C1.1 How has the Earth's atmosphere changed over time, and why?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*
The Earth, its atmosphere and its oceans are made up from elements and compounds in different states. The particle model can be used to describe the states of these substances and what happens to the particles when they change state. The particle model can be represented in different ways, but these are limited because they do not accurately represent the scale or behaviour of actual particles, they assume that particles are inelastic spheres, and they do not fully take into account the different interactions between particles. The formation of our early atmosphere and oceans, and the state changes involved in the water cycle, can be described using the particle model.	1. recall and explain the main features of the particle model in terms of the states of matter and change of state, distinguishing between physical and chemical changes and recognise that the particles themselves do not have the same properties as the bulk substances 2. **explain the limitations of the particle model in relation to changes of state when particles are represented by inelastic spheres** 3. use ideas about energy transfers and the relative strength of forces between particles to explain the different temperatures at which changes of state occur 4. use data to predict states of substances under given conditions
Explanations about how the atmosphere was formed and has changed over time are based on evidence, including the types and chemical composition of ancient rocks, and fossil evidence of early life (IaS3). Explanations include ideas about early volcanic activity followed by cooling of the Earth resulting in formation of the oceans. The evolution of photosynthesising organisms, formation of sedimentary rocks, oil and gas, and the evolution of animals led to changes in the amounts of carbon dioxide and oxygen in the atmosphere.	5. interpret evidence for how it is thought the atmosphere was originally formed 6. describe how it is thought an oxygen-rich atmosphere developed over time

Linked learning opportunities

Practical work:

- measure temperature against time and plot a cooling curve for stearic acid or heating curve for ice

Ideas about Science:

- use the particle model to explain state changes (IaS3)
- distinguish data from explanatory ideas in accounts of how the atmosphere was formed (IaS3)

C1.1 How has the Earth's atmosphere changed over time, and why?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	Linked learning opportunities
Our modern lifestyle has created a high demand for energy. Combustion of fossil fuels for transport and energy generation leads to emissions of pollutants. Carbon monoxide, sulfur dioxide, nitrogen oxides and particulates directly harm human health. Some pollutants cause indirect problems to humans and the environment by the formation of acid rain and smog. Scientists monitor the concentration of these pollutants in the atmosphere and strive to develop approaches to maintaining air quality (IaS4).	7. describe the major sources of carbon monoxide and particulates (incomplete combustion), sulfur dioxide (combustion of sulfur impurities in fuels), oxides of nitrogen (oxidation of nitrogen at high temperatures and further oxidation in the air)	**Ideas about Science:** • unintended impacts of burning fossil fuels on air quality (IaS4) • catalytic converters, low sulfur petrol and gas scrubbers as positive applications of science (IaS4)
	8. explain the problems caused by increased amounts of these substances and describe approaches to decreasing the emissions of these substances into the atmosphere including the use of catalytic converters, low sulfur petrol and gas scrubbers to decrease emissions	
The combustion reactions of fuels and the formation of pollutants can be represented using word and symbol equations. The formulae involved in these reactions can be represented by models, diagrams or written formulae. The equations should be balanced. When a substance chemically combines with oxygen it is an example of oxidation. Combustion reactions are therefore oxidation. Some gases involved in combustion reactions can be identified by their chemical reactions.	9. use chemical symbols to write the formulae of elements and simple covalent compounds	
	10. use the names and symbols of common elements and compounds and the principle of conservation of mass to write formulae and balanced chemical equations	
	11. use arithmetic computations and ratios when balancing equations M1a, M1c	
	12. describe tests to identify oxygen, hydrogen and carbon dioxide *PAG2*	
	13. explain oxidation in terms of gain of oxygen	

2

C1.2 Why are there temperature changes in chemical reactions?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
When a fuel is burned in oxygen the surroundings are warmed; this is an example of an exothermic reaction. There are also chemical reactions that cool their surroundings; these are endothermic reactions.	1. distinguish between endothermic and exothermic reactions on the basis of the temperature change of the surroundings	**Practical work:** • investigate different chemical reactions to find out if they are exothermic or endothermic
Energy has to be supplied before a fuel burns. For all reactions, there is a certain minimum energy needed to break bonds so that the reaction can begin. This is the activation energy. The activation energy, and the amount of energy associated with the reactants and products, can be represented using a a reaction profile.	2. draw and label a reaction profile for an exothermic and an endothermic reaction, identifying activation energy	
	3. explain activation energy as the energy needed for a reaction to occur	
	4. interpret charts and graphs when dealing with reaction profiles	
Atoms are rearranged in chemical reactions. This means that bonds between the atoms must be broken and then reformed. Breaking bonds requires energy (the activation energy) whilst making bonds gives out energy. **Energy changes in a reaction can be calculated if we know the bond energies involved in the reaction.**	5. **calculate energy changes in a chemical reaction by considering bond breaking and bond making energies** M1a, M1c, M1d	
	6. carry out arithmetic computations when calculating energy changes M1a, M1c, M1d	
	7. describe how you would investigate a chemical reaction to determine whether it is endothermic or exothermic *(separate science only)*	
Using hydrogen fuel cells as an alternative to fossil fuels for transport is one way to decrease the emission of pollutants in cities (IaS4). The reaction in the fuel cell is equivalent to the combustion of hydrogen and gives the same product (water) but the energy drives an electric motor rather than an internal combustion engine. However, hydrogen is usually produced by electrolysis, which may use electricity generated from fossil fuels so pollutants may be produced elsewhere. There are difficulties in storing gaseous fuel for fuel cells which limits their practical value for use in cars.	8. recall that a chemical cell produces a potential difference until the reactants are used up *(separate science only)*	**Ideas about Science:** • fuel cells as a positive application of science to mitigate the effects of emissions (IaS4)
	9. evaluate the advantages and disadvantages of hydrogen/oxygen and other fuel cells for given uses *(separate science only)*	

C1.3 What is the evidence for climate change, why is it occurring?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	
Some electromagnetic radiation from the Sun passes through the atmosphere and is absorbed by the Earth warming it. The warm Earth emits infrared radiation which some gases, including carbon dioxide and methane, absorb and re-emit in all directions; this keeps the Earth warmer than it would otherwise be and is called the greenhouse effect. Without the greenhouse effect the Earth would be too cold to support life. The proportion of greenhouse gases in the Earth's atmosphere has increased over the last 200 years as a result of human activities. There are correlations between changes in the composition of the atmosphere, consumption of fossil fuels and global temperatures over time. Although there are uncertainties in the data, most scientists now accept that recent climate change can be explained by increased greenhouse gas emissions. Patterns in the data have been used to propose models to predict future climate changes. As more data is collected, the uncertainties in the data decrease, and our confidence in models and their predictions increases (IaS3). Scientists aim to reduce emissions of greenhouse gases, for example by reducing fossil fuel use and removing gases from the atmosphere by carbon capture and reforestation. These actions need to be supported by public regulation. Even so, it is difficult to mitigate the effect of emissions due to the very large scales involved. Each new measure may have unforeseen impacts on the environment, making it difficult to make reasoned judgments about benefits and risks (IaS4).	1.	describe the greenhouse effect in terms of the interaction of radiation with matter
	2.	evaluate the evidence for additional anthropogenic causes of climate change, including the correlation between change in atmospheric carbon dioxide concentration and the consumption of fossil fuels, and describe the uncertainties in the evidence base
	3.	describe the potential effects of increased levels of carbon dioxide and methane on the Earth's climate, including where crops can be grown, extreme weather patterns, melting of polar ice and flooding of low land
	4.	describe how the effects of increased levels of carbon dioxide and methane may be mitigated, including consideration of scale, risk and environmental implications
	5.	extract and interpret information from charts, graphs and tables M2c, M4a
	6.	use orders of magnitude to evaluate the significance of data M2h

Linked learning opportunities

Specification links:
- What is global warming and what is the evidence for it? (P1.3)

Practical work:
- Investigate climate change models – both physical models and computer models

Ideas about Science:
- Use ideas about correlation and cause, about models and the way science explanations are developed when discussing climate change (IaS3)
- Risks, costs and benefits of fuel use and its sustainability and effects on climate (IaS4)
- public regulation of targets for emissions and reasons why different decisions on issues related to climate change might be made in view of differences in personal, social, or economic context (IaS4)

C1.4 How can scientists help improve the supply of potable water?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*
The increase in global population means there is a greater need for potable water. Obtaining potable water depends on the availability of waste, ground or salt water and treatment methods. Chlorine is used to kill microorganisms in water. The benefits of adding chlorine to water to stop the spread of waterborne diseases outweigh risks of toxicity. In some countries the chlorination of water is subject to public regulation, but other parts of the world are still without chlorinated water and this leads to a higher risk of disease (IaS4).	1. describe the principal methods for increasing the availability of potable water, in terms of the separation techniques used, including the ease of treating waste, ground and salt water including filtration and membrane filtration; aeration, use of bacteria; chlorination and distillation (for salt water) 2. describe a test to identify chlorine (using blue litmus paper) *PAG2*

Linked learning opportunities

Ideas about Science:

- technologies to increase the availability of potable water can make a positive difference to people's lives (IaS4)
- access to treated water raises issues about risk, cost and benefit and providing treated water for all raises ethical issues (IaS4)

Practical work:

- identify unknown gases

Chapter C2: Chemical patterns

Overview

This chapter features a central theme of modern chemistry: it traces the development of ideas about the structure of the atom and the arrangement of elements in the modern Periodic Table. Both stories show how scientific theories develop as new evidence is made available that either supports or contradicts current ideas.

Atomic structure is used to help explain the behaviour of the elements. Trends and patterns shown by the physical and chemical properties in groups and in the transition metals are studied.

The first two topics of the chapter give opportunities for learners to develop understanding of ideas about science; how scientific knowledge develops, the relationship between evidence and explanations, and how the scientific community responds to new ideas. The later topics present some of the most important models which underpin an understanding of atoms, chemical behaviour and patterns and how reactions are represented in chemical equations.

Topic C2.1 looks at the development of ideas about the atom and introduces the modern model for atomic structure, including electron arrangements. Topic C2.2 considers the development of the modern Periodic Table and the patterns that exist within it, focusing on Groups 1 and 7, with some reference to Group 0. Topic C2.3 focuses on extending an understanding of atomic structure to explain the ionic bonding between ions in ionic compound. This leads on to Topic C2.4 which studies using equations and symbols to summarise reactions**.** Finally, in Topic C2.5, separate science only content addresses the unique nature of the transition elements.

Learning about Chemical Patterns before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

- know the properties of the different states of matter (solid, liquid and gas) in terms of the particle model, including gas pressure
- know changes of state in terms of the particle model
- be aware of a simple (Dalton) atomic model
- know differences between atoms, elements and compounds
- know chemical symbols and formulae for elements and compounds
- know conservation of mass in changes of state and chemical reactions
- understand chemical reactions as the rearrangement of atoms
- be able to represent chemical reactions using formulae and using equations
- know some displacement reactions
- know what catalysts do
- be aware of the principles underpinning the Mendeleev Periodic Table
- know some ideas about the Periodic Table: periods and groups; metals and non-metals
- know how some patterns in reactions can be predicted with reference to the Periodic Table
- know some properties of metals and non-metals.

Tiering

Statements shown in **bold** type will only be tested in the Higher Tier papers.

All other statements will be assessed in both Foundation and Higher Tier papers.

C2.1 How have our ideas about atoms developed over time?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	***Linked learning opportunities***
The modern model of the atom developed over time. Stages in the development of the model included ideas by the ancient Greeks (4 element ideas), Dalton (first particle model), Thomson ('plum pudding' model), Rutherford (idea of atomic nucleus) and Bohr (shells of electrons). Models were rejected, modified and extended as new evidence became available. The development of the atomic model involved scientists suggesting explanations, making and checking predictions based on their explanations, and building on each other's work (IaS3). The Periodic Table can be used to find the atomic number and relative atomic mass of an atom of an element, and then work out the numbers of protons, neutrons and electrons. The number of electrons in each shell can be represented by simple conventions such as dots in circles or as a set of numbers (for example, sodium as 2.8.1). Atoms are small – about 10^{-10} m across, and the nucleus is at the centre, about a hundred-thousandth of the diameter of the atom. Molecules are larger, containing from two to hundreds of atoms. Objects that can be seen with the naked eye contain millions of atoms.	1. describe how and why the atomic model has changed over time to include the main ideas of Dalton, Thomson, Rutherford and Bohr 2. describe the atom as a positively charged nucleus surrounded by negatively charged electrons, with the nuclear radius much smaller than that of the atom and with most of the mass in the nucleus 3. recall relative charges and approximate relative masses of protons, neutrons and electrons 4. estimate the size and scale of atoms relative to other particles M1d 5. recall the typical size (order of magnitude) of atoms and small molecules 6. relate size and scale of atoms to objects in the physical world M1d 7. calculate numbers of protons, neutrons and electrons in atoms, given atomic number and mass number of isotopes or by extracting data from the Periodic Table M1a	**Specification links:** • atoms and radiation (P5.1 What is radioactivity?) **Ideas about Science:** • understanding how scientific explanations and models develop in the context of changing ideas about the atomic model (IaS3)

C2.2 What does the Periodic Table tell us about the elements?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	Linked learning opportunities
Elements in the modern Periodic Table are arranged in periods and groups, based on their atomic numbers. Elements in the same group have the same number of electrons in their outer shells. The number of electron shells increases down a group but stays the same across a period. Mendeleev proposed the first arrangement of elements in the Periodic Table. Although he did not know about atomic structure, he reversed the order of some elements with respect to their masses, left gaps for undiscovered elements and predicted their properties. His ideas were accepted because when certain elements were discovered they fitted his gaps and the development of a model for atomic structure supported his arrangement. The later determination of the number of protons in atoms provided an explanation for the order he proposed (IaS3). The Periodic Table shows repeating patterns in the properties of the elements. Metals and non-metals can be identified by their position in the Periodic Table and by comparing their properties (physical properties including electrical conductivity). Properties of elements within a group show trends. The reactivity of Group 1 metal elements increases down the group, shown by their reactivity with moist air, water and chlorine. The Group 7 halogens are non-metals and become less reactive down the group. This is shown in reactions such as their displacement reactions with compounds of other halogens in the group.	1. explain how the position of an element in the Periodic Table is related to the arrangement of electrons in its atoms and hence to its atomic number 2. describe how Mendeleev organised the elements based on their properties and relative atomic masses 3. describe how discovery of new elements and the ordering elements by atomic number supports Mendeleev's decisions to leave gaps and reorder some elements 4. describe metals and non-metals and explain the differences between them on the basis of their characteristic physical and chemical properties, including melting point, boiling point, state and appearance, density, formulae of compounds, relative reactivity and electrical conductivity 5. recall the simple properties of Group 1 elements including their reaction with moist air, water, and chlorine 6. recall the simple properties of Group 7 elements including their states and colours at room temperature and pressure, their colours as gases, their reactions with Group 1 elements and their displacement reactions with other metal halides 7. predict possible reactions and probable reactivity of elements from their positions in the Periodic Table 8. describe experiments to identify the reactivity pattern of Group 7 elements including displacement reactions *PAG1* 9. describe experiments to identify the reactivity pattern of Group 1 elements	**Practical work:** • reactions of Group 1 (demonstration) and Group 7 (for example displacement) **Ideas about Science:** • understanding how scientific explanations and models develop, in the context of the Periodic Table (IaS3) **Ideas about Science**: • making and testing predictions about trends and patterns in the Periodic Table (IaS1)

2

C2.3 How do metals and non-metals combine to form compounds?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*
Group 0 contains elements with a full outer shell of electrons. This arrangement is linked to their inert, unreactive properties. They exist as single atoms and hence are gases with low melting and boiling points.	1. recall the simple properties of Group 0 including their low melting and boiling points, their state at room temperature and pressure and their lack of chemical reactivity
Group 1 elements combine with Group 7 elements by ionic bonding. This involves a transfer of electrons leading to charged ions. Atoms and ions can be represented using dot and cross diagrams as simple models (IaS3). Metals, such as Group 1 metals, lose electrons from the outer shell of their atoms to form ions with complete outer shells and with a positive charge. Non-metals, such as Group 7, form ions with a negative charge by gaining electrons to fill their outer shell. The number of electrons lost or gained determines the charge on the ion.	2. explain how observed simple properties of Groups 1, 7 and 0 depend on the outer shell of electrons of the atoms and predict properties from given trends down the groups 3. explain how the reactions of elements are related to the arrangement of electrons in their atoms and hence to their atomic number 4. explain how the atomic structure of metals and non-metals relates to their position in the Periodic Table
The properties of ionic compounds such as Group 1 halides can be explained in terms of the ionic bonding. Positive ions and negative ions are strongly attracted together and form giant lattices. Ionic compounds have high melting points in comparison to many other substances due to the strong attraction between ions which means a large amount of energy is needed to break the attraction between the ions. They dissolve in water because their charges allow them to interact with water molecules. They conduct electricity when molten or in solution because the charged ions can move, but not when solid because the ions are held in fixed positions.	5. describe the nature and arrangement of chemical bonds in ionic compounds 6. explain ionic bonding in terms of electrostatic forces and transfer of electrons 7. calculate numbers of protons, neutrons and electrons in atoms and ions, given atomic number and mass number or by using the Periodic Table M1a 8. construct dot and cross diagrams for simple ionic substances

Linked learning opportunities

Practical work:
- test the properties of ionic compounds

Ideas about Science:
- dot and cross diagrams as models of atoms and ions, and the limitations of these models (IaS3)
- 2-D and 3-D representations as simple models of the arrangement of ions, and the limitations of these models (IaS3)

C2.3 How do metals and non-metals combine to form compounds?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
The arrangement of ions can be represented in both 2-D and 3-D. These representations are simple models which have limitations, for example they do not fully show the nature or movement of the electrons or ions, the interaction between the ions, their arrangement in space, their relative sizes or scale (IaS3).	9. explain how the bulk properties of ionic materials are related to the type of bonds they contain	
	10. use ideas about energy transfers and the relative strength of attraction between ions to explain the melting points of ionic compounds compared to substances with other types of bonding	
	11. describe the limitations of particular representations and models of ions and ionically bonded compounds, including dot and cross diagrams, and 3-D representations	
	12. translate information between diagrammatic and numerical forms and represent three dimensional shapes in two dimensions and vice versa when looking at chemical structures for ionic compounds M4a, M5b	

2

C2.4 How are equations used to represent chemical reactions?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
The reactions of Group 1 and Group 7 elements can be represented using word equations and balanced symbol equations with state symbols. The formulae of ionic compounds, including Group 1 and Group 7 compounds can be worked out from the charges on their ions. Balanced equations for reactions can be constructed using the formulae of the substances involved, including hydrogen, water, halogens (chlorine, bromine and iodine) and the hydroxides, chlorides, bromides and iodides (halides) of Group 1 metals.	1. use chemical symbols to write the formulae of elements and simple covalent and ionic compounds 2. use the formulae of common ions to deduce the formula of Group 1 and Group 7 compounds 3. use the names and symbols of the first 20 elements, Groups 1, 7 and 0 and other common elements from a supplied Periodic Table to write formulae and balanced chemical equations where appropriate 4. describe the physical states of products and reactants using state symbols (s, l, g and aq)	

C2.5 What are the properties of the transition metals? *(separate science only)*

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
The transition metals do not show group properties like the elements in Group 1 and Group 7; they form a family of elements with general properties that are different from those of other metals. These properties make the transition metals particularly useful. They all have relatively high melting points and densities. Transitions metals are generally less reactive than Group 1 metals, and some are very unreactive (for example silver and gold). Some transition metal elements and their compounds are used widely in the manufacture of consumer goods and as catalysts in industry, both of which represent beneficial applications of science (IaS4).	1. recall the general properties of transition metals (melting point, density, reactivity, formation of coloured ions with different charges and uses as catalysts) and exemplify these by reference to copper, iron, chromium, silver and gold	**Practical work:** • investigate colours of transition metal compounds, and their effectiveness as catalysts

2

Chapter C3: Chemicals of the natural environment

Overview

Our way of life depends on a wide range of products made from natural resources. The Earth's crust provides us with metal ores and crude oil and our use of these impacts on the natural environment. Chemistry is fundamental to an understanding of the scale and significance of this human activity.

In Topic C3.1 the properties of metals are related to their structure and bonding, and in Topic C3.2 learners discover why the reactivity of a metal determines how it is extracted from its ores and how new technologies enable us to extract metals from poor quality ores.

Electrolysis is explained in Topic C3.3, and learners learn about the wide variety of products made by electrolysis.

Finally, Topic C3.4 covers the separation of crude oil into fractions and the use of these fractions to make other chemicals and polymers. Within this context learners study the properties of simple molecules in relation to covalent bonding and intermolecular forces.

Learning about chemicals of the natural environment before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

- know the differences between atoms, elements and compounds
- be familiar with the use of chemical symbols and formulae for elements and compounds
- be familiar with the use of formulae and equations to represent chemical reactions
- understand chemical reactions as the rearrangement of atoms
- know about reactions of acids with metals to produce a salt plus hydrogen
- know some displacement reactions
- know the order of metals and carbon in the reactivity series
- know that carbon is used to obtain metals from metal oxides.

Tiering

Statements shown in **bold** type will only be tested in the Higher Tier papers.

All other statements will be assessed in both Foundation and Higher Tier papers.

C3.1 How are the atoms held together in a metal?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
Chemists use a model of metal structure to explain the properties of metals (IaS3). In the model, metal atoms are arranged closely together in a giant structure, held together by attraction between the positively charged atoms and a ‘sea’ of negatively charged electrons. Metals are malleable and ductile because the ions can slide over each other but still be held together by the electrons; they conduct electricity and heat because their electrons are free to move; and they have high boiling points and melting points due to the strong electrostatic attraction between metal ions and the electrons. These properties of metals make them useful.	1. describe the nature and arrangement of chemical bonds in metals 2. explain how the bulk properties of metals are related to the type of bonds they contain	**Ideas about Science:** • use the model of metal structure to explain properties of metals (IaS3)

C3.2 How are metals with different reactivities extracted?

<table>
<tr><th>Teaching and learning narrative</th><th colspan="2">Assessable learning outcomes
Learners will be required to:</th><th>Linked learning opportunities</th></tr>
<tr><td rowspan="6">Metals can be placed in an order of reactivity by looking at their reactions with water, dilute acid and compounds of other metals. The relative reactivity of metals enables us to make predictions about which metals react fastest or which metal will displace another.

When metals react they form ionic compounds. The metal atoms gain one or more electrons to become positive ions. The more easily this happens the more reactive the metal.

These reactions can be represented by word and symbol equations including state symbols. Ionic equations show only the ions that change in the reaction and show the gain or loss of electrons. They are useful for representing displacement reactions because they show what happens to the metal ions during the reaction.

The way a metal is extracted depends on its reactivity. Some metals are extracted by reacting the metal compound in their ores with carbon.

Carbon is a non-metal but can be placed in the reactivity series of the metals between aluminium and zinc.

Metals below carbon in the reactivity series are extracted from their ores by displacement by carbon. The metal in the ore is reduced and carbon is oxidised.

Highly reactive metals above carbon in the reactivity series are extracted by electrolysis.

Scientists are developing methods of extracting the more unreactive metals from their ores using bacteria or plants. These methods can extract metals from waste material, reduce the need to extract ‘new’ ores, reduce energy costs, and reduce the amount of toxic metals in landfill. However, these methods do not produce large quantities of metals quickly (IaS4).</td><td>1.</td><td>deduce an order of reactivity of metals based on experimental results including reactions with water, dilute acid and displacement reactions with other metals</td><td rowspan="6">Practical work:
• Investigate the reactivity of different metals with water and dilute acid
• Investigate the reactivity of Zn, Fe and Cu by heating each metal with oxides of each of the other two metals

Specification links:
• C1.1 introduces oxidation

Ideas about Science:
• impacts of metal extraction on the environment, the measures scientists are taking to mitigate them, and the risks, costs and benefits of different courses of action (IaS4)</td></tr>
<tr><td>2.</td><td>explain how the reactivity of metals with water or dilute acids is related to the tendency of the metal to form its positive ion to include potassium, sodium, calcium, aluminium, magnesium, zinc, iron, lead, [hydrogen], copper, silver</td></tr>
<tr><td>3.</td><td>use the names and symbols of common elements and compounds and the principle of conservation of mass to write formulae and balanced chemical equations and ionic equations</td></tr>
<tr><td>4.</td><td>explain, using the position of carbon in the reactivity series, the principles of industrial processes used to extract metals, including the extraction of zinc</td></tr>
<tr><td>5.</td><td>explain why electrolysis is used to extract some metals from their ores</td></tr>
<tr><td>6.</td><td>evaluate alternative biological methods of metal extraction (bacterial and phytoextraction)</td></tr>
</table>

C3.3 What are electrolytes and what happens during electrolysis?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
Electrolysis is used to extract reactive metals from their ores. Electrolysis is the decomposition of an electrolyte by an electric current. Electrolytes include molten and dissolved ionic compounds. In both cases the ions are free to move. During electrolysis non-metal ions lose electrons to the anode to become neutral atoms. Metal (or hydrogen) ions gain electrons at the cathode to become neutral atoms. The addition or removal of electrons can be used to identify which species are reduced and which are oxidised. These changes can be summarised using half equations.	1. describe electrolysis in terms of the ions present and reactions at the electrodes	**Practical work:** • investigate what type of substances are electrolytes
	2. predict the products of electrolysis of binary ionic compounds in the molten state	
	3. recall that metals (or hydrogen) are formed at the cathode and non-metals are formed at the anode in electrolysis using inert electrodes	
	4. use the names and symbols of common elements and compounds and the principle of conservation of mass to write half equations	
Electrolysis is used to extract reactive metals from their molten compounds. During the electrolysis of aluminium, aluminium oxide is heated to a very high temperature. Positively charged aluminium ions gain electrons from the cathode to form atoms. Oxygen ions lose electrons at the anode and form oxygen molecules which react with carbon electrodes to form carbon dioxide. The process uses a large amount of energy for both the high temperature and the electricity involved in electrolysis.	**5. explain reduction and oxidation in terms of gain or loss of electrons, identifying which species are oxidised and which are reduced**	
	6. explain how electrolysis is used to extract some metals from their ores including the extraction of aluminium	
Some extraction methods, such as the recovery of metals from waste heaps, give a dilute aqueous solution of metals ions. When an electric current is passed through an aqueous solution the water is electrolysed as well as the ionic compound. Less reactive metals such as silver or copper form on the negative electrode. If the solution contains ions of more reactive metals, hydrogen gas forms from the hydrogen ions from the water. Similarly, oxygen usually forms at the positive electrode from hydroxide ions from the water. A concentrated solution of chloride ions forms chlorine at the positive electrode.	7. describe competing reactions in the electrolysis of aqueous solutions of ionic compounds in terms of the different species present, including the formation of oxygen, chlorine and the discharge of metals or hydrogen linked to their relative reactivity	**Practical work:** • investigate the effects of concentration of aqueous solution, current, voltage on the electrolysis of sodium chloride
	8. describe the technique of electrolysis of an aqueous solution of a salt *PAG2*	

C3.4 Why is crude oil important as a source of new materials?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
Crude oil is mixture of hydrocarbons. It is used as a source of fuels and as a feedstock for making chemicals (including polymers) for a very wide range of consumer products. Almost all of the consumer products we use involve the use of crude oil in their manufacture or transport. Crude oil is finite. If we continue to burn it at our present rate it will run out in the near future. Crude oil makes a significant positive difference to our lives, but our current use of crude oil is not sustainable. Decisions about the use of crude oil must balance short-term benefits with the need to conserve this resource for the future. Crude oil is a mixture. It needs to be separated into groups of molecules of similar size called fractions. This is done by fractional distillation. Fractional distillation depends on the different boiling points of the hydrocarbons, which in turn is related to the size of the molecules and the intermolecular forces between them. The fractions are mixtures, mainly of alkanes, with a narrow range of boiling points. The first four alkanes show typical properties of a homologous series: each subsequent member increases in size by CH_2, they have a general formula and show trends in their physical and chemical properties.	1. recall that crude oil is a main source of hydrocarbons and is a feedstock for the petrochemical industry 2. explain how modern life is crucially dependent upon hydrocarbons and recognise that crude oil is a finite resource 3. describe and explain the separation of crude oil by fractional distillation *PAG*3 4. describe the fractions of crude oil as largely a mixture of compounds of formula C_nH_{2n+2} which are members of the alkane homologous series 5. use ideas about energy transfers and the relative strength of chemical bonds and intermolecular forces to explain the different temperatures at which changes of state occur 6. deduce the empirical formula of a compound from the relative numbers of atoms present or from a model or diagram and vice versa 7. use arithmetic computation and ratio when determining empirical formulae M1c	**Ideas about Science**: • decision making in the context of the use of crude oil for fuels and as a feedstock (IaS3)

C3.4 Why is crude oil important as a source of new materials?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
The molecular formula of an alkane shows the number of atoms present in each molecule. These formulae can be simplified to show the simplest ratio of carbon to hydrogen atoms. This type of formula is an empirical formula (IaS4). Small molecules like alkanes and many of those met in chapter C1 contain non-metal atoms which are bonded to each other by covalent bonds. A covalent bond is a strong bond between two atoms that formed from a shared pair of electrons. A covalent bond can be represented by a dot and cross diagram. Molecules can be shown as molecular or empirical formulae, displayed formulae (which show all of the bonds in the molecule) or in a 3 dimensional 'balls and stick' model.	8. describe the arrangement of chemical bonds in simple molecules 9. explain covalent bonding in terms of the sharing of electrons 10. construct dot and cross diagrams for simple covalent substances 11. represent three dimensional shapes in two dimensions and vice versa when looking at chemical structures for simple molecules M5b 12. describe the limitations of dot and cross diagrams, ball and stick models and two and three dimensional representations when used to represent simple molecules	**Ideas about Science:** • the use and limitations of models to represent bonding in simple molecules (IaS3)
Simple molecules have strong covalent bonds joining the atoms within the molecule, but they only have weak intermolecular forces. No covalent bonds are broken when simple molecules boil. The molecules move apart when given enough energy to overcome the intermolecular forces. This explains their low melting and boiling points.	13. translate information between diagrammatic and numerical forms M4a 14. explain how the bulk properties of simple molecules are related to the covalent bonds they contain and their bond strengths in relation to intermolecular forces	
Cracking long chain alkanes makes smaller more useful molecules that are in great demand as fuels (for example petrol). Cracking also yields alkenes – hydrocarbons with carbon-carbon double bonds. Alkenes are much more reactive than alkanes and can react to make a very wide range of products including polymers. Without cracking, we would need to extract a lot more crude oil to meet demand for petrol and would waste some longer chain alkanes which are not as useful.	15. describe the production of materials that are more useful by cracking	**Ideas about Science**: • cracking as a positive application of science, to reduce extraction of crude oil and so conserves oil reserves (IaS4)

C3.4 Why is crude oil important as a source of new materials?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
Alkanes and alkenes burn in plenty of air to make carbon dioxide and water. The double bond makes alkenes more reactive than alkanes. Addition across the double bond means that alkenes decolourise bromine water and can form polymers. An alcohol has a structure like an alkane, but with one hydrogen replaced by an OH group. Alcohols burn to make carbon dioxide and water, and can also be oxidised to make carboxylic acids. All of these compounds are useful to make consumer products. They have different properties due to their different functional groups. Alkanes do not have a functional group and so are unreactive. The functional group of alkenes – the double bond – is used for addition reactions. The OH functional group in alcohols give them a range of uses including their use as solvents that are miscible with water. The carboxylic acid functional group behaves as a weak acid, and these acids are found in foods and personal care products.	16. recognise functional groups and identify members of the same homologous series *(separate science only)* 17. name and draw the structural formulae, using fully displayed formulae, of the first four members of the straight chain alkanes and alkenes, alcohols and carboxylic acids *(separate science only)* 18. predict the formulae and structures of products of reactions (combustion, addition across a double bond and oxidation of alcohols to carboxylic acids) of the first four and other given members of these homologous series *(separate science only)* 19. recall that it is the generality of reactions of functional groups that determine the reactions of organic compounds *(separate science only)*	**Practical work:** • investigate the reactions of alkanes, alkenes and alcohols **Ideas about Science:** • the use of models to represent functional groups in homologous series (IaS3)

2

Chapter C4: Material choices

Overview

Our society uses a large range of materials and products that have been developed, tested and modified by the work of chemists. Materials used to make a particular product need to meet a specification which describes the properties the material needs to make it suitable for a particular use. This chapter looks at a range of different materials and investigates their properties in the context of their suitability for making consumer products. The chapter also considers how the life cycle of a product is assessed in its journey from raw material to final disposal.

Topic C4.1 considers the variety of materials that we use. Learners use data and information about the properties of 'pure' and composite materials to consider their suitability for making consumer products. Ceramics, glass, materials with giant structure and polymers are all considered.

Topic C4.2 moves on to look in detail at materials made using polymers. The topic covers the chemical reactions that happen when addition and condensation polymers form, and also studies naturally occurring polymers. This topic links closely to the discussion of bonding and structure in Topic C4.3.

Topic C4.3 extends the study of properties to looking at bonding and structure in order to explain why a particular material behaves as it does. Learners learn about the bonding in metals, polymers and giant covalent structures and link the bonding and structure to the properties of the materials. They consider the usefulness of diagrams and models of bonding and structure to chemists who need to investigate and predict properties of materials so that they can make judgements about their usefulness or model likely changes in their properties if their structures are modified. A range of materials are studied, including new materials such as fullerenes and graphene.

Topic C4.4 looks specifically at the nature and uses of nanoparticles.

Topic C4.5 considers the life cycle of materials. The learners learn about the corrosion of metals such as iron and look at ways of extending the life of metal products by working to prevent corrosion. They also learn how the impact of our manufacture, use and disposal of consumer products is assessed using life cycle assessments.

2

Learning about material choices before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

- distinguish between an object and the material from which it is made
- identify and name a variety of everyday materials, including wood, plastic, glass, metal, water, and rock
- describe the simple physical properties of a variety of everyday materials
- compare and group together a variety of everyday materials on the basis of their simple physical properties.
- have observed that some materials change state when they are heated or cooled, and measured the temperature at which this happens in degrees Celsius (°C)
- compare and group together everyday materials on the basis of their properties, including their hardness, solubility, transparency, conductivity (electrical and thermal), and response to magnets
- identify and compare the suitability of a variety of everyday materials, including wood, metal, plastic, glass, brick, rock, paper and cardboard for particular use
- know the differences between atoms, elements and compounds
- recognise chemical symbols and formulae for some elements and compounds
- know about the properties of ceramics, polymers and composites (qualitative).

Tiering

Statements shown in **bold** type will only be tested in the Higher Tier papers.

All other statements will be assessed in both Foundation and Higher Tier papers.

C4.1 How is data used to choose a material for a particular use?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
Our society uses a large range of materials and products developed by chemists. Chemists assess materials by measuring their physical properties, and use data to compare different materials and to match materials to the specification of a useful product (IaS4). Composites have a very broad range of uses as they allow the properties of several materials to be combined. Composites may have materials combined on a bulk scale (for example using steel to reinforce concrete) or have nanoparticles incorporated in a material or embedded in a matrix. The range of uses of metals has been extended by the development of alloys. Alloys have different properties to pure metals due to the disruption of the metal lattice by atoms of different sizes. Chemists can match an alloy to the specification of properties for a new product.	1. compare quantitatively the physical properties of glass and clay ceramics, polymers, composites and metals, including melting point, softening temperature (for polymers), electrical conductivity, strength (in tension or compression), stiffness, flexibility, brittleness, hardness, density, ease of reshaping 2. explain how the properties of materials are related to their uses and select appropriate materials given details of the usage required 3. describe the composition of some important alloys in relation to their properties and uses, including steel *(separate science only)*	**Practical work**: • Practical investigation of a range of materials leading to classification into categories. **Ideas about Science:** • The range of materials developed by chemists enhances the quality of life. (IaS4) • Use and limitations of a model to represent alloy structure. (IaS3)

2

C4.2 What are the different types of polymers? *(separate science only)*

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	***Linked learning opportunities***
Polymers are long chain molecules that occur naturally and can also be made synthetically. Monomers based on alkenes from crude oil can be used to make a wide range of addition polymers that are generally known as 'plastics'. Addition polymers form when the double bonds in small molecules open to join the monomers together into a long chain. **Condensation polymers were developed to make materials that are substitutes for natural fibres such as wool and silk.** **Condensation polymers usually form from two different monomer molecules which contain different functional groups. The OH group from a carboxylic acid monomer and an H atom from another monomer join together to form a water molecule. Monomers that react with carboxylic acid monomers include alcohols (to make polyesters) and amines (to make polyamides). To make a polymer, each monomer needs two functional groups. The structure of the repeating unit of a condensation polymer can be worked out from the formulae of its monomers and vice versa.**	1. recall the basic principles of addition polymerisation by reference to the functional group in the monomer and the repeating units in the polymer 2. deduce the structure of an addition polymer from a simple monomer with a double bond and vice versa **3. explain the basic principles of condensation polymerisation by reference to the functional groups of the monomers, the minimum number of functional groups within a monomer, the number of repeating units in the polymer, and simultaneous formation of a small molecule** ***ⓘ Learners are not expected to recall the formulae of dicarboxylic acid, diamine and diol monomers***	**Specification links:** • The extraction and processing of crude oil, including the formation of alkenes by cracking. (C3.4) • Functional groups including carboxylic acids and alcohols. (C3.4) **Practical work**: • Cracking poly(ethane) and testing the gas for unsaturation. • Testing properties of different polymer fibres.

C4.2 What are the different types of polymers? *(separate science only)*

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
Many natural polymers are essential to life. Genes are made of DNA, a polymer of four nucleotide monomers. Proteins (which are similar in structure to polyamides) are polymers of amino acids. Carbohydrates, including starch and cellulose, are polymers of sugars.	4. recall that DNA is a polymer made from four different monomers called nucleotides and that other important naturally-occurring polymers are based on sugars and amino-acids	**Specification links:** • Structure and function of DNA, and protein synthesis (B1.1) • The synthesis and breakdown of carbohydrates and proteins (B3.3) **Practical work** • Breaking down starch using an enzyme and using food tests to identify starch and sugars

2

C4.3 How do bonding and structure affect properties of materials?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*
Different materials can be made from the same atoms but have different properties if they have different types of bonding or structures. Chemists use ideas about bonding and structure when they predict the properties of a new material or when they are researching how an existing material can be adapted to enhance its properties.	1. explain how the bulk properties of materials (including strength, melting point, electrical and thermal conductivity, brittleness, flexibility, hardness and ease of reshaping) are related to the different types of bonds they contain, their bond strengths in relation to intermolecular forces and the ways in which their bonds are arranged, recognising that the atoms themselves do not have these properties
Carbon is an unusual element because it can form chains and rings with itself. This leads to a vast array of natural and synthetic compounds of carbon with a very wide range of properties and uses. 'Families' of carbon compounds are homologous series.	2. recall that carbon can form four covalent bonds 3. explain that the vast array of natural and synthetic organic compounds occurs due to the ability of carbon to form families of similar compounds, chains and rings

Linked learning opportunities

Specification links
- ionic bonding and structure (C2.3)
- metallic bonding (C3.1)
- covalent bonds and intermolecular forces (C3.4)

Practical work:
- Testing properties of simple covalent compounds, giant ionic and giant covalent substances, metals and polymers.

Specification link:
- The alkanes as a homologous series. (C3.4)

Ideas about Science:
- Identify patterns in data related to polymers and allotropes of carbon.(IaS2)
- Use and limitations of a model to represent the structures of a range of materials. (IaS3)

C4.3 How do bonding and structure affect properties of materials?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
Polymer molecules have the same strong covalent bonding as simple molecular compounds, but there are more intermolecular forces between the molecules due to their length. The strength of the intermolecular forces affects the properties of the solid. Giant covalent structures contain many atoms bonded together in a three-dimensional arrangement by covalent bonds. The ability of carbon to bond with itself gives rise to a variety of materials which have different giant covalent structures of carbon atoms. These are allotropes, and include diamond and graphite. These materials have different properties which arise from their different structures.	4. describe the nature and arrangement of chemical bonds in polymers with reference to their properties including strength, flexibility or stiffness, hardness and melting point of the solid 5. describe the nature and arrangement of chemical bonds in giant covalent structures 6. explain the properties of diamond and graphite in terms of their structures and bonding, include melting point, hardness and (for graphite) conductivity and lubricating action 7. represent three dimensional shapes in two dimensions and vice versa when looking at chemical structures e.g. allotropes of carbon M5b 8. describe and compare the nature and arrangement of chemical bonds in ionic compounds, simple molecules, giant covalent structures, polymers and metals	

2

C4.4 Why are nanoparticles so useful?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
Nanoparticles have a similar scale to individual molecules. Their extremely small size means they can penetrate into biological tissues and can be incorporated into other materials to modify their properties. Nanoparticles have a very high surface area to volume ratio. This makes them excellent catalysts. Fullerenes form nanotubes and balls. The ball structure enables them to carry small molecules, for example carrying drugs into the body. The small size of fullerene nanotubes enables them to be used as molecular sieves and to be incorporated into other materials (for example to increase strength of sports equipment). Graphene sheets have specialised uses because they are only a single atom thick but are very strong with high electrical and thermal conductivity. Developing technologies based on fullerenes and graphene required leaps of imagination from creative thinkers (IaS3).	1. compare 'nano' dimensions to typical dimensions of atoms and molecules 2. describe the surface area to volume relationship for different-sized particles and describe how this affects properties 3. describe how the properties of nanoparticulate materials are related to their uses including properties which arise from their size, surface area and arrangement of atoms in tubes or rings 4. explain the properties fullerenes and graphene in terms of their structures 5. explain the possible risks associated with some nanoparticulate materials including: a) possible effects on health due to their size and surface area b) reasons that there is more data about uses of nanoparticles than about possible health effects c) the relative risks and benefits of using nanoparticles for different purposes	**Ideas about Science:** • Discuss the potential benefits and risks of developments in nanotechnology (IaS4) • Development of nanoparticles and graphene relied on imaginative thinking. (IaS3)

C4.4 Why are nanoparticles so useful?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
There are concerns about the safety of some nanoparticles because not much is known about their effects on the human body. Judgements about a particular use for nanoparticles depend on balancing the perceived benefit and risk (IaS4).	6. estimate size and scale of atoms and nanoparticles including the ideas that: a) nanotechnology is the use and control of structures that are very small (1 to 100 nanometres in size) b) data expressed in nanometres is used to compare the sizes of nanoparticles, atoms and molecules M1d	
	7. interpret, order and calculate with numbers written in standard form when dealing with nanoparticles M1b	
	8. use ratios when considering relative sizes and surface area to volume comparisons M1c	
	9. calculate surface areas and volumes of cubes M5c	

C4.5 What happens to products at the end of their useful life?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*
Iron is the most widely used metal in the world. The useful life of products made from iron is limited because iron corrodes. This involves an oxidation reaction with oxygen from the air. Barrier methods to prevent corrosion extend the useful life of metal products, which is good for consumers and has a positive outcome in terms of the life cycle assessment. Sacrificial protection uses a more reactive metal such as zinc to oxidise in preference to iron. This continues to prevent corrosion even if the coating on the metal is damaged. Life cycle assessments (LCAs) are used to consider the overall impact of our making, using and disposing of a product. LCAs involve considering the use of resources and the impact on the environment of all stages of making materials for a product from raw materials, making the finished product, the use of the product, transport and the method used for its disposal at the end of its useful life. It is difficult to make secure judgments when writing LCAs because there is not always enough data and people do not always follow recommended disposal advice (IaS4). Some products can be recycled at the end of their useful life. In recycling, the products are broken down into the materials used to make them; these materials are then used to make something else. Reusing products uses less energy than recycling them. Reusing and recycling both affects the LCA.	1. describe the conditions which cause corrosion and the process of corrosion, and explain how mitigation is achieved by creating a physical barrier to oxygen and water and by sacrificial protection *(separate science only)* 2. explain reduction and oxidation in terms of loss or gain of oxygen, identifying which species are oxidised and which are reduced **3. explain reduction and oxidation in terms of gain or loss of electrons, identifying which species are oxidised and which are reduced** 4. describe the basic principles in carrying out a life-cycle assessment of a material or product including a) the use of water, energy and the environmental impact of each stage in a life cycle, including its manufacture, transport and disposal b) incineration, landfill and electricity generation schemes c) biodegradable and non-biodegradable materials 5. interpret data from a life-cycle assessment of a material or product

Linked learning opportunities

Practical work:
- Investigating the factors needed for rusting of iron or corrosion of other metals.
- Investigating the effectiveness of corrosion prevention (barrier and sacrificial protection methods).

Ideas about Science:
- use the example of applying scientific solutions to the problem of corrosion of metals to explain the idea of improving sustainability (IaS4)
- use life cycle assessments to compare the sustainability of products and processes (IaS4)

C4.5 What happens to products at the end of their useful life?

Teaching and learning narrative	**Assessable learning outcomes** *Learners will be required to:*	***Linked learning opportunities***
Recycling conserves resources such as crude oil and metal ores, but will not be sufficient to meet future demand for these resources unless habits change. The viability of a recycling process depends on a number of factors: the finite nature of some deposits of raw materials (such as metal ores and crude oil), availability of the material to be recycled, economic and practical considerations of collection and sorting, removal of impurities, energy use in transport and processing, scale of demand for new product, environmental impact of the process. Products made from recycled materials do not always have a lower environmental impact than those made from new resources (IaS4).	6. describe the process where PET drinks bottles are reused and recycled for different uses, and explain why this is viable 7. evaluate factors that affect decisions on recycling with reference to products made from crude oil and metal ores	

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Chapter C5: Chemical analysis

Overview

This chapter looks at how chemicals are analysed. Chemical analysis is important in chemistry for the quality control of manufactured products and also to identify or quantify components in testing of new products, mineral extraction, forensics and environmental monitoring. Chemists need to both identify which substances are present (qualitative analysis) and the quantity of each substance (quantitative analysis). Measuring purity and separating mixtures is important in manufacturing to ensure quality and to separate useful products from bi-products and waste. Being able to analyse quantities of chemicals enables chemists to plan for the amounts of reactants they need to use to make a product, or predict quantities of products from known amounts of reactants.

The chapter begins in Topic C5.1 by considering why it is necessary to purify chemicals and how the components of mixtures are separated. Methods of testing for purity and separating mixtures are studied, including chromatography and a range of practical separation techniques.

Topic C5.2 is concerned with qualitative analysis. This topic uses standard laboratory techniques, such as flame tests, precipitation reactions and anion tests to identify the ions in unknown substances. Gas chromatography is introduced as an example of an instrumental technique, and used as a context for comparison between standard laboratory and instrumental techniques.

Topic C5.3 introduces quantitative work. The mole is used as a measure of amounts of substance and learners process data from formulae and equations to work out quantities of reactants and products. This topic ends by considering how molar amounts of gas relate to their volumes.

Topic C5.4 develops quantitative work further to show how the concentrations of solutions are determined. This has applications for the testing and quality control of manufactured chemical products and also allows the analysis of unknown chemicals for a range of purposes (for example in forensics, in drug production, mineral exploration and environmental monitoring). Learners make a standard solution and analyse the concentration of unknown solutions using titrations.

Learning about Chemical analysis before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

- use knowledge of solids, liquids and gases to decide how mixtures might be separated, including through filtering, sieving and evaporating
- understand the concept of a pure substance and how to identify a pure substance
- know about simple techniques for separating mixtures: filtration, evaporation, distillation and chromatography
- know about the pH scale for measuring acidity/alkalinity; and indicators.

Tiering

Statements shown in **bold** type will only be tested in the Higher Tier papers.

All other statements will be assessed in both Foundation and Higher Tier papers.

C5.1 How are chemicals separated and tested for purity?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
Many useful products contain mixtures. It is important that consumer products such as drugs or personal care products do not include impurities. Mixtures in many consumer products contain pure substances mixed together in definite proportions called formulations.	1. explain that many useful materials are formulations of mixtures	**Specification links:** • particle model and changes of state (C1.1) • Fractional distillation of crude oil on an industrial scale (C3.4) **Ideas about Science** • use the particle model to explain the idea of a pure substance
	2. explain what is meant by the purity of a substance, distinguishing between the scientific and everyday use of the term ‘pure’	
Pure substances contain a single element or compound. Chemists test substances made in the laboratory and in manufacturing processes to check that they are pure. One way of assessing the purity of a substance is by testing its melting point; pure substances have sharp melting points and can be identified by matching melting point data to reference values.	3. use melting point data to distinguish pure from impure substances	
	4. recall that chromatography involves a stationary and a mobile phase and that separation depends on the distribution between the phases	
Chromatography is used to see if a substance is pure or to identify the substances in a mixture. Components of a mixture are identified by the relative distance travelled compared to the distance travelled by the solvent. Rf values can be calculated and used to identify unknown components by comparison to reference samples. Some substances are insoluble in water, so other solvents are used. Chromatography can be used on colourless substances but locating agents are needed to show the spots.	5. interpret chromatograms, including calculating Rf values M3c	
	6. suggest chromatographic methods for distinguishing pure from impure substances *PAG4* Including the use of: a) paper chromatography b) aqueous and non-aqueous solvents c) locating agents	
Preparation of chemicals often produces impure products or a mixture of products. Separation processes in both the laboratory and in industry enable useful products to be separated from bi-products and waste products. The components of mixtures are separated using processes that exploit the different properties of the components, for example state, boiling points or solubility in different solvents.	7. describe, explain and exemplify the processes of filtration, crystallisation, simple distillation, and fractional distillation *PAG3, PAG7*	
Separation processes are rarely completely successful and mixtures often need to go through several stages or through repeated processes to reach an acceptable purity.	8. suggest suitable purification techniques given information about the substances involved *PAG3, PAG7*	

C5.2 How do chemists find the composition of unknown samples? *(separate science only)*

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
Chemists use qualitative analysis to identify components in a sample. The procedures have a wide range of applications, including testing chemicals during manufacturing process, testing mineral samples, checking for toxins in waste, environmental testing of water, testing soils. Chemists use sampling techniques to make sure that the samples used for the analysis are representative and will identify any variations in the bulk of the material that is represented in the analysis (IaS1). Laboratory analysis can be used to identify the metal cations and the anions in salts. Cations can be identified using flame tests or by adding dilute sodium hydroxide. Anions can be identified using a range of dilute reagents. Instrumental analysis is widely used in research and in industry. Emission spectroscopy is a technique which relies on looking at the spectrum of light emitted from a hot sample. Each element gives a unique pattern of lines. Elements can be identified by matching the patterns and wavelengths of lines to reference data from known elements. Emission spectroscopy is used to identify elements in stars and in substances such as steel in industry. Instrumental analysis is preferred due to its greater sensitivity, speed and accuracy. Data is automatically recorded. However, the technology is expensive and is not as freely available as the standard glassware used in laboratory analysis.	1. describe the purpose of representative sampling in qualitative analysis 2. interpret flame tests to identify metal ions, including the ions of lithium, sodium, potassium, calcium and copper 3. describe the technique of using flame tests to identify metal ions *PAG5* 4. describe tests to identify aqueous cations and aqueous anions and identify species from test results including: *PAG5* a) tests and expected results for metal ions in solution by precipitation reactions using dilute sodium hydroxide (calcium, copper, iron(II), iron(III), zinc) b) tests and expected results for carbonate ions (using dilute acid), chloride, bromide and iodide ions (using acidified dilute silver nitrate) and sulfate ions (using acidified dilute barium chloride or acidified barium nitrate) 5. interpret an instrumental result for emission spectroscopy given appropriate data in chart or tabular form, when accompanied by a reference set in the same form 6. describe the advantages of instrumental methods of analysis (sensitivity, accuracy and speed) 7. interpret charts, particularly in spectroscopy M4a	**Specification links:** • Symbols, formulae and ionic equations. (C2.4 and C3.2) **Ideas about Science:** • Suggest equipment and techniques and a strategy to carry out qualitative analysis (IaS1)

C5.3 How are the amounts of substances in reactions calculated?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*		*Linked learning opportunities*
During reactions, atoms are rearranged but the total mass does not change. Reactions in open systems often appear to have a change in mass because substances are gained or lost, usually to the air. Chemists use relative masses to measure the amounts of chemicals. Relative atomic masses for atoms of elements can be obtained from the Periodic Table. The relative formula mass of a compound can be calculated using its formula and the relative atomic masses of the atoms it contains. **Relative masses are based on the mass of carbon 12. Counting atoms or formula units of compounds involves very large numbers, so chemists use a mole as a unit of counting. One mole contains the same number of particles as there are atoms in 12g of carbon –12, and has the value 6.0 x 10^{23} atoms; this is the Avogadro constant. It is more convenient to count atoms as 'numbers of moles'.** **The number of moles of a substance can be worked out from its mass, this is useful to chemists because they can use the equations for reactions to work out the amounts of reactants to use in the correct proportions to make a particular product, or to work out which reactant is used up when a reaction stops.**	1.	recall and use the law of conservation of mass	**Specification links** • The particle model (C1.1) • Maximising industrial yields (C6.3) **Practical Work:** • Comparison of theoretical and actual yield from the preparation of an organic compound (introduced in C3) or a salt (introduced in C5). • Testing predictions of volumes of gases produced from reactions of acids. **Practical work:** • Making and testing predictions. Carrying out investigations. Analysing and evaluating data. Using measuring apparatus. Safe handling of chemicals.
	2.	explain any observed changes in mass in non-enclosed systems during a chemical reaction and explain them using the particle model	
	3.	calculate relative formula masses of species separately and in a balanced chemical equation	
	4.	**recall and use the definitions of the Avogadro constant (in standard form) and of the mole**	
	5.	**explain how the mass of a given substance is related to the amount of that substance in moles and vice versa and use the relationship:** **number of moles =** $\frac{\textbf{mass of substance (g)}}{\textbf{relative formula mass (g)}}$ M3b, M3c, M2a	
	6.	**deduce the stoichiometry of an equation from the masses of reactants and products and explain the effect of a limiting quantity of a reactant**	
	7.	**use a balanced equation to calculate masses of reactants or products** M1a, M1c	

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C5.3 How are the amounts of substances in reactions calculated?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	***Linked learning opportunities***
The equation for a reaction can also be used to work out how much product can be made starting from a known amount of reactants. This is useful to determine the amounts of reacting chemicals to be used in industrial processes so that processes can run as efficiently as possible. Chemists use the equation for a reaction to calculate the theoretical, expected yield of a product. This can then be compared to the actual yield. Actual yields are usually much lower than theoretical yields. This can be caused by a range of factors including reversible reactions, impurities in reactants or reactants and products being lost during the procedure. Information about actual yields is used to make improvements to procedures to maximise yields.	8. use arithmetic computation, ratio, percentage and multistep calculations throughout quantitative chemistry M1a, M1c, M1d **9. carry out calculations with numbers written in standard form when using the Avogadro constant** M1b 10. change the subject of a mathematical equation M3b, M3c 11. calculate the theoretical amount of a product from a given amount of reactant *(separate science only)* M1a, M1c, M1d 12. calculate the percentage yield of a reaction product from the actual yield of a reaction *(separate science only)* M1a, M1c, M1d, M3c 13. suggest reasons for low yields for a given procedure *(separate science only)*	**Ideas about Science:** • Using data to make quantitative predictions about yields and comparing them to actual yields. (IaS1, IaS2)
One mole of any gas has the same volume – 24 dm^3 at room temperature and pressure. **So the number of moles of molecules in a known volume of gas can be calculated, using the formula** $\text{number of moles of gas} = \frac{\text{volume of gas in sample } (dm^3)}{24\ (dm^3)}$ **For reactions involving only gases, the relative volumes of reactant or product gases can be worked out directly from the equation.** **For reactions with substances in a mixture of states, calculations may involve using both masses and gas volumes to calculate amounts of products and reactants.**	**14. describe the relationship between molar amounts of gases and their volumes and vice versa, and calculate the volumes of gases involved in reactions, using the molar gas volume at room temperature and pressure (assumed to be 24dm^3)** ***(separate science only)***	

C5.4 How are the amounts of chemicals in solution measured?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
Quantitative analysis is used by chemists to make measurements and calculations to show the amounts of each component in a sample. **Concentrations sometimes use the units g/dm³ but more often are expressed using moles, with the units mol/dm³. Expressing concentration using moles is more useful because it links more easily to the reacting ratios in the equation.** The concentration of acids and alkalis can be analysed using titrations. Alkalis neutralise acids. An indicator is used to identify the point when neutralisation is just reached. During the reaction, hydrogen ions from the acid react with hydroxide ions from the alkali to form water. The reaction can be represented using the equation $H^+ (aq) + OH^- (aq) \rightarrow H_2O(l)$ As with all quantitative analysis techniques, titrations follow a standard procedure to ensure that the data is collected safely and is of high quality, including selecting samples, making rough and multiple repeat readings and using equipment of an appropriate precision (such as a burette and pipette).	1. identify the difference between qualitative and quantitative analysis *(separate science only)* **2. explain how the mass of a solute and the volume of the solution is related to the concentration of the solution and calculate concentration using the formula:** **$\text{concentration (g/dm}^3\text{)} = \frac{\text{mass of solute (g)}}{\text{volume (dm}^3\text{)}}$** M3b, M3c **3. explain how the concentration of a solution in mol/dm³ is related to the mass of the solute and the volume of the solution and calculate the molar concentration using the formula** **$\text{concentration (mol/dm}^3\text{)} = \frac{\text{number of moles of solute}}{\text{volume (dm}^3\text{)}}$** M3b, M3c 4. describe neutralisation as acid reacting with alkali to form a salt plus water including the common laboratory acids hydrochloric acid, nitric acid and sulfuric acid and the common alkalis, the hydroxides of sodium, potassium and calcium	**Specification links:** • Strong and weak acid chemistry (C6.1) **Practical Work:** • Making up a standard solution. **Practical work** • Acid-base titrations. • Use of appropriate measuring apparatus, measuring pH, use of a volumetric flask to make a standard solution, titrations using burettes and pipettes, use of acid-base indicators, safe handling of chemicals.

C5.4 How are the amounts of chemicals in solution measured?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*		Linked learning opportunities
Data from titrations can be assessed in terms of its accuracy, precision and validity. An initial rough measurement is used as an estimate and titrations are repeated until a level of confidence can be placed in the data; the readings must be close together with a narrow range. The true value of a titration measurement can be estimated by discarding roughs and taking a mean of the results which are in close agreement. The results of a titration and the equation for the reaction are used to work out the concentration of an unknown acid or alkali.	5.	recall that acids form hydrogen ions when they dissolve in water and solutions of alkalis contain hydroxide ions	**Ideas about Science:** • Justify a technique in terms of precision, accuracy and validity of data to be collected, minimising risk. Use of range and mean when processing titration results, analysis of data. (IaS1, IaS2)
	6.	recognise that aqueous neutralisation reactions can be generalised to hydrogen ions reacting with hydroxide ions to form water	
	7.	describe and explain the procedure for a titration to give precise, accurate, valid and repeatable results *PAG6*	
	8.	Evaluate the quality of data from titrations	
	9.	**explain the relationship between the volume of a solution of known concentration of a substance and the volume or concentration of another substance that react completely together *(separate science only)***	

Chapter C6: Making useful chemicals

Overview

This chapter considers the laboratory and large-scale production of useful chemicals.

Topic C6.1 begins with the laboratory synthesis of salts from acid reactions, and also looks at the characteristics of both acids and bases.

In Topic C6.2, the story moves on to study how chemists manage the rate of reaction when these reactions take place, in the context of managing conditions both in the laboratory and in industry. This topic gives the opportunity for a wide range of practical investigation and mathematical analysis of rates.

Topic C6.3 looks at reversible reactions, with particular emphasis on the large-scale production of ammonia.

Topic C6.4 develops all the ideas in the chapter together to look at both how the conditions and 'routes' for a chemical process are chosen by thinking about the economic and environmental issues surrounding the production of chemicals on a large scale. The manufacture of fertilisers is used as a context for considering how chemists reach decisions about the optimum processes for large- scale production of bulk chemicals.

Learning about Making useful Chemicals before GCSE (9–1)

From study at Key Stages 1 to 3 learners should:

- explain that some changes result in the formation of new materials, and that this kind of change is not usually reversible
- represent chemical reactions using formulae and using equations
- define acids and alkalis in terms of neutralisation reactions
- describe the pH scale for measuring acidity/ alkalinity; and indicators
- recall reactions of acids with metals to produce a salt plus hydrogen and reactions of acids with alkalis to produce a salt plus water
- know what catalysts do.
- know about energy changes on changes of state (qualitative)
- know about exothermic and endothermic chemical reactions (qualitative).

Tiering

Statements shown in **bold** type will only be tested in the Higher Tier papers.

All other statements will be assessed in both Foundation and Higher Tier papers.

C6.1 What useful products can be made from acids?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
Many products that we use every day are based on the chemistry of acid reactions. Products made using acids include cleaning products, pharmaceutical products and food additives. In addition, acids are made on an industrial scale to be used to make bulk chemicals such as fertilisers. Acids react in neutralisation reactions with metals, hydroxides and carbonates. All neutralisation reactions produce salts, which have a wide range of uses and can be made on an industrial scale. **The strength of an acid depends on the degree of ionisation and hence the concentration of H^+ ions, which determines the reactivity of the acid. The pH of a solution is a measure of the concentration of H^+ ions in the solution. Strong acids ionise completely in solution, weak acids do not. Both strong and weak acids can be prepared at a range of different concentrations (i.e. different amounts of substance per unit volume).** **Weak acids and strong acids of the same concentration have different pH values. Weak acids are less reactive than strong acids of the same concentration (for example they react more slowly with metals and carbonates).**	1. recall that acids react with some metals and with carbonates and write equations predicting products from given reactants 2. describe practical procedures to make salts to include appropriate use of filtration, evaporation, crystallisation and drying *PAG7* 3. use the formulae of common ions to deduce the formula of a compound 4. recall that relative acidity and alkalinity are measured by pH including the use of universal indicator and pH meters **5. use and explain the terms dilute and concentrated (amount of substance) and weak and strong (degree of ionisation) in relation to acids including differences in reactivity with metals and carbonates** **6. use the idea that as hydrogen ion concentration increases by a factor of ten the pH value of a solution decreases by one** **7. describe neutrality and relative acidity and alkalinity in terms of the effect of the concentration of hydrogen ions on the numerical value of pH (whole numbers only)**	**Specification links** • Writing formulae, balanced symbol and ionic equations.(C3.2) • Concentration of solutions (C5.4) **Practical Work:** • Reactions of acids and preparation of salts. • pH testing • Investigating strong and weak acid reactivity. • use of indicators to test strong and weak acids, making standard solutions using volumetric flasks.

C6.2 How do chemists control the rate of reactions?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*
Controlling rate of reaction enables industrial chemists to optimise the rate at which a chemical product can be made safely. The rate of a reaction can be altered by altering conditions such as temperature, concentration, pressure and surface area. A model of particles colliding helps to explain why and how each of these factors affects rate; for example, increasing the temperature increases the rate of collisions and, more significantly, increases the energy available to the particles to overcome the activation energy and react. A catalyst increases the rate of a reaction but can be recovered, unchanged, at the end. Catalysts work by providing an alternative route for a reaction with a lower activation energy. Energy changes for uncatalysed and catalysed reactions have different reaction profiles. The use of a catalyst can reduce the economic and environmental cost of an industrial process, leading to more sustainable 'green' chemical processes.	1. describe the effect on rate of reaction of changes in temperature, concentration, pressure, and surface area 2. explain the effects on rates of reaction of changes in temperature, concentration and pressure in terms of frequency and energy of collision between particles 3. explain the effects on rates of reaction of changes in the size of the pieces of a reacting solid in terms of surface area to volume ratio 4. describe the characteristics of catalysts and their effect on rates of reaction 5. identify catalysts in reactions 6. explain catalytic action in terms of activation energy

Linked learning opportunities

Specification links

- Endothermic and exothermic reactions and energy level diagrams. (C1)

Practical Work:

- Investigate the effect of temperature and concentration on rate of reactions.
- Compare methods of following rate

Ideas about Science:

- Use the particle model to explain factors that affect rates of reaction (IaS3)
- The use of catalysts supports more sustainable industrial processes.(IaS4)

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C6.2 How do chemists control the rate of reactions?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
Rate of reaction can be determined by measuring the rate at which a product is made or the rate at which a reactant is used. Some reactions involve a colour change or form a solid in a solution; the rate of these reactions can be measured by timing the changes that happen in the solutions by eye or by using apparatus such as a colorimeter. Reactions that make gases can be followed by measuring the volume of gas or the change in mass over time. On graphs showing the change in a variable such as concentration over time, the gradient of a tangent to the curve is an indicator of rate of change at that time. The average rate of a reaction can be calculated from the time taken to make a fixed amount of product.	7. suggest practical methods for determining the rate of a given reaction including*: PAG8* for reactions that produce gases: i. gas syringes or collection over water can be used to measure the volume of gas produced ii. mass change can be followed using a balance **measurement of physical factors:** **iii. colour change** **iv. formation of a precipitate**	**Practical work:** • Designing and carrying out investigations into rates. Analysing and interpreting data. Use of apparatus to make measurements. Use of heating equipment. Safe handling of chemicals. Measuring rates of reaction using two different methods. **Specification link:** • enzymes in biological processes (B3.1)
	8. interpret rate of reaction graphs M4a, M4b	
	9. interpret graphs of reaction conditions versus rate *(separate science only)* M4a, M4b ⓘ *an understanding of orders of reaction is not required*	
	10. use arithmetic computation and ratios when measuring rates of reaction M1a, M1c	
	11. draw and interpret appropriate graphs from data to determine rate of reaction M2b, M4b, M4c	
	12. determine gradients of graphs as a measure of rate of change to determine rate M4b, M4d, M4e	

C6.2 How do chemists control the rate of reactions?

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*		***Linked learning opportunities***
Enzymes are proteins that catalyse processes in living organisms. They work at their optimum within a narrow range of temperature and pH. Enzymes can be adapted and sometimes synthesised for use in industrial processes. Enzymes limit the conditions that can be used but this can be an advantage because if a process can be designed to use an enzyme at a lower temperature than a traditional process, this reduces energy demand.	13.	use proportionality when comparing factors affecting rate of reaction M1c	
	14.	describe the use of enzymes as catalysts in biological systems and some industrial processes	

C6.3 What factors affect the yield of chemical reactions?

Teaching and learning narrative	**Assessable learning outcomes** *Learners will be required to:*	***Linked learning opportunities***
Industrial processes are managed to get the best yield as quickly and economically as possible. Chemists select the conditions that give the best economic outcome in terms of safety, maintaining the conditions and equipment, and energy use. The reactions in some processes are reversible. This can be problematic in industry because the reactants never completely react to make the products. This wastes reactants and means that the products have to be separated out from the reactants, which requires extra stages and costs. Data about yield and rate of chemical processes are used to choose the best conditions to make a product. On industrial scales, very high temperatures and pressures are expensive to maintain due to the cost of energy and because equipment may fail under extreme conditions. Catalysts can be used to increase the rate of reaction without affecting yield. Chemical engineers choose the conditions that will make the process as safe and efficient as possible, reduce the energy costs and reduce the waste produced at all stages of the process.	1. recall that some reactions may be reversed by altering the reaction conditions including: a) reversible reactions are shown by the symbol $\rightleftharpoons$ b) reversible reactions (in closed systems) do not reach 100% yield	**Specification links:** • Calculations of yields (C5.1) **Practical Work:** • Investigating reversible reactions.
	2. recall that dynamic equilibrium occurs when the rates of forward and reverse reactions are equal	
	3. predict the effect of changing reaction conditions (concentration, temperature and pressure) on equilibrium position and suggest appropriate conditions to produce a particular product, including: **a) catalysts increase rate but do not affect yield** **b) the disadvantages of using very high temperatures or pressures**	**Ideas about Science:** • Make predictions from data and graphs about yield of chemical products. (IaS2) • Consider the risks and costs of different operating conditions in an ammonia plant. (IaS4) **Practical work** • Analyse and evaluate data about yield and rate of ammonia production.

C6.4 How are chemicals made on an industrial scale? *(separate science only)*

Teaching and learning narrative	**Assessable learning outcomes** *Learners will be required to:*	***Linked learning opportunities***
Nitrogen, phosphorus and potassium are essential plant nutrient elements; they are lost from the soil when crops use them for growth and then are harvested. Fertilisers are added to the soil to replace these essential elements. The world demand for food cannot be met without the use of synthetic fertilisers. Natural fertilisers are not available in large enough quantities, their supply is difficult to manage and transport and their composition is variable. However, fertilisers can cause environmental harm when overused; if they are washed into rivers they cause excessive weed growth, which can lead to the death of the organisms that live there.	1. recall the importance of nitrogen, phosphorus and potassium compounds in agricultural production 2. explain the importance of the Haber process in agricultural production and the benefits and costs of making and using fertilisers, including: a) the balance between demand and supply of food worldwide b) the sustainability and practical issues of producing and using synthetic and natural fertilisers on a large scale c) the environmental impact of over-use of synthetic fertilisers (eutrophication)	**Specification links** • Haber Process (C4.3) **Practical Work:** • Laboratory preparation and purification of salts that are used as fertilisers. **Ideas about Science:** • Make predictions from data and graphs about yield of chemical products. (IaS2) • Consider the risks and costs of different operating conditions in an ammonia plant. (IaS4) • Production of fertilisers to enhance the quality of people's lives (IaS4) • Evaluation of industrial processes in terms of sustainability, risk, costs and benefits. (IaS4)
Ammonia is one of the most important compounds used to make synthetic fertilisers. Ammonia is made in the Haber process, which involves a reversible reaction. **To get the greatest output as quickly and economically as possible chemical engineers consider the rate and the position of equilibrium for the reaction. In practice, industrial processes rarely reach equilibrium. In the Haber process unreacted reactants are continuously separated from the ammonia and recycled so that the nitrogen and hydrogen are not wasted.**	**3. explain how the commercially used conditions for the Haber process are related to the availability and cost of raw materials and energy supplies, control of equilibrium position and rate including:** **a) the sourcing of raw materials and production of the feedstocks; nitrogen (from air), and hydrogen (from natural gas and steam)** **b) the effect of a catalyst, temperature and pressure on the yield and rate of reaction** **c) the separation of the ammonia and recycling of unreacted nitrogen and hydrogen**	
Industrial processes need to be as economically profitable as possible.	**4. explain the trade-off between rate of production of a desired product and position of equilibrium in some industrially important processes**	
Atom economy is an indicator of the amount of useful product that is made in a reaction. This is a theoretical value based on the reaction equation and is used alongside data about yields and efficiency when processes are evaluated.	5. define the atom economy of a reaction	

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C6.4 How are chemicals made on an industrial scale? *(separate science only)*

Teaching and learning narrative	Assessable learning outcomes *Learners will be required to:*	*Linked learning opportunities*
Modern processes incorporate 'green chemistry' ideas, to provide a sustainable approach to production. Sustainability is a measure of how a process is able to meet current demand without having a long term impact on the environment. Reactions with high atom economy are more sustainable. Other issues which affect the sustainability of a process include; whether or not the raw materials are renewable; the impact of other competing uses for the same raw materials; the nature and amount of by-products or wastes; the energy inputs or outputs. Synthetic fertilisers contain salts that are made in acid-base reactions and can be synthesised on a laboratory scale. Scaling up of fertiliser manufacture for industrial production uses some similar processes to the laboratory preparation, but these are adapted to handle the much larger quantities involved. Any one compound used in fertilisers can often be made using several different processes. An example is the manufacture of ammonium sulfate. The synthesis stage of manufacture could be the same as the process used in the laboratory; but alternatively a manufacturer might make use of bi-product or waste products from other production processes. Finding uses for bi-products is an important factor in ensuring the sustainability of industrial processes. Laboratory scale procedures such as choosing reactants, synthesis, monitoring the reaction, separation techniques, disposal of waste and testing of purity have parallel counterparts in the industrial process.	6. calculate the atom economy of a reaction to form a desired product from the balanced equation using the formula: $\text{atom economy} = \frac{\text{mass of atoms in desired product}}{\text{total mass of atoms in reactants}}$ M3b, M3c 7. use arithmetic computation when calculating atom economy M1a, M1c **8. explain why a particular reaction pathway is chosen to produce a specified product given appropriate data such as atom economy (if not calculated), yield, rate, equilibrium position, usefulness of by-products and evaluate the sustainability of the process** 9. describe the industrial production of fertilisers as several integrated processes using a variety of raw materials and compare with laboratory syntheses. including: a) demand for fertilisers (including ammonium sulfate) is often met from more than one process b) some fertilisers are made as a bi-product or waste product of another process c) process flow charts are used to summarise industrial processes and give information about raw materials, stages in the process, products, by-products and waste d) lab processes prepare chemicals in batches, industrial processes are usually continuous. 10. compare the industrial production of fertilisers with laboratory syntheses of the same products	**Ideas about Science** • Industrial processes can be modelled in the laboratory and using computers before making decisions about full scale production (IaS3)