3.3 Unit 1: Chemistry 1

Throughout this unit candidates will be expected to write word equations for reactions specified. **Higher Tier candidates will also be expected to write and balance symbol equations for reactions specified throughout the unit.**

C1.1 The fundamental ideas in chemistry

Atoms and elements are the building blocks of chemistry. Atoms contain protons, neutrons and electrons. When elements react they produce compounds.

C1.1.1 Atoms

a) All substances are made of atoms. A substance that is made of only one sort of atom is called an element. There are about 100 different elements. Elements are shown in the periodic table. The groups contain elements with similar properties.

Additional guidance:
Candidates should understand where metals and non-metals appear in the periodic table.

b) Atoms of each element are represented by a chemical symbol, eg O represents an atom of oxygen, and Na represents an atom of sodium.

Additional guidance:
Knowledge of the chemical symbols for elements other than those named in the specification is **not** required.

c) Atoms have a small central nucleus, which is made up of protons and neutrons and around which there are electrons.

d) The relative electrical charges are as shown:

Name of particle	Charge
Proton	+1
Neutron	0
Electron	–1

e) In an atom, the number of electrons is equal to the number of protons in the nucleus. Atoms have no overall electrical charge.

f) All atoms of a particular element have the same number of protons. Atoms of different elements have different numbers of protons.

g) The number of protons in an atom of an element is its atomic number. The sum of the protons and neutrons in an atom is its mass number.

Additional guidance:
Candidates will be expected to calculate the number of each sub-atomic particle in an atom from its atomic number and mass number.

h) Electrons occupy particular energy levels. Each electron in an atom is at a particular energy level (in a particular shell). The electrons in an atom occupy the lowest available energy levels (innermost available shells). Candidates may answer questions in terms of either energy levels or shells.

Additional guidance:

Candidates should be able to represent the electronic structure of the first 20 elements of the periodic table in the following forms:

sodium
2,8,1

C1.1.2 The periodic table

a) Elements in the same group in the periodic table have the same number of electrons in their highest energy level (outer electrons) and this gives them similar chemical properties.

Additional guidance:

Knowledge is limited to the reactions of Group 1 elements with water and oxygen.

Candidates are **not** required to know of trends within each group in the periodic table, but should be aware of similarities between the elements within a group.

b) The elements in Group 0 of the periodic table are called the noble gases. They are unreactive because their atoms have stable arrangements of electrons.

Candidates should know that the noble gases have eight electrons in their outer energy level, except for helium, which has only two electrons.

C1.1.3 Chemical reactions

a) When elements react, their atoms join with other atoms to form compounds. This involves giving, taking or sharing electrons to form ions or molecules. Compounds formed from metals and non-metals consist of ions. Compounds formed from non-metals consist of molecules. In molecules the atoms are held together by covalent bonds.

Additional guidance:

Further details of the types of bonding are **not** required.

Candidates should know that metals lose electrons to form positive ions, whereas non-metals gain electrons to form negative ions. Knowledge of such transfers is limited to single electrons.

b) Chemical reactions can be represented by word equations or by symbol equations.

Candidates should be able to write word equations for reactions in the specification. The ability to interpret given symbol equations in terms of numbers of atoms is required.

Higher Tier candidates should be able to balance symbol equations.

c) No atoms are lost or made during a chemical reaction so the mass of the products equals the mass of the reactants.

Knowledge and understanding of masses in chemical reactions is limited to conservation of mass. Calculations based on relative atomic masses are **not** required but candidates should be able to calculate the mass of a reactant or product from information about the masses of the other reactants and products in the reaction.

Suggested ideas for practical work to develop skills and understanding include the following:

- modelling of atoms (using physical models or computer simulations) to illustrate chemical reactions at the atomic level
- precipitation reactions, such as lead nitrate with potassium iodide, to show conservation of mass.

C1.2 Limestone and building materials

Rocks provide essential building materials. Limestone is a naturally occurring resource that provides a starting point for the manufacture of cement and concrete.

Candidates should use their skills, knowledge and understanding to:	Additional guidance:
consider and evaluate the environmental, social and economic effects of exploiting limestone and producing building materials from it	Candidates should know that limestone is needed for buildings and that the positive benefits of using this material should be considered against the negative aspects of quarrying. Knowledge of building materials is limited to limestone, cement and concrete.
evaluate the developments in using limestone, cement and concrete as building materials, and their advantages and disadvantages over other materials.	Knowledge of particular developments is **not** required, but information may be supplied in examination questions for candidates to evaluate. Knowledge of the properties of other building materials is **not** required, but candidates may be provided with information about materials such as timber, stone, glass and steels in the examination so that they can make comparisons about their uses.

C1.2.1 Calcium carbonate

	Additional guidance:
a) Limestone, mainly composed of the compound calcium carbonate ($CaCO_3$), is quarried and can be used as a building material.	
b) Calcium carbonate can be decomposed by heating (thermal decomposition) to make calcium oxide and carbon dioxide.	
c) The carbonates of magnesium, copper, zinc, calcium and sodium decompose on heating in a similar way.	Knowledge and understanding of metal carbonates is limited to metal carbonates decomposing on heating to give carbon dioxide and the metal oxide. Candidates should be aware that not all carbonates of metals in Group 1 of the periodic table decompose at the temperatures reached by a Bunsen burner.
d) Calcium oxide reacts with water to produce calcium hydroxide, which is an alkali that can be used in the neutralisation of acids.	Knowledge of the common names quicklime and slaked lime is **not** required.

	Additional guidance:
e) A solution of calcium hydroxide in water (limewater) reacts with carbon dioxide to produce calcium carbonate. Limewater is used as a test for carbon dioxide. Carbon dioxide turns limewater cloudy.	Candidates should be familiar with using limewater to test for carbon dioxide gas.
f) Carbonates react with acids to produce carbon dioxide, a salt and water. Limestone is damaged by acid rain.	The reaction of carbonates with acids is limited to the reactions of magnesium, copper, zinc, calcium and sodium.
g) Limestone is heated with clay to make cement. Cement is mixed with sand to make mortar and with sand and aggregate to make concrete.	

Suggested ideas for practical work to develop skills and understanding include the following:

- investigation of the limestone cycle: decomposition of $CaCO_3$ to give CaO, reaction with water to give $Ca(OH)_2$, addition of more water and filtering to give limewater and use of limewater to test for CO_2
- thermal decomposition of $CaCO_3$ to show limelight
- honeycomb demonstration: heat sugar syrup mixture to 150 °C and add sodium bicarbonate
- making concrete blocks in moulds, investigation of variation of content and carrying out strength tests
- design and carry out an investigation of trends in the thermal decomposition of metal carbonates
- investigation of the reaction of carbonates with acids.

C1.3 Metals and their uses

Metals are very useful in our everyday lives. Ores are naturally occurring rocks that provide an economic starting point for the manufacture of metals. Iron ore is used to make iron and steel. Copper can be easily extracted but copper-rich ores are becoming scarce so new methods of extracting copper are being developed. Aluminium and titanium are useful metals but are expensive to produce. Metals can be mixed together to make alloys.

Candidates should use their skills, knowledge and understanding to:	Additional guidance:
■ consider and evaluate the social, economic and environmental impacts of exploiting metal ores, of using metals and of recycling metals	Candidates should know that metal ores are obtained by mining and that this may involve digging up and processing large amounts of rock. Knowledge and understanding of obtaining, using and recycling metals is limited to the metals named in the subject content.
■ evaluate the benefits, drawbacks and risks of using metals as structural materials.	Knowledge and understanding of the uses and properties of metals and alloys is limited to those specified in the subject content. Information may be given in examination questions so that candidates can evaluate their uses.

C1.3.1 Extracting metals

	Additional guidance:
a) Ores contain enough metal to make it economical to extract the metal. The economics of extraction may change over time.	Knowledge of specific examples is **not** required. Data may be provided in examination questions for candidates to analyse.
b) Ores are mined and may be concentrated before the metal is extracted and purified.	Knowledge of specific examples other than those given below is **not** required.
c) Unreactive metals such as gold are found in the Earth as the metal itself but most metals are found as compounds that require chemical reactions to extract the metal.	

	Additional guidance:
d) Metals that are less reactive than carbon can be extracted from their oxides by reduction with carbon, for example iron oxide is reduced in the blast furnace to make iron.	Knowledge and understanding is limited to the reduction of oxides using carbon. Knowledge of reduction is limited to the removal of oxygen. Knowledge of the details of the extraction of other metals is **not** required. Examination questions may provide further information about specific processes for candidates to interpret or evaluate. Details of the blast furnace are **not** required.
e) Metals that are more reactive than carbon, such as aluminium, are extracted by electrolysis of molten compounds. The use of large amounts of energy in the extraction of these metals makes them expensive.	Knowledge of the details of industrial methods of electrolysis is **not** required.
f) Copper can be extracted from copper-rich ores by heating the ores in a furnace (smelting). The copper can be purified by electrolysis. The supply of copper-rich ores is limited.	Details of industrial smelting processes are **not** required. ■ copper is extracted from its ores by chemical processes that involve heat or electricity ■ copper-rich ores are being depleted and traditional mining and extraction have major environmental impacts.

	Additional guidance:
g) New ways of extracting copper from low-grade ores are being researched to limit the environmental impact of traditional mining. Copper can be extracted by phytomining, or by bioleaching.	Candidates should know and understand that: ■ phytomining uses plants to absorb metal compounds and that the plants are burned to produce ash that contains the metal compounds ■ bioleaching uses bacteria to produce leachate solutions that contain metal compounds. Further specific details of these processes are **not** required.
h) Copper can be obtained from solutions of copper salts by electrolysis or by displacement using scrap iron.	Candidates should know that during electrolysis positive ions move towards the negative electrode. They do **not** need to describe this in terms of oxidation and reduction, or to understand half equations.
i) Aluminium and titanium cannot be extracted from their oxides by reduction with carbon. Current methods of extraction are expensive because: ■ there are many stages in the processes ■ large amounts of energy are needed.	Candidates do **not** need to know the details of methods used to extract these metals, but should be able to comment on and evaluate information that is given about the chemical processes that can be used.
j) We should recycle metals because extracting them uses limited resources and is expensive in terms of energy and effects on the environment.	Candidates are **not** required to know details of specific examples of recycling, but should understand the benefits of recycling in the general terms specified here.

C1.3.2 Alloys

	Additional guidance:
a) Iron from the blast furnace contains about 96% iron. The impurities make it brittle and so it has limited uses.	Knowledge of uses of blast furnace iron is limited to blast furnace iron being used as cast iron because of its strength in compression.
b) Most iron is converted into steels. Steels are alloys since they are mixtures of iron with carbon. Some steels contain other metals. Alloys can be designed to have properties for specific uses. Low-carbon steels are easily shaped, high-carbon steels are hard, and stainless steels are resistant to corrosion.	Knowledge and understanding of the types of steel and their properties is limited to those specified in the subject content. Information about the composition of specific types of steel may be given in examination questions so that candidates can evaluate their uses.
c) Most metals in everyday use are alloys. Pure copper, gold, iron and aluminium are too soft for many uses and so are mixed with small amounts of similar metals to make them harder for everyday use.	Candidates should be familiar with these specified examples but examination questions may contain information about alloys other than those named in the subject content to enable candidates to make comparisons.

C1.3.3 Properties and uses of metals

	Additional guidance:
a) The elements in the central block of the periodic table are known as transition metals. Like other metals they are good conductors of heat and electricity and can be bent or hammered into shape. They are useful as structural materials and for making things that must allow heat or electricity to pass through them easily.	Knowledge of the properties of specific transition metals other than those named in this unit is **not** required.
b) Copper has properties that make it useful for electrical wiring and plumbing.	Candidates should know and understand that copper: ■ is a good conductor of electricity and heat ■ can be bent but is hard enough to be used to make pipes or tanks ■ does not react with water.
c) Low density and resistance to corrosion make aluminium and titanium useful metals.	

Suggested ideas for practical work to develop skills and understanding include the following:

- comparing less reactive metals (gold, silver, copper) with more reactive metals, eg in acid
- heating metal oxides with carbon to compare reactivity, eg CuO, PbO, Fe_2O_3
- heating copper carbonate with charcoal to produce copper
- displacement reactions, eg $CuSO_4$(aq) + Fe (using temperature sensors to investigate differences in metal reactivity)
- investigation of the physical properties of metals and alloys, eg density / thermal and electrical conductivity
- electrolysis of copper sulfate solution using copper electrodes
- ignition tube demonstration of blast furnace – potassium permanganate, mineral wool plug, iron oxide mixed with carbon
- investigation of phytomining: growing brassica plants in compost with added copper sulfate or spraying brassica plants (eg cabbage leaves) with copper sulfate solution, ashing the plants (fume cupboard), adding sulfuric acid to the ash, filtering and obtaining the metal from the solution by displacement or electrolysis.

C1.4 Crude oil and fuels

Crude oil is derived from an ancient biomass found in rocks. Many useful materials can be produced from crude oil. Crude oil can be fractionally distilled. Some of the fractions can be used as fuels. Biofuels are produced from plant material. There are advantages and disadvantages to their use as fuels. Fuels can come from renewable or non-renewable resources.

Candidates should use their skills, knowledge and understanding to:	Additional guidance:
■ evaluate the impact on the environment of burning hydrocarbon fuels	Knowledge and understanding of the products of burning hydrocarbon fuels and the effects of these products is limited to those named in the subject content for this section.
■ consider and evaluate the social, economic and environmental impacts of the uses of fuels	Candidates may be given information and data about other fuels and their products of combustion for comparison and evaluation in the examinations.
■ evaluate developments in the production and uses of better fuels, for example ethanol and hydrogen	Candidates should know and understand the benefits and disadvantages of ethanol and hydrogen as fuels in terms of: ■ use of renewable resources ■ storage and use of the fuels ■ their products of combustion.
■ evaluate the benefits, drawbacks and risks of using plant materials to produce fuels.	

C1.4.1 Crude oil

a) Crude oil is a mixture of a very large number of compounds.	
b) A mixture consists of two or more elements or compounds not chemically combined together. The chemical properties of each substance in the mixture are unchanged. It is possible to separate the substances in a mixture by physical methods including distillation.	
c) Most of the compounds in crude oil consist of molecules made up of hydrogen and carbon atoms only (hydrocarbons). Most of these are saturated hydrocarbons called alkanes, which have the general formula C_nH_{2n+2}.	**Additional guidance:** Candidates are **not** expected to know the names of specific alkanes other than methane, ethane and propane.

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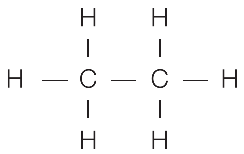
C1.4.2 Hydrocarbons

a) Alkane molecules can be represented in the following forms:

- C_2H_6
- 

Additional guidance:

Candidates should be able to recognise alkanes from their formulae in any of the forms but do not need to know the names of individual alkanes other than methane, ethane, propane and butane.

Candidates should know that in displayed structures — represents a covalent bond.

b) The many hydrocarbons in crude oil may be separated into fractions, each of which contains molecules with a similar number of carbon atoms, by evaporating the oil and allowing it to condense at a number of different temperatures. This process is fractional distillation.

Candidates should know and understand the main processes in continuous fractional distillation in a fractionating column.

Knowledge of the names of specific fractions or fuels is **not** required.

c) Some properties of hydrocarbons depend on the size of their molecules. These properties influence how hydrocarbons are used as fuels.

Knowledge of trends in properties of hydrocarbons is limited to:

- boiling points
- viscosity
- flammability.

C1.4.3 Hydrocarbon fuels

a) Most fuels, including coal, contain carbon and/or hydrogen and may also contain some sulfur. The gases released into the atmosphere when a fuel burns may include carbon dioxide, water (vapour), carbon monoxide, sulfur dioxide and oxides of nitrogen. Solid particles (particulates) may also be released.

Additional guidance:

Candidates should be able to relate products of combustion to the elements present in compounds in the fuel and to the extent of combustion (whether complete or partial).

No details of how the oxides of nitrogen are formed are required, other than the fact that they are formed at high temperatures.

Solid particles may contain soot (carbon) and unburnt fuels.

b) The combustion of hydrocarbon fuels releases energy. During combustion the carbon and hydrogen in the fuels are oxidised.

	Additional guidance:
c) Sulfur dioxide and oxides of nitrogen cause acid rain, carbon dioxide causes global warming, and solid particles cause global dimming.	Candidates are not required to know details of any other causes of acid rain or global warming.
d) Sulfur can be removed from fuels before they are burned, for example in vehicles. Sulfur dioxide can be removed from the waste gases after combustion, for example in power stations.	Knowledge of the methods of removing sulfur is **not** required.
e) Biofuels, including biodiesel and ethanol, are produced from plant material. There are economic, ethical and environmental issues surrounding their use.	Knowledge of the methods of biofuel production is **not** required but candidates may be given information from which a range of questions may be asked.

Suggested ideas for practical work to develop skills and understanding include the following:

- demonstration of fractional distillation of crude oil using CLEAPSS mixture (take care to avoid confusion with the continuous process in a fractionating column)
- design an investigation on viscosity, ease of ignition or sootiness of flame of oils or fuels
- comparison of the energy content of different fuels, for example by heating a fixed volume of water
- demonstration of the production of solid particles by incomplete combustion using a Bunsen burner yellow flame or a candle flame to heat a boiling tube of cold water
- collecting and testing the products of combustion of candle wax and methane
- demonstration of burning sulfur or coal in oxygen and then testing the pH of the gas produced
- design an investigation on growing cress from seeds in various concentrations of sodium metabisulfite solution to show how acid rain affects plants.

C1.5 Other useful substances from crude oil

Fractions from the distillation of crude oil can be broken down (cracked) to make smaller molecules including unsaturated hydrocarbons such as ethene. Unsaturated hydrocarbons can be used to make polymers and ethene can be used to make ethanol. Ethanol can also be made by fermentation.

Candidates should use their skills, knowledge and understanding to:

- evaluate the social and economic advantages and disadvantages of using products from crude oil as fuels or as raw materials for plastics and other chemicals

Additional guidance:

Candidates should be aware that crude oil is used to produce fuels and chemicals, and that it is a limited resource.

Candidates should be able to evaluate information about the ways in which crude oil and its products are used. Although candidates will probably know the names of some common polymers, these are **not** required knowledge, unless they are included in the subject content for this section.

- evaluate the social, economic and environmental impacts of the uses, disposal and recycling of polymers

- evaluate the advantages and disadvantages of making ethanol from renewable and non-renewable sources.

Additional guidance:

Candidates should be able to compare the environmental impact of producing ethanol from renewable and non-renewable sources.

C1.5.1 Obtaining useful substances from crude oil

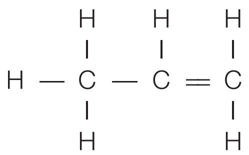
a) Hydrocarbons can be cracked to produce smaller, more useful molecules. This process involves heating the hydrocarbons to vaporise them. The vapours are either passed over a hot catalyst or mixed with steam and heated to a very high temperature so that thermal decomposition reactions then occur.

b) The products of cracking include alkanes and unsaturated hydrocarbons called alkenes. Alkenes have the general formula C_nH_{2n}.

Additional guidance:

Candidates should be able to recognise alkenes from their names or formulae, but do **not** need to know the names of individual alkenes, other than ethene and propene.

c) Unsaturated hydrocarbon molecules can be represented in the following forms:

- C_3H_6
- 

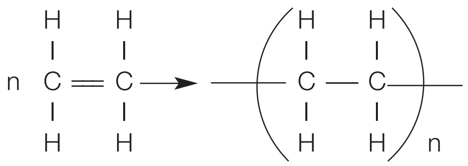
Candidates should know that in displayed structures = represents a double bond.

d) Alkenes react with bromine water, turning it from orange to colourless.

e) Some of the products of cracking are useful as fuels.

C1.5.2 Polymers

a) Alkenes can be used to make polymers such as poly(ethene) and poly(propene). In these reactions, many small molecules (monomers) join together to form very large molecules (polymers).
For example:



ethene — poly(ethene)

Additional guidance:

Candidates should be able to recognise the molecules involved in these reactions in the forms shown in the subject content. They should be able to represent the formation of a polymer from a given alkene monomer.

Further details of polymerisation are **not** required.

b) Polymers have many useful applications and new uses are being developed, for example: new packaging materials, waterproof coatings for fabrics, dental polymers, wound dressings, hydrogels, smart materials (including shape memory polymers).

Candidates should consider the ways in which new materials are being developed and used, but will **not** need to recall the names of specific examples.

c) Many polymers are not biodegradable, so they are not broken down by microbes and this can lead to problems with waste disposal.

Knowledge of specific named examples is **not** required, but candidates should be aware of the problems that are caused by landfill sites and by litter.

d) Plastic bags are being made from polymers and cornstarch so that they break down more easily. Biodegradable plastics made from cornstarch have been developed.

C1.5.3 Ethanol

a) Ethanol can be produced by hydration of ethene with steam in the presence of a catalyst.

Additional guidance:

No further details of these processes are required.

b) Ethanol can also be produced by fermentation with yeast, using renewable resources. This can be represented by:

sugar ⟶ carbon dioxide + ethanol

Suggested ideas for practical work to develop skills and understanding include the following:

- demonstration of the cracking of liquid paraffin using broken pottery as the catalyst
- testing for unsaturation in the alkenes using bromine water
- making a polymer from cornstarch
- demonstration of making Perspex
- molecular modelling of polymers
- design an investigation of a property of different plastics, eg strength, flexibility, biodegradability
- investigate the amount of water that can be absorbed by a hydrogel (eg those used as additives to garden composts)
- testing coated fabrics for water penetration.

C1.6 Plant oils and their uses

Many plants produce useful oils that can be converted into consumer products including processed foods. Emulsions can be made and have a number of uses. Vegetable oils can be hardened to make margarine. Biodiesel fuel can be produced from vegetable oils.

Candidates should use their skills, knowledge and understanding to:	Additional guidance:
evaluate the effects of using vegetable oils in foods and the impacts on diet and health	Knowledge is limited to the high-energy content of vegetable oils, the possible health benefits of unsaturated fats compared with saturated fats, and the effects of cooking foods in oil. Information may be provided in examinations for candidates to evaluate.
evaluate the use, benefits, drawbacks and risks of emulsifiers in foods.	Candidates do **not** need to recall the names of specific additives. Further information will be provided in questions for evaluation and comparison.

C1.6.1 Vegetable oils

	Additional guidance:
a) Some fruits, seeds and nuts are rich in oils that can be extracted. The plant material is crushed and the oil removed by pressing or in some cases by distillation. Water and other impurities are removed.	Candidates should study the general principles of the extraction of vegetable oils, such as olive oil, rapeseed oil or lavender oil. Knowledge of specific examples or processes is **not** required.
b) Vegetable oils are important foods and fuels as they provide a lot of energy. They also provide us with nutrients.	Knowledge of the details of the production of biodiesel is **not** required. Knowledge of specific nutrients is **not** required.

c) Vegetable oils have higher boiling points than water and so can be used to cook foods at higher temperatures than by boiling. This produces quicker cooking and different flavours but increases the energy that the food releases when it is eaten.

C1.6.2 Emulsions

	Additional guidance:
a) Oils do not dissolve in water. They can be used to produce emulsions. Emulsions are thicker than oil or water and have many uses that depend on their special properties. They provide better texture, coating ability and appearance, for example in salad dressings, ice creams, cosmetics and paints.	Candidates should study how emulsions are made and should understand the role of emulsifiers in producing emulsions that are more stable. Knowledge of specific names of ingredients in proprietary products is **not** required.
b) **Emulsifiers have hydrophilic and hydrophobic properties.**	**HT only** **Knowledge is limited to a simple model of the structure of emulsifier molecules.**

C1.6.3 Saturated and unsaturated oils

	Additional guidance:
a) Vegetable oils that are unsaturated contain double carbon–carbon bonds. These can be detected by reacting with bromine water.	Candidates should be familiar with a test for unsaturation using bromine water.
b) **Vegetable oils that are unsaturated can be hardened by reacting them with hydrogen in the presence of a nickel catalyst at about 60 °C. Hydrogen adds to the carbon–carbon double bonds. The hydrogenated oils have higher melting points so they are solids at room temperature, making them useful as spreads and in cakes and pastries.**	**HT only** **Candidates should know how and why vegetable oils are hardened for use in foods. Knowledge of trans fats is not required.** **Examination questions may provide further information from which candidates may be asked to make comparisons.**

Suggested ideas for practical work to develop skills and understanding include the following:

- pressing nuts (eg walnuts) between paper towels and studying the grease marks
- steam distillation of lavender oil, orange oil, lemon oil, olive oil, rapeseed oil or vegetable oil
- simple calorimetery investigations using small spirit burners or bottle tops to measure the energy released from various oils (weigh before and after, and measure the temperature change for a known mass of water)
- making emulsions, eg oil/water, oil/vinegar
- design and carry out an investigation into the effect of emulsifiers on the stability of emulsions
- using bromine water to test fats and oils for unsaturation, eg testing sunflower oil against butter (using colorimeter to measure level of unsaturation).

C1.7 Changes in the Earth and its atmosphere

The Earth and its atmosphere provide everything we need. The Earth has a layered structure. The surface of the Earth and its atmosphere have changed since the Earth was formed and are still changing. The atmosphere has been much the same for the last 200 million years and provides the conditions needed for life on Earth. Recently human activities have resulted in further changes in the atmosphere. There is more than one theory about how life was formed.

Candidates should use their skills, knowledge and understanding to:

- recognise that the Earth's crust, the atmosphere and the oceans are the only source of minerals and other resources that humans need

	Additional guidance:
explain why Wegener's theory of crustal movement (continental drift) was not generally accepted for many years	Candidates should have studied accounts of Wegener's work. Knowledge is limited to the theories relating to mountain building and continental drift. Candidates should know that scientists once thought that the features of the Earth's surface were the result of the shrinking of the crust as the Earth cooled down following its formation.
explain why scientists cannot accurately predict when earthquakes and volcanic eruptions will occur	Candidates may be given information which they will be expected to interpret.
explain and evaluate theories of the changes that have occurred and are occurring in the Earth's atmosphere	Candidates should be able to compare and evaluate different theories when given suitable information.
explain and evaluate the effects of human activities on the atmosphere	Knowledge of the effects of human activities is limited to those in the subject content.
describe why we do not know how life was first formed.	**HT only**

C1.7.1 The Earth's crust

	Additional guidance:
a) The Earth consists of a core, mantle and crust, and is surrounded by the atmosphere.	Knowledge is limited to the names of the three major parts, and an awareness of the relative sizes of these features.
b) The Earth's crust and the upper part of the mantle are cracked into a number of large pieces (tectonic plates).	Knowledge of the names, shapes or locations of specific plates is **not** required.
c) Convection currents within the Earth's mantle driven by heat released by natural radioactive processes cause the plates to move at relative speeds of a few centimetres per year.	Candidates should know that the mantle is mostly solid, but that it is able to move slowly.

d) The movements can be sudden and disastrous. Earthquakes and / or volcanic eruptions occur at the boundaries between tectonic plates.	**Additional guidance:** Knowledge of the changes that occur at plate boundaries is limited to earthquakes and volcanic eruptions. Knowledge of the mechanism of these changes is **not** required.

C1.7.2 The Earth's atmosphere

a) For 200 million years, the proportions of different gases in the atmosphere have been much the same as they are today: ■ about four-fifths (80 %) nitrogen ■ about one-fifth (20 %) oxygen ■ small proportions of various other gases, including carbon dioxide, water vapour and noble gases.	
b) During the first billion years of the Earth's existence there was intense volcanic activity. This activity released the gases that formed the early atmosphere and water vapour that condensed to form the oceans.	
c) There are several theories about how the atmosphere was formed. One theory suggests that during this period the Earth's atmosphere was mainly carbon dioxide and there would have been little or no oxygen gas (like the atmospheres of Mars and Venus today). There may also have been water vapour and small proportions of methane and ammonia.	**Additional guidance:** No knowledge of other theories is required. Information may be given in questions which candidates will be expected to interpret.
d) There are many theories as to how life was formed billions of years ago.	
e) One theory as to how life was formed involves the interaction between hydrocarbons, ammonia and lightning.	**Additional guidance:** **HT only** **Candidates should be aware of the Miller-Urey experiment and the 'primordial soup' theory, but they should know that this is not the only theory.**
f) Plants and algae produced the oxygen that is now in the atmosphere.	Candidates should be aware that plants and algae produce oxygen by a process called photosynthesis and that this process uses carbon dioxide from the atmosphere. Knowledge of the process of photosynthesis is **not** required.

g) Most of the carbon from the carbon dioxide in the air gradually became locked up in sedimentary rocks as carbonates and fossil fuels.

Additional guidance:

Candidates should know that carbon dioxide dissolves in the oceans and that limestone was formed from the shells and skeletons of marine organisms. Fossil fuels contain carbon and hydrocarbons that are the remains of plants and animals.

h) The oceans also act as a reservoir for carbon dioxide but increased amounts of carbon dioxide absorbed by the oceans has an impact on the marine environment.

i) Nowadays the release of carbon dioxide by burning fossil fuels increases the level of carbon dioxide in the atmosphere.

Additional guidance:

Candidates should be aware that this increase in carbon dioxide is thought to be causing global warming but, for this unit, candidates do **not** need to know how CO_2 causes this effect.

j) Air is a mixture of gases with different boiling points and can be fractionally distilled to provide a source of raw materials used in a variety of industrial processes.

HT only

Knowledge of the boiling points of the different gases is not required.

Suggested ideas for practical work to develop skills and understanding include the following:

- investigating the composition of air by passing air over heated copper using gas syringes and measuring the percentage of oxygen. Then burning magnesium in the nitrogen to form Mg_3N_2. Add water to produce ammonia (nitrogen must have come from the air)
- collecting gas produced by aquatic plants and testing for oxygen (using dissolved oxygen sensor)
- measuring the amount of carbon dioxide in inhaled and exhaled air (using carbon dioxide sensor)
- testing the products of combustion of fuels to show that carbon dioxide is produced
- design an investigation to compare the amount of carbon dioxide released by reacting crushed shells (eg cockle, oyster) with dilute hydrochloric acid.

3.4 Unit 2: Chemistry 2

Throughout this unit candidates will be expected to write word equations for reactions specified. **Higher tier candidates will also be expected to write and balance symbol equations for reactions specified throughout the unit.**

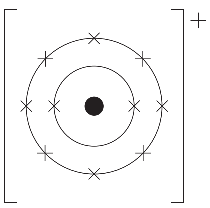
C2.1 Structure and bonding

Simple particle theory is developed in this unit to include atomic structure and bonding. The arrangement of electrons in atoms can be used to explain what happens when elements react and how atoms join together to form different types of substances.

Candidates should use their skills, knowledge and understanding to:

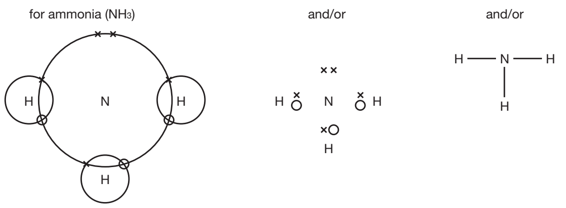
- write formulae for ionic compounds from given symbols and ionic charges

- represent the electronic structure of the ions in sodium chloride, magnesium oxide and calcium chloride in the following form:

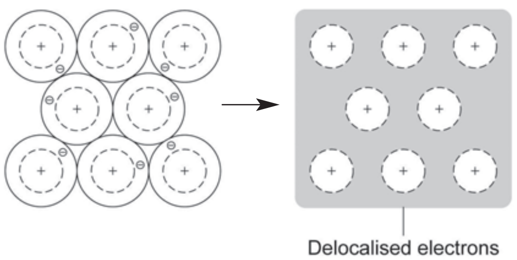


for sodium ion (Na+)

- represent the covalent bonds in molecules such as water, ammonia, hydrogen, hydrogen chloride, methane and oxygen, and in giant structures such as diamond and silicon dioxide, in the following forms:



- **represent the bonding in metals in the following form:**



Additional guidance:

HT only

C2.1.1 Structure and bonding

	Additional guidance:
a) Compounds are substances in which atoms of two or more elements are chemically combined.	
b) Chemical bonding involves either transferring or sharing electrons in the highest occupied energy levels (shells) of atoms in order to achieve the electronic structure of a noble gas.	
c) When atoms form chemical bonds by transferring electrons, they form ions. Atoms that lose electrons become positively charged ions. Atoms that gain electrons become negatively charged ions. Ions have the electronic structure of a noble gas (Group 0).	Candidates should be able to relate the charge on simple ions to the group number of the element in the periodic table.
d) The elements in Group 1 of the periodic table, the alkali metals, all react with non-metal elements to form ionic compounds in which the metal ion has a single positive charge.	Knowledge of the chemical properties of alkali metals is limited to their reactions with non-metal elements.
e) The elements in Group 7 of the periodic table, the halogens, all react with the alkali metals to form ionic compounds in which the halide ions have a single negative charge.	Knowledge of the chemical properties of the halogens is limited to reactions with alkali metals.
f) An ionic compound is a giant structure of ions. Ionic compounds are held together by strong electrostatic forces of attraction between oppositely charged ions. These forces act in all directions in the lattice and this is called ionic bonding.	Candidates should be familiar with the structure of sodium chloride but do **not** need to know the structures of other ionic compounds.
g) When atoms share pairs of electrons, they form covalent bonds. These bonds between atoms are strong. Some covalently bonded substances consist of simple molecules such as H_2, Cl_2, O_2, HCl, H_2O, NH_3 and CH_4. Others have giant covalent structures (macromolecules), such as diamond and silicon dioxide.	Candidates should know the bonding in the examples in the specification for this unit, and should be able to recognise simple molecules and giant structures from diagrams that show their bonding.
h) Metals consist of giant structures of atoms arranged in a regular pattern.	

	Additional guidance:
i) The electrons in the highest occupied energy levels (outer shell) of metal atoms are delocalised and so free to move through the whole structure. This corresponds to a structure of positive ions with electrons between the ions holding them together by strong electrostatic attractions.	**HT only**

Suggested ideas for practical work to develop skills and understanding include the following:

- molecular modelling
- modelling electron transfer and electron sharing using computer simulations
- Group 1 and Group 7 reactions, eg sodium with chlorine
- the reactions of bromine, chlorine and iodine with iron wool
- growing metal crystals by displacement reactions using metals and salts
- modelling metal structures using polyspheres and bubble rafts.

C2.2 How structure influences the properties and uses of substances

Substances that have simple molecular, giant ionic and giant covalent structures have very different properties. Ionic, covalent and metallic bonds are strong. However, the forces between molecules are weaker, eg in carbon dioxide and iodine. Metals have many uses. When different metals are combined, alloys are formed. Shape memory alloys have a range of uses. There are different types of polymers with different uses. Nanomaterials have new properties because of their very small size.

Candidates should use their skills, knowledge and understanding to:

- relate the properties of substances to their uses

Additional guidance:

Candidates may be provided with information about the properties of substances that are not specified in this unit to enable them to relate these to their uses.

- suggest the type of structure of a substance given its properties

- evaluate developments and applications of new materials, eg nanomaterials, fullerenes and shape memory materials.

Additional guidance:

Candidates should be familiar with some examples of new materials but do **not** need to know the properties or names of specific new materials.

C2.2.1 Molecules

a) Substances that consist of simple molecules are gases, liquids or solids that have relatively low melting points and boiling points.

b) **Substances that consist of simple molecules have only weak forces between the molecules (intermolecular forces). It is these intermolecular forces that are overcome, not the covalent bonds, when the substance melts or boils.**

Additional guidance:

HT only

Candidates need to be able to explain that intermolecular forces are weak in comparison with covalent bonds.

c) Substances that consist of simple molecules do not conduct electricity because the molecules do not have an overall electric charge.

C2.2.2 Ionic compounds

	Additional guidance:
a) Ionic compounds have regular structures (giant ionic lattices) in which there are strong electrostatic forces in all directions between oppositely charged ions. These compounds have high melting points and high boiling points because of the large amounts of energy needed to break the many strong bonds.	Knowledge of the structures of specific ionic compounds other than sodium chloride is **not** required.
b) When melted or dissolved in water, ionic compounds conduct electricity because the ions are free to move and carry the current.	

C2.2.3 Covalent structures

	Additional guidance:
a) Atoms that share electrons can also form giant structures or macromolecules. Diamond and graphite (forms of carbon) and silicon dioxide (silica) are examples of giant covalent structures (lattices) of atoms. All the atoms in these structures are linked to other atoms by strong covalent bonds and so they have very high melting points.	Candidates should be able to recognise other giant structures or macromolecules from diagrams showing their bonding.
b) In diamond, each carbon atom forms four covalent bonds with other carbon atoms in a giant covalent structure, so diamond is very hard.	

	Additional guidance:
c) In graphite, each carbon atom bonds to three others, forming layers. The layers are free to slide over each other because there are no covalent bonds between the layers and so graphite is soft and slippery.	**Higher Tier candidates should be able to explain the properties of graphite in terms of weak intermolecular forces between the layers.**
d) **In graphite, one electron from each carbon atom is delocalised. These delocalised electrons allow graphite to conduct heat and electricity.**	**HT only** **Candidates should realise that graphite is similar to metals in that it has delocalised electrons.**
e) **Carbon can also form fullerenes with different numbers of carbon atoms. Fullerenes can be used for drug delivery into the body, in lubricants, as catalysts, and in nanotubes for reinforcing materials, eg in tennis rackets.**	**HT only** **Candidates' knowledge is limited to the fact that the structure of fullerenes is based on hexagonal rings of carbon atoms.**

C2.2.4 Metals

a) **Metals conduct heat and electricity because of the delocalised electrons in their structures.**

Additional guidance:

HT only

Candidates should know that conduction depends on the ability of electrons to move throughout the metal.

b) The layers of atoms in metals are able to slide over each other and so metals can be bent and shaped.

c) Alloys are usually made from two or more different metals. The different sized atoms of the metals distort the layers in the structure, making it more difficult for them to slide over each other and so make alloys harder than pure metals.

d) Shape memory alloys can return to their original shape after being deformed, eg Nitinol used in dental braces.

C2.2.5 Polymers

a) The properties of polymers depend on what they are made from and the conditions under which they are made. For example, low density (LD) and high density (HD) poly(ethene) are produced using different catalysts and reaction conditions.

b) Thermosoftening polymers consist of individual, tangled polymer chains. Thermosetting polymers consist of polymer chains with cross-links between them so that they do not melt when they are heated.

Additional guidance:

Higher Tier candidates should be able to explain the properties of thermosoftening polymers in terms of intermolecular forces.

C2.2.6 Nanoscience

a) Nanoscience refers to structures that are 1–100 nm in size, of the order of a few hundred atoms. Nanoparticles show different properties to the same materials in bulk and have a high surface area to volume ratio, which may lead to the development of new computers, new catalysts, new coatings, highly selective sensors, stronger and lighter construction materials, and new cosmetics such as sun tan creams and deodorants.

Additional guidance:

Candidates should know what is meant by nanoscience and nanoparticles and should consider some of the applications of these materials, but do **not** need to know specific examples or properties.

Questions may be set on information that is provided about these materials and their uses.

Suggested ideas for practical work to develop skills and understanding include the following:

- demonstration of heating sulfur and pouring it into cold water to produce plastic sulfur
- investigating the properties of ionic compounds, eg NaCl:
  - melting point, conductivity, solubility, use of hand lens to study crystal structure
- investigating the properties of covalent compounds:
  - simple molecules, eg wax, methane, hexane
  - macromolecules, eg SiO_2 (sand)
- investigating the properties of graphite
- demonstrations involving shape memory alloys
- investigating the properties of metals and alloys:
  - melting point and conductivity, hardness, tensile strength, flexibility
  - using models, for example using expanded polystyrene spheres or computer animations to show how layers of atoms slide
  - making metal crystals by displacement reactions, eg copper wire in silver nitrate solution
- distinguishing between LD and HD poly(ethene) using 50:50 ethanol:water
- making slime using different concentrations of poly(ethenol) and borax solutions
- investigating the effect of heat on polymers to find which are thermosoftening and which are thermosetting.

C2.3 Atomic structure, analysis and quantitative chemistry

The relative masses of atoms can be used to calculate how much to react and how much we can produce, because no atoms are gained or lost in chemical reactions. There are various methods used to analyse these substances.

Candidates should use their skills, knowledge and understanding to:

- evaluate sustainable development issues relating the starting materials of an industrial process to the product yield and the energy requirements of the reactions involved.

Additional guidance:

Candidates may be given appropriate information from which to draw conclusions.

C2.3.1 Atomic structure

a) Atoms can be represented as shown in this example:

Mass number $^{23}_{11}Na$
Atomic number

b) The relative masses of protons, neutrons and electrons are:

Name of particle	Mass
Proton	1
Neutron	1
Electron	Very small

c) The total number of protons and neutrons in an atom is called its mass number.

d) Atoms of the same element can have different numbers of neutrons; these atoms are called isotopes of that element.

e) **The relative atomic mass of an element (A_r) compares the mass of atoms of the element with the ^{12}C isotope. It is an average value for the isotopes of the element.**

Additional guidance:

HT only

f) The relative formula mass (M_r) of a compound is the sum of the relative atomic masses of the atoms in the numbers shown in the formula.

Candidates are expected to use relative atomic masses in the calculations specified in the subject content. Candidates should be able to calculate the relative formula mass (M_r) of a compound from its formula.

g) The relative formula mass of a substance, in grams, is known as one mole of that substance.

C2.3.2 Analysing substances

a) Elements and compounds can be detected and identified using instrumental methods. Instrumental methods are accurate, sensitive and rapid and are particularly useful when the amount of a sample is very small.

b) Chemical analysis can be used to identify additives in foods. Artificial colours can be detected and identified by paper chromatography.

Additional guidance:

Knowledge of methods other than paper chromatography is **not** required, but questions may include information based on the results of chemical analysis.

c) Gas chromatography linked to mass spectroscopy (GC-MS) is an example of an instrumental method:

- gas chromatography allows the separation of a mixture of compounds
- the time taken for a substance to travel through the column can be used to help identify the substance
- the output from the gas chromatography column can be linked to a mass spectrometer, which can be used to identify the substances leaving the end of the column
- **the mass spectrometer can also give the relative molecular mass of each of the substances separated in the column.**

Additional guidance:

Candidates need only a basic understanding of how GC-MS works, limited to:

- different substances, carried by a gas, travel through a column packed with a solid material at different speeds, so that they become separated
- the number of peaks on the output of a gas chromatograph shows the number of compounds present
- the position of the peaks on the output indicates the retention time
- a mass spectrometer can identify substances very quickly and accurately and can detect very small quantities.

HT only

The molecular mass is given by the molecular ion peak.

Knowledge of fragmentation patterns is not required.

C2.3.3 Quantitative chemistry

a) The percentage of an element in a compound can be calculated from the relative mass of the element in the formula and the relative formula mass of the compound.

Additional guidance:

Candidates should be able to calculate the percentage of an element in a compound, given its formula

b) **The empirical formula of a compound can be calculated from the masses or percentages of the elements in a compound.**

HT only

Candidates should be able to calculate empirical formulae.

c) **The masses of reactants and products can be calculated from balanced symbol equations.**

HT only

Candidates should be able to calculate the masses of individual products from a given mass of a reactant and the balanced symbol equation.

d) Even though no atoms are gained or lost in a chemical reaction, it is not always possible to obtain the calculated amount of a product because:

- the reaction may not go to completion because it is reversible
- some of the product may be lost when it is separated from the reaction mixture
- some of the reactants may react in ways different from the expected reaction.

e) The amount of a product obtained is known as the yield. When compared with the maximum theoretical amount as a percentage, it is called the percentage yield.

Additional guidance:

Higher Tier candidates will be expected to calculate percentage yields of reactions.

f) In some chemical reactions, the products of the reaction can react to produce the original reactants. Such reactions are called reversible reactions and are represented:

$A + B \rightleftharpoons C + D$

For example:

ammonium chloride $\rightleftharpoons$ ammonia + hydrogen chloride

Suggested ideas for practical work to develop skills and understanding include the following:

- investigating food colours using paper chromatography
- working out the empirical formulae of copper oxide and magnesium oxide
- calculating yields, for example magnesium burning to produce magnesium oxide or wire wool burning to produce iron oxide
- there are opportunities in this section to build in the idea of instrumentation precision, eg for the collection of gases, the use of boiling tubes, gas jars or gas syringes
- copper sulfate – hydration/dehydration
- heating ammonium chloride in a test tube
- adding alkali and acid alternately to bromine water or to potassium chromate solution
- 'blue bottle' reaction (RSC Classic Chemistry Experiments no. 83)
- oscillating reaction (RSC Classic Chemistry Experiments no.140).

C2.4 Rates of reaction

Being able to speed up or slow down chemical reactions is important in everyday life and in industry. Changes in temperature, concentration of solution, gas pressure, surface area of solids and the presence of catalysts all affect the rates of reactions. Catalysts can help to reduce the cost of some industrial processes.

Candidates should use their skills, knowledge and understanding to:	Additional guidance:
■ interpret graphs showing the amount of product formed (or reactant used up) with time, in terms of the rate of the reaction	Knowledge of specific reactions other than those in the subject content for this unit is **not** expected, but candidates will be expected to have studied examples of chemical reactions and processes in developing their skills during their study of this section.
■ explain and evaluate the development, advantages and disadvantages of using catalysts in industrial processes.	Information may be given in examination questions so that candidates can make evaluations.

C2.4.1 Rates of reaction

a) The rate of a chemical reaction can be found by measuring the amount of a reactant used or the amount of product formed over time:

$$\text{Rate of reaction} = \frac{\text{amount of reactant used}}{\text{time}}$$

$$\text{Rate of reaction} = \frac{\text{amount of product formed}}{\text{time}}$$

b) Chemical reactions can only occur when reacting particles collide with each other and with sufficient energy. The minimum amount of energy particles must have to react is called the activation energy.

c) Increasing the temperature increases the speed of the reacting particles so that they collide more frequently and more energetically. This increases the rate of reaction.

d) Increasing the pressure of reacting gases increases the frequency of collisions and so increases the rate of reaction.

e) Increasing the concentration of reactants in solutions increases the frequency of collisions and so increases the rate of reaction.

f) Increasing the surface area of solid reactants increases the frequency of collisions and so increases the rate of reaction.

g) Catalysts change the rate of chemical reactions but are not used up during the reaction. Different reactions need different catalysts.

Additional guidance:

Knowledge of named catalysts other than those specified in the subject content for this unit is **not** required, but candidates should be aware of some examples of chemical reactions and processes that use catalysts.

h) Catalysts are important in increasing the rates of chemical reactions used in industrial processes to reduce costs.

Suggested ideas for practical work to develop skills and understanding include the following:

- designing and carrying out investigations into factors such as:
  - temperature, eg magnesium with acids at different temperatures
  - surface area, eg different sizes of marble chips
  - catalysts, eg the decomposition of hydrogen peroxide using manganese(IV) oxide, potato and/or liver; the ignition of hydrogen using platinum; oxidation of ammonia using platinum; cracking liquid paraffin using broken pot
  - concentration, eg sodium thiosulfate solution and dilute hydrochloric acid.

There are opportunities here for measurements using sensors (eg carbon dioxide, oxygen, light, pH, gas pressure and temperature) to investigate reaction rates.

C2.5 Exothermic and endothermic reactions

Chemical reactions involve energy transfers. Many chemical reactions involve the release of energy. For other chemical reactions to occur, energy must be supplied.

Candidates should use their skills, knowledge and understanding to:

- evaluate everyday uses of exothermic and endothermic reactions.

Additional guidance:

Candidates may be given data from which to draw conclusions.

C2.5.1 Energy transfer in chemical reactions

a) When chemical reactions occur, energy is transferred to or from the surroundings.

Additional guidance:

Knowledge of delta H (ΔH) conventions and enthalpy changes, including the use of positive values for endothermic reactions and negative values for exothermic reactions, is **not** required.

b) An exothermic reaction is one that transfers energy to the surroundings. Examples of exothermic reactions include combustion, many oxidation reactions and neutralisation. Everyday uses of exothermic reactions include self-heating cans (eg for coffee) and hand warmers.

c) An endothermic reaction is one that takes in energy from the surroundings. Endothermic reactions include thermal decompositions. Some sports injury packs are based upon endothermic reactions.

d) If a reversible reaction is exothermic in one direction, it is endothermic in the opposite direction. The same amount of energy is transferred in each case.
For example:

$$\text{hydrated copper sulfate (blue)} \underset{\text{exothermic}}{\overset{\text{endothermic}}{\rightleftharpoons}} \text{anhydrous copper sulfate (white)} + \text{water}$$

Suggested ideas for practical work to develop skills and understanding include the following:

- investigating temperature changes of neutralisations and displacement reactions, eg zinc and copper sulfate
- investigating temperature changes when dissolving ammonium nitrate, or reacting citric acid and sodium hydrogencarbonate
- adding ammonium nitrate to barium hydroxide
- demonstration of the addition of concentrated sulfuric acid to sugar
- demonstration of the reaction between iodine and aluminium after activation by a drop of water
- demonstration of the screaming jelly baby
- demonstration of the thermite reaction, ie aluminium mixed with iron(III) oxide
- investigation of hand warmers, self-warming cans, sports injury packs.

There are opportunities here for measurements using temperature sensors to investigate energy transfer.

C2.6 Acids, bases and salts

Soluble salts can be made from acids and insoluble salts can be made from solutions of ions. When acids and alkalis react the result is a neutralisation reaction.

Candidates should use their skills, knowledge and understanding to:

- select an appropriate method for making a salt, given appropriate information.

C2.6.1 Making salts

a) The state symbols in equations are (s), (l), (g) and (aq).

b) Soluble salts can be made from acids by reacting them with:

- metals – not all metals are suitable; some are too reactive and others are not reactive enough
- insoluble bases – the base is added to the acid until no more will react and the excess solid is filtered off
- alkalis – an indicator can be used to show when the acid and alkali have completely reacted to produce a salt solution.

Additional guidance:

Candidates should be able to suggest methods to make a named soluble salt.

c) Salt solutions can be crystallised to produce solid salts.

d) Insoluble salts can be made by mixing appropriate solutions of ions so that a precipitate is formed. Precipitation can be used to remove unwanted ions from solutions, for example in treating water for drinking or in treating effluent.

Additional guidance:

Candidates should be able to name the substances needed to make a named insoluble salt.

C2.6.2 Acids and bases

a) Metal oxides and hydroxides are bases. Soluble hydroxides are called alkalis.

b) The particular salt produced in any reaction between an acid and a base or alkali depends on:

- the acid used (hydrochloric acid produces chlorides, nitric acid produces nitrates, sulfuric acid produces sulfates)
- the metal in the base or alkali.

c) Ammonia dissolves in water to produce an alkaline solution. It is used to produce ammonium salts. Ammonium salts are important as fertilisers.

d) Hydrogen ions, $H^+(aq)$, make solutions acidic and hydroxide ions, $OH^-(aq)$, make solutions alkaline. The pH scale is a measure of the acidity or alkalinity of a solution.

Additional guidance:

Candidates should be familiar with the pH scale from 0 to 14, and that pH 7 is a neutral solution.

e) In neutralisation reactions, hydrogen ions react with hydroxide ions to produce water. This reaction can be represented by the equation:

$$H^+(aq) + OH^-(aq) \longrightarrow H_2O(l)$$

Suggested ideas for practical work to develop skills and understanding include the following:

- the preparation of soluble salts:
  - copper sulfate by adding copper oxide to sulfuric acid
  - magnesium sulfate by adding magnesium oxide to sulfuric acid
  - copper chloride by adding copper oxide to hydrochloric acid
  - zinc nitrate by adding zinc oxide to nitric acid
  - sodium chloride by adding sodium hydroxide to hydrochloric acid
  - copper sulfate by adding copper carbonate to sulfuric acid
  - investigation of the effect of conditions on the yield of the salt
- the preparation of insoluble salts:
  - lead iodide by mixing solutions of lead nitrate and potassium iodide
  - barium sulfate by mixing solutions of barium chloride and sodium sulfate
  - investigation of the effect of conditions on the formation of precipitates.

There are opportunities here for using pH sensors to investigate neutralisation.

C2.7 Electrolysis

Ionic compounds have many uses and can provide other substances. Electrolysis is used to produce alkalis and elements such as aluminium, chlorine and hydrogen. Oxidation–reduction reactions do not just involve oxygen.

Candidates should use their skills, knowledge and understanding to:

- predict the products of electrolysing solutions of ions

Additional guidance:

Knowledge and understanding is limited to the methods indicated in the subject content.

- explain and evaluate processes that use the principles described in this unit, including the use of electroplating.

C2.7.1 Electrolysis

a) When an ionic substance is melted or dissolved in water, the ions are free to move about within the liquid or solution.

b) Passing an electric current through ionic substances that are molten, for example lead bromide, or in solution breaks them down into elements.
This process is called electrolysis and the substance that is broken down is called the electrolyte.

c) During electrolysis, positively charged ions move to the negative electrode, and negatively charged ions move to the positive electrode.

d) Electrolysis is used to electroplate objects. This may be for a variety of reasons and includes copper plating and silver plating.

e) At the negative electrode, positively charged ions gain electrons (reduction) and at the positive electrode, negatively charged ions lose electrons (oxidation).

f) If there is a mixture of ions, the products formed depend on the reactivity of the elements involved.

g) Reactions at electrodes can be represented by half equations, for example:

$$2Cl^- \longrightarrow Cl_2 + 2e^-$$

or

$$2Cl^- - 2e^- \longrightarrow Cl_2$$

Additional guidance:

HT only

Candidates should be able to complete and balance half equations for the reactions occurring at the electrodes during electrolysis.

h) Aluminium is manufactured by the electrolysis of a molten mixture of aluminium oxide and cryolite. Aluminium forms at the negative electrode and oxygen at the positive electrode. The positive electrode is made of carbon, which reacts with the oxygen to produce carbon dioxide.

Additional guidance:

Candidates should understand why cryolite is used in this process.

i) The electrolysis of sodium chloride solution produces hydrogen and chlorine. Sodium hydroxide solution is also produced. These are important reagents for the chemical industry, eg sodium hydroxide for the production of soap and chlorine for the production of bleach and plastics.

Suggested ideas for practical work to develop skills and understanding include the following:

- the electrolysis of molten lead bromide or zinc chloride
- investigation of the electrolysis of any solutions of a soluble ionic compound, eg copper chloride, sodium chloride, zinc bromide, zinc iodide
- a demonstration of the Hoffman voltameter
- the electroplating of copper foil with nickel in a nickel sulfate solution
- the movement of ions, eg by the electrolysis of a crystal of $KMnO_4$ on filter paper dampened with sodium chloride solution, or the electrolysis of $CuCrO_4$ in a saturated urea solution using a U-tube
- using conductivity sensors to monitor conductivity and changes in conductivity.

3.5 Unit 3: Chemistry 3

Throughout this unit candidates will be expected to write word equations for reactions specified. **Higher tier candidates will also be expected to write and balance symbol equations for reactions specified throughout the unit**.

C3.1 The periodic table

The modern periodic table has been developed from work begun by Newlands and Mendeleev. There are trends in chemical properties within the periodic table linked to how easily the element gains or loses electrons.

Candidates should use their skills, knowledge and understanding to:

- evaluate the work of Newlands and Mendeleev in terms of their contributions to the development of the modern periodic table

Additional guidance:

Knowledge of the history of the periodic table is limited to that specified in the subject content.

Candidates may consider other models, but knowledge is limited to the work of Newlands and Mendeleev. Examination questions would give information about other models so that comparisons can be made.

- explain why scientists regarded a periodic table of the elements first as a curiosity, then as a useful tool and finally as an important summary of the structure of atoms.

C3.1.1 The early periodic table

a) Newlands, and then Mendeleev, attempted to classify the elements by arranging them in order of their atomic weights. The list can be arranged in a table so that elements with similar properties are in columns, known as groups. The table is called a periodic table because similar properties occur at regular intervals.

b) The early periodic tables were incomplete and some elements were placed in inappropriate groups if the strict order of atomic weights was followed. Mendeleev overcame some of the problems by leaving gaps for elements that he thought had not been discovered.

C3.1.2 The modern periodic table

a) When electrons, protons and neutrons were discovered early in the 20th century, the periodic table was arranged in order of atomic (proton) numbers. When this was done, all elements were placed in appropriate groups.

b) The modern periodic table can be seen as an arrangement of the elements in terms of their electronic structures. Elements in the same group have the same number of electrons in their highest occupied energy level (outer shell).

Additional guidance:

The periodic table that will be used in the examinations is on the Data Sheet, with main groups numbered from 1 to 7 and the noble gases as Group 0.

Candidates are **not** expected to know detailed electronic configurations for elements beyond calcium, but should understand that the number of electrons in the highest occupied energy level (outer shell) for elements in the main groups is equal to the group number.

C3.1.3 Trends within the periodic table

a) The elements in Group 1 of the periodic table (known as the alkali metals):

- are metals with low density (the first three elements in the group are less dense than water)
- react with non-metals to form ionic compounds in which the metal ion carries a charge of +1. The compounds are white solids that dissolve in water to form colourless solutions
- react with water, releasing hydrogen
- form hydroxides that dissolve in water to give alkaline solutions.

b) In Group 1, the further down the group an element is:

- the more reactive the element
- the lower its melting point and boiling point.

c) Compared with the elements in Group 1, transition elements:

- have higher melting points (except for mercury) and higher densities
- are stronger and harder
- are much less reactive and so do not react as vigorously with water or oxygen.

d) Many transition elements have ions with different charges, form coloured compounds and are useful as catalysts.

e) The elements in Group 7 of the periodic table (known as the halogens) react with metals to form ionic compounds in which the halide ion carries a charge of –1.

f) In Group 7, the further down the group an element is:

- the less reactive the element
- the higher its melting point and boiling point.

g) A more reactive halogen can displace a less reactive halogen from an aqueous solution of its salt.

h) The trends in reactivity within groups in the periodic table can be explained because the higher the energy level of the outer electrons:

- **the more easily electrons are lost**
- **the less easily electrons are gained.**

Additional guidance:

HT only

Suggested ideas for practical work to develop skills and understanding include the following:

- demonstration of the combustion of reactions of sodium and potassium
- demonstration of the reactions of sodium and potassium with chlorine
- demonstration of the reactions of lithium, sodium and potassium with water
- demonstration of the reactions of the halogens with iron wool
- investigation of the displacement of halogens from solutions of their salts by more reactive halogens
- heating transition metals in air (any of Ti, Cr, Co, Ni, Fe, Cu) to compare reactivity and melting points with Group 1
- demonstration of the reaction of iron wool with steam
- observation of as many salts of transition metals as possible (bottles with formulae clearly displayed)
- demonstrations of transition metals and their salts as catalysts
- investigation of the catalysis of hydrogen peroxide decomposition by different transition metals and their compounds.

C3.2 Water

The water we drink is not pure water because it contains dissolved substances. It should be safe to drink water that has been treated. This means that the water does not contain anything that could cause us harm. Some of the dissolved substances are beneficial to our health but some cause hard water.

Candidates should use their skills, knowledge and understanding to:

- evaluate the use of commercial water softeners

	Additional guidance:
■ consider and evaluate the environmental, social and economic aspects of water quality and hardness	Candidates may be asked to evaluate different methods of softening water, or of providing drinking water of sufficient quality.
■ consider the advantages and disadvantages of adding chlorine and fluoride to drinking water.	Candidates will be expected to interpret and evaluate information and data that is provided in questions set within these contexts.

C3.2.1 Hard and soft water

	Additional guidance:
a) Soft water readily forms lather with soap. Hard water reacts with soap to form scum and so more soap is needed to form lather. Soapless detergents do not form scum.	Candidates should be able to measure the hardness of water by titration with soap solution.
b) Hard water contains dissolved compounds, usually of calcium or magnesium. The compounds are dissolved when water comes into contact with rocks.	

	Additional guidance:
c) There are two types of hard water. Permanent hard water remains hard when it is boiled. Temporary hard water is softened by boiling.	Candidates should be able to distinguish between temporary hard water and permanent hard water.
d) **Temporary hard water contains hydrogencarbonate ions (HCO_3^-) that decompose on heating to produce carbonate ions which react with calcium and magnesium ions to form precipitates.**	**HT only**
e) Using hard water can increase costs because more soap is needed. When temporary hard water is heated it can produce scale that reduces the efficiency of heating systems and kettles.	
f) Hard water has some benefits because calcium compounds are good for the development and maintenance of bones and teeth and also help to reduce heart disease.	

g) Hard water can be made soft by removing the dissolved calcium and magnesium ions. This can be done by:

- adding sodium carbonate, which reacts with the calcium and magnesium ions to form a precipitate of calcium carbonate and magnesium carbonate
- using commercial water softeners such as ion exchange columns containing hydrogen ions or sodium ions, which replace the calcium and magnesium ions when hard water passes through the column.

C3.2.2 Purifying water

	Additional guidance:
a) Water of the correct quality is essential for life. For humans, drinking water should have sufficiently low levels of dissolved salts and microbes.	Water of the correct quality is produced by: ■ choosing an appropriate source ■ passing the water through filter beds to remove any solids ■ sterilising with chlorine.
b) Water filters containing carbon, silver and ion exchange resins can remove some dissolved substances from tap water to improve the taste and quality.	Detailed knowledge of specific water filters is **not** required. Examination questions may give information about water filters so that comparisons can be made. Candidates should understand the principles of how ion exchange resins work but do **not** need detailed knowledge of the structure or chemical nature of specific resins.
c) Chlorine may be added to drinking water to reduce microbes and fluoride may be added to improve dental health.	Candidates should be aware of the arguments for and against the addition of fluoride to drinking water.
d) Pure water can be produced by distillation.	Candidates should be aware of the large amount of energy needed for distillation and, as a consequence, of the high costs involved.

Suggested ideas for practical work to develop skills and understanding include the following:

- investigation of which ions cause hard water, eg adding soap solution to solutions of NaCl, $CaCl_2$, KCl, and $MgCl_2$
- making temporary hard water by adding excess carbon dioxide to limewater
- determining hardness of samples of water – shake with soap solution – measuring cm^3 of soap to get permanent lather
- the removal of hardness:
  - temporary hardness: test before and after boiling, with soap
  - permanent hardness: test before and after addition of sodium carbonate
- testing hard water before and after passing through an ion exchange column
- using conductivity sensors to analyse different samples of hard and soft water
- design and carry out an investigation to compare the effectiveness of commercial water softeners using soap titration
- investigating the various types of water ‘filters’ that are commercially available
- distillation of seawater – design a simple apparatus to do the distillation and check the quality of the distillate (boiling point and evaporation to dryness of a sample on a watch glass).

C3.3 Calculating and explaining energy change

Knowing the amount of energy involved in chemical reactions is useful so that resources are used efficiently and economically. It is possible to measure the amount of energy experimentally or to calculate it.

Candidates should use their skills, knowledge and understanding to:

- consider the social, economic and environmental consequences of using fuels

Additional guidance:

Candidates may be provided with information for comparison and evaluation. For example, they may be given information about the ingredients of a particular food or the components of a fuel, but will **not** be expected to have knowledge of the constituents of commercial products beyond that specified in the subject content for this unit.

- interpret simple energy level diagrams in terms of bond breaking and bond formation (including the idea of activation energy and the effect on this of catalysts)
- evaluate the use of hydrogen to power cars compared to other fuels

C3.3.1 Energy from reactions

a) The relative amounts of energy released when substances burn can be measured by simple calorimetry, eg by heating water in a glass or metal container. This method can be used to compare the amount of energy released by fuels and foods.

Additional guidance:

Candidates should be able to calculate and compare the amount of energy released by different fuels given the equation:

$Q = mc\,\Delta T$

b) Energy is normally measured in joules (J).

For comparison purposes, energy values could be given in kJ or calories for a given mass or amount of substance, eg calories per gram, kJ per mole or kJ per gram. If candidates are required to convert from calories to joules, the conversion factor will be given in questions.

c) The amount of energy released or absorbed by a chemical reaction in solution can be calculated from the measured temperature change of the solution when the reagents are mixed in an insulated container. This method can be used for reactions of solids with water or for neutralisation reactions.

d) Simple energy level diagrams can be used to show the relative energies of reactants and products, the activation energy and the overall energy change of a reaction.	**Additional guidance:** Candidates will be expected to understand simple energy level diagrams showing the relative energies of reactants and products, the activation energy and the overall energy change, with a curved arrow to show the energy as the reaction proceeds. Candidates should be able to relate these to exothermic and endothermic reactions.

e) During a chemical reaction:

- energy must be supplied to break bonds
- energy is released when bonds are formed.

f) In an exothermic reaction, the energy released from forming new bonds is greater than the energy needed to break existing bonds.	**Additional guidance:** **HT only** **Candidates should be able to calculate the energy transferred in reactions using supplied bond energies.**
g) In an endothermic reaction, the energy needed to break existing bonds is greater than the energy released from forming new bonds.	**HT only**
h) Catalysts provide a different pathway for a chemical reaction that has a lower activation energy.	Candidates should be able to represent the effect of a catalyst on an energy level diagram.
i) Hydrogen can be burned as a fuel in combustion engines. hydrogen + oxygen ⟶ water It can also be used in fuel cells that produce electricity to power vehicles.	Knowledge of the details of the reactions in fuel cells is **not** required. Candidates should be able to compare the advantages and disadvantages of the combustion of hydrogen with the use of hydrogen fuel cells from information that is provided.

Suggested ideas for practical work to develop skills and understanding include the following:

- design an investigation to compare the energy produced by different liquid fuels and different foods using a simple calorimeter
- measuring and calculating the energy change for exothermic reactions (eg react acid with *Mg* ribbon) and endothermic reactions (eg dissolving potassium nitrate)
- carrying out some reactions and measuring the energy produced, assuming that it is only the water in the solution that is being heated and that 4.2 joules will raise the temperature of 1 cm^3 of water by 1 °C.

C3.4 Further analysis and quantitative chemistry

A range of chemical tests can be used for the detection and identification of elements and compounds. Titrations can be used to find the amounts of acid or alkali in a solution.

Candidates should use their skills, knowledge and understanding to:

- interpret results of the chemical tests in this specification

Additional guidance:

Candidates are expected to know the chemical tests specified in the subject content and may be asked to interpret results of any of those tests applied to solutions or mixtures of substances in different contexts.

- interpret and evaluate the results of analyses carried out to identify elements and compounds for forensic, health or environmental purposes.

Candidates should be able to comment on results and data from such analyses that are presented to them. This will **not** include interpretation of detailed information that uses knowledge beyond that expected at GCSE.

C3.4.1 Analysing substances

a) Flame tests can be used to identify metal ions. Lithium, sodium, potassium, calcium and barium compounds produce distinctive colours in flame tests:

- lithium compounds result in a crimson flame
- sodium compounds result in a yellow flame
- potassium compounds result in a lilac flame
- calcium compounds result in a red flame
- barium compounds result in a green flame.

Additional guidance:

Flame colours of other metal ions are **not** required knowledge.

b) Aluminium, calcium and magnesium ions form white precipitates with sodium hydroxide solution but only the aluminium hydroxide precipitate dissolves in excess sodium hydroxide solution.

c) Copper(II), iron(II) and iron(III) ions form coloured precipitates with sodium hydroxide solution. Copper forms a blue precipitate, iron(II) a green precipitate and iron(III) a brown precipitate.

d) Carbonates react with dilute acids to form carbon dioxide. Carbon dioxide produces a white precipitate with limewater. This turns limewater cloudy.

e) Halide ions in solution produce precipitates with silver nitrate solution in the presence of dilute nitric acid. Silver chloride is white, silver bromide is cream and silver iodide is yellow.

f) Sulfate ions in solution produce a white precipitate with barium chloride solution in the presence of dilute hydrochloric acid.

g) The volumes of acid and alkali solutions that react with each other can be measured by titration using a suitable indicator.

Additional guidance:

Candidates should be able to carry out titrations using strong acids and strong alkalis only (sulfuric, hydrochloric and nitric acids only).

h) **If the concentration of one of the reactants is known, the results of a titration can be used to find the concentration of the other reactant.**

HT only

Candidates should be able to calculate the chemical quantities in titrations involving concentrations (in moles per dm^3) and masses (in grams per dm^3).

Suggested ideas for practical work to develop skills and understanding include the following:

- flame tests – spray solution into flame or use wooden splints soaked in solutions overnight or use nichrome wire loops
- try tests using mixtures of two salts, eg flame tests on solutions containing pairs of the listed ions
- Fe^{2+} with sodium hydroxide solution – note that the initial colour is quickly oxidised
- react carbonates with acid and test the gas for CO_2 using a drop of limewater on a glass rod
- distinguishing between the halide ions using silver nitrate solution
- identifying unknown single salts using the tests in the content
- plan a suitable order of tests to use on a solution that contains an unknown single salt
- strong acid/strong alkali titrations (HCl/NaOH) to find unknown concentration (using indicators and pH sensors to determine titration endpoints).

C3.5 The production of ammonia

In industrial processes, energy requirements and emissions need to be considered both for economic reasons and for sustainable development.

Candidates should use their skills, knowledge and understanding to:

- evaluate the conditions necessary in an industrial process to maximise yield and minimise environmental impact
- **describe and evaluate the effects of changing the conditions of temperature and pressure on a given reaction or process**

Additional guidance:

HT only

- evaluate the conditions used in industrial processes in terms of energy requirements.

C3.5.1 Making ammonia

	Additional guidance:
a) The raw materials for the Haber process are nitrogen and hydrogen. Nitrogen is obtained from the air and hydrogen may be obtained from natural gas or other sources.	
b) The purified gases are passed over a catalyst of iron at a high temperature (about 450 °C) and a high pressure (about 200 atmospheres). Some of the hydrogen and nitrogen reacts to form ammonia. The reaction is reversible so ammonia breaks down again into nitrogen and hydrogen: nitrogen + hydrogen $\rightleftharpoons$ ammonia On cooling, the ammonia liquefies and is removed. The remaining hydrogen and nitrogen are recycled.	
c) When a reversible reaction occurs in a closed system, equilibrium is reached when the reactions occur at exactly the same rate in each direction.	**HT only**
d) The relative amounts of all the reacting substances at equilibrium depend on the conditions of the reaction.	**HT only**
e) If the temperature is raised, the yield from the endothermic reaction increases and the yield from the exothermic reaction decreases.	**HT only**
f) If the temperature is lowered, the yield from the endothermic reaction decreases and the yield from the exothermic reaction increases.	**HT only**
g) In gaseous reactions, an increase in pressure will favour the reaction that produces the least number of molecules as shown by the symbol equation for that reaction.	**HT only**
h) These factors, together with reaction rates, are important when determining the optimum conditions in industrial processes, including the Haber process.	**HT only**

Suggested ideas for practical work to develop skills and understanding include the following:

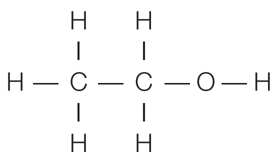
- demonstration of the effect of adding acid and then alkali to bromine water to show the effect of changing conditions on equilibrium
- investigation of the effect of adding acid and then alkali to a solution of potassium chromate
- modelling dynamic equilibrium with two 25 cm^3 measuring cylinders, each with an open-ended glass tube but with different diameters. Put 25 cm^3 of water into one cylinder. Transfer water from one cylinder to the other using a finger over the end of each tube in turn (keep the tubes in the same cylinder) until the level in each cylinder does not change any more
- demonstration of effect of temperature and pressure on equilibrium using 50 cm^3 of NO_2/N_2O_4 in a gas syringe.

C3.6 Alcohols, carboxylic acids and esters

Alcohols and carboxylic acids are important organic chemicals that have many uses. Alcohols react with carboxylic acids to produce esters.

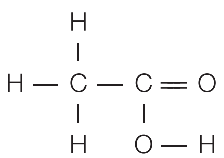
Candidates should use their skills, knowledge and understanding to:

- represent the structures of alcohols in the following forms:



CH_3CH_2OH

- represent the structures of carboxylic acids in the following forms:



CH_3COOH

- evaluate the social and economic advantages and disadvantages of the uses of alcohols, carboxylic acids and esters.

Additional guidance:

Candidates may be given information and data about alcohols, carboxylic acids and esters for comparison and evaluation in the examination.

C3.6.1 Alcohols

	Additional guidance:
a) Alcohols contain the functional group –OH. Methanol, ethanol and propanol are the first three members of a homologous series of alcohols.	Candidates should be able to recognise alcohols from their names or formulae, but do **not** need to know the names of individual alcohols, other than methanol, ethanol and propanol.
b) Methanol, ethanol and propanol: ■ dissolve in water to form a neutral solution ■ react with sodium to produce hydrogen ■ burn in air ■ are used as fuels and solvents, and ethanol is the main alcohol in alcoholic drinks.	Candidates are **not** expected to write balanced chemical equations for the reactions of alcohols other than combustion reactions.
c) Ethanol can be oxidised to ethanoic acid, either by chemical oxidising agents or by microbial action. Ethanoic acid is the main acid in vinegar.	Candidates should be aware that vinegar is an aqueous solution that contains ethanoic acid.

C3.6.2 Carboxylic acids

	Additional guidance:
a) Ethanoic acid is a member of the carboxylic acids, which have the functional group –COOH.	Candidates should be able to recognise carboxylic acids from their names or formulae, but do **not** need to know the names of individual carboxylic acids, other than methanoic acid, ethanoic acid and propanoic acid.
b) Carboxylic acids: ■ dissolve in water to produce acidic solutions ■ react with carbonates to produce carbon dioxide ■ react with alcohols in the presence of an acid catalyst to produce esters	Candidates are **not** expected to write balanced chemical equations for the reactions of carboxylic acids.
■ **do not ionise completely when dissolved in water and so are weak acids**	**HT only**
■ **aqueous solutions of weak acids have a higher pH value than aqueous solutions of strong acids with the same concentration.**	**HT only**

C3.6.3 Esters

a) Ethyl ethanoate is the ester produced from ethanol and ethanoic acid. Esters have the functional group –COO–. They are volatile compounds with distinctive smells and are used as flavourings and perfumes.

Additional guidance:

Candidates will **not** be expected to give the names of esters other than ethyl ethanoate, but should be able to recognise a compound as an ester from its name or its structural formula.

Suggested ideas for practical work to develop skills and understanding include the following:

- investigation of the reactions of ethanol
- comparison of properties of ethanol with water
- oxidation of ethanol using aqueous potassium dichromate
- design and carry out an investigation of the oxidation of dilute solutions of ethanol (eg wine or beer) by exposing to the air for several days
- comparison of the reactions of methanol, ethanol and propanol
- investigation of the reactions of ethanoic acid
- distinguishing between samples of ethanol, ethanoic acid and ethyl ethanoate using simple chemical tests
- preparation of ethyl ethanoate using ethanol and ethanoic acid with sulfuric acid as a catalyst. Recognise the ester by smell after neutralising the acid with sodium hydrogencarbonate
- add drops of esters to water to smell more effectively.