</sub> O, OH <sup>-</sup> and NH <sub>3</sub> as ligands
<b>17.14</b>	know that transition metal ions may form tetrahedral complexes with relatively large ions such as Cl <sup>-</sup>
<b>17.15</b>	know that square planar complexes are also formed by transition metal ions and that <i>cis</i> -platin is an example of such a complex which is used in cancer treatment where it is supplied as a single isomer and not in a mixture with the <i>trans</i> form
<b>17.16</b>	understand the terms 'bidentate' and 'hexadentate' in relation to ligands, and be able to identify examples such as NH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> NH <sub>2</sub> and EDTA <sup>4-</sup>
<b>17.17</b>	know that haemoglobin is an iron(II) complex containing a polydentate ligand and that ligand exchange occurs when an oxygen molecule bound to haemoglobin is replaced by a carbon monoxide molecule  <i>The structure of the haem group will not be assessed.</i>
<b>17.18</b>	know the colours of the oxidation states of vanadium (+5, +4, +3 and +2) in its compounds
<b>17.19</b>	understand redox reactions for the interconversion of the oxidation states of vanadium (+5, +4, +3 and +2), in terms of the relevant <i>E</i> <sup>o</sup> values



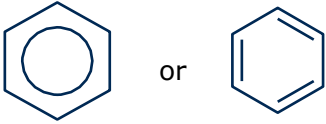
<b>17.20</b>	understand, in terms of the relevant $E$ values, that the dichromate(VI) ion, $\text{Cr}_2\text{O}_7^{2-}$ i can be reduced to $\text{Cr}^{3+}$ and $\text{Cr}^{2+}$ ions using zinc in acidic conditions ii can be produced by the oxidation of $\text{Cr}^{3+}$ ions using hydrogen peroxide in alkaline conditions (followed by acidification)
<b>17.21</b>	know that the dichromate(VI) ion, $\text{Cr}_2\text{O}_7^{2-}$ can be converted into chromate(VI) ions as a result of the equilibrium $\text{Cr}_2\text{O}_7^{2-} + \text{H}_2\text{O} \rightleftharpoons 2\text{CrO}_4^{2-} + 2\text{H}^+$
<b>17.22</b>	be able to record observations and write suitable equations for the reactions of $\text{Cr}^{3+}(\text{aq})$ , $\text{Mn}^{2+}(\text{aq})$ , $\text{Fe}^{2+}(\text{aq})$ , $\text{Fe}^{3+}(\text{aq})$ , $\text{Co}^{2+}(\text{aq})$ , $\text{Ni}^{2+}(\text{aq})$ , $\text{Cu}^{2+}(\text{aq})$ and $\text{Zn}^{2+}(\text{aq})$ with aqueous sodium hydroxide and aqueous ammonia, including in excess
<b>17.23</b>	be able to write ionic equations to show the meaning of amphoteric behaviour, deprotonation and ligand exchange in the reactions in 17.22
<b>17.24</b>	understand that ligand exchange, and an accompanying colour change, occurs in the formation of: i $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ from $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ via $\text{Cu}(\text{OH})_2(\text{H}_2\text{O})_4$ ii $[\text{CuCl}_4]^{2-}$ from $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ iii $[\text{CoCl}_4]^{2-}$ from $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$
<b>17.25</b>	understand, in terms of the positive increase in $\Delta S_{\text{system}}$ , that the substitution of a monodentate ligand by a bidentate or hexadentate ligand leads to a more stable complex ion
<b>17.26</b>	know that transition metals and their compounds can act as heterogeneous and homogeneous catalysts
<b>17.27</b>	know that a heterogeneous catalyst is in a different phase from the reactants and that the reaction occurs at the surface of the catalyst
<b>17.28</b>	understand, in terms of oxidation number, how $\text{V}_2\text{O}_5$ acts as a catalyst in the contact process
<b>17.29</b>	understand how a catalytic converter decreases carbon monoxide and nitrogen monoxide emissions from internal combustion engines by: i adsorption of CO and NO molecules onto the surface of the catalyst, resulting in the weakening of bonds and chemical reaction ii desorption of $\text{CO}_2$ and $\text{N}_2$ product molecules from the surface of the catalyst
<b>17.30</b>	know that a homogeneous catalyst is in the same phase as the reactants and appreciate that the catalysed reaction will proceed via an intermediate species
<b>17.31</b>	understand the role of $\text{Fe}^{2+}$ ions in catalysing the reaction between $\text{I}^-$ and $\text{S}_2\text{O}_8^{2-}$ ions
<b>17.32</b>	know the role of $\text{Mn}^{2+}$ ions in autocatalysing the reaction between $\text{MnO}_4^-$ and $\text{C}_2\text{O}_4^{2-}$ ions
<b>17.33</b>	<b>CORE PRACTICAL 14</b> <b>The preparation of a transition metal complex.</b>

	<b>Further suggested practicals:</b> <ul style="list-style-type: none"> <li>i prepare the different oxidation states of vanadium (17.18/19)</li> <li>ii investigate the equilibrium reaction in 17.21</li> <li>iii carry out the reactions of transition metal ions with sodium hydroxide and ammonia solutions (17.22)</li> <li>iv carry out the ligand exchange reactions in 17.24</li> <li>v investigate the kinetics of the reaction between <math>\text{MnO}_4^-</math> and <math>\text{C}_2\text{O}_4^{2-}</math> in 17.32</li> </ul>
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## Topic 18: Organic Chemistry – Arenes

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

**Students will be assessed on their ability to:**

<b>18.1</b>	<p>be able to use thermochemical, X-ray diffraction and infrared data as evidence for the structure and stability of the benzene ring</p> <p><i>Students may represent the structure of benzene as</i></p> <div style="text-align: center;"></div> <p><i>as appropriate in equations and mechanisms.</i></p>
<b>18.2</b>	understand that the delocalised model for the structure of benzene involves overlap of <i>p</i> -orbitals to form $\pi$ -bonds
<b>18.3</b>	understand why benzene is resistant to bromination, compared to alkenes, in terms of delocalisation of $\pi$ -bonds in benzene compared to the localised electron density of the $\pi$ -bond in alkenes
<b>18.4</b>	<p>know the following reactions of benzene, limited to:</p> <ul style="list-style-type: none"><li>i oxygen in air (combustion to form a smoky flame)</li><li>ii bromine, in the presence of a catalyst</li><li>iii a mixture of concentrated nitric and sulfuric acids</li><li>iv fuming sulfuric acid</li><li>v halogenoalkanes and acyl chlorides with aluminium chloride as catalyst (Friedel-Crafts reaction)</li></ul>
<b>18.5</b>	understand the mechanism of the electrophilic substitution reactions of benzene in halogenation, nitration and Friedel-Crafts reactions, including the generation of the electrophile
<b>18.6</b>	understand the reaction of phenol with bromine water and the reasons for the relative ease of this reaction compared to benzene
	<p><b>Further suggested practical:</b></p> <p>Carry out the reactions in 18.4, and 18.6 where appropriate (using methylbenzene or methoxybenzene)</p>

## Topic 19: Organic Nitrogen Compounds: Amines, Amides, Amino Acids and Proteins

Students will be assessed on their ability to:

<b>19.1</b>	understand the nomenclature of amides, amines and amino acids and be able to draw their structural, displayed and skeletal formulae
<b>19.2</b>	understand the reactions of primary aliphatic amines (using butylamine as an example) and aromatic amines (using phenylamine as an example) with: <ul style="list-style-type: none"> <li>i water to form an alkaline solution</li> <li>ii acids to form salts</li> <li>iii halogenoalkanes</li> <li>iv ethanoyl chloride</li> <li>v copper(II) ions to form a complex ion</li> </ul>
<b>19.3</b>	understand that amines are miscible with water as a result of hydrogen bonding, and the reasons for the difference in basicity between ammonia, primary aliphatic amines and primary aromatic amines
<b>19.4</b>	understand, in terms of reagents and general reaction conditions, the preparation of primary aliphatic amines: <ul style="list-style-type: none"> <li>i from halogenoalkanes</li> <li>ii by the reduction of nitriles</li> </ul>
<b>19.5</b>	know the preparation of aromatic amines by the reduction of aromatic nitro-compounds using tin and concentrated hydrochloric acid
<b>19.6</b>	be able to describe the reaction of aromatic amines with nitrous acid to form benzenediazonium ions, followed by a coupling reaction with phenol to form a dye
<b>19.7</b>	understand that amides can be prepared from acyl chlorides
<b>19.8</b>	be able to describe: <ul style="list-style-type: none"> <li>i condensation polymerisation for the formation of polyamides such as nylon and proteins</li> <li>ii addition polymerisation, including poly(propenamide) and poly(ethenol)</li> </ul>
<b>19.9</b>	be able to draw the structural formulae of the repeat units of the polymers in 19.8
<b>19.10</b>	be able to comment on the physical properties of polyamides and the solubility in water of the addition polymer poly(ethenol) in terms of hydrogen bonding, including soluble laundry bags or liquid-detergent capsules (liquitabs)
<b>19.11</b>	be able to describe experiments to investigate the characteristic behaviour of amino acids limited to: <ul style="list-style-type: none"> <li>i acidity and basicity and the formation of zwitterions</li> <li>ii effect of aqueous solutions on plane-polarised monochromatic light</li> <li>iii formation of peptide bonds by condensation polymerisation</li> </ul>
<b>19.12</b>	<b>CORE PRACTICAL 15</b> <b>Analysis of some inorganic and organic unknowns.</b>

	<b>Further suggested practicals:</b> i carry out some of the reactions of amines from 19.2 i, ii and v ii prepare an azo dye from 19.6 iii carry out reactions of amino acids from 19.11 i iv prepare nylon-6.6 or 6.10 from 19.8
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## Topic 20: Organic Synthesis

Students will be assessed on their ability to:

<b>20.1</b>	be able to deduce the empirical formulae, molecular formulae and structural formulae from data drawn from combustion analysis, element percentage composition, characteristic reactions of functional groups, infrared spectra, mass spectra and NMR spectra (both $^{13}\text{C}$ and proton)
<b>20.2</b>	understand methods of increasing the length of the carbon chain in a molecule by the use of magnesium to form Grignard reagents and the reactions of the latter with carbon dioxide and with carbonyl compounds in dry ether
<b>20.3</b>	<p>be able to use knowledge of organic chemistry contained given in this specification to solve problems such as:</p> <ul style="list-style-type: none"> <li>i predicting the properties of unfamiliar compounds containing one or more of the functional groups included in the specification and explain these predictions</li> <li>ii planning reaction schemes of up to four steps, recalling familiar reactions and using unfamiliar reactions given sufficient information</li> <li>iii selecting suitable practical procedures for carrying out reactions involving compounds with functional groups included in this specification</li> <li>iv identifying appropriate control measures to reduce risk based on data of hazards</li> </ul>
<b>20.4</b>	<p><b>CORE PRACTICAL 16</b></p> <p><b>The preparation of aspirin.</b></p>
<b>20.5</b>	<p>understand the following techniques used in the preparation and purification of organic compounds:</p> <ul style="list-style-type: none"> <li>i refluxing</li> <li>ii purification by washing, including with water and sodium carbonate solution</li> <li>iii solvent extraction</li> <li>iv recrystallisation</li> <li>v drying</li> <li>vi distillation</li> <li>vii steam distillation</li> <li>viii melting temperature determination</li> <li>ix boiling temperature determination</li> </ul>
	<p><b>Further suggested practicals:</b></p> <ul style="list-style-type: none"> <li>i carry out the preparation of an organic compound, including cholesteryl benzoate (a liquid crystal) or methyl 3-nitrobenzoate</li> <li>ii preparation of oil of wintergreen</li> </ul>

# Unit 6: Practical Skills in Chemistry II

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## IA2 compulsory unit

## Externally assessed

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### Unit description

#### Introduction

This unit consists of a written practical examination, covering the skills and techniques developed during practical work in Units 4 and 5, as well as the tests for anions and cations, gases and organic functional groups from Units 1 and 2.

Although the unit content contains eight core practical activities, the examination will not be limited to recall of these core practicals, there may be questions where students need to apply their knowledge to new practical situations.

Students should, therefore, develop their practical skills by completing a range of different practicals that require a variety of different techniques.

As students carry out practical activities, they should be encouraged to write laboratory reports using appropriate scientific, technical and mathematical language, conventions and symbols.

#### Development of practical skills, knowledge and understanding

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

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

To prepare for assessment of this unit, centres should give students opportunities to carry out practical activities, to collect and analyse data, and to draw conclusions. Students should – at the least – carry out the eight core practicals in class. By completing these practicals, students will be able to:

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

## Assessment information

- First assessment: June 2020.
  - The assessment is 1 hour and 20 minutes.
  - The assessment is out of 50 marks.
  - Students must answer all questions.
  - This paper may include short-open, open-response and calculation questions.
  - This paper will include a minimum of 6 marks that target mathematics at Level 2 or above.
  - Students will be expected to apply their knowledge and understanding of practical skills to familiar and unfamiliar situations.
  - Calculators may be used in the examination (see *Appendix 8: Use of calculators*).
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**The question paper will assess the following abilities.**

**Independent thinking in a practical context**

- Solve problems set in a practical context.
- Apply scientific knowledge to practical contexts.

**Use and application of scientific methods and practices**

- Identify and state how to control variables to improve experimental validity.
- Present data in appropriate ways.
- Evaluate results and draw conclusions.
- Appreciate measurement uncertainties and errors.
- Comment on the method for an experiment.

**Numeracy and the application of mathematical concepts in a practical context**

- Plot and interpret graphs.
- Process and analyse data using appropriate mathematical skills.
- Use appropriate numbers of significant figures based on the experimental data.
- Consider the accuracy and precision of data.

**Use of apparatus and equipment**

- Recognise a range of laboratory apparatus and select appropriate apparatus for a particular scenario.
- Understand how to use a range of apparatus and techniques appropriate to the knowledge and understanding included in this specification.
- Consider the range and resolution of apparatus.
- Identify health and safety issues and discuss how these may be dealt with.

Although Unit 6 will predominantly assess knowledge and understanding related to Units 4 and 5, questions may also require students to draw on knowledge and understanding from Units 1 and 2.

**Questions may require students to:**

- recall and/or interpret observations relating to tests for ions and gases across the whole specification
  - recall and/or interpret observations relating to tests for organic functional groups across the whole specification
  - manipulate data and comment on experimental methods and techniques for a range of experiments involving measurements across the whole specification, including titrations, thermochemical investigations, equilibrium systems and kinetics experiments
  - comment on experimental methods and techniques in the preparation of inorganic or organic compounds across the whole specification.
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