

3.2 AS Unit F322: *Chains, Energy and Resources*

This unit builds upon the chemical concepts that have been developed at Key Stage 4.

This unit consists of **four** teaching modules:

Module 1: **Basic Concepts and Hydrocarbons**

- 2.1.1 Basic Concepts
- 2.1.2 Alkanes
- 2.1.3 Alkenes

Module 2: **Alcohols, Halogenoalkanes and Analysis**

- 2.2.1 Alcohols
- 2.2.2 Halogenoalkanes
- 2.2.3 Modern Analytical Techniques

Module 3: **Energy**

- 2.3.1 Enthalpy Changes
- 2.3.2 Rates and Equilibrium

Module 4: **Resources**

- 2.4.1 Chemistry of the Air
- 2.4.2 Green Chemistry

Candidates are expected to apply knowledge, understanding and other skills gained in this unit to new situations and/or to solve related problems.

Recommended Prior Knowledge

Candidates should:

- have achieved Grade C or above in both GCSE Science and GCSE Additional Science, or GCSE Chemistry, or an equivalent standard in other appropriate Level 2 qualifications;
- have studied Unit F321: *Atoms, Bonds and Groups*.

Links

Science in the National Curriculum

This unit expands upon the Key Stage 4: Programme of Study in Science.

3.7 GCSE Science

(ii) Chemical and Material Behaviour

- (a) chemical change takes place by the rearrangement of atoms in substances;
- (b) there are patterns in the chemical reactions between substances;
- (c) new materials are made from natural resources by chemical reactions;
- (d) the properties of a material determine its uses.

(iv) Environment, Earth and Universe

- (a) the effects of human activity on the environment can be assessed using living and non-living indicators;
- (b) the surface and the atmosphere of the Earth have changed since the Earth's origin and are changing at present.

3.7 GCSE Additional Science

(ii) Chemistry

(a) Structure and Bonding

The outer electrons of atoms are involved in chemical reactions. The structure and properties of a substance are strongly dependent on the nature of the bonding which results from the forces between the electrons and nuclei of atoms.

(b) Chemical Synthesis

Raw materials are converted into new and useful substances by chemical reactions. The theoretical yield of a chemical reaction can be calculated.

2.1 Module 1: Basic Concepts and Hydrocarbons

This module provides a foundation for the study of organic chemistry and to illustrate and raise issues regarding the applications of organic chemistry to everyday life.

This module provides candidates with a knowledge and understanding of chemical ideas that underpin the study of organic chemistry:

2.1.1 Basic Concepts

- nomenclature and formula representation;
- functional groups, organic reactions and isomerism;
- reaction mechanisms, percentage yield and atom economy.

2.1.2 Alkanes

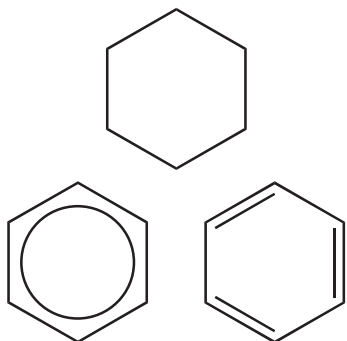
- hydrocarbons from crude oil;
- hydrocarbons as fuels.

2.1.3 Alkenes

- addition reactions;
- polymers and industrial importance of alkenes.

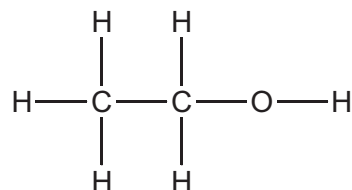
Representing formulae of organic compounds

- See also unit F321: 1.1.2.c,d.
- In structural formulae, the carboxyl group will be represented as COOH and the ester group as COOR.
- The symbols below will be used for cyclohexane and benzene.

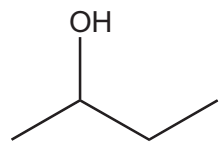


Candidates should be able to:

- (a) interpret and use the terms:
- empirical formula* as the simplest whole number ratio of atoms of each element present in a compound,
 - molecular formula* as the actual number of atoms of each element in a molecule,
 - general formula* as the simplest algebraic formula of a member of a homologous series, ie for an alkane: C_nH_{2n+2} ,
 - structural formula* as the minimal detail that shows the arrangement of atoms in a molecule, eg for butane: $CH_3CH_2CH_2CH_3$ or $CH_3(CH_2)_2CH_3$,
 - displayed formula* as the relative positioning of atoms and the bonds between them, ie for ethanol:



- (vi) *skeletal formula* as the simplified organic formula, shown by removing hydrogen atoms from alkyl chains, leaving just a carbon skeleton and associated functional groups, ie for butan-2-ol:

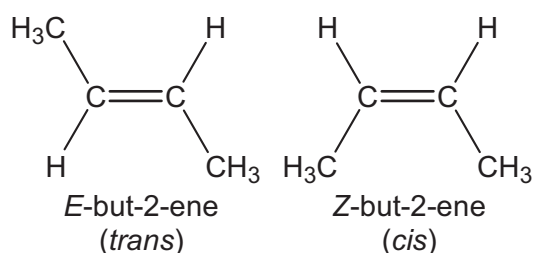
**Functional groups and the naming of organic compounds**

- (b) interpret, and use, the terms:
- homologous series* as a series of organic compounds having the same functional group but with each successive member differing by CH_2 ,
 - functional group* as a group of atoms responsible for the characteristic reactions of a compound;
- (c) use the general formula of a homologous series to predict the formula of any member of the series;
- (d) state the names of the first ten members of the alkanes homologous series;

- For AS, nomenclature will be limited to the functional groups studied, ie $\text{CH}_3\text{CH}_2\text{CH}(\text{CH}_3)\text{CH}_2\text{OH}$ has the systematic name: 2-methylbutan-1-ol.

Isomerism

- Knowledge of *E/Z* isomerism is restricted to understanding that this system is needed where there are more than two different substituents around the double bond, ie 1,-bromo-2-chloropropene.
- Candidates are required to identify the *E* and *Z* stereoisomers in examples that also have *cis* and *trans* isomers such as but-2-ene.



For more complex examples, candidates may be required to identify the feature giving *E/Z* isomerism, or to draw the *E/Z* stereoisomers but they will not be required to use Cahn–Ingold–Prelog priority rules to identify which stereoisomer is which.

- Note that the term *geometric isomer* is no longer recommended by IUPAC.

Reaction mechanisms

- Any relevant dipoles should be included.
- Curly arrows should start from a bond, a lone pair of electrons or a negative charge.

Percentage yields and atom economy

How Science Works 6a, 7c:

- Benefits to society of a high atom economy: see also sustainability: unit F322: 2.4.2.

- (e) use IUPAC rules of nomenclature for systematically naming organic compounds;
- (f) describe and explain the terms:
 - (i) *structural isomers* as compounds with the same molecular formula but different structural formulae,
 - (ii) *stereoisomers* as compounds with the same structural formula but with a different arrangement in space,
 - (iii) *E/Z* isomerism as an example of stereoisomerism, in terms of restricted rotation about a double bond and the requirement for two different groups to be attached to each carbon atom of the C=C group,
 - (iv) *cis-trans isomerism* as a special case of *E/Z* isomerism in which two of the substituent groups are the same;
- (g) determine the possible structural formulae and/or stereoisomers of an organic molecule, given its molecular formula;
- (h) describe the different types of covalent bond fission:
 - (i) homolytic fission forming two radicals,
 - (ii) heterolytic fission forming a cation and an anion;
- (i) describe a 'curly arrow' as the movement of an electron pair, showing either breaking or formation of a covalent bond;
- (j) outline reaction mechanisms, using diagrams, to show clearly the movement of an electron pair with 'curly arrows';
- (k) carry out calculations to determine the percentage yield of a reaction;
- (l) explain the *atom economy* of a reaction as:

$$\frac{\text{molecular mass of the desired products}}{\text{sum of molecular masses of all products}} \times 100\%$$
- (m) explain that addition reactions have an atom economy of 100%, whereas substitution reactions are less efficient;
- (n) carry out calculations to determine the atom

economy of a reaction;

- (o) describe the benefits of developing chemical processes with a high atom economy in terms of fewer waste materials;
- (p) explain that a reaction may have a high percentage yield but a low atom economy.

2.1.2 Alkanes

Context and exemplification

Assessable learning outcomes

Hydrocarbons from crude oil

Candidates should be able to:

- (a) explain that a *hydrocarbon* is a compound of hydrogen and carbon only;
- (b) explain the use of crude oil as a source of hydrocarbons, separated as fractions with different boiling points by fractional distillation, which can be used as fuels or for processing into petrochemicals;
- (c) state that alkanes and cycloalkanes are saturated hydrocarbons;
- (d) state and explain the tetrahedral shape around each carbon atom in alkanes (see also unit F321: 1.2.2.i);
- (e) explain, in terms of van der Waals' forces, the variations in the boiling points of alkanes with different carbon-chain length and branching;

Hydrocarbons as fuels

How Science Works 6b:

- Toxicity from CO production during incomplete combustion of fuels.
- Candidates should be aware that a catalyst is required but no detail is expected.

How Science Works 6a, 7b:

- Desirability of renewable fuels by 'rich' countries may lead to problems of food supply for countries supplying the 'crops for fuel'.

- (f) describe the combustion of alkanes, leading to their use as fuels in industry, in the home and in transport;
- (g) explain, using equations, the incomplete combustion of alkanes in a limited supply of oxygen and outline the potential dangers arising from production of CO in the home and from car use;
- (h) describe the use of catalytic cracking to obtain more useful alkanes and alkenes;
- (i) explain that the petroleum industry processes straight-chain hydrocarbons into branched alkanes and cyclic hydrocarbons to promote efficient combustion;
- (j) contrast the value of fossil fuels for providing energy and raw materials with:
- (i) the problem of an over-reliance on non-renewable fossil fuel reserves and the importance of developing renewable plant-based fuels, ie alcohols and biodiesel (see also 2.4.2),
 - (ii) increased CO₂ levels from combustion of fossil fuels leading to global warming and climate change (see also 2.4.1.d);

Substitution reactions of alkanes

- Candidates are not required to use 'half curly arrows' in this mechanism. Equations should show which species are radicals using a single 'dot' to represent the unpaired electron.

- (k) describe the substitution of alkanes using ultraviolet radiation, by Cl_2 and by Br_2 , to form halogenoalkanes;
- (l) define the term *radical* as a species with an unpaired electron;
- (m) describe how homolytic fission leads to the mechanism of radical substitution in alkanes in terms of initiation, propagation and termination reactions (see also 2.1.1.h);
- (n) explain the limitations of radical substitution in synthesis, arising from further substitution with formation of a mixture of products.

2.1.3 Alkenes

Context and exemplification

Assessable learning outcomes

Properties of alkenes

- Hybridisation not required.

Candidates should be able to:

- (a) state that alkenes and cycloalkenes are unsaturated hydrocarbons;
- (b) describe the overlap of adjacent p-orbitals to form a π -bond;
- (c) state and explain the trigonal planar shape around each carbon in the $\text{C}=\text{C}$ of alkenes (see also unit F321: 1.2.2.i);

Addition reactions of alkenes

- Candidates are expected to realise that addition to an unsymmetrical alkene such as propene may result in two isomeric products. However, candidates will not be required to predict the relative proportions of these isomers, nor to apply or explain Markovnikoff's rule.

- (d) describe addition reactions of alkenes, ie by ethene and propene, with:
 - (i) hydrogen in the presence of a suitable catalyst, ie Ni, to form alkanes,
 - (ii) halogens to form dihalogenoalkanes, including the use of bromine to detect the presence of a double $\text{C}=\text{C}$ bond as a test for unsaturation,
 - (iii) hydrogen halides to form halogenoalkanes,
 - (iv) steam in the presence of an acid catalyst to form alcohols;
- (e) define an *electrophile* as an electron pair acceptor;
- (f) describe how heterolytic fission leads to the mechanism of electrophilic addition in alkenes (see also 2.1.1.h-j.);

Polymers from alkenes

- (g) describe the addition polymerisation of alkenes;
- (h) deduce the repeat unit of an addition polymer obtained from a given monomer;
- (i) identify the monomer that would produce a given section of an addition polymer;

Industrial importance of alkenes

- (j) outline the use of alkenes in the industrial production of organic compounds:
 - (i) the manufacture of margarine by catalytic hydrogenation of unsaturated vegetable

oils using hydrogen and a nickel catalyst,

- (ii) the formation of a range of polymers using unsaturated monomer units based on the ethene molecule, ie $\text{H}_2\text{C}=\text{CHCl}$, $\text{F}_2\text{C}=\text{CF}_2$;

How Science Works 6a, 6b, 7c:

- Benefits from processing of alkenes to produce polymers and plastics; drawbacks from waste polymers.
- Increased political and social desire to reduce plastic waste, to recycle or to use for energy production.
- Developments of new degradable plastics produced from renewable resources.

- (k) outline the processing of waste polymers (see also 2.4.2) by:

- (i) separation into types (ie PTFE, etc.) and recycling,
- (ii) combustion for energy production (see 2.1.2.f),
- (iii) use as a feedstock for cracking (see 2.1.2.h) in the production of plastics and other chemicals;

- (l) outline the role of chemists in minimising environmental damage by:

- (i) removal of toxic waste products, ie removal of HCl formed during disposal by combustion of halogenated plastics (ie PVC),
- (ii) development of biodegradable and compostable polymers, ie from isoprene (2-methyl-1,3-butadiene), maize and starch (see also 2.4.2).

Practical Skills are assessed using OCR set tasks. The practical work suggested below may be carried out as part of skill development. Centres are not required to carry out all of these experiments.

For simplicity, this module refers to reactions of methane, ethane and propene. It is more convenient to use liquid alkanes and alkenes in practical work. For example, cyclohexane and cyclohexene can be used instead of these gaseous alkanes.

- Cracking of paraffin oil.
 - Test-tube reactions of alkanes and alkenes with bromine.
 - Extraction of limonene from orange peel.
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2.2 Module 2: Alcohols, Halogenoalkanes and Analysis

This module extends the knowledge base in organic chemistry by study of two further functional groups:

2.2.1 Alcohols

- properties of alcohols and the preparation of ethanol;
- reactions, including oxidation, esterification and elimination.

2.2.2 Halogenoalkanes

- substitution reactions and uses.

2.2.3 Modern Analytical Techniques

- infrared spectroscopy;
- mass spectrometry.

This analytical work is developed further in Advanced GCE Chemistry.

Links

AS Unit F321: *Atoms, Bonds and Groups*

- 1.2.2 Bonding and Structure (intermolecular forces)

AS Unit F322: *Chains, Energy and Resources*

- 2.1.1 Basic Concepts
- 2.1.2 Alkanes
- 2.1.3 Alkenes
- 2.4.1 Chemistry of the Air

2.2.1 Alcohols

Context and exemplification

Properties and preparation of ethanol

- H_3PO_4 is usually used as the acid catalyst.

Assessable learning outcomes

Candidates should be able to:

- (a) explain, in terms of hydrogen bonding, the water solubility and the relatively low volatility of alcohols;
- (b) describe the industrial production of ethanol by:
 - (i) fermentation from sugars, ie from glucose,
 - (ii) the reaction of ethene with steam in the presence of an acid catalyst;
- (c) outline, for alcohols:
 - (i) the use of ethanol in alcoholic drinks and as a solvent in the form of methylated spirits,

- (ii) the use of methanol as a petrol additive to improve combustion and its increasing importance as a feedstock in the production of organic chemicals;

Reactions of alcohols

- Equations should use [O] to represent the oxidising agent.
- Mechanism for elimination not required.
- H_3PO_4 or H_2SO_4 is usually used as the acid catalyst.

- (d) classify alcohols into primary, secondary and tertiary alcohols;
- (e) describe the combustion of alcohols;
- (f) describe the oxidation of alcohols using $\text{Cr}_2\text{O}_7^{2-}/\text{H}^+$ (ie $\text{K}_2\text{Cr}_2\text{O}_7/\text{H}_2\text{SO}_4$), including:
 - (i) the oxidation of primary alcohols to form aldehydes and carboxylic acids; the control of the oxidation product using different reaction conditions,
 - (ii) the oxidation of secondary alcohols to form ketones,
 - (iii) the resistance to oxidation of tertiary alcohols;
- (g) describe the esterification of alcohols with carboxylic acids in the presence of an acid catalyst;
- (h) describe elimination of H_2O from alcohols in the presence of an acid catalyst and heat to form alkenes.

2.2.2 Halogenoalkanes

Context and exemplification

Assessable learning outcomes

Substitution reactions of halogenoalkanes

- Aqueous silver nitrate in ethanol can be used to compare these rates. In this reaction, H_2O can be assumed to be the nucleophile.
- Alternatively, hot aqueous alkali can be used (followed by neutralisation and addition of aqueous silver nitrate). In this reaction, OH^- is the nucleophile.

- Candidates should be able to:
- (a) describe the hydrolysis of halogenoalkanes as a substitution reaction;
 - (b) define the term *nucleophile* as an electron pair donor;
 - (c) describe the mechanism of nucleophilic substitution in the hydrolysis of primary halogenoalkanes with hot aqueous alkali (see also 2.1.1.i,j);
 - (d) explain the rates of hydrolysis of primary halogenoalkanes in terms of the relative bond enthalpies of carbon–halogen bonds (C–F, C–Cl, C–Br and C–I);

Uses of halogenoalkanes

How Science Works 6a, 6b, 7a–c:

- Initial use of CFCs as harmless aerosol propellants offset when scientists discovered that CFCs damaged the ozone layer.

- (e) outline the uses of chloroethene and tetrafluoroethene to produce the plastics PVC and PTFE (see also 2.1.3.g–i);
- (f) explain that CFCs:
 - (i) were developed as aerosols, refrigerants, and in air-conditioning

- This provided important evidence which enabled international action to be taken to reduce and phase out CFC use.
 - This has subsequently led to development of ozone-friendly alternatives and natural repair of the ozone layer.
- because of their low reactivity, volatility and non-toxicity,
- (ii) have caused environmental damage to the ozone layer (see also 2.4.1.g);
 - (g) outline the role of green chemistry in minimising damage to the environment by promoting biodegradable alternatives to CFCs, such as hydrocarbons and HCFCs; CO₂ as a blowing agent for expanded polymers (see also 2.4.2).

2.2.3 Modern Analytical Techniques

Context and exemplification

Assessable learning outcomes

Infrared spectroscopy

- In examinations, infrared absorption data will be provided on the *Data Sheet*.
- Candidates should be aware that most organic compounds produce a peak at approximately 3000 cm⁻¹ due to absorption by C–H bonds.

Candidates should be able to:

- (a) state that absorption of infrared radiation causes covalent bonds to vibrate;
- (b) identify, using an infrared spectrum of an organic compound:
 - (i) an alcohol from an absorption peak of the O–H bond,
 - (ii) an aldehyde or ketone from an absorption peak of the C=O bond,
 - (iii) a carboxylic acid from an absorption peak of the C=O bond and a broad absorption peak of the O–H bond;

How Science Works 7c:

- Use of analytical techniques to inform decision making, ie breathalysers in drink driving cases.

- (c) state that modern breathalysers measure ethanol in the breath by analysis using infrared spectroscopy;

Mass spectrometry

How Science Works 3:

- Is there life on Mars?, how much lead/pesticides enters the food chain via vegetables, etc.
- Knowledge of the mass spectrometer is **not** required.
- Limited to ions with single charges.
- Rearrangement reactions are not required.
- Mass spectra limited to alkanes, alkenes and alcohols.

- (d) outline the use of mass spectrometry:
 - (i) in the determination of relative isotopic masses,
 - (ii) as a method for identifying elements, ie use in the Mars space probe and in monitoring levels of environmental pollution, such as lead;
- (e) interpret mass spectra of elements in terms of isotopic abundances;
- (f) use the molecular ion peak in a mass spectrum of an organic molecule to determine its molecular mass;
- (g) suggest the identity of the major fragment ions, ie $m/z = 29$ as CH₃CH₂⁺, in a given mass spectrum (limited to alkanes, alkenes and alcohols);
- (h) use molecular ion peaks and fragmentation peaks to identify structures (limited to

unipositive ions);

- (i) explain that a mass spectrum is essentially a fingerprint for the molecule that can be identified by computer using a spectral database.
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Practical Skills are assessed using OCR set tasks. The practical work suggested below may be carried out as part of skill development. Centres are not required to carry out all of these experiments:

- Fermentation of glucose.
 - Oxidation of ethanol to aldehyde and carboxylic acid.
 - Elimination of water from cyclohexanol.
 - Preparation of esters on a test-tube scale.
 - Rates of hydrolysis of different halogenoalkanes.
 - Interpretation of spectra – spectra available at: http://riodb01.ibase.aist.go.jp/sdbs/cgi-bin/cre_index.cgi?lang=eng
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2.3 Module 3: Energy

This module provides candidates with a knowledge and understanding of chemical reasoning that underpins the study of physical chemistry.

2.3.1 Enthalpy Changes

- enthalpy changes of reaction, combustion and formation;
- bond enthalpies;
- Hess' law and enthalpy cycles.

2.3.2 Rates and Equilibrium

- collision theory, the Boltzmann distribution and catalysis;
- a qualitative study of reaction rates;
- dynamic equilibrium and le Chatelier's principle.

Links

AS Unit F321: Atoms, Bonds and Groups

- 1.1.2 Moles and Equations
- 1.3.2 Group 2 (acid reactions with metals, carbonates and bases)

AS Unit F322: Chains, Energy and Resources

- 2.1.2 Alkanes (combustion of fuels)
- 2.2.1 Alcohols (combustion of alcohols)

2.3.1 Enthalpy Changes

Context and exemplification

Assessable learning outcomes

Enthalpy changes: ΔH of reaction, formation and combustion

Candidates should be able to:

- (a) explain that some chemical reactions are accompanied by enthalpy changes that can be exothermic (ΔH , negative) or endothermic (ΔH , positive);
- (b) describe the importance of oxidation as an exothermic process in the combustion of fuels and the oxidation of carbohydrates such as glucose in respiration;
- (c) describe that endothermic processes require an input of heat energy, eg the thermal decomposition of calcium carbonate;
- (d) construct a simple enthalpy profile diagram for a reaction to show the difference in the enthalpy of the reactants compared with that of the products;
- (e) explain qualitatively, using enthalpy profile diagrams, the term *activation energy*;

- Standard conditions can be considered as 100 kPa and a stated temperature, 298 K.
- (f) define and use the terms:
- standard conditions*,
 - enthalpy change of reaction*,
 - enthalpy change of formation*,
 - enthalpy change of combustion*;
- (g) calculate enthalpy changes from appropriate experimental results directly, including use of the relationship: energy change = $mc\Delta T$;

Bond enthalpies

- (h) explain exothermic and endothermic reactions in terms of enthalpy changes associated with the breaking and making of chemical bonds;
- (i) define and use the term *average bond enthalpy* (ΔH positive; bond breaking of one mole of bonds);
- (j) calculate an enthalpy change of reaction from average bond enthalpies;

Hess' law and enthalpy cycles

- Unfamiliar enthalpy cycles will be provided.

- (k) use Hess' law to construct enthalpy cycles and carry out calculations to determine:
- an enthalpy change of reaction from enthalpy changes of combustion,
 - an enthalpy change of reaction from enthalpy changes of formation,
 - an enthalpy change of reaction from an unfamiliar enthalpy cycle.

2.3.2 Rates and Equilibrium

Context and exemplification

Assessable learning outcomes

Simple collision theory

Candidates should be able to:

- describe qualitatively, in terms of collision theory, the effect of concentration changes on the rate of a reaction;
- explain why an increase in the pressure of a gas, increasing its concentration, may increase the rate of a reaction involving gases;

Catalysts

- (c) state that a catalyst speeds up a reaction without being consumed by the overall reaction;

How Science Works 6a:

- Benefits of catalysis in terms of possible lower production costs but also implications for their disposal (toxicity).
- Details of processes are not required.

- (d) explain that catalysts:

- affect the conditions that are needed, often requiring lower temperatures and reducing energy demand and CO_2 emissions from burning of fossil fuels,

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- (ii) enable different reactions to be used, with better atom economy and with reduced waste,
 - (iii) are often enzymes, generating very specific products, and operating effectively close to room temperatures and pressures,
 - (iv) have great economic importance, eg iron in ammonia production, Ziegler–Natta catalyst in poly(ethene) production, platinum/palladium/rhodium in catalytic converters (see also 2.4.1.i);
- (e) explain, using enthalpy profile diagrams, how the presence of a catalyst allows a reaction to proceed via a different route with a lower activation energy, giving rise to an increased reaction rate;

The Boltzmann distribution

How Science Works 1:

- The Boltzmann distribution as a theoretical model arising from kinetic theory.

- (f) explain qualitatively the Boltzmann distribution and its relationship with activation energy;
- (g) describe qualitatively, using the Boltzmann distribution, the effect of temperature changes on the proportion of molecules exceeding the activation energy and hence the reaction rate;
- (h) interpret the catalytic behaviour in (e), in terms of the Boltzmann distribution;

Dynamic equilibrium and le Chatelier's principle

- (i) explain that a dynamic equilibrium exists when the rate of the forward reaction is equal to the rate of the reverse reaction;
- (j) state le Chatelier's principle;
- (k) apply le Chatelier's principle to deduce qualitatively (from appropriate information) the effect of a change in temperature, concentration or pressure, on a homogeneous system in equilibrium;
- (l) explain, from given data, the importance in the chemical industry of a compromise between chemical equilibrium and reaction rate.

Practical Skills are assessed using OCR set tasks. The practical work suggested below may be carried out as part of skill development. Centres are not required to carry out all of these experiments.

- Direct enthalpy changes of reaction for simple reactions:
Zn + CuSO₄ (exo); NaHCO₃ + citric acid (endo); NaOH + HCl (exo).
 - Enthalpy change of combustion of alcohols.
 - Indirect enthalpy change of reaction:
2KHCO₃ → K₂CO₃ + H₂O + CO₂ indirectly using HCl.
 - Rate graphs for gas products, eg CaCO₃ + HCl; Mg + HCl
 - Changing equilibrium position with heat: [Cu(H₂O)₆]²⁺ ⇌ CuCl₄²⁻
 - Changing equilibrium position with concentration: Fe³⁺ and SCN⁻
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2.4 Module 4: Resources

The emphasis here is on the application of chemical facts and principles to processes occurring in the environment and to the difficulties in providing solutions to pollution. It is important that candidates should appreciate this aspect, bearing in mind the increasing concern, both national and international, for protecting the environment and promoting 'Green Chemistry'.

2.4.1 Chemistry of the Air

- the 'Greenhouse Effect';
- the ozone layer;
- controlling pollution.

2.4.2 Green Chemistry

- sustainability.

Links

AS Unit F322: *Chains, Energy and Resources*

- 2.1.2 Alkanes (radicals; combustion of fuels)
- 2.2.2 Halogenoalkanes (CFCs)
- 2.2.3 Modern Analytical Techniques
- 2.3.2 Rates and Equilibrium (reversible reactions; catalysts)

2.4.1 Chemistry of the Air

Context and exemplification

Assessable learning outcomes

The 'Greenhouse Effect'

How Science Works 7a, 7c:

- Collecting data to confirm whether or not climate change is occurring; monitoring measures to abate the change; modelling the potential damage.

Candidates should be able to:

- (a) explain that infrared radiation is absorbed by C=O, O–H and C–H bonds in H₂O, CO₂ and CH₄, and that these absorptions contribute to global warming;
- (b) explain that the 'Greenhouse Effect' of a given gas is dependent both on its atmospheric concentration and its ability to absorb infrared radiation;
- (c) outline the importance of controlling global warming resulting from atmospheric increases in greenhouse gases;
- (d) outline the role of chemists in minimising climate change resulting from global warming by:
 - (i) providing scientific evidence to governments to verify that global warming is taking place,
 - (ii) investigating solutions to environmental problems, such as *carbon capture and*

storage, CCS, ie the removal of waste carbon dioxide as a liquid injected deep in the oceans, storage in deep geological formations, by reaction with metal oxides to form stable carbonate minerals,

- (iii) monitoring progress against initiatives such as the Kyoto protocol;

The ozone layer

- (e) explain that ozone is continuously being formed and broken down in the stratosphere by the action of ultraviolet radiation;

- (f) using the chemical equilibrium, below:

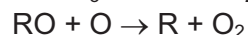
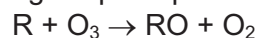


- (i) describe and explain how the concentration of ozone is maintained in the ozone layer, including the role of ultraviolet radiation,
- (ii) outline the role of ozone in the absorption of harmful ultraviolet radiation and the essential benefit of this process for life on Earth;

How Science Works 6a, 6b:

- Benefits of use of CFCs and consequent breakdown of ozone layer.
- No specific equations will be required beyond this simple representation of this catalysis.

- (g) understand that radicals, eg from CFCs, and NO_x from thunderstorms or aircraft, may catalyse the breakdown of ozone by the following simple representation:



where R represents Cl^\cdot from a CFC or NO from nitrogen oxides;

Controlling air pollution

- No details are required of the chemical processes involved in formation of photochemical smog.

- Candidates should understand that bonding to the catalyst surface must be weak enough for adsorption and desorption to take place but strong enough to weaken bonds and allow reaction to take place.

- (h) for carbon monoxide, oxides of nitrogen and unburnt hydrocarbons:

- (i) explain their formation from the internal combustion engine,
- (ii) state environmental concerns from their toxicity and contribution to low-level ozone and photochemical smog;

- (i) outline how a catalytic converter decreases carbon monoxide and nitrogen monoxide emissions from internal combustion engines by:

- (i) adsorption of CO and NO to the catalyst surface,
- (ii) chemical reaction,
- (iii) desorption of CO_2 and N_2 from the catalyst surface;

- (j) outline the use of infrared spectroscopy in monitoring air pollution.

How Science Works 6a, 6b, 7c:

- The use of context case studies such as those below to demonstrate current principles of chemical sustainability; desirability of such processes economically and environmentally; appreciation that legislation may be required to enforce environmentally desirable processes; the inbuilt desirability from within the chemical community to clean up their act.

Context and exemplification
Assessable learning outcomes

Sustainability

Examples for (a) (not examinable):

- Lead has largely been eliminated from use in petrol, paints and electrical components.
- New foams such as Pyrocool® FEF have been invented to put out fires effectively without producing the toxic or ozone-depleting waste products found in other halogenated fire-fighting materials.
- Solvent-free reactions, ie use of reagent as solvent.
- For dry cleaning, liquid 'supercritical' CO₂ can be used as a safer solvent than chlorinated hydrocarbons.
- Fossil fuels are being replaced or supplemented by renewable fuels, such as biodiesel, alcohol and fuel cells.
- Increased use of recycling of manufactured materials such as plastics, glass and metals.

Examples for (b) (not examinable):

- Production of biodiesel uses grain crops and land needed for food, with poorer countries being worse affected.

Examples for (c) (not examinable):

- Montreal Protocol on Substances that Deplete the Ozone Layer.
- Global Treaty on Persistent Organic Pollutants.
- Rio Declaration on Environment and Development.

Candidates should be able to:

- (a) describe principles of chemical sustainability:
- using industrial processes that reduce or eliminate hazardous chemicals and which involve the use of fewer chemicals,
 - designing processes with a high atom economy that minimise the production of waste materials,
 - using renewable resources such as plant-based substances,
 - seeking alternative energy sources such as solar energy, rather than consuming finite resources such as fossil fuels that will eventually be exhausted,
 - ensuring that any waste products produced are non-toxic, and can be recycled or biodegraded by being broken down into harmless substances in the environment;
- (b) explain that the apparent benefits may be offset by unexpected and detrimental side-effects;
- (c) explain the importance of establishing international cooperation to promote the reduction of pollution levels;
- (d) discuss issues of sustainability in contexts based on the principles in a–c;
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