

## Topic 1: Atomic Structure and the Periodic Table

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

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

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

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

**Students should:**

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| 15. understand how ideas about electronic configuration developed from: <ul style="list-style-type: none"><li>i the fact that atomic emission spectra provide evidence for the existence of quantum shells</li><li>ii the fact that successive ionisation energies provide evidence for the existence of quantum shells and the group to which the element belongs</li><li>iii the fact that the first ionisation energy of successive elements provides evidence for electron sub-shells</li></ul> |
| 16. know the number of electrons that can fill the first four quantum shells  |
| 17. know that an orbital is a region within an atom that can hold up to two electrons with opposite spins   |
| 18. know the shape of an <i>s</i> -orbital and a <i>p</i> -orbital  |
| 19. know the number of electrons that occupy <i>s</i> , <i>p</i> and <i>d</i> -subshells  |
| 20. know that electrons fill subshells singly, before pairing up, and that two electrons in the same orbital must have opposite spins   |
| 21. be able to predict the electronic configurations, using 1s notation and electrons-in-boxes notation, of: <ul style="list-style-type: none"><li>i atoms, given the atomic number, <i>Z</i>, up to <i>Z</i> = 36</li><li>ii ions, given the atomic number, <i>Z</i>, and the ionic charge, for <i>s</i> and <i>p</i> block ions only, up to <i>Z</i> = 36</li></ul>   |
| 22. know that elements can be classified as <i>s</i> , <i>p</i> and <i>d</i> -block elements  |
| 23. understand that electronic configuration determines the chemical properties of an element   |
| 24. understand periodicity in terms of a repeating pattern across different periods   |
| 25. understand reasons for the trends in the following properties of the elements from periods 2 and 3 of the Periodic Table: <ul style="list-style-type: none"><li>i the melting and boiling temperatures of the elements, based on given data, in terms of structure and bonding</li><li>ii ionisation energy based on given data or recall of the plots of ionisation energy versus atomic number</li></ul>  |
| 26. be able to illustrate periodicity using data, including electronic configurations, atomic radii, melting and boiling temperatures and first ionisation energies   |

## Topic 2: Bonding and Structure

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

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

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

Students should:	
Topic 2A: Bonding	
1.	know that ionic bonding is the strong electrostatic attraction between oppositely charged ions
2.	understand the effects that ionic radius and ionic charge have on the strength of ionic bonding
3.	understand the formation of ions in terms of electron loss or gain
4.	be able to draw electronic configuration diagrams of cations and anions using dot-and-cross diagrams
5.	understand reasons for the trends in ionic radii down a group and for a set of isoelectronic ions, e.g. $\text{N}^{3-}$ to $\text{Al}^{3+}$
6.	understand that the physical properties of ionic compounds and the migration of ions provide evidence for the existence of ions
7.	know that a covalent bond is the strong electrostatic attraction between two nuclei and the shared pair of electrons between them
8.	be able to draw dot-and-cross diagrams to show electrons in covalent substances, including: <ol style="list-style-type: none"> <li>molecules with single, double and triple bonds</li> <li>species exhibiting dative covalent (coordinate) bonding, including <math>\text{Al}_2\text{Cl}_6</math> and ammonium ion</li> </ol>
9.	understand the relationship between bond lengths and bond strengths for covalent bonds
10.	understand that the shape of a simple molecule or ion is determined by the repulsion between the electron pairs that surround a central atom
11.	understand reasons for the shapes of, and bond angles in, simple molecules and ions with up to six outer pairs of electrons (any combination of bonding pairs and lone pairs) <i>Examples should include <math>\text{BeCl}_2</math>, <math>\text{BCl}_3</math>, <math>\text{CH}_4</math>, <math>\text{NH}_3</math>, <math>\text{NH}_4^+</math>, <math>\text{H}_2\text{O}</math>, <math>\text{CO}_2</math>, <math>\text{PCl}_5(\text{g})</math> and <math>\text{SF}_6(\text{g})</math> and related molecules and ions; as well as simple organic molecules in this specification.</i>

<b>Students should:</b>	
12.	be able to predict the shapes of, and bond angles in, simple molecules and ions analogous to those specified above using electron-pair repulsion theory
13.	know that electronegativity is the ability of an atom to attract the bonding electrons in a covalent bond
14.	know that ionic and covalent bonding are the extremes of a continuum of bonding type and that electronegativity differences lead to bond polarity in bonds and molecules
15.	understand that molecules with polar bonds may not be polar molecules and be able to predict whether or not a given molecule is likely to be polar
16.	understand the nature of intermolecular forces resulting from the following interactions: <ul style="list-style-type: none"> <li>i London forces (instantaneous dipole – induced dipole)</li> <li>ii permanent dipoles</li> <li>iii hydrogen bonds</li> </ul>
17.	understand the interactions in molecules, such as H <sub>2</sub> O, liquid NH <sub>3</sub> and liquid HF, which give rise to hydrogen bonding
18.	understand the following anomalous properties of water resulting from hydrogen bonding: <ul style="list-style-type: none"> <li>i its relatively high melting temperature and boiling temperature</li> <li>ii the density of ice compared to that of water</li> </ul>
19.	be able to predict the presence of hydrogen bonding in molecules analogous to those mentioned above
20.	understand, in terms of intermolecular forces, physical properties shown by materials, including: <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, HF to HI</li> </ul>
21.	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 halogenoalkanes), 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>
22.	know that metallic bonding is the strong electrostatic attraction between metal ions and the delocalised electrons

**Students should:**

**Topic 2B: Structure**

23. know that giant lattices are present in:
- i ionic solids (giant ionic lattices)
  - ii covalently bonded solids, such as diamond, graphite and silicon(IV) oxide (giant covalent lattices)
  - iii solid metals (giant metallic lattices)
24. know that the structure of covalently bonded substances such as iodine,  $I_2$ , and ice,  $H_2O$ , is simple molecular
25. know the different structures formed by carbon atoms, including graphite, diamond and graphene
26. be able to predict the type of structure and bonding present in a substance from numerical data and/or other information
27. be able to predict the physical properties of a substance, including melting and boiling temperature, electrical conductivity and solubility in water, in terms of:
- i the types of particle present (atoms, molecules, ions, electrons)
  - ii the structure of the substance
  - iii the type of bonding and the presence of intermolecular forces, where relevant

## Topic 3: Redox I

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

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

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

### Students should:

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

## Topic 4: Inorganic Chemistry and the Periodic Table

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

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

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

### Students should:

#### Topic 4A: The elements of Groups 1 and 2

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

Students should:	
Topic 4B: The elements of Group 7 (halogens)	
9.	understand reasons for the trends in melting and boiling temperatures, physical state at room temperature, and electronegativity for Group 7 elements
10.	understand reasons for the trend in reactivity of Group 7 elements down the group
11.	understand the trend in reactivity of Group 7 elements in terms of the redox reactions of $\text{Cl}_2$ , $\text{Br}_2$ and $\text{I}_2$ with halide ions in aqueous solution, followed by the addition of an organic solvent
12.	understand, in terms of changes in oxidation number, the following reactions of the halogens: <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>
13.	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, followed by aqueous ammonia solution</li> <li>iii hydrogen halides with ammonia and with water (to produce acids)</li> </ul>
14.	be able to make predictions about fluorine and astatine and their compounds, in terms of knowledge of trends in halogen chemistry
Topic 4C: Analysis of inorganic compounds	
15.	<p>know reactions, including ionic equations where appropriate, for identifying:</p> <ul style="list-style-type: none"> <li>i carbonate ions, <math>\text{CO}_3^{2-}</math>, and hydrogencarbonate ions, <math>\text{HCO}_3^-</math>, using an aqueous acid to form carbon dioxide</li> <li>ii sulfate ions, <math>\text{SO}_4^{2-}</math>, using acidified barium chloride solution</li> <li>iii ammonium ions, <math>\text{NH}_4^+</math>, using sodium hydroxide solution and warming to form ammonia</li> </ul> <p><i>Tests for halide ions and for the ions of Group 1 and 2 metals are also required, but are covered elsewhere in this Topic.</i></p>



## Topic 5: Formulae, Equations and Amounts of Substance

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

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

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

Students should:
1. know that the mole (mol) is the unit for amount of a substance
2. be able to use the Avogadro constant, $L$ , ( $6.02 \times 10^{23} \text{ mol}^{-1}$ ) in calculations
3. know that the molar mass of a substance is the mass per mole of the substance in $\text{g mol}^{-1}$
4. know what is meant by the terms 'empirical formula' and 'molecular formula'
5. be able to use experimental data to calculate <ol style="list-style-type: none"><li>empirical formulae</li><li>molecular formulae including the use of <math>pV = nRT</math> for gases and volatile liquids</li></ol> <i>Calculations of empirical formula may involve composition by mass or percentage composition by mass data.</i>
6. be able to write balanced full and ionic equations, including state symbols, for chemical reactions
7. be able to calculate amounts of substances (in mol) in reactions involving mass, volume of gas, volume of solution and concentration <i>These calculations may involve reactants and/or products.</i>
8. be able to calculate reacting masses from chemical equations, and vice versa, using the concepts of amount of substance and molar mass
9. be able to calculate reacting volumes of gases from chemical equations, and vice versa, using the concepts of amount of substance
10. be able to calculate reacting volumes of gases from chemical equations, and vice versa, using the concepts of molar volume of gases
<b>CORE PRACTICAL 1: Measure the molar volume of a gas</b>
11. be able to calculate solution concentrations, in $\text{mol dm}^{-3}$ and $\text{g dm}^{-3}$ , including simple acid-base titrations using a range of acids, alkalis and indicators <i>The use of both phenolphthalein and methyl orange as indicators will be expected.</i>

**Students should:**

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

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

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| 12. be able to: <ul style="list-style-type: none"><li>i calculate measurement uncertainties and measurement errors in experimental results</li><li>ii comment on sources of error in experimental procedures</li></ul>  |
| 13. understand how to minimise the percentage error and percentage uncertainty in experiments involving measurements  |
| 14. be able to calculate percentage yields and percentage atom economies using chemical equations and experimental results<br><br>Atom economy of a reaction = $\frac{\text{molar mass of the desired product}}{\text{sum of the molar masses of all products}} \times 100\%$ |
| 15. be able to relate ionic and full equations, with state symbols, to observations from simple test tube reactions, to include: <ul style="list-style-type: none"><li>i displacement reactions</li><li>ii reactions of acids</li><li>iii precipitation reactions</li></ul>   |
| 16. understand risks and hazards in practical procedures and suggest appropriate precautions where necessary  |

## Topic 6: Organic Chemistry I

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

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

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

Students should:	
Topic 6A: Introduction to organic chemistry	
1.	know that a hydrocarbon is a compound of hydrogen and carbon only
2.	be able to represent organic molecules using empirical formulae, molecular formulae, general formulae, structural formulae, displayed formulae and skeletal formulae
3.	know what is meant by the terms 'homologous series' and 'functional group'
4.	be able to name compounds relevant to this specification using the rules of International Union of Pure and Applied Chemistry (IUPAC) nomenclature <i>Students will be expected to know prefixes for compounds up to C<sub>10</sub></i>
5.	be able to classify reactions as addition, elimination, substitution, oxidation, reduction, hydrolysis or polymerisation
6.	understand the term 'structural isomerism' and determine the possible structural, displayed and skeletal formulae of an organic molecule, given its molecular formula
7.	understand the term 'stereoisomerism', as illustrated by <i>E/Z</i> isomerism (including <i>cis-trans</i> isomerism where two of the substituent groups are the same)
Topic 6B: Alkanes	
8.	know the general formula for alkanes
9.	know that alkanes and cycloalkanes are saturated hydrocarbons
10.	understand that alkane fuels are obtained from the fractional distillation, cracking and reforming of crude oil <i>Reforming is described as the processing of straight-chain hydrocarbons into branched-chain alkanes and cyclic hydrocarbons for efficient combustion.</i>
11.	know that pollutants, including carbon monoxide, oxides of nitrogen and sulfur, carbon particulates and unburned hydrocarbons, are formed during the combustion of alkane fuels

<b>Students should:</b>	
12.	understand the problems arising from pollutants from the combustion of fuels, limited to the toxicity of carbon monoxide and the acidity of oxides of nitrogen and sulfur
13.	understand how the use of a catalytic converter solves some problems caused by pollutants
14.	understand the use of alternative fuels, including biodiesel and alcohols derived from renewable sources such as plants, in terms of a comparison with non-renewable fossil fuels
15.	<p>know that a radical:</p> <ul style="list-style-type: none"> <li>i is a species with an unpaired electron and is represented in mechanisms by a single dot</li> <li>ii is formed by homolytic fission of a covalent bond and results in the formation of radicals</li> </ul>
16.	<p>understand the reactions of alkanes with:</p> <ul style="list-style-type: none"> <li>i oxygen in air (combustion)</li> <li>ii halogens, in terms of the mechanism of radical substitution through initiation, propagation and termination steps</li> </ul> <p><i>The use of curly half-arrows is not expected in this mechanism.</i></p>
17.	understand the limitations of the use of radical substitution reactions in the synthesis of organic molecules, in terms of further substitution reactions and the formation of a mixture of products
<b>Topic 6C: Alkenes</b>	
18.	know the general formula for alkenes
19.	know that alkenes and cycloalkenes are unsaturated hydrocarbons
20.	understand the bonding in alkenes in terms of $\sigma$ - and $\pi$ - bonds
21.	know what is meant by the term 'electrophile'
22.	<p>understand the addition reactions of alkenes with:</p> <ul style="list-style-type: none"> <li>i hydrogen, in the presence of a nickel catalyst, to form an alkane <i>Knowledge of the application of this reaction to the manufacture of margarine by catalytic hydrogenation of unsaturated vegetable oils is expected.</i></li> <li>ii halogens to produce dihalogenoalkanes</li> <li>iii hydrogen halides to produce halogenoalkanes</li> <li>iv steam, in the presence of an acid catalyst, to produce alcohols</li> <li>v potassium manganate(VII), in acid conditions, to oxidise the double bond and produce a diol</li> </ul>
23.	understand that heterolytic bond fission of a covalent bond results in the formation of ions

**Students should:**

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

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

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

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

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

26. know that alkenes form polymers through addition polymerisation

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

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

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

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

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

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

**Topic 6D: Halogenoalkanes**

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

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

32. understand the reactions of halogenoalkanes with:

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

**Students should:**

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

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

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

**Topic 6E: Alcohols**

37. know that alcohols can be classified as primary, secondary or tertiary
38. understand the reactions of alcohols with:
- oxygen in air (combustion)
  - halogenating agents:
    - $\text{PCl}_5$  to produce chloroalkanes
    - 50% concentrated sulfuric acid and potassium bromide to produce bromoalkanes
    - red phosphorus and iodine to produce iodoalkanes
  - potassium dichromate(VI) in dilute sulfuric acid to oxidise primary alcohols to aldehydes (including a test for the aldehyde using Benedict's/Fehling's solution) and carboxylic acids, and secondary alcohols to ketones  
*In equations, the oxidising agent can be represented as  $[\text{O}]$ .*
  - concentrated phosphoric acid to form alkenes by elimination  
*Descriptions of the mechanisms of these reactions are not expected.*
39. understand the following techniques used in the preparation and purification of a liquid organic compound:
- heating under reflux
  - extraction with a solvent in a separating funnel
  - distillation
  - drying with an anhydrous salt
  - boiling temperature determination

**CORE PRACTICAL 5: The oxidation of ethanol****CORE PRACTICAL 6: Chlorination of 2-methylpropan-2-ol using concentrated hydrochloric acid**

## Topic 7: Modern Analytical Techniques I

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

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

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

### Students should:

#### Topic 7A: Mass spectrometry

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

#### Topic 7B: Infrared (IR) spectroscopy

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

#### **CORE PRACTICAL 7: Analysis of some inorganic and organic unknowns**

## Topic 8: Energetics I

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

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

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

Students should:	
1.	know that standard conditions are 100 kPa and a specified temperature, usually 298 K
2.	know that the enthalpy change is the heat energy change measured at constant pressure
3.	be able to construct and interpret enthalpy level diagrams showing an enthalpy change, including appropriate signs for exothermic and endothermic reactions <i>Activation energy is not shown in enthalpy level diagrams but it is shown in reaction profile diagrams.</i>
4.	be able to define standard enthalpy change of: i reaction ii formation iii combustion iv neutralisation
5.	understand experiments to measure enthalpy changes in terms of: i processing results using the expression: energy transferred = mass $\times$ specific heat capacity $\times$ temperature change ( $Q=mc\Delta T$ ) ii evaluating sources of error and assumptions made in the experiments <i>Students will need to consider experiments where:</i> <ul style="list-style-type: none"><li><i>substances are mixed in an insulated container and the temperature change is measured</i></li><li><i>enthalpy of combustion is measured, such as using a series of alcohols in a spirit burner</i></li><li><i>the enthalpy change cannot be measured directly.</i></li></ul>
6.	be able to calculate enthalpy changes in $\text{kJ mol}^{-1}$ from given experimental results <i>Both a sign and units are expected in the final answer.</i>



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

## Topic 9: Kinetics I

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

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

Within this topic, students can consider how the use of models in chemistry is illustrated by the way in which the Maxwell-Boltzmann distribution and collision theory can account for the effects of changing variables on the rate of a chemical reaction.

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

## Topic 10: Equilibrium I

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

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

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

### Students should:

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

## Topic 11: Equilibrium II

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

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

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

### Students should:

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

## Topic 12: Acid-base Equilibria

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

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

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

Students should:
1. know that a Brønsted–Lowry acid is a proton donor and a Brønsted–Lowry base is a proton acceptor
2. know that acid-base reactions involve the transfer of protons
3. be able to identify Brønsted–Lowry conjugate acid-base pairs
4. be able to define the term 'pH'
5. be able to calculate pH from hydrogen ion concentration
6. be able to calculate the concentration of hydrogen ions, in $\text{mol dm}^{-3}$ , in a solution from its pH, using the expression $[\text{H}^+] = 10^{-\text{pH}}$
7. understand the difference between a strong acid and a weak acid in terms of degree of dissociation
8. be able to calculate the pH of a strong acid
9. be able to deduce the expression for the acid dissociation constant, $K_a$ , for a weak acid and carry out relevant calculations
10. be able to calculate the pH of a weak acid making relevant assumptions
11. be able to define the ionic product of water, $K_w$
12. be able to calculate the pH of a strong base from its concentration, using $K_w$
13. be able to define the terms ' $\text{p}K_a$ ' and ' $\text{p}K_w$ '
14. be able to analyse data from the following experiments: <ul style="list-style-type: none"><li>i measuring the pH of a variety of substances, e.g. equimolar solutions of strong and weak acids, strong and weak bases, and salts</li><li>ii comparing the pH of a strong acid and a weak acid after dilution 10, 100 and 1000 times</li></ul>
15. be able to calculate $K_a$ for a weak acid from experimental data given the pH of a solution containing a known mass of acid

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

## Topic 13: Energetics II

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

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

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

Students should:	
Topic 13A: Lattice energy	
1.	be able to define lattice energy as the energy change when one mole of an ionic solid is formed from its gaseous ions
2.	be able to define the terms: i enthalpy change of atomisation, $\Delta_{\text{at}}H$ ii electron affinity
3.	be able to construct Born-Haber cycles and carry out related calculations
4.	know that lattice energy provides a measure of ionic bond strength
5.	understand that a comparison of the experimental lattice energy value (from a Born-Haber cycle) with the theoretical value (obtained from electrostatic theory) in a particular compound indicates the degree of covalent bonding
6.	understand the meaning of polarisation as applied to ions
7.	know that the polarising power of a cation depends on its radius and charge
8.	know that the polarisability of an anion depends on its radius and charge
9.	be able to define the terms 'enthalpy change of solution, $\Delta_{\text{sol}}H'$ , and 'enthalpy change of hydration, $\Delta_{\text{hyd}}H'$
10.	be able to use energy cycles and energy level diagrams to carry out calculations involving enthalpy change of solution, enthalpy change of hydration and lattice energy
11.	understand the effect of ionic charge and ionic radius on the values of: i lattice energy ii enthalpy change of hydration

**Students should:**

**Topic 13B: Entropy**

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

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

14. understand why entropy changes occur during:

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

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

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

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

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

16. be able to calculate the entropy change for the system,  $\Delta S_{\text{system}}$ , in a reaction, given the entropies of the reactants and products

17. be able to calculate the entropy change in the surroundings, and hence  $\Delta S_{\text{total}}$ , using the expression:

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

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

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

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

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

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

21. understand why a reaction for which the  $\Delta G$  value is negative may not occur in practice

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



## Topic 14: Redox II

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

Mathematical skills that could be developed in this topic include calculating redox potentials, balancing redox equations from half cells, calculations involving redox titrations.

Within this topic, students can consider how ideas developed in different contexts within chemistry can be shown to be related to a major explanatory principle. Here, cell emfs and equilibrium constants are shown to be related to the fundamental criterion for the feasibility of a chemical reaction: the total entropy change. Students can also consider how chemists continue to search for alternative sources of energy, through the development of fuel cells.

Students should:	
1.	understand the terms 'oxidation' and 'reduction' in terms of electron transfer, applied to <i>s</i> -, <i>p</i> - and <i>d</i> -block elements
2.	understand the terms 'oxidation' and 'reduction' in terms of changes in oxidation number, applied to <i>s</i> -, <i>p</i> - and <i>d</i> -block elements
3.	know what is meant by the term 'standard electrode potential', $E^\ominus$
4.	know that the standard electrode potential, $E^\ominus$ , refers to conditions of: i 298 K temperature ii 100 kPa pressure of gases iii 1.00 mol dm <sup>-3</sup> concentration of ions
5.	know the features of the standard hydrogen electrode and understand why a reference electrode is necessary
6.	understand that different methods are used to measure standard electrode potentials of: i metals or non-metals in contact with their ions in aqueous solution ii ions of the same element with different oxidation numbers
<b>CORE PRACTICAL 10: Investigating some electrochemical cells</b>	
7.	be able to calculate a standard emf, $E^\ominus_{\text{cell}}$ , by combining two standard electrode potentials
8.	be able to write cell diagrams using the conventional representation of half-cells
9.	understand the importance of the conditions when measuring the electrode potential, $E$
10.	be able to predict the thermodynamic feasibility of a reaction using standard electrode potentials

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

## Topic 15: Transition Metals

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

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

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

Students should:	
Topic 15A: Principles of transition metal chemistry	
1.	be able to deduce the electronic configurations of atoms and ions of the <i>d</i> -block elements of period 4 (Sc–Zn), given the atomic number and charge (if any)
2.	know that transition metals are <i>d</i> -block elements that form one or more stable ions with incompletely-filled <i>d</i> -orbitals
3.	understand why transition metals show variable oxidation number
4.	know what is meant by the term 'ligand'
5.	understand that dative (coordinate) bonding is involved in the formation of complex ions
6.	know that a complex ion is a central metal ion surrounded by ligands
7.	know that transition metals form coloured ions in solution
8.	understand that the colour of aqueous ions, and other complex ions, results from the splitting of the energy levels of the <i>d</i> -orbitals by ligands
9.	understand why there is a lack of colour in some aqueous ions and other complex ions
10.	understand that colour changes in transition metal ions may arise as a result of changes in: i oxidation number ii ligand iii coordination number
11.	understand the meaning of the term 'coordination number'
12.	understand why H <sub>2</sub> O, OH <sup>–</sup> and NH <sub>3</sub> act as monodentate ligands
13.	understand why complexes with six-fold coordination have an octahedral shape, such as those formed by metal ions with H <sub>2</sub> O, OH <sup>–</sup> and NH <sub>3</sub> as ligands

Students should:	
14.	know that transition metal ions may form tetrahedral complexes with relatively large ligands such as $\text{Cl}^-$
15.	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
16.	understand why <i>cis</i> -platin used in cancer treatment is supplied as a single isomer and not in a mixture with the <i>trans</i> form
17.	be able to identify bidentate ligands, such as $\text{NH}_2\text{CH}_2\text{CH}_2\text{NH}_2$ and multidentate ligands, such as $\text{EDTA}^{4-}$
18.	know that haemoglobin is an iron(II) complex containing a multidentate ligand <i>The structure of the haem group will not be assessed.</i>
19.	know that a ligand exchange reaction occurs when an oxygen molecule bound to haemoglobin is replaced by a carbon monoxide molecule
Topic 15B: Reactions of transition metal elements	
20.	know the colours of the oxidation states of vanadium (+5, +4, +3 and +2) in its compounds
21.	understand redox reactions for the interconversion of the oxidation states of vanadium (+5, +4, +3 and +2), in terms of the relevant $E^\ominus$ values
22.	understand, in terms of the relevant $E^\ominus$ 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)
23.	know that the dichromate(VI) ion, $\text{Cr}_2\text{O}_7^{2-}$ , can be converted into chromate(VI) ions as a result of the equilibrium $2\text{CrO}_4^{2-} + 2\text{H}^+ \rightleftharpoons \text{Cr}_2\text{O}_7^{2-} + \text{H}_2\text{O}$
24.	be able to record observations and write suitable equations for the reactions of $\text{Cr}^{3+}(\text{aq})$ , $\text{Fe}^{2+}(\text{aq})$ , $\text{Fe}^{3+}(\text{aq})$ , $\text{Co}^{2+}(\text{aq})$ and $\text{Cu}^{2+}(\text{aq})$ with aqueous sodium hydroxide and aqueous ammonia, including in excess
25.	be able to write ionic equations to show the difference between ligand exchange and amphoteric behaviour for the reactions in (24) above
26.	understand that ligand exchange, and an accompanying colour change, occurs in the formation of: i $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ from $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ via $\text{Cu}(\text{OH})_2(\text{H}_2\text{O})_4$ ii $[\text{CuCl}_4]^{2-}$ from $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ iii $[\text{CoCl}_4]^{2-}$ from $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$
27.	understand that the substitution of small, uncharged ligands (such as $\text{H}_2\text{O}$ ) by larger, charged ligands (such as $\text{Cl}^-$ ) can lead to a change in coordination number
28.	understand, in terms of the large positive increase in $\Delta S_{\text{system}}$ , that the substitution of a monodentate ligand by a bidentate or multidentate ligand leads to a more stable complex ion

<b>Students should:</b>
29. know that transition metals and their compounds can act as heterogeneous and homogeneous catalysts
30. know that a heterogeneous catalyst is in a different phase from the reactants and that the reaction occurs at the surface of the catalyst
31. understand, in terms of oxidation number, how $V_2O_5$ acts as a catalyst in the contact process
32. understand how a catalytic converter decreases carbon monoxide and nitrogen monoxide emissions from internal combustion engines by: <ul style="list-style-type: none"> <li>i adsorption of CO and NO molecules onto the surface of the catalyst</li> <li>ii weakening of bonds and chemical reaction</li> <li>iii desorption of <math>CO_2</math> and <math>N_2</math> product molecules from the surface of the catalyst</li> </ul>
33. know that a homogeneous catalyst is in the same phase as the reactants and appreciate that the catalysed reaction will proceed via an intermediate species
34. understand the role of $Fe^{2+}$ ions in catalysing the reaction between $I^-$ and $S_2O_8^{2-}$ ions
35. know the role of $Mn^{2+}$ ions in autocatalysing the reaction between $MnO_4^-$ and $C_2O_4^{2-}$ ions
<b>CORE PRACTICAL 12: The preparation of a transition metal complex</b>

## Topic 16: Kinetics II

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

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

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

### Students should:

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

<b>Students should:</b>	
5.	be able to calculate the rate of reaction and the half-life of a first-order reaction using data from a concentration-time or a volume-time graph
6.	be able to deduce the order (0, 1 or 2) with respect to a substance in a rate equation using data from: <ul style="list-style-type: none"> <li>i a concentration-time graph</li> <li>ii a rate-concentration graph</li> </ul>
7.	be able to deduce the order (0, 1 or 2) with respect to a substance in a rate equation using data from an initial-rate method
8.	understand how to: <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>
9.	be able to deduce a rate-determining step from a rate equation and vice versa
10.	be able to deduce a reaction mechanism, using knowledge from a rate equation and the stoichiometric equation for a reaction
11.	understand that knowledge of the rate equations for the hydrolysis of halogenoalkanes can be used to provide evidence for S <sub>N</sub> 1 or S <sub>N</sub> 2 mechanisms for tertiary and primary halogenoalkane hydrolysis
12.	be able to use graphical methods to find the activation energy for a reaction from experimental data <i>The Arrhenius equation will be given if needed.</i>
<b>CORE PRACTICAL 13a and 13b: Rates of reaction</b>	
<b><i>Following the rate of the iodine-propanone reaction by a titrimetric method and investigating a 'clock reaction' (Harcourt-Esson, iodine clock)</i></b>	
<b>CORE PRACTICAL 14: Finding the activation energy of a reaction</b>	

## Topic 17: Organic Chemistry II

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

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

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

Students should:	
Topic 17A: Chirality	
1.	know that optical isomerism is a result of chirality in molecules with a single chiral centre
2.	understand that optical isomerism results from chiral centre(s) in a molecule with asymmetric carbon atom(s) and that optical isomers are object and non-superimposable mirror images
3.	know that optical activity is the ability of a single optical isomer to rotate the plane of polarisation of plane-polarised monochromatic light in molecules containing a single chiral centre
4.	understand the nature of a racemic mixture
5.	be able to use data on optical activity of reactants and products as evidence for $S_N1$ and $S_N2$ mechanisms
Topic 17B: Carbonyl compounds	
6.	be able to identify the aldehyde and ketone functional groups
7.	understand that aldehydes and ketones: <ul style="list-style-type: none"><li>i do not form intermolecular hydrogen bonds and this affects their physical properties</li><li>ii can form hydrogen bonds with water and this affects their solubility</li></ul>



**Students should:**

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

**Topic 17C: Carboxylic acids**

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

## Topic 18: Organic Chemistry III

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

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

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

### Students should:

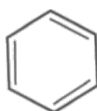
#### Topic 18A: Arenes - benzene

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

*Students may represent the structure of benzene as:*



or



*as appropriate in equations and mechanisms.*

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

**Students should:****Topic 18B: Amines, amides, amino acids and proteins**

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

**CORE PRACTICAL 15: Analysis of some inorganic and organic unknowns**

<b>Students should:</b>	
<b>Topic 18C: Organic Synthesis</b>	
18.	be able to deduce the empirical formulae, molecular formulae and structural formulae of compounds from data obtained from combustion analysis, elemental percentage composition, characteristic reactions of functional groups, infrared spectra, mass spectra and nuclear magnetic resonance
19.	be able to plan reaction schemes, of up to four steps, to form both familiar and unfamiliar compounds
20.	understand methods of increasing the length of the carbon chain in a molecule by the use of magnesium to form Grignard reagents and the reactions of the latter with carbon dioxide and with carbonyl compounds in dry ether
21.	be able to select and justify suitable practical procedures for carrying out reactions involving compounds with functional groups included in the specification, including identifying appropriate control measures to reduce risk, based on data about hazards
22.	understand the following techniques used in the preparation and purification of organic compounds: <ul style="list-style-type: none"> <li>i refluxing</li> <li>ii purification by washing</li> <li>iii solvent extraction</li> <li>iv recrystallisation</li> <li>v drying</li> <li>vi distillation, including steam distillation</li> <li>vii melting temperature determination</li> <li>viii boiling temperature determination</li> </ul>
<b>CORE PRACTICAL 16: The preparation of aspirin</b>	

## Topic 19: Modern Analytical Techniques II

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

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

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

### Students should:

#### Topic 19A: Mass Spectrometry

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

#### Topic 19B: Nuclear magnetic resonance (NMR)

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

**Students should:**

**Topic 19C: Chromatography**

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