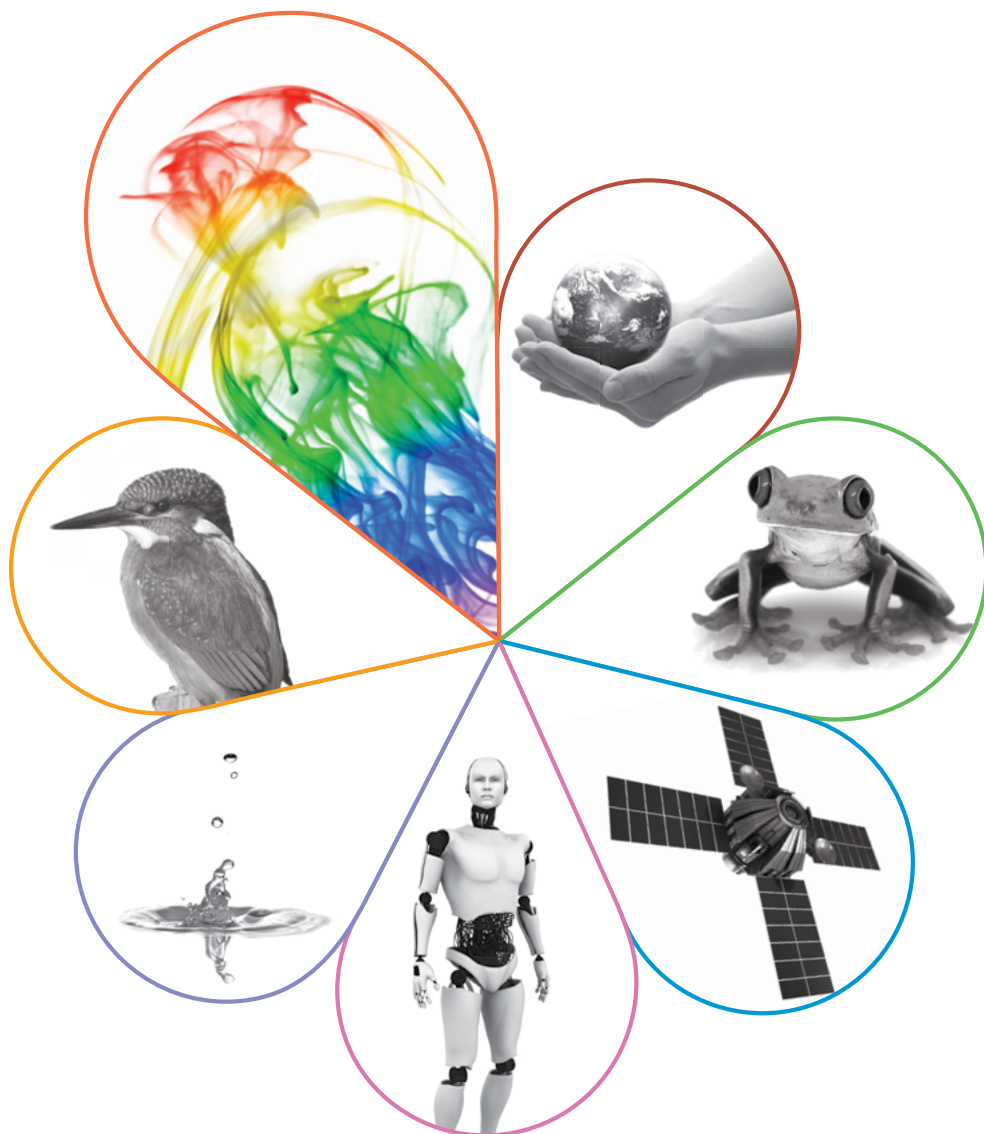

GCSE CHEMISTRY

(8462)

Specification

For teaching from September 2016 onwards
For exams in 2018 onwards

Version 1.1 04 October 2019



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Are you using the latest version of this specification?

- You will always find the most up-to-date version of this specification on our website at [aqa.org.uk/8462](https://www.aqa.org.uk/8462)
- We will write to you if there are significant changes to the specification.

1 Introduction

1.1 Why choose AQA for GCSE Chemistry

Our philosophy: science for all

We believe that science has something to offer every student. That's why we have a suite of science qualifications for Key Stage 4 – to suit students of all abilities and all aspirations.

You'll see that our GCSE Chemistry, along with Biology and Physics, is a clear straightforward specification, with clear straightforward exams, so all your students can realise their potential.

Our specification has been developed with teachers

We've involved over a thousand teachers in developing our specification, exams and resources. So you can be confident that our GCSE Chemistry is relevant and interesting to teach and to learn. We've ensured that:

- the subject content is presented clearly, in a logical teaching order. We've also given teaching guidance and signposted opportunities for skills development throughout the specification
- the subject content and required practicals in our GCSE Combined Science: Trilogy are also in our GCSE Biology, Chemistry and Physics. So you have the flexibility to co-teach or to move your students between courses
- all our science qualifications provide opportunities for progression. Our GCSE includes progression in the subject content and consistency in the exam questions, so that your students have the best preparation for A-level.

Our practicals have been trialled by teachers

There's no better way to learn about science than through purposeful practical activities as part of day-to-day teaching and learning. Our eight required practicals:

- are clearly laid out in the specification, so you know exactly what's required
- are deliberately open, so you can teach in the way that suits you and your students
- have already been trialled in schools.

You'll find even more support and guidance in our practical handbook, which includes recommendations and advice from teachers in the trial.

Straightforward exams, so students can give straightforward answers

We've improved our question papers. You'll find that our exams:

- use more straightforward language and fewer words so they're easier to understand
- have fewer contexts so students don't get confused
- have questions that increase in difficulty so students feel confident
- have been written with our GCSE Maths and A-level science teams, so students have consistency between content and questions.

Over 3,000 students have sat our specimen question papers and they agree that they're clearer and more straightforward than ever.

We don't profit from education – you do

We are an educational charity focused on the needs of teachers and students. This means that we spend our income on improving the quality of our specifications, exams, resources and support.

You can find out all about our Science qualifications at [aqa.org.uk/science](https://www.aqa.org.uk/science)

1.2 Support and resources to help you teach

We've worked with experienced teachers to provide you with a range of resources that will help you confidently plan, teach and prepare for exams.

Teaching resources

Visit [aqa.org.uk/8462](https://www.aqa.org.uk/8462) to see all our teaching resources. They include:

- additional practice papers to help students prepare for exams
- schemes of work, written by experienced teachers
- a practical handbook, including recommendations and advice from teachers who've trialled our practicals
- AQA-approved textbooks reviewed by experienced senior examiners
- subject expertise courses for all teachers, from newly qualified teachers who are just getting started to experienced teachers looking for fresh inspiration.

Preparing for exams

Visit [aqa.org.uk/8462](https://www.aqa.org.uk/8462) for everything you need to prepare for our exams, including:

- past papers, mark schemes and examiners' reports
- sample papers and mark schemes for new courses
- Exampro: a searchable bank of past AQA exam questions
- example student answers with examiner commentaries.

Analyse your students' results with Enhanced Results Analysis (ERA)

Find out which questions were the most challenging, how the results compare to previous years and where your students need to improve. ERA, our free online results analysis tool, will help you see where to focus your teaching. Register at [aqa.org.uk/era](https://www.aqa.org.uk/era)

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- Prepare for a new role with our leadership and management courses.

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Alternatively, you can call or email our subject team direct.

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T: 01483 477 756

2 Specification at a glance

This qualification is linear. Linear means that students will sit all their exams at the end of the course.

2.1 Subject content

1. [Atomic structure and the periodic table](#) (page 17)
2. [Bonding, structure, and the properties of matter](#) (page 26)
3. [Quantitative chemistry](#) (page 36)
4. [Chemical changes](#) (page 43)
5. [Energy changes](#) (page 51)
6. [The rate and extent of chemical change](#) (page 55)
7. [Organic chemistry](#) (page 61)
8. [Chemical analysis](#) (page 70)
9. [Chemistry of the atmosphere](#) (page 75)
10. [Using resources](#) (page 80)
11. [Key ideas](#) (page 89)

2.2 Assessments

Paper 1:
<p>What's assessed</p> <p>Topics 1–5: Atomic structure and the periodic table; Bonding, structure, and the properties of matter; Quantitative chemistry, Chemical changes; and Energy changes.</p>
<p>How it's assessed</p> <ul style="list-style-type: none"> • Written exam: 1 hour 45 minutes • Foundation and Higher Tier • 100 marks • 50% of GCSE
<p>Questions</p> <p>Multiple choice, structured, closed short answer and open response.</p>



Paper 2:

What's assessed

Topics 6–10: The rate and extent of chemical change; Organic chemistry; Chemical analysis, Chemistry of the atmosphere; and Using resources.

Questions in Paper 2 may draw on fundamental concepts and principles from sections 4.1 to 4.3.

How it's assessed

- Written exam: 1 hour 45 minutes
- Foundation and Higher Tier
- 100 marks
- 50% of GCSE

Questions

Multiple choice, structured, closed short answer and open response.

3 Working scientifically

Science is a set of ideas about the material world. We have included all the parts of what good science is at GCSE level: whether it be investigating, observing, experimenting or testing out ideas and thinking about them. The way scientific ideas flow through the specification will support you in building a deep understanding of science with your students. We know this will involve talking about, reading and writing about science plus the actual doing, as well as representing science in its many forms both mathematically and visually through models.

This specification encourages the development of knowledge and understanding in science through opportunities for working scientifically. Working scientifically is the sum of all the activities that scientists do. We feel it is so important that we have woven it throughout our specification and written papers.

Our schemes of work will take this further for you and signpost a range of ways to navigate through this qualification so your students are engaged and enthused. These free resources support the use of mathematics as a tool for thinking through the use of mathematical language in explanations, applications and evaluations.

The tables below show examples of the ways working scientifically could be assessed.

1 Development of scientific thinking

Students should be able to:	Examples of what students could be asked to do in an exam
WS 1.1 Understand how scientific methods and theories develop over time.	<p>Give examples to show how scientific methods and theories have changed over time.</p> <p>Explain, with an example, why new data from experiments or observations led to changes in models or theories.</p> <p>Decide whether or not given data supports a particular theory.</p>
WS 1.2 Use a variety of models such as representational, spatial, descriptive, computational and mathematical to solve problems, make predictions and to develop scientific explanations and understanding of familiar and unfamiliar facts.	<p>Recognise/draw/interpret diagrams.</p> <p>Translate from data to a representation with a model.</p> <p>Use models in explanations, or match features of a model to the data from experiments or observations that the model describes or explains.</p> <p>Make predictions or calculate quantities based on the model or show its limitations.</p> <p>Give examples of ways in which a model can be tested by observation or experiment.</p>

Students should be able to:	Examples of what students could be asked to do in an exam
WS 1.3 Appreciate the power and limitations of science and consider any ethical issues which may arise.	<p>Explain why data is needed to answer scientific questions, and why it may be uncertain, incomplete or not available.</p> <p>Outline a simple ethical argument about the rights and wrongs of a new technology.</p>
WS 1.4 Explain everyday and technological applications of science; evaluate associated personal, social, economic and environmental implications; and make decisions based on the evaluation of evidence and arguments.	<p>Describe and explain specified examples of the technological applications of science.</p> <p>Describe and evaluate, with the help of data, methods that can be used to tackle problems caused by human impacts on the environment.</p>
WS 1.5 Evaluate risks both in practical science and the wider societal context, including perception of risk in relation to data and consequences.	<p>Give examples to show that there are hazards associated with science-based technologies which have to be considered alongside the benefits.</p> <p>Suggest reasons why the perception of risk is often very different from the measured risk (eg voluntary vs imposed risks, familiar vs unfamiliar risks, visible vs invisible hazards).</p>
WS 1.6 Recognise the importance of peer review of results and of communicating results to a range of audiences.	<p>Explain that the process of peer review helps to detect false claims and to establish a consensus about which claims should be regarded as valid.</p> <p>Explain that reports of scientific developments in the popular media are not subject to peer review and may be oversimplified, inaccurate or biased.</p>

2 Experimental skills and strategies

Students should be able to:	Examples of what students could be asked to do in an exam
WS 2.1 Use scientific theories and explanations to develop hypotheses.	Suggest a hypothesis to explain given observations or data.

Students should be able to:	Examples of what students could be asked to do in an exam
WS 2.2 Plan experiments or devise procedures to make observations, produce or characterise a substance, test hypotheses, check data or explore phenomena.	<p>Describe a practical procedure for a specified purpose.</p> <p>Explain why a given practical procedure is well designed for its specified purpose.</p> <p>Explain the need to manipulate and control variables.</p> <p>Identify in a given context:</p> <ul style="list-style-type: none"> • the independent variable as the one that is changed or selected by the investigator • the dependent variable that is measured for each change in the independent variable • control variables and be able to explain why they are kept the same. <p>Apply understanding of apparatus and techniques to suggest a procedure for a specified purpose.</p>
WS 2.3 Apply a knowledge of a range of techniques, instruments, apparatus, and materials to select those appropriate to the experiment.	Describe/suggest/select the technique, instrument, apparatus or material that should be used for a particular purpose, and explain why.
WS 2.4 Carry out experiments appropriately having due regard for the correct manipulation of apparatus, the accuracy of measurements and health and safety considerations.	<p>Identify the main hazards in specified practical contexts.</p> <p>Suggest methods of reducing the risk of harm in practical contexts.</p>
WS 2.5 Recognise when to apply a knowledge of sampling techniques to ensure any samples collected are representative.	Suggest and describe an appropriate sampling technique in a given context.
WS 2.6 Make and record observations and measurements using a range of apparatus and methods.	Read measurements off a scale in a practical context and record appropriately.
WS 2.7 Evaluate methods and suggest possible improvements and further investigations.	<p>Assess whether sufficient, precise measurements have been taken in an experiment.</p> <p>Evaluate methods with a view to determining whether or not they are valid.</p>

3 Analysis and evaluation

Apply the cycle of collecting, presenting and analysing data, including:

Students should be able to:	Examples of what students could be asked to do in an exam
WS 3.1 Presenting observations and other data using appropriate methods.	Construct and interpret frequency tables and diagrams, bar charts and histograms. Plot two variables from experimental or other data.
WS 3.2 Translating data from one form to another.	Translate data between graphical and numeric form.
WS 3.3 Carrying out and represent mathematical and statistical analysis.	For example: <ul style="list-style-type: none"> • use an appropriate number of significant figures • find the arithmetic mean and range of a set of data • construct and interpret frequency tables and diagrams, bar charts and histograms • make order of magnitude calculations • change the subject of an equation • substitute numerical values into algebraic equations using appropriate units for physical quantities • determine the slope and intercept of a linear graph • draw and use the slope of a tangent to a curve as a measure of rate of change • understand the physical significance of area between a curve and the x-axis and measure it by counting squares as appropriate.
WS 3.4 Representing distributions of results and make estimations of uncertainty.	Apply the idea that whenever a measurement is made, there is always some uncertainty about the result obtained. Use the range of a set of measurements about the mean as a measure of uncertainty.
WS 3.5 Interpreting observations and other data (presented in verbal, diagrammatic, graphical, symbolic or numerical form), including identifying patterns and trends, making inferences and drawing conclusions.	Use data to make predictions. Recognise or describe patterns and trends in data presented in a variety of tabular, graphical and other forms. Draw conclusions from given observations.
WS 3.6 Presenting reasoned explanations including relating data to hypotheses.	Comment on the extent to which data is consistent with a given hypothesis. Identify which of two or more hypotheses provides a better explanation of data in a given context.

Students should be able to:	Examples of what students could be asked to do in an exam
<p>WS 3.7 Being objective, evaluating data in terms of accuracy, precision, repeatability and reproducibility and identifying potential sources of random and systematic error.</p>	<p>Apply the following ideas to evaluate data to suggest improvements to procedures and techniques.</p> <ul style="list-style-type: none"> • An accurate measurement is one that is close to the true value. • Measurements are precise if they cluster closely. • Measurements are repeatable when repetition, under the same conditions by the same investigator, gives similar results. • Measurements are reproducible if similar results are obtained by different investigators with different equipment. • Measurements are affected by random error due to results varying in unpredictable ways; these errors can be reduced by making more measurements and reporting a mean value. • Systematic error is due to measurement results differing from the true value by a consistent amount each time. • Any anomalous values should be examined to try to identify the cause and, if a product of a poor measurement, ignored.
<p>WS 3.8 Communicating the scientific rationale for investigations, methods used, findings and reasoned conclusions through paper-based and electronic reports and presentations using verbal, diagrammatic, graphical, numerical and symbolic forms.</p>	<p>Present coherent and logically structured responses, using the ideas in 2 Experimental skills and strategies and 3 Analysis and evaluation, applied to the required practicals, and other practical investigations given appropriate information.</p>

4 Scientific vocabulary, quantities, units, symbols and nomenclature

Students should be able to:	Examples of what students could be asked to do in an exam
<p>WS 4.1 Use scientific vocabulary, terminology and definitions.</p> <p>WS 4.2 Recognise the importance of scientific quantities and understand how they are determined.</p> <p>WS 4.3 Use SI units (eg kg, g, mg; km, m, mm; kJ, J) and IUPAC chemical nomenclature unless inappropriate.</p> <p>WS 4.4 Use prefixes and powers of ten for orders of magnitude (eg tera, giga, mega, kilo, centi, milli, micro and nano).</p> <p>WS 4.5 Interconvert units.</p> <p>WS 4.6 Use an appropriate number of significant figures in calculation.</p>	<p>The knowledge and skills in this section apply across the specification, including the required practicals.</p>

4 Subject content

This specification is presented in a two column format. The left hand column contains the specification content that all students must cover and that can be assessed in the written papers. The right hand column exemplifies some key opportunities for the following skills to be developed: WS refers to [Working scientifically](#) (page 11), MS refers to [Mathematical requirements](#) (page 99) and AT refers to [Use of apparatus and techniques](#) (page 101). These are not the only opportunities. Teachers are encouraged to introduce all of these skills where appropriate throughout the course.

Each topic begins with an overview. The overview puts the topic into a broader context and is intended to encourage an overarching approach to both the teaching and learning of each of the topic areas. It is not directly assessed. Any assessable content in this overview is replicated in the left hand column.

Most of the content is co-teachable with GCSE Combined Science: Trilogy. Content that is only applicable to chemistry is indicated by (chemistry only) either next to the topic heading where it applies to the whole topic or immediately preceding each paragraph or bullet point as applicable. Content that is only applicable to Higher Tier is indicated by (HT only) either next to the topic heading where it applies to the whole topic or immediately preceding each paragraph or bullet point as applicable.

It is good practice to teach and develop all of the mathematical skills throughout the course. Some mathematical skills will only be assessed in certain subject areas. These are detailed in [Mathematical requirements](#) (page 99)

Science is a practical subject. Details of the assessment of required practicals can be found in [Required practical activities](#) (page 102). [Working scientifically](#) (page 11) and [Use of apparatus and techniques](#) (page 101) skills will be assessed across all papers.

The concepts and principles in Sections 4.1, 4.2 and 4.3 are fundamental to an understanding of chemistry and underpin much of the content detailed in later sections of the specification.

Students will be directly examined on these fundamental concepts in Paper 1. Students should be able to apply these concepts in their answers in Paper 2.

4.1 Atomic structure and the periodic table

The periodic table provides chemists with a structured organisation of the known chemical elements from which they can make sense of their physical and chemical properties. The historical development of the periodic table and models of atomic structure provide good examples of how scientific ideas and explanations develop over time as new evidence emerges. The arrangement of elements in the modern periodic table can be explained in terms of atomic structure which provides evidence for the model of a nuclear atom with electrons in energy levels.

4.1.1 A simple model of the atom, symbols, relative atomic mass, electronic charge and isotopes

4.1.1.1 Atoms, elements and compounds

Content	Key opportunities for skills development
<p>All substances are made of atoms. An atom is the smallest part of an element that can exist.</p> <p>Atoms of each element are represented by a chemical symbol, eg O represents an atom of oxygen, Na represents an atom of sodium.</p> <p>There are about 100 different elements. Elements are shown in the periodic table.</p> <p>Compounds are formed from elements by chemical reactions. Chemical reactions always involve the formation of one or more new substances, and often involve a detectable energy change. Compounds contain two or more elements chemically combined in fixed proportions and can be represented by formulae using the symbols of the atoms from which they were formed. Compounds can only be separated into elements by chemical reactions.</p> <p>Chemical reactions can be represented by word equations or equations using symbols and formulae.</p> <p>Students will be supplied with a periodic table for the exam and should be able to:</p> <ul style="list-style-type: none">• use the names and symbols of the first 20 elements in the periodic table, the elements in Groups 1 and 7, and other elements in this specification• name compounds of these elements from given formulae or symbol equations• write word equations for the reactions in this specification• write formulae and balanced chemical equations for the reactions in this specification. <p>(HT only) write balanced half equations and ionic equations where appropriate.</p>	

4.1.1.2 Mixtures

Content	Key opportunities for skills development
<p>A mixture consists of two or more elements or compounds not chemically combined together. The chemical properties of each substance in the mixture are unchanged.</p> <p>Mixtures can be separated by physical processes such as filtration, crystallisation, simple distillation, fractional distillation and chromatography. These physical processes do not involve chemical reactions and no new substances are made.</p> <p>Students should be able to:</p> <ul style="list-style-type: none"> describe, explain and give examples of the specified processes of separation suggest suitable separation and purification techniques for mixtures when given appropriate information. 	<p>WS 2.2, 2.3</p> <p>AT 4</p> <p>Safe use of a range of equipment to separate chemical mixtures.</p>

4.1.1.3 The development of the model of the atom (common content with physics)

Content	Key opportunities for skills development
<p>New experimental evidence may lead to a scientific model being changed or replaced.</p> <p>Before the discovery of the electron, atoms were thought to be tiny spheres that could not be divided.</p> <p>The discovery of the electron led to the plum pudding model of the atom. The plum pudding model suggested that the atom is a ball of positive charge with negative electrons embedded in it.</p> <p>The results from the alpha particle scattering experiment led to the conclusion that the mass of an atom was concentrated at the centre (nucleus) and that the nucleus was charged. This nuclear model replaced the plum pudding model.</p> <p>Niels Bohr adapted the nuclear model by suggesting that electrons orbit the nucleus at specific distances. The theoretical calculations of Bohr agreed with experimental observations.</p> <p>Later experiments led to the idea that the positive charge of any nucleus could be subdivided into a whole number of smaller particles, each particle having the same amount of positive charge. The name proton was given to these particles.</p> <p>The experimental work of James Chadwick provided the evidence to show the existence of neutrons within the nucleus. This was about 20 years after the nucleus became an accepted scientific idea.</p> <p>Students should be able to describe:</p>	<p>WS 1.1, 1.6</p> <p>This historical context provides an opportunity for students to show an understanding of why and describe how scientific methods and theories develop over time.</p> <p>WS 1.2</p>

Content	Key opportunities for skills development
<ul style="list-style-type: none"> why the new evidence from the scattering experiment led to a change in the atomic model 	WS 1.1
<ul style="list-style-type: none"> the difference between the plum pudding model of the atom and the nuclear model of the atom. 	WS 1.2
<p>Details of experimental work supporting the Bohr model are not required.</p> <p>Details of Chadwick's experimental work are not required.</p>	

4.1.1.4 Relative electrical charges of subatomic particles

Content	Key opportunities for skills development								
<p>The relative electrical charges of the particles in atoms are:</p> <table border="1"> <thead> <tr> <th>Name of particle</th> <th>Relative charge</th> </tr> </thead> <tbody> <tr> <td>Proton</td> <td>+1</td> </tr> <tr> <td>Neutron</td> <td>0</td> </tr> <tr> <td>Electron</td> <td>-1</td> </tr> </tbody> </table> <p>In an atom, the number of electrons is equal to the number of protons in the nucleus. Atoms have no overall electrical charge.</p> <p>The number of protons in an atom of an element is its atomic number. All atoms of a particular element have the same number of protons. Atoms of different elements have different numbers of protons.</p>	Name of particle	Relative charge	Proton	+1	Neutron	0	Electron	-1	
Name of particle	Relative charge								
Proton	+1								
Neutron	0								
Electron	-1								
<p>Students should be able to use the nuclear model to describe atoms.</p>	WS 1.2								

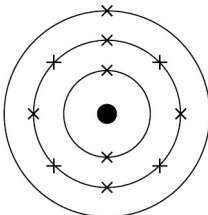
4.1.1.5 Size and mass of atoms

Content	Key opportunities for skills development								
<p>Atoms are very small, having a radius of about 0.1 nm (1×10^{-10} m).</p> <p>The radius of a nucleus is less than 1/10 000 of that of the atom (about 1×10^{-14} m).</p> <p>Almost all of the mass of an atom is in the nucleus.</p> <p>The relative masses of protons, neutrons and electrons are:</p> <table border="1" style="margin-left: 20px;"> <thead> <tr> <th>Name of particle</th> <th>Relative mass</th> </tr> </thead> <tbody> <tr> <td>Proton</td> <td>1</td> </tr> <tr> <td>Neutron</td> <td>1</td> </tr> <tr> <td>Electron</td> <td>Very small</td> </tr> </tbody> </table> <p>The sum of the protons and neutrons in an atom is its mass number.</p> <p>Atoms of the same element can have different numbers of neutrons; these atoms are called isotopes of that element.</p> <p>Atoms can be represented as shown in this example:</p> <p>(Mass number) 23 Na (Atomic number) 11</p> <p>Students should be able to calculate the numbers of protons, neutrons and electrons in an atom or ion, given its atomic number and mass number.</p>	Name of particle	Relative mass	Proton	1	Neutron	1	Electron	Very small	<p>WS 4.3, 4</p> <p>Use SI units and the prefix nano.</p> <p>MS 1b</p> <p>Recognise expressions in standard form.</p>
Name of particle	Relative mass								
Proton	1								
Neutron	1								
Electron	Very small								
<p>Students should be able to relate size and scale of atoms to objects in the physical world.</p>	<p>MS 1d</p>								

4.1.1.6 Relative atomic mass

Content	Key opportunities for skills development
<p>The relative atomic mass of an element is an average value that takes account of the abundance of the isotopes of the element.</p> <p>Students should be able to calculate the relative atomic mass of an element given the percentage abundance of its isotopes.</p>	

4.1.1.7 Electronic structure

Content	Key opportunities for skills development
<p>The electrons in an atom occupy the lowest available energy levels (innermost available shells). The electronic structure of an atom can be represented by numbers or by a diagram. For example, the electronic structure of sodium is 2,8,1 or</p>  <p>showing two electrons in the lowest energy level, eight in the second energy level and one in the third energy level.</p> <p>Students may answer questions in terms of either energy levels or shells.</p>	<p>WS 1.2</p> <p>Students should be able to represent the electronic structures of the first twenty elements of the periodic table in both forms.</p> <p>MS 5b</p> <p>Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects.</p>

4.1.2 The periodic table

4.1.2.1 The periodic table

Content	Key opportunities for skills development
<p>The elements in the periodic table are arranged in order of atomic (proton) number and so that elements with similar properties are in columns, known as groups. The table is called a periodic table because similar properties occur at regular intervals.</p> <p>Elements in the same group in the periodic table have the same number of electrons in their outer shell (outer electrons) and this gives them similar chemical properties.</p>	
<p>Students should be able to:</p> <ul style="list-style-type: none">• 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• predict possible reactions and probable reactivity of elements from their positions in the periodic table.	<p>WS 1.2</p>

4.1.2.2 Development of the periodic table

Content	Key opportunities for skills development
<p>Before the discovery of protons, neutrons and electrons, scientists attempted to classify the elements by arranging them in order of their atomic weights.</p> <p>The early periodic tables were incomplete and some elements were placed in inappropriate groups if the strict order of atomic weights was followed.</p> <p>Mendeleev overcame some of the problems by leaving gaps for elements that he thought had not been discovered and in some places changed the order based on atomic weights.</p> <p>Elements with properties predicted by Mendeleev were discovered and filled the gaps. Knowledge of isotopes made it possible to explain why the order based on atomic weights was not always correct.</p> <p>Students should be able to describe these steps in the development of the periodic table.</p>	<p>WS 1.1, 1.6</p> <p>Explain how testing a prediction can support or refute a new scientific idea.</p>

4.1.2.3 Metals and non-metals

Content	Key opportunities for skills development
<p>Elements that react to form positive ions are metals.</p> <p>Elements that do not form positive ions are non-metals.</p> <p>The majority of elements are metals. Metals are found to the left and towards the bottom of the periodic table. Non-metals are found towards the right and top of the periodic table.</p> <p>Students should be able to:</p> <ul style="list-style-type: none"> explain the differences between metals and non-metals on the basis of their characteristic physical and chemical properties. This links to Group 0 (page 24), Group 1 (page 24), Group 7 (page 25) and Bonding, structure and the properties of matter (page 26) explain how the atomic structure of metals and non-metals relates to their position in the periodic table explain how the reactions of elements are related to the arrangement of electrons in their atoms and hence to their atomic number. 	

4.1.2.4 Group 0

Content	Key opportunities for skills development
<p>The elements in Group 0 of the periodic table are called the noble gases. They are unreactive and do not easily form molecules because their atoms have stable arrangements of electrons. The noble gases have eight electrons in their outer shell, except for helium, which has only two electrons.</p> <p>The boiling points of the noble gases increase with increasing relative atomic mass (going down the group).</p>	
<p>Students should be able to:</p> <ul style="list-style-type: none">• explain how properties of the elements in Group 0 depend on the outer shell of electrons of the atoms• predict properties from given trends down the group.	WS 1.2

4.1.2.5 Group 1

Content	Key opportunities for skills development
<p>The elements in Group 1 of the periodic table are known as the alkali metals and have characteristic properties because of the single electron in their outer shell.</p> <p>Students should be able to describe the reactions of the first three alkali metals with oxygen, chlorine and water.</p> <p>In Group 1, the reactivity of the elements increases going down the group.</p>	
<p>Students should be able to:</p> <ul style="list-style-type: none">• explain how properties of the elements in Group 1 depend on the outer shell of electrons of the atoms• predict properties from given trends down the group.	WS 1.2

4.1.2.6 Group 7

Content	Key opportunities for skills development
<p>The elements in Group 7 of the periodic table are known as the halogens and have similar reactions because they all have seven electrons in their outer shell. The halogens are non-metals and consist of molecules made of pairs of atoms.</p> <p>Students should be able to describe the nature of the compounds formed when chlorine, bromine and iodine react with metals and non-metals.</p> <p>In Group 7, the further down the group an element is the higher its relative molecular mass, melting point and boiling point.</p> <p>In Group 7, the reactivity of the elements decreases going down the group.</p> <p>A more reactive halogen can displace a less reactive halogen from an aqueous solution of its salt.</p>	<p>AT 6</p> <p>Offers an opportunity within displacement reactions of halogens.</p>
<p>Students should be able to:</p> <ul style="list-style-type: none"> explain how properties of the elements in Group 7 depend on the outer shell of electrons of the atoms predict properties from given trends down the group. 	<p>WS 1.2</p>

4.1.3 Properties of transition metals (chemistry only)

4.1.3.1 Comparison with Group 1 elements

Content	Key opportunities for skills development
<p>The transition elements are metals with similar properties which are different from those of the elements in Group 1.</p> <p>Students should be able to describe the difference compared with Group 1 in melting points, densities, strength, hardness and reactivity with oxygen, water and halogens.</p> <p>Students should be able to exemplify these general properties by reference to Cr, Mn, Fe, Co, Ni, Cu.</p>	

4.1.3.2 Typical properties

Content	Key opportunities for skills development
<p>Many transition elements have ions with different charges, form coloured compounds and are useful as catalysts.</p> <p>Students should be able to exemplify these general properties by reference to compounds of Cr, Mn, Fe, Co, Ni, Cu.</p>	

4.2 Bonding, structure, and the properties of matter

Chemists use theories of structure and bonding to explain the physical and chemical properties of materials. Analysis of structures shows that atoms can be arranged in a variety of ways, some of which are molecular while others are giant structures. Theories of bonding explain how atoms are held together in these structures. Scientists use this knowledge of structure and bonding to engineer new materials with desirable properties. The properties of these materials may offer new applications in a range of different technologies.

4.2.1 Chemical bonds, ionic, covalent and metallic

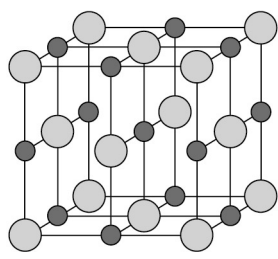
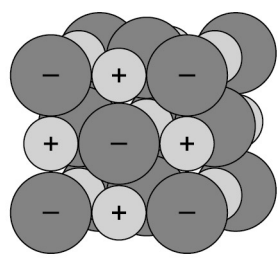
4.2.1.1 Chemical bonds

Content	Key opportunities for skills development
<p>There are three types of strong chemical bonds: ionic, covalent and metallic. For ionic bonding the particles are oppositely charged ions. For covalent bonding the particles are atoms which share pairs of electrons. For metallic bonding the particles are atoms which share delocalised electrons.</p> <p>Ionic bonding occurs in compounds formed from metals combined with non-metals.</p> <p>Covalent bonding occurs in most non-metallic elements and in compounds of non-metals.</p> <p>Metallic bonding occurs in metallic elements and alloys.</p> <p>Students should be able to explain chemical bonding in terms of electrostatic forces and the transfer or sharing of electrons.</p>	

4.2.1.2 Ionic bonding

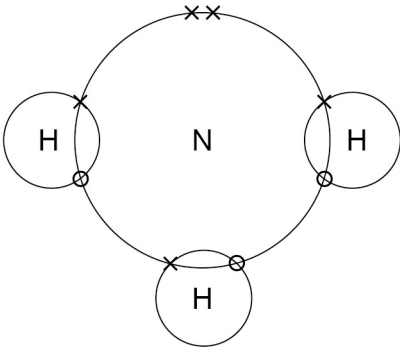
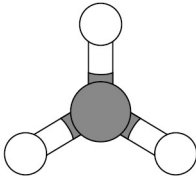
Content	Key opportunities for skills development
<p>When a metal atom reacts with a non-metal atom electrons in the outer shell of the metal atom are transferred. Metal atoms lose electrons to become positively charged ions. Non-metal atoms gain electrons to become negatively charged ions. The ions produced by metals in Groups 1 and 2 and by non-metals in Groups 6 and 7 have the electronic structure of a noble gas (Group 0).</p> <p>The electron transfer during the formation of an ionic compound can be represented by a dot and cross diagram, eg for sodium chloride</p> $\text{Na} \cdot + \begin{array}{c} \times \times \\ \times \text{Cl} \times \\ \times \times \end{array} \longrightarrow \left[\text{Na} \right]^+ \left[\begin{array}{c} \times \times \\ \times \text{Cl} \times \\ \times \times \end{array} \right]^-$ <p>(2,8,1) (2,8,7) (2,8) (2,8,8)</p>	<p>MS 5b</p> <p>Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects.</p>
<p>Students should be able to draw dot and cross diagrams for ionic compounds formed by metals in Groups 1 and 2 with non-metals in Groups 6 and 7.</p> <p>The charge on the ions produced by metals in Groups 1 and 2 and by non-metals in Groups 6 and 7 relates to the group number of the element in the periodic table.</p> <p>Students should be able to work out the charge on the ions of metals and non-metals from the group number of the element, limited to the metals in Groups 1 and 2, and non-metals in Groups 6 and 7.</p>	<p>WS 1.2</p>

4.2.1.3 Ionic compounds

Content	Key opportunities for skills development
<p>An ionic compound is a giant structure of ions. Ionic compounds are held together by strong electrostatic forces of attraction between oppositely charged ions. These forces act in all directions in the lattice and this is called ionic bonding.</p> <p>The structure of sodium chloride can be represented in the following forms:</p> <div style="display: flex; align-items: center;"> <div style="margin-right: 20px;">  </div> <div style="margin-right: 20px;"> <p>Key</p> <ul style="list-style-type: none"> ● Na⁺ ○ Cl⁻ </div> <div>  </div> </div>	<p>MS 5b</p> <p>Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects.</p>

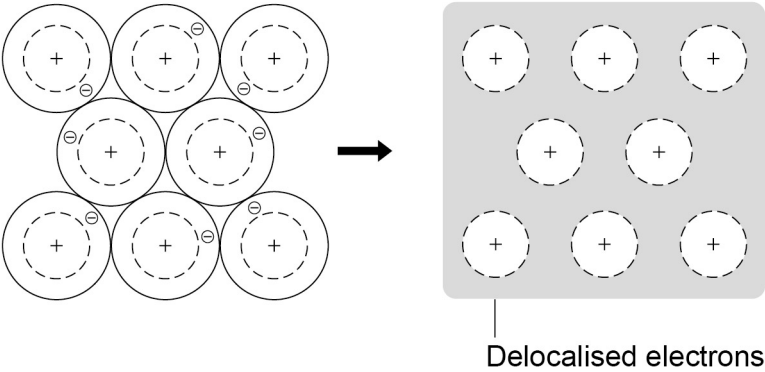
Content	Key opportunities for skills development
<p>Students should be able to:</p> <ul style="list-style-type: none"> • deduce that a compound is ionic from a diagram of its structure in one of the specified forms • describe the limitations of using dot and cross, ball and stick, two and three-dimensional diagrams to represent a giant ionic structure • work out the empirical formula of an ionic compound from a given model or diagram that shows the ions in the structure. <p>Students should be familiar with the structure of sodium chloride but do not need to know the structures of other ionic compounds.</p>	<p>WS 1.2</p> <p>MS 4a</p> <p>MS 1a, 1c</p>

4.2.1.4 Covalent bonding

Content	Key opportunities for skills development
<p>When atoms share pairs of electrons, they form covalent bonds. These bonds between atoms are strong.</p> <p>Covalently bonded substances may consist of small molecules.</p> <p>Students should be able to recognise common substances that consist of small molecules from their chemical formula.</p> <p>Some covalently bonded substances have very large molecules, such as polymers.</p> <p>Some covalently bonded substances have giant covalent structures, such as diamond and silicon dioxide.</p> <p>The covalent bonds in molecules and giant structures can be represented in the following forms:</p> <p>For ammonia (NH₃)</p> <div style="display: flex; justify-content: space-around; align-items: center;"> <div style="text-align: center;">  </div> <div style="text-align: center;"> <p>and/or</p> $\begin{array}{ccc} & \times \times & \\ \text{H} \times & \text{N} & \times \text{H} \\ \times & & \times \\ & \times \times & \\ & \text{H} & \end{array}$ </div> </div> <div style="display: flex; justify-content: space-around; align-items: center; margin-top: 20px;"> <div style="text-align: center;"> <p>and/or</p> $\begin{array}{c} \text{H} - \text{N} - \text{H} \\ \\ \text{H} \end{array}$ </div> <div style="text-align: center;"> <p>and/or</p>  </div> </div> <p>Polymers can be represented in the form:</p> $\left(\begin{array}{cc} \text{H} & \text{H} \\ & \\ -\text{C} & - \text{C}- \\ & \\ \text{H} & \text{H} \end{array} \right)_n$ <p>poly(ethene)</p> <p>where n is a large number.</p>	<p>WS 1.2</p> <p>Recognise substances as small molecules, polymers or giant structures from diagrams showing their bonding.</p>

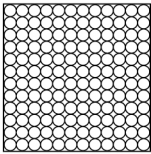
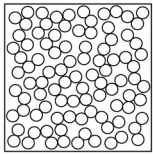
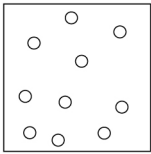
Content	Key opportunities for skills development
<p>Students should be able to:</p> <ul style="list-style-type: none"> draw dot and cross diagrams for the molecules of hydrogen, chlorine, oxygen, nitrogen, hydrogen chloride, water, ammonia and methane represent the covalent bonds in small molecules, in the repeating units of polymers and in part of giant covalent structures, using a line to represent a single bond describe the limitations of using dot and cross, ball and stick, two and three-dimensional diagrams to represent molecules or giant structures deduce the molecular formula of a substance from a given model or diagram in these forms showing the atoms and bonds in the molecule. 	<p>MS 5b</p>

4.2.1.5 Metallic bonding

Content	Key opportunities for skills development
<p>Metals consist of giant structures of atoms arranged in a regular pattern.</p> <p>The electrons in the outer shell of metal atoms are delocalised and so are free to move through the whole structure. The sharing of delocalised electrons gives rise to strong metallic bonds. The bonding in metals may be represented in the following form:</p> 	<p>WS 1.2</p> <p>Recognise substances as metallic giant structures from diagrams showing their bonding.</p> <p>MS 5b</p> <p>Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects.</p>

4.2.2 How bonding and structure are related to the properties of substances

4.2.2.1 The three states of matter

Content	Key opportunities for skills development
<p>The three states of matter are solid, liquid and gas. Melting and freezing take place at the melting point, boiling and condensing take place at the boiling point.</p> <p>The three states of matter can be represented by a simple model. In this model, particles are represented by small solid spheres. Particle theory can help to explain melting, boiling, freezing and condensing.</p> <div style="display: flex; justify-content: space-around; align-items: center;"> <div style="text-align: center;">  <p>Solid</p> </div> <div style="text-align: center;">  <p>Liquid</p> </div> <div style="text-align: center;">  <p>Gas</p> </div> </div> <p>The amount of energy needed to change state from solid to liquid and from liquid to gas depends on the strength of the forces between the particles of the substance. The nature of the particles involved depends on the type of bonding and the structure of the substance. The stronger the forces between the particles the higher the melting point and boiling point of the substance.</p> <p>(HT only) Limitations of the simple model above include that in the model there are no forces, that all particles are represented as spheres and that the spheres are solid.</p>	<p>MS 5b</p> <p>Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects.</p>
<p>Students should be able to:</p> <ul style="list-style-type: none"> • predict the states of substances at different temperatures given appropriate data • explain the different temperatures at which changes of state occur in terms of energy transfers and types of bonding • recognise that atoms themselves do not have the bulk properties of materials • (HT only) explain the limitations of the particle theory in relation to changes of state when particles are represented by solid inelastic spheres which have no forces between them. 	<p>WS 1.2</p>

4.2.2.2 State symbols

Content	Key opportunities for skills development
<p>In chemical equations, the three states of matter are shown as (s), (l) and (g), with (aq) for aqueous solutions.</p> <p>Students should be able to include appropriate state symbols in chemical equations for the reactions in this specification.</p>	

4.2.2.3 Properties of ionic compounds

Content	Key opportunities for skills development
<p>Ionic compounds have regular structures (giant ionic lattices) in which there are strong electrostatic forces of attraction in all directions between oppositely charged ions.</p> <p>These compounds have high melting points and high boiling points because of the large amounts of energy needed to break the many strong bonds.</p> <p>When melted or dissolved in water, ionic compounds conduct electricity because the ions are free to move and so charge can flow.</p> <p>Knowledge of the structures of specific ionic compounds other than sodium chloride is not required.</p>	

4.2.2.4 Properties of small molecules

Content	Key opportunities for skills development
<p>Substances that consist of small molecules are usually gases or liquids that have relatively low melting points and boiling points.</p> <p>These substances have only weak forces between the molecules (intermolecular forces). It is these intermolecular forces that are overcome, not the covalent bonds, when the substance melts or boils.</p> <p>The intermolecular forces increase with the size of the molecules, so larger molecules have higher melting and boiling points.</p> <p>These substances do not conduct electricity because the molecules do not have an overall electric charge.</p> <p>Students should be able to use the idea that intermolecular forces are weak compared with covalent bonds to explain the bulk properties of molecular substances.</p>	WS 1.2

4.2.2.5 Polymers

Content	Key opportunities for skills development
<p>Polymers have very large molecules. The atoms in the polymer molecules are linked to other atoms by strong covalent bonds. The intermolecular forces between polymer molecules are relatively strong and so these substances are solids at room temperature.</p> <p>Students should be able to recognise polymers from diagrams showing their bonding and structure.</p>	

4.2.2.6 Giant covalent structures

Content	Key opportunities for skills development
<p>Substances that consist of giant covalent structures are solids with very high melting points. All of the atoms in these structures are linked to other atoms by strong covalent bonds. These bonds must be overcome to melt or boil these substances. Diamond and graphite (forms of carbon) and silicon dioxide (silica) are examples of giant covalent structures.</p> <p>Students should be able to recognise giant covalent structures from diagrams showing their bonding and structure.</p>	<p>MS 5b</p> <p>Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects.</p> <p>WS 1.2</p>

4.2.2.7 Properties of metals and alloys

Content	Key opportunities for skills development
<p>Metals have giant structures of atoms with strong metallic bonding. This means that most metals have high melting and boiling points.</p> <p>In pure metals, atoms are arranged in layers, which allows metals to be bent and shaped. Pure metals are too soft for many uses and so are mixed with other metals to make alloys which are harder.</p>	
<p>Students should be able to explain why alloys are harder than pure metals in terms of distortion of the layers of atoms in the structure of a pure metal.</p>	<p>WS 1.2</p>

4.2.2.8 Metals as conductors

Content	Key opportunities for skills development
<p>Metals are good conductors of electricity because the delocalised electrons in the metal carry electrical charge through the metal.</p> <p>Metals are good conductors of thermal energy because energy is transferred by the delocalised electrons.</p>	

4.2.3 Structure and bonding of carbon

4.2.3.1 Diamond

Content	Key opportunities for skills development
In diamond, each carbon atom forms four covalent bonds with other carbon atoms in a giant covalent structure, so diamond is very hard, has a very high melting point and does not conduct electricity.	MS 5b Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects.
Students should be able to explain the properties of diamond in terms of its structure and bonding.	WS 1.2

4.2.3.2 Graphite

Content	Key opportunities for skills development
<p>In graphite, each carbon atom forms three covalent bonds with three other carbon atoms, forming layers of hexagonal rings which have no covalent bonds between the layers.</p> <p>In graphite, one electron from each carbon atom is delocalised.</p> <p>Students should be able to explain the properties of graphite in terms of its structure and bonding.</p> <p>Students should know that graphite is similar to metals in that it has delocalised electrons.</p>	WS 1.2

4.2.3.3 Graphene and fullerenes

Content	Key opportunities for skills development
<p>Graphene is a single layer of graphite and has properties that make it useful in electronics and composites.</p> <p>Students should be able to explain the properties of graphene in terms of its structure and bonding.</p> <p>Fullerenes are molecules of carbon atoms with hollow shapes. The structure of fullerenes is based on hexagonal rings of carbon atoms but they may also contain rings with five or seven carbon atoms. The first fullerene to be discovered was Buckminsterfullerene (C₆₀) which has a spherical shape.</p> <p>Carbon nanotubes are cylindrical fullerenes with very high length to diameter ratios. Their properties make them useful for nanotechnology, electronics and materials.</p> <p>Students should be able to:</p> <ul style="list-style-type: none"> recognise graphene and fullerenes from diagrams and descriptions of their bonding and structure give examples of the uses of fullerenes, including carbon nanotubes. 	<p>WS 1.2, 1.4</p> <p>MS 5b</p> <p>Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects.</p>

4.2.4 Bulk and surface properties of matter including nanoparticles (chemistry only)

4.2.4.1 Sizes of particles and their properties

Content	Key opportunities for skills development
<p>Nanoscience refers to structures that are 1–100 nm in size, of the order of a few hundred atoms. Nanoparticles, are smaller than fine particles (PM_{2.5}), which have diameters between 100 and 2500 nm (1×10^{-7} m and 2.5×10^{-6} m). Coarse particles (PM₁₀) have diameters between 1×10^{-5} m and 2.5×10^{-6} m. Coarse particles are often referred to as dust.</p> <p>As the side of cube decreases by a factor of 10 the surface area to volume ratio increases by a factor of 10.</p> <p>Nanoparticles may have properties different from those for the same materials in bulk because of their high surface area to volume ratio. It may also mean that smaller quantities are needed to be effective than for materials with normal particle sizes.</p>	<p>WS 1.2, 1.4, 4.1, 4.2, 4.3 4.4, 4.5</p> <p>MS 2h</p> <p>Make order of magnitude calculations.</p> <p>MS 5c</p> <p>Calculate areas of triangles and rectangles, surface areas and volumes of cubes.</p>

Content	Key opportunities for skills development
Students should be able to compare 'nano' dimensions to typical dimensions of atoms and molecules.	MS 1b Recognise and use expressions in standard form. MS 1c Use ratios, fractions and percentages. MS 1d Make estimates of the results of simple calculations.

4.2.4.2 Uses of nanoparticles

Content	Key opportunities for skills development
<p>Nanoparticles have many applications in medicine, in electronics, in cosmetics and sun creams, as deodorants, and as catalysts. New applications for nanoparticulate materials are an important area of research.</p> <p>Students should consider advantages and disadvantages of the applications of these nanoparticulate materials, but do not need to know specific examples or properties other than those specified.</p>	
<p>Students should be able to:</p> <ul style="list-style-type: none"> • given appropriate information, evaluate the use of nanoparticles for a specified purpose • explain that there are possible risks associated with the use of nanoparticles. 	WS 1.3, 1.4, 1.5

4.3 Quantitative chemistry

Chemists use quantitative analysis to determine the formulae of compounds and the equations for reactions. Given this information, analysts can then use quantitative methods to determine the purity of chemical samples and to monitor the yield from chemical reactions.

Chemical reactions can be classified in various ways. Identifying different types of chemical reaction allows chemists to make sense of how different chemicals react together, to establish patterns and to make predictions about the behaviour of other chemicals. Chemical equations provide a means of representing chemical reactions and are a key way for chemists to communicate chemical ideas.

4.3.1 Chemical measurements, conservation of mass and the quantitative interpretation of chemical equations

4.3.1.1 Conservation of mass and balanced chemical equations

Content	Key opportunities for skills development
<p>The law of conservation of mass states that no atoms are lost or made during a chemical reaction so the mass of the products equals the mass of the reactants.</p> <p>This means that chemical reactions can be represented by symbol equations which are balanced in terms of the numbers of atoms of each element involved on both sides of the equation.</p> <p>Students should understand the use of the multipliers in equations in normal script before a formula and in subscript within a formula.</p>	WS 1.2

4.3.1.2 Relative formula mass

Content	Key opportunities for skills development
<p>The relative formula mass (M_r) of a compound is the sum of the relative atomic masses of the atoms in the numbers shown in the formula.</p> <p>In a balanced chemical equation, the sum of the relative formula masses of the reactants in the quantities shown equals the sum of the relative formula masses of the products in the quantities shown.</p> <p>Students should be able to calculate the percentage by mass in a compound given the relative formula mass and the relative atomic masses.</p>	

4.3.1.3 Mass changes when a reactant or product is a gas

Content	Key opportunities for skills development
<p>Some reactions may appear to involve a change in mass but this can usually be explained because a reactant or product is a gas and its mass has not been taken into account. For example: when a metal reacts with oxygen the mass of the oxide produced is greater than the mass of the metal or in thermal decompositions of metal carbonates carbon dioxide is produced and escapes into the atmosphere leaving the metal oxide as the only solid product.</p> <p>Students should be able to explain any observed changes in mass in non-enclosed systems during a chemical reaction given the balanced symbol equation for the reaction and explain these changes in terms of the particle model.</p>	<p>AT 1, 2,6</p> <p>Opportunities within investigation of mass changes using various apparatus.</p>

4.3.1.4 Chemical measurements

Content	Key opportunities for skills development
<p>Whenever a measurement is made there is always some uncertainty about the result obtained.</p> <p>Students should be able to:</p> <ul style="list-style-type: none">represent the distribution of results and make estimations of uncertaintyuse the range of a set of measurements about the mean as a measure of uncertainty.	WS 3.4

4.3.2 Use of amount of substance in relation to masses of pure substances

4.3.2.1 Moles (HT only)

Content	Key opportunities for skills development
<p>Chemical amounts are measured in moles. The symbol for the unit mole is mol.</p> <p>The mass of one mole of a substance in grams is numerically equal to its relative formula mass.</p> <p>One mole of a substance contains the same number of the stated particles, atoms, molecules or ions as one mole of any other substance.</p> <p>The number of atoms, molecules or ions in a mole of a given substance is the Avogadro constant. The value of the Avogadro constant is 6.02×10^{23} per mole.</p> <p>Students should understand that the measurement of amounts in moles can apply to atoms, molecules, ions, electrons, formulae and equations, for example that in one mole of carbon (C) the number of atoms is the same as the number of molecules in one mole of carbon dioxide (CO₂).</p>	WS 4.1, 4.2, 4.3, 4.5, 4.6 MS 1a Recognise and use expressions in decimal form. MS 1b Recognise and use expressions in standard form. MS 2a Use an appropriate number of significant figures. MS 3a Understand and use the symbols: =, <, <<, >>, >, ∞, ~ MS 3b Change the subject of an equation.
<p>Students should be able to use the relative formula mass of a substance to calculate the number of moles in a given mass of that substance and vice versa.</p>	MS 1c

4.3.2.2 Amounts of substances in equations (HT only)

Content	Key opportunities for skills development
<p>The masses of reactants and products can be calculated from balanced symbol equations.</p> <p>Chemical equations can be interpreted in terms of moles. For example:</p> $\text{Mg} + 2\text{HCl} \rightarrow \text{MgCl}_2 + \text{H}_2$ <p>shows that one mole of magnesium reacts with two moles of hydrochloric acid to produce one mole of magnesium chloride and one mole of hydrogen gas.</p> <p>Students should be able to:</p> <ul style="list-style-type: none"> calculate the masses of substances shown in a balanced symbol equation calculate the masses of reactants and products from the balanced symbol equation and the mass of a given reactant or product. 	<p>MS 1a</p> <p>Recognise and use expressions in decimal form.</p> <p>MS 1c</p> <p>Use ratios, fractions and percentages.</p> <p>MS 3b</p> <p>Change the subject of an equation.</p> <p>MS 3c</p> <p>Substitute numerical values into algebraic equations using appropriate units for physical quantities.</p>

4.3.2.3 Using moles to balance equations (HT only)

Content	Key opportunities for skills development
<p>The balancing numbers in a symbol equation can be calculated from the masses of reactants and products by converting the masses in grams to amounts in moles and converting the numbers of moles to simple whole number ratios.</p> <p>Students should be able to balance an equation given the masses of reactants and products.</p> <p>Students should be able to change the subject of a mathematical equation.</p>	<p>MS 3b</p> <p>Change the subject of an equation.</p> <p>MS 3c</p> <p>Substitute numerical values into algebraic equations using appropriate units for physical quantities.</p>

4.3.2.4 Limiting reactants (HT only)

Content	Key opportunities for skills development
<p>In a chemical reaction involving two reactants, it is common to use an excess of one of the reactants to ensure that all of the other reactant is used. The reactant that is completely used up is called the limiting reactant because it limits the amount of products.</p> <p>Students should be able to explain the effect of a limiting quantity of a reactant on the amount of products it is possible to obtain in terms of amounts in moles or masses in grams.</p>	WS 4.1

4.3.2.5 Concentration of solutions

Content	Key opportunities for skills development
<p>Many chemical reactions take place in solutions. The concentration of a solution can be measured in mass per given volume of solution, eg grams per dm³ (g/dm³).</p> <p>Students should be able to:</p> <ul style="list-style-type: none">• calculate the mass of solute in a given volume of solution of known concentration in terms of mass per given volume of solution• (HT only) explain how the mass of a solute and the volume of a solution is related to the concentration of the solution.	MS 1c Use ratios, fractions and percentages. MS 3b Change the subject of an equation.

4.3.3 Yield and atom economy of chemical reactions (chemistry only)

4.3.3.1 Percentage yield

Content	Key opportunities for skills development
<p>Even though no atoms are gained or lost in a chemical reaction, it is not always possible to obtain the calculated amount of a product because:</p> <ul style="list-style-type: none"> the reaction may not go to completion because it is reversible some of the product may be lost when it is separated from the reaction mixture some of the reactants may react in ways different to the expected reaction. <p>The amount of a product obtained is known as the yield. When compared with the maximum theoretical amount as a percentage, it is called the percentage yield.</p> $\% \text{ Yield} = \frac{\text{Mass of product actually made}}{\text{Maximum theoretical mass of product}} \times 100$ <p>Students should be able to:</p> <ul style="list-style-type: none"> calculate the percentage yield of a product from the actual yield of a reaction (HT only) calculate the theoretical mass of a product from a given mass of reactant and the balanced equation for the reaction. 	<p>WS 4.2, 4.6</p> <p>MS 1a</p> <p>Recognise and use expressions in decimal form.</p> <p>MS 1c</p> <p>Use ratios, fractions and percentages.</p> <p>MS 2a</p> <p>Use an appropriate number of significant figures.</p> <p>MS 3b</p> <p>Change the subject of an equation.</p>

4.3.3.2 Atom economy

Content	Key opportunities for skills development
<p>The atom economy (atom utilisation) is a measure of the amount of starting materials that end up as useful products. It is important for sustainable development and for economic reasons to use reactions with high atom economy.</p> <p>The percentage atom economy of a reaction is calculated using the balanced equation for the reaction as follows:</p> $\frac{\text{Relative formula mass of desired product from equation}}{\text{Sum of relative formula masses of all reactants from equation}} \times 100$ <p>Students should be able to:</p> <ul style="list-style-type: none"> calculate the atom economy of a reaction to form a desired product from the balanced equation (HT only) 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 and usefulness of by-products. 	<p>WS 4.2, 4.6</p> <p>MS 1a</p> <p>Recognise and use expressions in decimal form.</p> <p>MS 1c</p> <p>Use ratios, fractions and percentages.</p> <p>MS 3b</p> <p>Change the subject of an equation.</p>

4.3.4 Using concentrations of solutions in mol/dm³ (chemistry only) (HT only)

Content	Key opportunities for skills development
<p>The concentration of a solution can be measured in mol/dm³.</p> <p>The amount in moles of solute or the mass in grams of solute in a given volume of solution can be calculated from its concentration in mol/dm³.</p> <p>If the volumes of two solutions that react completely are known and the concentration of one solution is known, the concentration of the other solution can be calculated.</p> <p>Students should be able to explain how the concentration of a solution in mol/dm³ is related to the mass of the solute and the volume of the solution.</p>	<p>WS 4.2, 4.3, 4.6</p> <p>MS 1a</p> <p>Recognise and use expressions in decimal form.</p> <p>MS 1c</p> <p>Use ratios, fractions and percentages.</p> <p>MS 3b</p> <p>Change the subject of an equation.</p> <p>MS 3c</p> <p>Substitute numerical values into algebraic equations using appropriate units for physical quantities.</p> <p>AT 1, 3, 8</p> <p>Opportunities within titrations including to determine concentrations of strong acids and alkalis.</p>

4.3.5 Use of amount of substance in relation to volumes of gases (chemistry only) (HT only)

Content	Key opportunities for skills development
<p>Equal amounts in moles of gases occupy the same volume under the same conditions of temperature and pressure.</p> <p>The volume of one mole of any gas at room temperature and pressure (20°C and 1 atmosphere pressure) is 24 dm³.</p> <p>The volumes of gaseous reactants and products can be calculated from the balanced equation for the reaction.</p> <p>Students should be able to:</p> <ul style="list-style-type: none"> calculate the volume of a gas at room temperature and pressure from its mass and relative formula mass calculate volumes of gaseous reactants and products from a balanced equation and a given volume of a gaseous reactant or product change the subject of a mathematical equation. 	<p>WS 1.2, 4.1, 4.2, 4.3, 4.6</p> <p>MS 1a</p> <p>Recognise and use expressions in decimal form.</p> <p>MS 1c</p> <p>Use ratios, fractions and percentages.</p> <p>MS 3b</p> <p>Change the subject of an equation.</p> <p>MS 3c</p> <p>Substitute numerical values into algebraic equations using appropriate units for physical quantities.</p>

4.4 Chemical changes

Understanding of chemical changes began when people began experimenting with chemical reactions in a systematic way and organizing their results logically. Knowing about these different chemical changes meant that scientists could begin to predict exactly what new substances would be formed and use this knowledge to develop a wide range of different materials and processes. It also helped biochemists to understand the complex reactions that take place in living organisms. The extraction of important resources from the earth makes use of the way that some elements and compounds react with each other and how easily they can be 'pulled apart'.

4.4.1 Reactivity of metals

4.4.1.1 Metal oxides

Content	Key opportunities for skills development
<p>Metals react with oxygen to produce metal oxides. The reactions are oxidation reactions because the metals gain oxygen.</p> <p>Students should be able to explain reduction and oxidation in terms of loss or gain of oxygen.</p>	

4.4.1.2 The reactivity series

Content	Key opportunities for skills development
<p>When metals react with other substances the metal atoms form positive ions. The reactivity of a metal is related to its tendency to form positive ions. Metals can be arranged in order of their reactivity in a reactivity series. The metals potassium, sodium, lithium, calcium, magnesium, zinc, iron and copper can be put in order of their reactivity from their reactions with water and dilute acids.</p> <p>The non-metals hydrogen and carbon are often included in the reactivity series.</p> <p>A more reactive metal can displace a less reactive metal from a compound.</p> <p>Students should be able to:</p> <ul style="list-style-type: none">• recall and describe the reactions, if any, of potassium, sodium, lithium, calcium, magnesium, zinc, iron and copper with water or dilute acids and where appropriate, to place these metals in order of reactivity• explain how the reactivity of metals with water or dilute acids is related to the tendency of the metal to form its positive ion• deduce an order of reactivity of metals based on experimental results. <p>The reactions of metals with water and acids are limited to room temperature and do not include reactions with steam.</p>	<p>AT 6</p> <p>Mixing of reagents to explore chemical changes and/or products.</p>

4.4.1.3 Extraction of metals and reduction

Content	Key opportunities for skills development
<p>Unreactive metals such as gold are found in the Earth as the metal itself but most metals are found as compounds that require chemical reactions to extract the metal.</p> <p>Metals less reactive than carbon can be extracted from their oxides by reduction with carbon.</p> <p>Reduction involves the loss of oxygen.</p> <p>Knowledge and understanding are limited to the reduction of oxides using carbon.</p> <p>Knowledge of the details of processes used in the extraction of metals is not required.</p> <p>Students should be able to:</p> <ul style="list-style-type: none"> • interpret or evaluate specific metal extraction processes when given appropriate information • identify the substances which are oxidised or reduced in terms of gain or loss of oxygen. 	

4.4.1.4 Oxidation and reduction in terms of electrons (HT only)

Content	Key opportunities for skills development
<p>Oxidation is the loss of electrons and reduction is the gain of electrons.</p> <p>Student should be able to:</p> <ul style="list-style-type: none"> • write ionic equations for displacement reactions • identify in a given reaction, symbol equation or half equation which species are oxidised and which are reduced. 	

4.4.2 Reactions of acids

4.4.2.1 Reactions of acids with metals

Content	Key opportunities for skills development
<p>Acids react with some metals to produce salts and hydrogen.</p> <p>(HT only) Students should be able to:</p> <ul style="list-style-type: none">• explain in terms of gain or loss of electrons, that these are redox reactions• identify which species are oxidised and which are reduced in given chemical equations. <p>Knowledge of reactions limited to those of magnesium, zinc and iron with hydrochloric and sulfuric acids.</p>	

4.4.2.2 Neutralisation of acids and salt production

Content	Key opportunities for skills development
<p>Acids are neutralised by alkalis (eg soluble metal hydroxides) and bases (eg insoluble metal hydroxides and metal oxides) to produce salts and water, and by metal carbonates to produce salts, water and carbon dioxide.</p> <p>The particular salt produced in any reaction between an acid and a base or alkali depends on:</p> <ul style="list-style-type: none">• the acid used (hydrochloric acid produces chlorides, nitric acid produces nitrates, sulfuric acid produces sulfates)• the positive ions in the base, alkali or carbonate. <p>Students should be able to:</p> <ul style="list-style-type: none">• predict products from given reactants• use the formulae of common ions to deduce the formulae of salts.	

4.4.2.3 Soluble salts

Content	Key opportunities for skills development
<p>Soluble salts can be made from acids by reacting them with solid insoluble substances, such as metals, metal oxides, hydroxides or carbonates. The solid is added to the acid until no more reacts and the excess solid is filtered off to produce a solution of the salt.</p> <p>Salt solutions can be crystallised to produce solid salts.</p> <p>Students should be able to describe how to make pure, dry samples of named soluble salts from information provided.</p>	

Required practical 1: preparation of a pure, dry sample of a soluble salt from an insoluble oxide or carbonate using a Bunsen burner to heat dilute acid and a water bath or electric heater to evaporate the solution.

AT skills covered by this practical activity: 2, 3, 4 and 6.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in [Key opportunities for skills development](#) (page 103).

4.4.2.4 The pH scale and neutralisation

Content	Key opportunities for skills development
<p>Acids produce hydrogen ions (H⁺) in aqueous solutions.</p> <p>Aqueous solutions of alkalis contain hydroxide ions (OH⁻).</p> <p>The pH scale, from 0 to 14, is a measure of the acidity or alkalinity of a solution, and can be measured using universal indicator or a pH probe.</p> <p>A solution with pH 7 is neutral. Aqueous solutions of acids have pH values of less than 7 and aqueous solutions of alkalis have pH values greater than 7.</p> <p>In neutralisation reactions between an acid and an alkali, hydrogen ions react with hydroxide ions to produce water.</p> <p>This reaction can be represented by the equation:</p> $\text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \longrightarrow \text{H}_2\text{O}(\text{l})$ <p>Students should be able to:</p> <ul style="list-style-type: none"> describe the use of universal indicator or a wide range indicator to measure the approximate pH of a solution use the pH scale to identify acidic or alkaline solutions. 	<p>AT 3</p> <p>This is an opportunity to investigate pH changes when a strong acid neutralises a strong alkali.</p>

4.4.2.5 Titrations (chemistry only)

Content	Key opportunities for skills development
<p>The volumes of acid and alkali solutions that react with each other can be measured by titration using a suitable indicator.</p> <p>Students should be able to:</p> <ul style="list-style-type: none">describe how to carry out titrations using strong acids and strong alkalis only (sulfuric, hydrochloric and nitric acids only) to find the reacting volumes accurately(HT Only) calculate the chemical quantities in titrations involving concentrations in mol/dm³ and in g/dm³.	

Required practical 2: (chemistry only) determination of the reacting volumes of solutions of a strong acid and a strong alkali by titration.

(HT only) determination of the concentration of one of the solutions in mol/dm³ and g/dm³ from the reacting volumes and the known concentration of the other solution.

AT skills covered by this practical activity: 1 and 8.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in [Key opportunities and skills development](#) (page 104).

4.4.2.6 Strong and weak acids (HT only)

Content	Key opportunities for skills development
<p>A strong acid is completely ionised in aqueous solution. Examples of strong acids are hydrochloric, nitric and sulfuric acids.</p> <p>A weak acid is only partially ionised in aqueous solution. Examples of weak acids are ethanoic, citric and carbonic acids.</p> <p>For a given concentration of aqueous solutions, the stronger an acid, the lower the pH.</p> <p>As the pH decreases by one unit, the hydrogen ion concentration of the solution increases by a factor of 10.</p> <p>Students should be able to:</p> <ul style="list-style-type: none">use and explain the terms dilute and concentrated (in terms of amount of substance), and weak and strong (in terms of the degree of ionisation) in relation to acids	<p>AT 8</p> <p>An opportunity to measure the pH of different acids at different concentrations.</p>
<ul style="list-style-type: none">describe neutrality and relative acidity in terms of the effect on hydrogen ion concentration and the numerical value of pH (whole numbers only).	<p>MS 2h</p> <p>Make order of magnitude calculations.</p>

4.4.3 Electrolysis

4.4.3.1 The process of electrolysis

Content	Key opportunities for skills development
<p>When an ionic compound is melted or dissolved in water, the ions are free to move about within the liquid or solution. These liquids and solutions are able to conduct electricity and are called electrolytes.</p> <p>Passing an electric current through electrolytes causes the ions to move to the electrodes. Positively charged ions move to the negative electrode (the cathode), and negatively charged ions move to the positive electrode (the anode). Ions are discharged at the electrodes producing elements. This process is called electrolysis.</p> <p>(HT only) Throughout Section 4.4.3 Higher Tier students should be able to write half equations for the reactions occurring at the electrodes during electrolysis, and may be required to complete and balance supplied half equations.</p>	

4.4.3.2 Electrolysis of molten ionic compounds

Content	Key opportunities for skills development
<p>When a simple ionic compound (eg lead bromide) is electrolysed in the molten state using inert electrodes, the metal (lead) is produced at the cathode and the non-metal (bromine) is produced at the anode.</p> <p>Students should be able to predict the products of the electrolysis of binary ionic compounds in the molten state.</p>	<p>A safer alternative for practical work is anhydrous zinc chloride.</p>

4.4.3.3 Using electrolysis to extract metals

Content	Key opportunities for skills development
<p>Metals can be extracted from molten compounds using electrolysis. Electrolysis is used if the metal is too reactive to be extracted by reduction with carbon or if the metal reacts with carbon. Large amounts of energy are used in the extraction process to melt the compounds and to produce the electrical current.</p> <p>Aluminium is manufactured by the electrolysis of a molten mixture of aluminium oxide and cryolite using carbon as the positive electrode (anode).</p> <p>Students should be able to:</p> <ul style="list-style-type: none">• explain why a mixture is used as the electrolyte• explain why the positive electrode must be continually replaced.	

4.4.3.4 Electrolysis of aqueous solutions

Content	Key opportunities for skills development
<p>The ions discharged when an aqueous solution is electrolysed using inert electrodes depend on the relative reactivity of the elements involved.</p> <p>At the negative electrode (cathode), hydrogen is produced if the metal is more reactive than hydrogen.</p> <p>At the positive electrode (anode), oxygen is produced unless the solution contains halide ions when the halogen is produced.</p> <p>This happens because in the aqueous solution water molecules break down producing hydrogen ions and hydroxide ions that are discharged.</p>	
<p>Students should be able to predict the products of the electrolysis of aqueous solutions containing a single ionic compound.</p>	WS 1.2

Required practical 3: investigate what happens when aqueous solutions are electrolysed using inert electrodes. This should be an investigation involving developing a hypothesis.

AT skills covered by this practical activity: 3, 7 and 8.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in [Key opportunities and skills development](#) (page 104).

4.4.3.5 Representation of reactions at electrodes as half equations (HT only)

Content	Key opportunities for skills development
<p>During electrolysis, at the cathode (negative electrode), positively charged ions gain electrons and so the reactions are reductions.</p> <p>At the anode (positive electrode), negatively charged ions lose electrons and so the reactions are oxidations.</p> <p>Reactions at electrodes can be represented by half equations, for example:</p> $2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$ <p>and</p> $4\text{OH}^- \rightarrow \text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^-$ <p>or</p> $4\text{OH}^- - 4\text{e}^- \rightarrow \text{O}_2 + 2\text{H}_2\text{O}$	

4.5 Energy changes

Energy changes are an important part of chemical reactions. The interaction of particles often involves transfers of energy due to the breaking and formation of bonds. Reactions in which energy is released to the surroundings are exothermic reactions, while those that take in thermal energy are endothermic. These interactions between particles can produce heating or cooling effects that are used in a range of everyday applications. Some interactions between ions in an electrolyte result in the production of electricity. Cells and batteries use these chemical reactions to provide electricity. Electricity can also be used to decompose ionic substances and is a useful means of producing elements that are too expensive to extract any other way.

4.5.1 Exothermic and endothermic reactions

4.5.1.1 Energy transfer during exothermic and endothermic reactions

Content	Key opportunities for skills development
<p>Energy is conserved in chemical reactions. The amount of energy in the universe at the end of a chemical reaction is the same as before the reaction takes place. If a reaction transfers energy to the surroundings the product molecules must have less energy than the reactants, by the amount transferred.</p> <p>An exothermic reaction is one that transfers energy to the surroundings so the temperature of the surroundings increases.</p> <p>Exothermic reactions include combustion, many oxidation reactions and neutralisation.</p> <p>Everyday uses of exothermic reactions include self-heating cans and hand warmers.</p> <p>An endothermic reaction is one that takes in energy from the surroundings so the temperature of the surroundings decreases.</p> <p>Endothermic reactions include thermal decompositions and the reaction of citric acid and sodium hydrogencarbonate. Some sports injury packs are based on endothermic reactions.</p> <p>Students should be able to:</p> <ul style="list-style-type: none">• distinguish between exothermic and endothermic reactions on the basis of the temperature change of the surroundings• evaluate uses and applications of exothermic and endothermic reactions given appropriate information. <p>Limited to measurement of temperature change. Calculation of energy changes or ΔH is not required.</p>	<p>AT 5</p> <p>An opportunity to measure temperature changes when substances react or dissolve in water.</p>

Required practical 4: investigate the variables that affect temperature changes in reacting solutions such as, eg acid plus metals, acid plus carbonates, neutralisations, displacement of metals.

AT skills covered by this practical activity: 1, 3, 5 and 6.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in [Key opportunities and skills development](#) (page 105).

4.5.1.2 Reaction profiles

Content	Key opportunities for skills development
<p>Chemical reactions can occur only when reacting particles collide with each other and with sufficient energy. The minimum amount of energy that particles must have to react is called the activation energy.</p> <p>Reaction profiles can be used to show the relative energies of reactants and products, the activation energy and the overall energy change of a reaction.</p>	
<p>Students should be able to:</p> <ul style="list-style-type: none"> draw simple reaction profiles (energy level diagrams) for exothermic and endothermic reactions showing the relative energies of reactants and products, the activation energy and the overall energy change, with a curved line to show the energy as the reaction proceeds use reaction profiles to identify reactions as exothermic or endothermic explain that the activation energy is the energy needed for a reaction to occur. 	

4.5.1.3 The energy change of reactions (HT only)

Content	Key opportunities for skills development
<p>During a chemical reaction:</p> <ul style="list-style-type: none"> energy must be supplied to break bonds in the reactants energy is released when bonds in the products are formed. <p>The energy needed to break bonds and the energy released when bonds are formed can be calculated from bond energies.</p> <p>The difference between the sum of the energy needed to break bonds in the reactants and the sum of the energy released when bonds in the products are formed is the overall energy change of the reaction.</p> <p>In an exothermic reaction, the energy released from forming new bonds is greater than the energy needed to break existing bonds.</p> <p>In an endothermic reaction, the energy needed to break existing bonds is greater than the energy released from forming new bonds.</p>	
<p>Students should be able to calculate the energy transferred in chemical reactions using bond energies supplied.</p>	MS 1a

4.5.2 Chemical cells and fuel cells (chemistry only)

4.5.2.1 Cells and batteries

Content	Key opportunities for skills development
<p>Cells contain chemicals which react to produce electricity.</p> <p>The voltage produced by a cell is dependent upon a number of factors including the type of electrode and electrolyte.</p> <p>A simple cell can be made by connecting two different metals in contact with an electrolyte.</p> <p>Batteries consist of two or more cells connected together in series to provide a greater voltage.</p> <p>In non-rechargeable cells and batteries the chemical reactions stop when one of the reactants has been used up. Alkaline batteries are non-rechargeable.</p> <p>Rechargeable cells and batteries can be recharged because the chemical reactions are reversed when an external electrical current is supplied.</p> <p>Students should be able to interpret data for relative reactivity of different metals and evaluate the use of cells.</p> <p>Students do not need to know details of cells and batteries other than those specified.</p>	<p>AT6</p> <p>Safe and careful use of liquids.</p>

4.5.2.2 Fuel cells

Content	Key opportunities for skills development
<p>Fuel cells are supplied by an external source of fuel (eg hydrogen) and oxygen or air. The fuel is oxidised electrochemically within the fuel cell to produce a potential difference.</p> <p>The overall reaction in a hydrogen fuel cell involves the oxidation of hydrogen to produce water.</p> <p>Hydrogen fuel cells offer a potential alternative to rechargeable cells and batteries.</p> <p>Students should be able to:</p> <ul style="list-style-type: none">• evaluate the use of hydrogen fuel cells in comparison with rechargeable cells and batteries• (HT only) write the half equations for the electrode reactions in the hydrogen fuel cell.	

4.6 The rate and extent of chemical change

Chemical reactions can occur at vastly different rates. Whilst the reactivity of chemicals is a significant factor in how fast chemical reactions proceed, there are many variables that can be manipulated in order to speed them up or slow them down. Chemical reactions may also be reversible and therefore the effect of different variables needs to be established in order to identify how to maximise the yield of desired product. Understanding energy changes that accompany chemical reactions is important for this process. In industry, chemists and chemical engineers determine the effect of different variables on reaction rate and yield of product. Whilst there may be compromises to be made, they carry out optimisation processes to ensure that enough product is produced within a sufficient time, and in an energy-efficient way.

4.6.1 Rate of reaction

4.6.1.1 Calculating rates of reactions

Content	Key opportunities for skills development
<p>The rate of a chemical reaction can be found by measuring the quantity of a reactant used or the quantity of product formed over time:</p> $\text{mean rate of reaction} = \frac{\text{quantity of reactant used}}{\text{time taken}}$ $\text{mean rate of reaction} = \frac{\text{quantity of product formed}}{\text{time taken}}$ <p>The quantity of reactant or product can be measured by the mass in grams or by a volume in cm³.</p> <p>The units of rate of reaction may be given as g/s or cm³/s.</p> <p>For the Higher Tier, students are also required to use quantity of reactants in terms of moles and units for rate of reaction in mol/s.</p> <p>Students should be able to:</p> <ul style="list-style-type: none">• calculate the mean rate of a reaction from given information about the quantity of a reactant used or the quantity of a product formed and the time taken• draw, and interpret, graphs showing the quantity of product formed or quantity of reactant used up against time• draw tangents to the curves on these graphs and use the slope of the tangent as a measure of the rate of reaction• (HT only) calculate the gradient of a tangent to the curve on these graphs as a measure of rate of reaction at a specific time.	<p>MS 1a</p> <p>Recognise and use expressions in decimal form.</p> <p>MS 1c</p> <p>Use ratios, fractions and percentages.</p> <p>MS 1d</p> <p>Make estimates of the results of simple calculations.</p> <p>MS 4a</p> <p>Translate information between graphical and numeric form.</p> <p>MS 4b</p> <p>Drawing and interpreting appropriate graphs from data to determine rate of reaction.</p> <p>MS 4c</p> <p>Plot two variables from experimental or other data.</p> <p>MS 4d</p> <p>Determine the slope and intercept of a linear graph.</p> <p>MS 4e</p> <p>Draw and use the slope of a tangent to a curve as a measure of rate of change.</p>

4.6.1.2 Factors which affect the rates of chemical reactions

Content	Key opportunities for skills development
Factors which affect the rates of chemical reactions include: the concentrations of reactants in solution, the pressure of reacting gases, the surface area of solid reactants, the temperature and the presence of catalysts.	
Students should be able to recall how changing these factors affects the rate of chemical reactions.	This topic offers opportunities for practical work and investigations in addition to required practical 5.

Required practical 5: investigate how changes in concentration affect the rates of reactions by a method involving measuring the volume of a gas produced and a method involving a change in colour or turbidity.

This should be an investigation involving developing a hypothesis.

AT skills covered by this practical activity: 1, 3, 5 and 6.

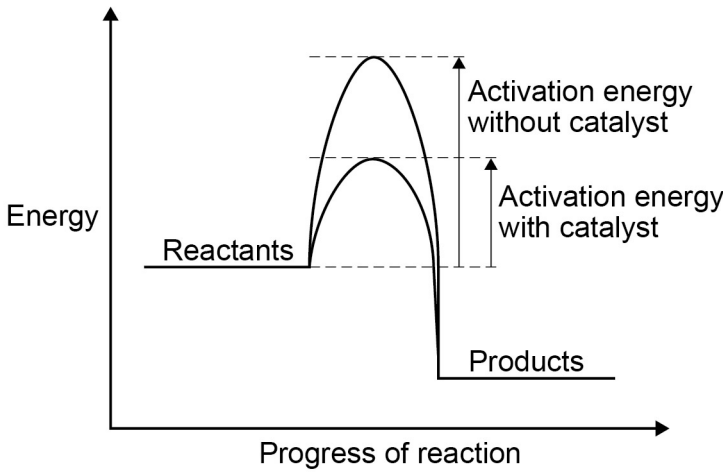
This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in [Key opportunities for skills development](#) (page 106).

4.6.1.3 Collision theory and activation energy

Content	Key opportunities for skills development
<p>Collision theory explains how various factors affect rates of reactions. According to this theory, chemical reactions can occur only when reacting particles collide with each other and with sufficient energy. The minimum amount of energy that particles must have to react is called the activation energy.</p> <p>Increasing the concentration of reactants in solution, the pressure of reacting gases, and the surface area of solid reactants increases the frequency of collisions and so increases the rate of reaction.</p> <p>Increasing the temperature increases the frequency of collisions and makes the collisions more energetic, and so increases the rate of reaction.</p>	
<p>Students should be able to :</p> <ul style="list-style-type: none"> predict and explain using collision theory the effects of changing conditions of concentration, pressure and temperature on the rate of a reaction 	WS 1.2

Content	Key opportunities for skills development
<ul style="list-style-type: none"> • predict and explain the effects of changes in the size of pieces of a reacting solid in terms of surface area to volume ratio • use simple ideas about proportionality when using collision theory to explain the effect of a factor on the rate of a reaction. 	MS 5c MS 1c

4.6.1.4 Catalysts

Content	Key opportunities for skills development
<p>Catalysts change the rate of chemical reactions but are not used up during the reaction. Different reactions need different catalysts. Enzymes act as catalysts in biological systems.</p> <p>Catalysts increase the rate of reaction by providing a different pathway for the reaction that has a lower activation energy.</p> <p>A reaction profile for a catalysed reaction can be drawn in the following form:</p>  <p>Students should be able to identify catalysts in reactions from their effect on the rate of reaction and because they are not included in the chemical equation for the reaction.</p> <p>Students should be able to explain catalytic action in terms of activation energy.</p> <p>Students do not need to know the names of catalysts other than those specified in the subject content.</p>	AT 5 An opportunity to investigate the catalytic effect of adding different metal salts to a reaction such as the decomposition of hydrogen peroxide.

4.6.2 Reversible reactions and dynamic equilibrium

4.6.2.1 Reversible reactions

Content	Key opportunities for skills development
<p>In some chemical reactions, the products of the reaction can react to produce the original reactants. Such reactions are called reversible reactions and are represented:</p> $A + B \rightleftharpoons C + D$ <p>The direction of reversible reactions can be changed by changing the conditions.</p> <p>For example:</p> <p>ammonium chloride $\xrightleftharpoons[\text{cool}]{\text{heat}}$ ammonia + hydrogen chloride</p>	

4.6.2.2 Energy changes and reversible reactions

Content	Key opportunities for skills development
<p>If a reversible reaction is exothermic in one direction, it is endothermic in the opposite direction. The same amount of energy is transferred in each case. For example:</p> <p>hydrated copper sulfate (blue) $\xrightleftharpoons[\text{exothermic}]{\text{endothermic}}$ anhydrous copper sulfate (white) + water</p>	

4.6.2.3 Equilibrium

Content	Key opportunities for skills development
<p>When a reversible reaction occurs in apparatus which prevents the escape of reactants and products, equilibrium is reached when the forward and reverse reactions occur at exactly the same rate.</p>	WS 1.2

4.6.2.4 The effect of changing conditions on equilibrium (HT only)

Content	Key opportunities for skills development
<p>The relative amounts of all the reactants and products at equilibrium depend on the conditions of the reaction.</p> <p>If a system is at equilibrium and a change is made to any of the conditions, then the system responds to counteract the change.</p> <p>The effects of changing conditions on a system at equilibrium can be predicted using Le Chatelier's Principle.</p> <p>Students should be able to make qualitative predictions about the effect of changes on systems at equilibrium when given appropriate information.</p>	

4.6.2.5 The effect of changing concentration (HT only)

Content	Key opportunities for skills development
<p>If the concentration of one of the reactants or products is changed, the system is no longer at equilibrium and the concentrations of all the substances will change until equilibrium is reached again.</p> <p>If the concentration of a reactant is increased, more products will be formed until equilibrium is reached again.</p> <p>If the concentration of a product is decreased, more reactants will react until equilibrium is reached again.</p> <p>Students should be able to interpret appropriate given data to predict the effect of a change in concentration of a reactant or product on given reactions at equilibrium.</p>	

4.6.2.6 The effect of temperature changes on equilibrium (HT only)

Content	Key opportunities for skills development
<p>If the temperature of a system at equilibrium is increased:</p> <ul style="list-style-type: none"> the relative amount of products at equilibrium increases for an endothermic reaction the relative amount of products at equilibrium decreases for an exothermic reaction. <p>If the temperature of a system at equilibrium is decreased:</p> <ul style="list-style-type: none"> the relative amount of products at equilibrium decreases for an endothermic reaction the relative amount of products at equilibrium increases for an exothermic reaction. <p>Students should be able to interpret appropriate given data to predict the effect of a change in temperature on given reactions at equilibrium.</p>	

4.6.2.7 The effect of pressure changes on equilibrium (HT only)

Content	Key opportunities for skills development
<p>For gaseous reactions at equilibrium:</p> <ul style="list-style-type: none"> an increase in pressure causes the equilibrium position to shift towards the side with the smaller number of molecules as shown by the symbol equation for that reaction a decrease in pressure causes the equilibrium position to shift towards the side with the larger number of molecules as shown by the symbol equation for that reaction. <p>Students should be able to interpret appropriate given data to predict the effect of pressure changes on given reactions at equilibrium.</p>	

4.7 Organic chemistry

The chemistry of carbon compounds is so important that it forms a separate branch of chemistry. A great variety of carbon compounds is possible because carbon atoms can form chains and rings linked by C-C bonds. This branch of chemistry gets its name from the fact that the main sources of organic compounds are living, or once-living materials from plants and animals. These sources include fossil fuels which are a major source of feedstock for the petrochemical industry. Chemists are able to take organic molecules and modify them in many ways to make new and useful materials such as polymers, pharmaceuticals, perfumes and flavourings, dyes and detergents.

4.7.1 Carbon compounds as fuels and feedstock

4.7.1.1 Crude oil, hydrocarbons and alkanes

Content	Key opportunities for skills development
<p>Crude oil is a finite resource found in rocks. Crude oil is the remains of an ancient biomass consisting mainly of plankton that was buried in mud.</p> <p>Crude oil is a mixture of a very large number of compounds. Most of the compounds in crude oil are hydrocarbons, which are molecules made up of hydrogen and carbon atoms only.</p> <p>Most of the hydrocarbons in crude oil are hydrocarbons called alkanes. The general formula for the homologous series of alkanes is C_nH_{2n+2}</p> <p>The first four members of the alkanes are methane, ethane, propane and butane.</p> <p>Alkane molecules can be represented in the following forms:</p> <p>C_2H_6 or</p> $\begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{H}-\text{C}-\text{C}-\text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array}$ <p>Students should be able to recognise substances as alkanes given their formulae in these forms.</p> <p>Students do not need to know the names of specific alkanes other than methane, ethane, propane and butane.</p>	<p>WS 1.2</p> <p>Make models of alkane molecules using the molecular modelling kits.</p>

4.7.1.2 Fractional distillation and petrochemicals

Content	Key opportunities for skills development
<p>The many hydrocarbons in crude oil may be separated into fractions, each of which contains molecules with a similar number of carbon atoms, by fractional distillation.</p> <p>The fractions can be processed to produce fuels and feedstock for the petrochemical industry.</p> <p>Many of the fuels on which we depend for our modern lifestyle, such as petrol, diesel oil, kerosene, heavy fuel oil and liquefied petroleum gases, are produced from crude oil.</p> <p>Many useful materials on which modern life depends are produced by the petrochemical industry, such as solvents, lubricants, polymers, detergents.</p> <p>The vast array of natural and synthetic carbon compounds occur due to the ability of carbon atoms to form families of similar compounds.</p> <p>Students should be able to explain how fractional distillation works in terms of evaporation and condensation.</p> <p>Knowledge of the names of other specific fractions or fuels is not required.</p>	WS 1.2

4.7.1.3 Properties of hydrocarbons

Content	Key opportunities for skills development
<p>Some properties of hydrocarbons depend on the size of their molecules, including boiling point, viscosity and flammability. These properties influence how hydrocarbons are used as fuels.</p> <p>Students should be able to recall how boiling point, viscosity and flammability change with increasing molecular size.</p> <p>The combustion of hydrocarbon fuels releases energy. During combustion, the carbon and hydrogen in the fuels are oxidised. The complete combustion of a hydrocarbon produces carbon dioxide and water.</p> <p>Students should be able to write balanced equations for the complete combustion of hydrocarbons with a given formula.</p> <p>Knowledge of trends in properties of hydrocarbons is limited to:</p> <ul style="list-style-type: none"> • boiling points • viscosity • flammability. 	<p>WS 1.2, 4.1</p> <p>Investigate the properties of different hydrocarbons.</p>

4.7.1.4 Cracking and alkenes

Content	Key opportunities for skills development
<p>Hydrocarbons can be broken down (cracked) to produce smaller, more useful molecules.</p> <p>Cracking can be done by various methods including catalytic cracking and steam cracking.</p> <p>Students should be able to describe in general terms the conditions used for catalytic cracking and steam cracking.</p> <p>The products of cracking include alkanes and another type of hydrocarbon called alkenes.</p> <p>Alkenes are more reactive than alkanes and react with bromine water, which is used as a test for alkenes.</p> <p>Students should be able to recall the colour change when bromine water reacts with an alkene.</p> <p>There is a high demand for fuels with small molecules and so some of the products of cracking are useful as fuels.</p> <p>Alkenes are used to produce polymers and as starting materials for the production of many other chemicals.</p> <p>Students should be able to balance chemical equations as examples of cracking given the formulae of the reactants and products.</p> <p>Students should be able to give examples to illustrate the usefulness of cracking. They should also be able to explain how modern life depends on the uses of hydrocarbons.</p> <p>(For Combined Science: Trilogy and Synergy students do not need to know the formulae or names of individual alkenes.)</p>	WS 1.2

4.7.2 Reactions of alkenes and alcohols (chemistry only)

4.7.2.1 Structure and formulae of alkenes

Content	Key opportunities for skills development
<p>Alkenes are hydrocarbons with a double carbon-carbon bond. The general formula for the homologous series of alkenes is C_nH_{2n}</p> <p>Alkene molecules are unsaturated because they contain two fewer hydrogen atoms than the alkane with the same number of carbon atoms.</p> <p>The first four members of the homologous series of alkenes are ethene, propene, butene and pentene.</p> <p>Alkene molecules can be represented in the following forms:</p> <p>C_3H_6</p> <p>or</p> $ \begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \\ \text{H}-\text{C}-\text{C}=\text{C} \\ \quad \quad \\ \text{H} \quad \quad \text{H} \end{array} $ <p>Students do not need to know the names of individual alkenes other than ethene, propene, butene and pentene.</p>	<p>WS 1.2</p> <p>Recognise substances that are alkenes from their names or from given formulae in these forms.</p> <p>MS 5b</p> <p>Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects.</p>

4.7.2.2 Reactions of alkenes

Content	Key opportunities for skills development
<p>Alkenes are hydrocarbons with the functional group $C=C$.</p> <p>It is the generality of reactions of functional groups that determine the reactions of organic compounds.</p> <p>Alkenes react with oxygen in combustion reactions in the same way as other hydrocarbons, but they tend to burn in air with smoky flames because of incomplete combustion.</p> <p>Alkenes react with hydrogen, water and the halogens, by the addition of atoms across the carbon-carbon double bond so that the double bond becomes a single carbon-carbon bond.</p>	
<p>Students should be able to:</p> <ul style="list-style-type: none"> describe the reactions and conditions for the addition of hydrogen, water and halogens to alkenes draw fully displayed structural formulae of the first four members of the alkenes and the products of their addition reactions with hydrogen, water, chlorine, bromine and iodine. 	<p>WS 1.2</p>

4.7.2.3 Alcohols

Content	Key opportunities for skills development
<p>Alcohols contain the functional group –OH.</p> <p>Methanol, ethanol, propanol and butanol are the first four members of a homologous series of alcohols.</p> <p>Alcohols can be represented in the following forms:</p> <p>CH₃CH₂OH</p> <p>or</p> $\begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{H}-\text{C}-\text{C}-\text{O}-\text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array}$ <p>Students should be able to:</p> <ul style="list-style-type: none">• describe what happens when any of the first four alcohols react with sodium, burn in air, are added to water, react with an oxidising agent• recall the main uses of these alcohols. <p>Aqueous solutions of ethanol are produced when sugar solutions are fermented using yeast.</p> <p>Students should know the conditions used for fermentation of sugar using yeast.</p> <p>Students should be able to recognise alcohols from their names or from given formulae.</p> <p>Students do not need to know the names of individual alcohols other than methanol, ethanol, propanol and butanol.</p> <p>Students are not expected to write balanced chemical equations for the reactions of alcohols other than for combustion reactions.</p>	<p>AT 2, 5, 6</p> <p>Opportunities when investigating reactions of alcohols.</p>

4.7.2.4 Carboxylic acids

Content	Key opportunities for skills development
<p>Carboxylic acids have the functional group -COOH.</p> <p>The first four members of a homologous series of carboxylic acids are methanoic acid, ethanoic acid, propanoic acid and butanoic acid.</p> <p>The structures of carboxylic acids can be represented in the following forms:</p> <p>CH_3COOH</p> <p>or</p> $ \begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{C}=\text{O} \\ \quad \\ \text{H} \quad \text{O}-\text{H} \end{array} $ <p>Students should be able to:</p> <ul style="list-style-type: none"> describe what happens when any of the first four carboxylic acids react with carbonates, dissolve in water, react with alcohols (HT only) explain why carboxylic acids are weak acids in terms of ionisation and pH (see Strong and weak acids (HT only) (page 48)). <p>Students should be able to recognise carboxylic acids from their names or from given formulae.</p> <p>Students do not need to know the names of individual carboxylic acids other than methanoic acid, ethanoic acid, propanoic acid and butanoic acid.</p> <p>Students are not expected to write balanced chemical equations for the reactions of carboxylic acids.</p> <p>Students do not need to know the names of esters other than ethyl ethanoate.</p>	<p>AT 2, 5, 6</p> <p>Opportunities within investigation of the reactions of carboxylic acids.</p>

4.7.3 Synthetic and naturally occurring polymers (chemistry only)

4.7.3.1 Addition polymerisation

Content	Key opportunities for skills development
<p>Alkenes can be used to make polymers such as poly(ethene) and poly(propene) by addition polymerisation.</p> <p>In addition polymerisation reactions, many small molecules (monomers) join together to form very large molecules (polymers).</p> <p>For example:</p> $\begin{array}{ccc} \begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ n \text{ C} = \text{C} \\ \quad \\ \text{H} \quad \text{H} \\ \text{ethene} \end{array} & \longrightarrow & \begin{array}{c} \left(\begin{array}{cc} \text{H} & \text{H} \\ & \\ -\text{C} & -\text{C}- \\ & \\ \text{H} & \text{H} \end{array} \right)_n \\ \text{poly(ethene)} \end{array} \end{array}$ <p>In addition polymers the repeating unit has the same atoms as the monomer because no other molecule is formed in the reaction.</p>	<p>WS 1.2</p> <p>Use models to represent addition polymerisation.</p>
<p>Students should be able to:</p> <ul style="list-style-type: none">• recognise addition polymers and monomers from diagrams in the forms shown and from the presence of the functional group C=C in the monomers• draw diagrams to represent the formation of a polymer from a given alkene monomer• relate the repeating unit to the monomer.	<p>MS 5b</p> <p>Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects.</p>

4.7.3.2 Condensation polymerisation (HT only)

Content	Key opportunities for skills development
<p>Condensation polymerisation involves monomers with two functional groups. When these types of monomers react they join together, usually losing small molecules such as water, and so the reactions are called condensation reactions.</p> <p>The simplest polymers are produced from two different monomers with two of the same functional groups on each monomer.</p> <p>For example:</p> <p>ethanediol</p> $\text{HO} - \text{CH}_2 - \text{CH}_2 - \text{OH} \quad \text{or} \quad \text{HO} - \square - \text{OH}$ <p>and</p> <p>hexanedioic acid</p> $\text{HOOC} - \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{COOH} \quad \text{or}$ $\text{HOOC} - \square - \text{COOH}$ <p>polymerise to produce a polyester:</p> $n \text{HO} - \square - \text{OH} + n \text{HOOC} - \square - \text{COOH} \longrightarrow$ $\left(\text{O} - \square - \text{O} - \text{CO} - \square - \text{CO} \right)_n + 2n \text{H}_2\text{O}$	<p>WS 1.2</p> <p>Use models to represent condensation polymerisation.</p>
<p>Students should be able to explain the basic principles of condensation polymerisation by reference to the functional groups in the monomers and the repeating units in the polymers.</p>	<p>MS 5b</p> <p>Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects.</p>

4.7.3.3 Amino acids (HT only)

Content	Key opportunities for skills development
<p>Amino acids have two different functional groups in a molecule. Amino acids react by condensation polymerisation to produce polypeptides.</p> <p>For example: glycine is $\text{H}_2\text{NCH}_2\text{COOH}$ and polymerises to produce the polypeptide</p> $\left(\text{HNCH}_2\text{CO} \right)_n \text{ and } n\text{H}_2\text{O}$ <p>Different amino acids can be combined in the same chain to produce proteins.</p>	

4.7.3.4 DNA (deoxyribonucleic acid) and other naturally occurring polymers

Content	Key opportunities for skills development
<p>DNA (deoxyribonucleic acid) is a large molecule essential for life. DNA encodes genetic instructions for the development and functioning of living organisms and viruses.</p> <p>Most DNA molecules are two polymer chains, made from four different monomers called nucleotides, in the form of a double helix. Other naturally occurring polymers important for life include proteins, starch and cellulose.</p> <p>Students should be able to name the types of monomers from which these naturally occurring polymers are made.</p>	

4.8 Chemical analysis

Analysts have developed a range of qualitative tests to detect specific chemicals. The tests are based on reactions that produce a gas with distinctive properties, or a colour change or an insoluble solid that appears as a precipitate.

Instrumental methods provide fast, sensitive and accurate means of analysing chemicals, and are particularly useful when the amount of chemical being analysed is small. Forensic scientists and drug control scientists rely on such instrumental methods in their work.

4.8.1 Purity, formulations and chromatography

4.8.1.1 Pure substances

Content	Key opportunities for skills development
<p>In chemistry, a pure substance is a single element or compound, not mixed with any other substance.</p> <p>Pure elements and compounds melt and boil at specific temperatures. Melting point and boiling point data can be used to distinguish pure substances from mixtures.</p> <p>In everyday language, a pure substance can mean a substance that has had nothing added to it, so it is unadulterated and in its natural state, eg pure milk.</p> <p>Students should be able to use melting point and boiling point data to distinguish pure from impure substances.</p>	WS 2.2, 4.1

4.8.1.2 Formulations

Content	Key opportunities for skills development
<p>A formulation is a mixture that has been designed as a useful product. Many products are complex mixtures in which each chemical has a particular purpose. Formulations are made by mixing the components in carefully measured quantities to ensure that the product has the required properties. Formulations include fuels, cleaning agents, paints, medicines, alloys, fertilisers and foods.</p> <p>Students should be able to identify formulations given appropriate information.</p> <p>Students do not need to know the names of components in proprietary products.</p>	WS 1.4, 2.2

4.8.1.3 Chromatography

Content	Key opportunities for skills development
<p>Chromatography can be used to separate mixtures and can give information to help identify substances. Chromatography involves a stationary phase and a mobile phase. Separation depends on the distribution of substances between the phases.</p> <p>The ratio of the distance moved by a compound (centre of spot from origin) to the distance moved by the solvent can be expressed as its R_f value:</p> $R_f = \frac{\text{distance moved by substance}}{\text{distance moved by solvent}}$ <p>Different compounds have different R_f values in different solvents, which can be used to help identify the compounds. The compounds in a mixture may separate into different spots depending on the solvent but a pure compound will produce a single spot in all solvents.</p> <p>Students should be able to:</p> <ul style="list-style-type: none"> • explain how paper chromatography separates mixtures • suggest how chromatographic methods can be used for distinguishing pure substances from impure substances • interpret chromatograms and determine R_f values from chromatograms 	<p>WS 2.2, 3.1, 2, 3</p> <p>MS 1a</p> <p>Recognise and use expressions in decimal form.</p> <p>MS 1c</p> <p>Use ratios, fractions and percentages.</p> <p>MS 1d</p> <p>Make estimates of the results of simple calculations.</p>
<ul style="list-style-type: none"> • provide answers to an appropriate number of significant figures. 	<p>MS 2a</p>

Required practical 6: investigate how paper chromatography can be used to separate and tell the difference between coloured substances. Students should calculate R_f values.

AT skills covered by this practical activity: 1 and 4.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in [Key opportunities for skills development](#) (page 107).

4.8.2 Identification of common gases

4.8.2.1 Test for hydrogen

Content	Key opportunities for skills development
<p>The test for hydrogen uses a burning splint held at the open end of a test tube of the gas. Hydrogen burns rapidly with a pop sound.</p>	

4.8.2.2 Test for oxygen

Content	Key opportunities for skills development
The test for oxygen uses a glowing splint inserted into a test tube of the gas. The splint relights in oxygen.	

4.8.2.3 Test for carbon dioxide

Content	Key opportunities for skills development
The test for carbon dioxide uses an aqueous solution of calcium hydroxide (lime water). When carbon dioxide is shaken with or bubbled through limewater the limewater turns milky (cloudy).	

4.8.2.4 Test for chlorine

Content	Key opportunities for skills development
The test for chlorine uses litmus paper. When damp litmus paper is put into chlorine gas the litmus paper is bleached and turns white.	

4.8.3 Identification of ions by chemical and spectroscopic means (chemistry only)

4.8.3.1 Flame tests

Content	Key opportunities for skills development
<p>Flame tests can be used to identify some metal ions (cations). Lithium, sodium, potassium, calcium and copper compounds produce distinctive colours in flame tests:</p> <ul style="list-style-type: none"> • lithium compounds result in a crimson flame • sodium compounds result in a yellow flame • potassium compounds result in a lilac flame • calcium compounds result in an orange-red flame • copper compounds result in a green flame. <p>If a sample containing a mixture of ions is used some flame colours can be masked.</p>	<p>AT 8</p> <p>An opportunity to investigate flame colours.</p>
<p>Students should be able to identify species from the results of the tests in 4.8.3.1 to 4.8.3.5.</p> <p>Flame colours of other metal ions are not required knowledge.</p>	<p>WS 2.2</p>

4.8.3.2 Metal hydroxides

Content	Key opportunities for skills development
<p>Sodium hydroxide solution can be used to identify some metal ions (cations).</p> <p>Solutions of aluminium, calcium and magnesium ions form white precipitates when sodium hydroxide solution is added but only the aluminium hydroxide precipitate dissolves in excess sodium hydroxide solution.</p> <p>Solutions of copper(II), iron(II) and iron(III) ions form coloured precipitates when sodium hydroxide solution is added.</p> <p>Copper(II) forms a blue precipitate, iron(II) a green precipitate and iron(III) a brown precipitate.</p>	<p>AT 8</p> <p>An opportunity to make precipitates of metal hydroxides.</p>
<p>Students should be able to write balanced equations for the reactions to produce the insoluble hydroxides.</p> <p>Students are not expected to write equations for the production of sodium aluminate.</p>	<p>WS 2.2</p>

4.8.3.3 Carbonates

Content	Key opportunities for skills development
<p>Carbonates react with dilute acids to form carbon dioxide gas. Carbon dioxide can be identified with limewater.</p>	

4.8.3.4 Halides

Content	Key opportunities for skills development
<p>Halide ions in solution produce precipitates with silver nitrate solution in the presence of dilute nitric acid. Silver chloride is white, silver bromide is cream and silver iodide is yellow.</p>	

4.8.3.5 Sulfates

Content	Key opportunities for skills development
<p>Sulfate ions in solution produce a white precipitate with barium chloride solution in the presence of dilute hydrochloric acid.</p>	

Required practical 7: use of chemical tests to identify the ions in unknown single ionic compounds covering the ions from sections [Flame tests](#) (page 73) to [Sulfates](#) (page 74).

AT skills covered by this practical activity: 1 and 8.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in [Key opportunities for skills development](#) (page 107).

4.8.3.6 Instrumental methods

Content	Key opportunities for skills development
<p>Elements and compounds can be detected and identified using instrumental methods. Instrumental methods are accurate, sensitive and rapid.</p> <p>Students should be able to state advantages of instrumental methods compared with the chemical tests in this specification.</p>	

4.8.3.7 Flame emission spectroscopy

Content	Key opportunities for skills development
<p>Flame emission spectroscopy is an example of an instrumental method used to analyse metal ions in solutions.</p> <p>The sample is put into a flame and the light given out is passed through a spectroscope. The output is a line spectrum that can be analysed to identify the metal ions in the solution and measure their concentrations.</p>	<p>AT 8</p> <p>An opportunity to observe flame spectra using a hand-held spectroscope.</p>
<p>Students should be able to interpret an instrumental result given appropriate data in chart or tabular form, when accompanied by a reference set in the same form, limited to flame emission spectroscopy.</p>	<p>WS 3.6</p> <p>MS 4a</p>

4.9 Chemistry of the atmosphere

The Earth's atmosphere is dynamic and forever changing. The causes of these changes are sometimes man-made and sometimes part of many natural cycles. Scientists use very complex software to predict weather and climate change as there are many variables that can influence this. The problems caused by increased levels of air pollutants require scientists and engineers to develop solutions that help to reduce the impact of human activity.

4.9.1 The composition and evolution of the Earth's atmosphere

4.9.1.1 The proportions of different gases in the atmosphere

Content	Key opportunities for skills development
<p>For 200 million years, the proportions of different gases in the atmosphere have been much the same as they are today:</p> <ul style="list-style-type: none">• about four-fifths (approximately 80%) nitrogen• about one-fifth (approximately 20%) oxygen• small proportions of various other gases, including carbon dioxide, water vapour and noble gases.	<p>MS 1c</p> <p>To use ratios, fractions and percentages.</p>

4.9.1.2 The Earth's early atmosphere

Content	Key opportunities for skills development
<p>Theories about what was in the Earth's early atmosphere and how the atmosphere was formed have changed and developed over time. Evidence for the early atmosphere is limited because of the time scale of 4.6 billion years.</p> <p>One theory suggests that during the first billion years of the Earth's existence there was intense volcanic activity that released gases that formed the early atmosphere and water vapour that condensed to form the oceans. At the start of this period the Earth's atmosphere may have been like the atmospheres of Mars and Venus today, consisting of mainly carbon dioxide with little or no oxygen gas.</p> <p>Volcanoes also produced nitrogen which gradually built up in the atmosphere and there may have been small proportions of methane and ammonia.</p> <p>When the oceans formed carbon dioxide dissolved in the water and carbonates were precipitated producing sediments, reducing the amount of carbon dioxide in the atmosphere. No knowledge of other theories is required.</p> <p>Students should be able to, given appropriate information, interpret evidence and evaluate different theories about the Earth's early atmosphere.</p>	<p>WS 1.1, 1.2, 1.3, 3.5, 3.6, 4.1</p>

4.9.1.3 How oxygen increased

Content	Key opportunities for skills development
<p>Algae and plants produced the oxygen that is now in the atmosphere by photosynthesis, which can be represented by the equation:</p> $6\text{CO}_2 + 6\text{H}_2\text{O} \xrightarrow{\text{light}} \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$ <p>carbon dioxide + water $\xrightarrow{\text{light}}$ glucose + oxygen</p> <p>Algae first produced oxygen about 2.7 billion years ago and soon after this oxygen appeared in the atmosphere. Over the next billion years plants evolved and the percentage of oxygen gradually increased to a level that enabled animals to evolve.</p>	<p>WS 1.2</p> <p>An opportunity to show that aquatic plants produce oxygen in daylight.</p>

4.9.1.4 How carbon dioxide decreased

Content	Key opportunities for skills development
<p>Algae and plants decreased the percentage of carbon dioxide in the atmosphere by photosynthesis.</p> <p>Carbon dioxide was also decreased by the formation of sedimentary rocks and fossil fuels that contain carbon.</p>	
<p>Students should be able to:</p> <ul style="list-style-type: none"> describe the main changes in the atmosphere over time and some of the likely causes of these changes describe and explain the formation of deposits of limestone, coal, crude oil and natural gas. 	<p>WS 1.2, 4.1</p>

4.9.2 Carbon dioxide and methane as greenhouse gases

4.9.2.1 Greenhouse gases

Content	Key opportunities for skills development
<p>Greenhouse gases in the atmosphere maintain temperatures on Earth high enough to support life. Water vapour, carbon dioxide and methane are greenhouse gases.</p> <p>Students should be able to describe the greenhouse effect in terms of the interaction of short and long wavelength radiation with matter.</p>	<p>WS 1.2</p>

4.9.2.2 Human activities which contribute to an increase in greenhouse gases in the atmosphere

Content	Key opportunities for skills development
<p>Some human activities increase the amounts of greenhouse gases in the atmosphere. These include:</p> <ul style="list-style-type: none">• carbon dioxide• methane. <p>Students should be able to recall two human activities that increase the amounts of each of the greenhouse gases carbon dioxide and methane.</p> <p>Based on peer-reviewed evidence, many scientists believe that human activities will cause the temperature of the Earth's atmosphere to increase at the surface and that this will result in global climate change.</p> <p>However, it is difficult to model such complex systems as global climate change. This leads to simplified models, speculation and opinions presented in the media that may be based on only parts of the evidence and which may be biased.</p>	
<p>Students should be able to:</p> <ul style="list-style-type: none">• evaluate the quality of evidence in a report about global climate change given appropriate information• describe uncertainties in the evidence base• recognise the importance of peer review of results and of communicating results to a wide range of audiences.	WS 1.2, 1.3, 1.6

4.9.2.3 Global climate change

Content	Key opportunities for skills development
<p>An increase in average global temperature is a major cause of climate change.</p> <p>There are several potential effects of global climate change.</p> <p>Students should be able to:</p> <ul style="list-style-type: none">• describe briefly four potential effects of global climate change• discuss the scale, risk and environmental implications of global climate change.	WS 1.5

4.9.2.4 The carbon footprint and its reduction

Content	Key opportunities for skills development
<p>The carbon footprint is the total amount of carbon dioxide and other greenhouse gases emitted over the full life cycle of a product, service or event.</p> <p>The carbon footprint can be reduced by reducing emissions of carbon dioxide and methane.</p> <p>Students should be able to:</p> <ul style="list-style-type: none"> describe actions to reduce emissions of carbon dioxide and methane give reasons why actions may be limited. 	WS 1.3

4.9.3 Common atmospheric pollutants and their sources

4.9.3.1 Atmospheric pollutants from fuels

Content	Key opportunities for skills development
<p>The combustion of fuels is a major source of atmospheric pollutants.</p> <p>Most fuels, including coal, contain carbon and/or hydrogen and may also contain some sulfur.</p> <p>The gases released into the atmosphere when a fuel is burned may include carbon dioxide, water vapour, carbon monoxide, sulfur dioxide and oxides of nitrogen. Solid particles and unburned hydrocarbons may also be released that form particulates in the atmosphere.</p> <p>Students should be able to:</p> <ul style="list-style-type: none"> describe how carbon monoxide, soot (carbon particles), sulfur dioxide and oxides of nitrogen are produced by burning fuels 	
<ul style="list-style-type: none"> predict the products of combustion of a fuel given appropriate information about the composition of the fuel and the conditions in which it is used. 	WS 1.2

4.9.3.2 Properties and effects of atmospheric pollutants

Content	Key opportunities for skills development
Carbon monoxide is a toxic gas. It is colourless and odourless and so is not easily detected. Sulfur dioxide and oxides of nitrogen cause respiratory problems in humans and cause acid rain. Particulates cause global dimming and health problems for humans.	
Students should be able to describe and explain the problems caused by increased amounts of these pollutants in the air.	WS 1.4

4.10 Using resources

Industries use the Earth's natural resources to manufacture useful products. In order to operate sustainably, chemists seek to minimise the use of limited resources, use of energy, waste and environmental impact in the manufacture of these products. Chemists also aim to develop ways of disposing of products at the end of their useful life in ways that ensure that materials and stored energy are utilised. Pollution, disposal of waste products and changing land use has a significant effect on the environment, and environmental chemists study how human activity has affected the Earth's natural cycles, and how damaging effects can be minimised.

4.10.1 Using the Earth's resources and obtaining potable water

4.10.1.1 Using the Earth's resources and sustainable development

Content	Key opportunities for skills development
<p>Humans use the Earth's resources to provide warmth, shelter, food and transport.</p> <p>Natural resources, supplemented by agriculture, provide food, timber, clothing and fuels.</p> <p>Finite resources from the Earth, oceans and atmosphere are processed to provide energy and materials.</p> <p>Chemistry plays an important role in improving agricultural and industrial processes to provide new products and in sustainable development, which is development that meets the needs of current generations without compromising the ability of future generations to meet their own needs.</p> <p>Students should be able to:</p> <ul style="list-style-type: none"> state examples of natural products that are supplemented or replaced by agricultural and synthetic products distinguish between finite and renewable resources given appropriate information. <p>Students should be able to:</p>	
<ul style="list-style-type: none"> extract and interpret information about resources from charts, graphs and tables 	WS 3.2 MS 2c, 4a
<ul style="list-style-type: none"> use orders of magnitude to evaluate the significance of data. 	MS 2h Translate information between graphical and numeric form.

4.10.1.2 Potable water

Content	Key opportunities for skills development
<p>Water of appropriate quality is essential for life. For humans, drinking water should have sufficiently low levels of dissolved salts and microbes. Water that is safe to drink is called potable water. Potable water is not pure water in the chemical sense because it contains dissolved substances.</p> <p>The methods used to produce potable water depend on available supplies of water and local conditions.</p> <p>In the United Kingdom (UK), rain provides water with low levels of dissolved substances (fresh water) that collects in the ground and in lakes and rivers, and most potable water is produced by:</p> <ul style="list-style-type: none">• choosing an appropriate source of fresh water• passing the water through filter beds• sterilising. <p>Sterilising agents used for potable water include chlorine, ozone or ultraviolet light.</p> <p>If supplies of fresh water are limited, desalination of salty water or sea water may be required. Desalination can be done by distillation or by processes that use membranes such as reverse osmosis. These processes require large amounts of energy.</p> <p>Students should be able to:</p> <ul style="list-style-type: none">• distinguish between potable water and pure water• describe the differences in treatment of ground water and salty water• give reasons for the steps used to produce potable water.	

Required practical 8: analysis and purification of water samples from different sources, including pH, dissolved solids and distillation.

AT skills covered by this practical activity: 2, 3 and 4.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in [Key opportunities and skills development](#) (page 107).

4.10.1.3 Waste water treatment

Content	Key opportunities for skills development
<p>Urban lifestyles and industrial processes produce large amounts of waste water that require treatment before being released into the environment. Sewage and agricultural waste water require removal of organic matter and harmful microbes. Industrial waste water may require removal of organic matter and harmful chemicals.</p> <p>Sewage treatment includes:</p> <ul style="list-style-type: none"> • screening and grit removal • sedimentation to produce sewage sludge and effluent • anaerobic digestion of sewage sludge • aerobic biological treatment of effluent. <p>Students should be able to comment on the relative ease of obtaining potable water from waste, ground and salt water.</p>	

4.10.1.4 Alternative methods of extracting metals (HT only)

Content	Key opportunities for skills development
<p>The Earth's resources of metal ores are limited.</p> <p>Copper ores are becoming scarce and new ways of extracting copper from low-grade ores include phytomining, and bioleaching. These methods avoid traditional mining methods of digging, moving and disposing of large amounts of rock.</p> <p>Phytomining uses plants to absorb metal compounds. The plants are harvested and then burned to produce ash that contains metal compounds.</p> <p>Bioleaching uses bacteria to produce leachate solutions that contain metal compounds.</p> <p>The metal compounds can be processed to obtain the metal. For example, copper can be obtained from solutions of copper compounds by displacement using scrap iron or by electrolysis.</p> <p>Students should be able to evaluate alternative biological methods of metal extraction, given appropriate information.</p>	

4.10.2 Life cycle assessment and recycling

4.10.2.1 Life cycle assessment

Content	Key opportunities for skills development
<p>Life cycle assessments (LCAs) are carried out to assess the environmental impact of products in each of these stages:</p> <ul style="list-style-type: none">• extracting and processing raw materials• manufacturing and packaging• use and operation during its lifetime• disposal at the end of its useful life, including transport and distribution at each stage. <p>Use of water, resources, energy sources and production of some wastes can be fairly easily quantified. Allocating numerical values to pollutant effects is less straightforward and requires value judgements, so LCA is not a purely objective process.</p> <p>Selective or abbreviated LCAs can be devised to evaluate a product but these can be misused to reach pre-determined conclusions, eg in support of claims for advertising purposes.</p> <p>Students should be able to carry out simple comparative LCAs for shopping bags made from plastic and paper.</p>	<p>WS 1.3, 4, 5</p> <p>LCAs should be done as a comparison of the impact on the environment of the stages in the life of a product, and only quantified where data is readily available for energy, water, resources and wastes.</p> <p>Interpret LCAs of materials or products given appropriate information.</p> <p>MS 1a</p> <p>Recognise and use expressions in decimal form.</p> <p>MS 1c</p> <p>Use ratios, fractions and percentages.</p> <p>MS 1d</p> <p>Make estimates of the results of simple calculations.</p> <p>MS 2a</p> <p>Use an appropriate number of significant figures.</p> <p>MS 4a</p> <p>Translate information between graphical and numeric form.</p>

4.10.2.2 Ways of reducing the use of resources

Content	Key opportunities for skills development
<p>The reduction in use, reuse and recycling of materials by end users reduces the use of limited resources, use of energy sources, waste and environmental impacts.</p> <p>Metals, glass, building materials, clay ceramics and most plastics are produced from limited raw materials. Much of the energy for the processes comes from limited resources. Obtaining raw materials from the Earth by quarrying and mining causes environmental impacts.</p> <p>Some products, such as glass bottles, can be reused. Glass bottles can be crushed and melted to make different glass products. Other products cannot be reused and so are recycled for a different use.</p> <p>Metals can be recycled by melting and recasting or reforming into different products. The amount of separation required for recycling depends on the material and the properties required of the final product. For example, some scrap steel can be added to iron from a blast furnace to reduce the amount of iron that needs to be extracted from iron ore.</p> <p>Students should be able to evaluate ways of reducing the use of limited resources, given appropriate information.</p>	

4.10.3 Using materials (chemistry only)

4.10.3.1 Corrosion and its prevention

Content	Key opportunities for skills development
<p>Corrosion is the destruction of materials by chemical reactions with substances in the environment. Rusting is an example of corrosion. Both air and water are necessary for iron to rust.</p> <p>Corrosion can be prevented by applying a coating that acts as a barrier, such as greasing, painting or electroplating. Aluminium has an oxide coating that protects the metal from further corrosion.</p> <p>Some coatings are reactive and contain a more reactive metal to provide sacrificial protection, eg zinc is used to galvanise iron.</p>	
<p>Students should be able to:</p> <ul style="list-style-type: none"> describe experiments and interpret results to show that both air and water are necessary for rusting explain sacrificial protection in terms of relative reactivity. 	<p>WS 2.2, 7, 3.5</p> <p>Investigate the conditions for rusting.</p>

4.10.3.2 Alloys as useful materials

Content	Key opportunities for skills development
<p>Most metals in everyday use are alloys.</p> <p>Bronze is an alloy of copper and tin. Brass is an alloy of copper and zinc.</p> <p>Gold used as jewellery is usually an alloy with silver, copper and zinc. The proportion of gold in the alloy is measured in carats. 24 carat being 100% (pure gold), and 18 carat being 75% gold.</p> <p>Steels are alloys of iron that contain specific amounts of carbon and other metals. High carbon steel is strong but brittle. Low carbon steel is softer and more easily shaped. Steels containing chromium and nickel (stainless steels) are hard and resistant to corrosion.</p> <p>Aluminium alloys are low density.</p>	
<p>Students should be able to:</p> <ul style="list-style-type: none">• recall a use of each of the alloys specified• interpret and evaluate the composition and uses of alloys other than those specified given appropriate information.	<p>MS 1a</p> <p>Recognise and use expressions in decimal form.</p> <p>MS 1c</p> <p>Use ratios, fractions and percentages.</p>

4.10.3.3 Ceramics, polymers and composites

Content	Key opportunities for skills development
<p>Most of the glass we use is soda-lime glass, made by heating a mixture of sand, sodium carbonate and limestone. Borosilicate glass, made from sand and boron trioxide, melts at higher temperatures than soda-lime glass.</p> <p>Clay ceramics, including pottery and bricks, are made by shaping wet clay and then heating in a furnace.</p> <p>The properties of polymers depend on what monomers they are made from and the conditions under which they are made. For example, low density (LD) and high density (HD) poly(ethene) are produced from ethene.</p> <p>Thermosoftening polymers melt when they are heated. Thermosetting polymers do not melt when they are heated.</p> <p>Students should be able to:</p> <ul style="list-style-type: none"> • explain how low density and high density poly(ethene) are both produced from ethene • explain the difference between thermosoftening and thermosetting polymers in terms of their structures. <p>Most composites are made of two materials, a matrix or binder surrounding and binding together fibres or fragments of the other material, which is called the reinforcement.</p> <p>Students should be able to recall some examples of composites.</p>	
<p>Students should be able to, given appropriate information:</p> <ul style="list-style-type: none"> • compare quantitatively the physical properties of glass and clay ceramics, polymers, composites and metals • explain how the properties of materials are related to their uses and select appropriate materials. 	<p>WS 1.4, 3.5, 3.8</p> <p>Compare the properties of thermosetting and thermosoftening polymers.</p>

4.10.4 The Haber process and the use of NPK fertilisers (chemistry only)

4.10.4.1 The Haber process

Content	Key opportunities for skills development
<p>The Haber process is used to manufacture ammonia, which can be used to produce nitrogen-based fertilisers.</p> <p>The raw materials for the Haber process are nitrogen and hydrogen.</p> <p>Students should be able to recall a source for the nitrogen and a source for the hydrogen used in the Haber process.</p> <p>The purified gases are passed over a catalyst of iron at a high temperature (about 450°C) and a high pressure (about 200 atmospheres). Some of the hydrogen and nitrogen reacts to form ammonia. The reaction is reversible so some of the ammonia produced breaks down into nitrogen and hydrogen:</p> $\text{nitrogen} + \text{hydrogen} \rightleftharpoons \text{ammonia}$ <p>On cooling, the ammonia liquefies and is removed. The remaining hydrogen and nitrogen are recycled.</p>	<p>MS 1a</p> <p>Recognise and use expressions in decimal form.</p> <p>MS 1c</p> <p>Use ratios, fractions and percentages.</p>
<p>(HT only) Students should be able to:</p> <ul style="list-style-type: none">interpret graphs of reaction conditions versus rate	<p>MS 1a</p> <p>Recognise and use expressions in decimal form.</p> <p>MS 1c</p> <p>Use ratios, fractions and percentages.</p>
<ul style="list-style-type: none">apply the principles of dynamic equilibrium in Reversible reactions and dynamic equilibrium (page 59) to the Haber processexplain the trade-off between rate of production and position of equilibriumexplain 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.	<p>WS 3.5, 3.8</p>

4.10.4.2 Production and uses of NPK fertilisers

Content	Key opportunities for skills development
<p>Compounds of nitrogen, phosphorus and potassium are used as fertilisers to improve agricultural productivity. NPK fertilisers contain compounds of all three elements.</p> <p>Industrial production of NPK fertilisers can be achieved using a variety of raw materials in several integrated processes. NPK fertilisers are formulations of various salts containing appropriate percentages of the elements.</p> <p>Ammonia can be used to manufacture ammonium salts and nitric acid.</p> <p>Potassium chloride, potassium sulfate and phosphate rock are obtained by mining, but phosphate rock cannot be used directly as a fertiliser.</p> <p>Phosphate rock is treated with nitric acid or sulfuric acid to produce soluble salts that can be used as fertilisers.</p> <p>Students should be able to:</p> <ul style="list-style-type: none"> recall the names of the salts produced when phosphate rock is treated with nitric acid, sulfuric acid and phosphoric acid compare the industrial production of fertilisers with laboratory preparations of the same compounds, given appropriate information. 	<p>AT 4</p> <p>Prepare an ammonium salt.</p>

4.11 Key ideas

The complex and diverse phenomena of the natural world can be described in terms of a small number of key ideas in chemistry.

These key ideas are of universal application, and we have embedded them throughout the subject content. They underpin many aspects of the science assessment and will therefore be assessed across all papers.

These ideas include:

- matter is composed of tiny particles called atoms and there are about 100 different naturally occurring types of atoms called elements
- elements show periodic relationships in their chemical and physical properties
- these periodic properties can be explained in terms of the atomic structure of the elements
- atoms bond by either transferring electrons from one atom to another or by sharing electrons
- the shapes of molecules (groups of atoms bonded together) and the way giant structures are arranged is of great importance in terms of the way they behave

-
- there are barriers to reaction so reactions occur at different rates
 - chemical reactions take place in only three different ways:
 - proton transfer
 - electron transfer
 - electron sharing
 - energy is conserved in chemical reactions so can therefore be neither created or destroyed.

5 Scheme of assessment

Find past papers and mark schemes, and specimen papers for new courses, on our website at aqa.org.uk/pastpapers

This specification is designed to be taken over two years.

This is a linear qualification. In order to achieve the award, students must complete all assessments at the end of the course and in the same series.

GCSE exams and certification for this specification are available for the first time in May/June 2018 and then every May/June for the life of the specification.

All materials are available in English only.

Our GCSE exams in Chemistry include questions that allow students to demonstrate:

- their knowledge and understanding of the content developed in one section or topic, including the associated mathematical and practical skills or
- their ability to apply mathematical and practical skills to areas of content they are not normally developed in or
- their ability to draw together different areas of knowledge and understanding within one answer.

A range of question types will be used, including multiple choice, short answer and those that require extended responses. Extended response questions will be of sufficient length to allow students to demonstrate their ability to construct and develop a sustained line of reasoning which is coherent, relevant, substantiated and logically structured. Extended responses may be prose, extended calculations, or a combination of both, as appropriate to the question.

5.1 Aims and learning outcomes

Chemistry should be taught in progressively greater depth over the course of Key Stage 3 and Key Stage 4. GCSE outcomes may reflect or build upon subject content which is typically taught at Key Stage 3. There is no expectation that teaching of such content should be repeated during the GCSE course where it has already been covered at an earlier stage.

GCSE study in chemistry provides the foundations for understanding the material world. Scientific understanding is changing our lives and is vital to the world's future prosperity, and all students should be taught essential aspects of the knowledge, methods, processes and uses of science. They should be helped to appreciate how the complex and diverse phenomena of the natural world can be described in terms of a small number of key ideas relating to the sciences which are both inter-linked, and are of universal application. These key ideas include:

- the use of conceptual models and theories to make sense of the observed diversity of natural phenomena
- the assumption that every effect has one or more cause
- that change is driven by differences between different objects and systems when they interact
- that many such interactions occur over a distance without direct contact

- that science progresses through a cycle of hypothesis, practical experimentation, observation, theory development and review
- that quantitative analysis is a central element both of many theories and of scientific methods of inquiry.

These key ideas are relevant in different ways and with different emphases in biology, chemistry and physics: examples of their relevance to chemistry are given below.

The GCSE specification in chemistry should enable students to:

- develop scientific knowledge and conceptual understanding through chemistry
- develop understanding of the nature, processes and methods of science through different types of scientific enquiries that help them to answer scientific questions about the world around them
- develop and learn to apply observational, practical, modelling, enquiry and problem-solving skills, both in the laboratory, in the field and in other learning environments
- develop their ability to evaluate claims based on chemistry through critical analysis of the methodology, evidence and conclusions, both qualitatively and quantitatively.

Chemistry should be studied in ways that help students to develop curiosity about the natural world, insight into how science works, and appreciation of its relevance to their everyday lives. The scope and nature of such study should be broad, coherent, practical and satisfying, and thereby encourage students to be inspired, motivated and challenged by the subject and its achievements.

5.2 Assessment objectives

Assessment objectives (AOs) are set by Ofqual and are the same across all GCSE Chemistry specifications and all exam boards.

The exams will measure how students have achieved the following assessment objectives.

- AO1: Demonstrate knowledge and understanding of: scientific ideas; scientific techniques and procedures.
- AO2: Apply knowledge and understanding of: scientific ideas; scientific enquiry, techniques and procedures.
- AO3: Analyse information and ideas to: interpret and evaluate; make judgments and draw conclusions; develop and improve experimental procedures.

5.2.1 Assessment objective weightings for GCSE Chemistry

Assessment objectives (AOs)	Component weightings (approx %)		Overall weighting (approx %)
	Paper 1	Paper 2	
AO1	37–43	37–43	40
AO2	37–43	37–43	40
AO3	17–23	17–23	20
Overall weighting of components	50	50	100

5.3 Assessment weightings

The marks awarded on the papers will be scaled to meet the weighting of the components. Students' final marks will be calculated by adding together the scaled marks for each component. Grade boundaries will be set using this total scaled mark. The scaling and total scaled marks are shown in the table below.

Component	Maximum raw mark	Scaling factor	Maximum scaled mark
Paper 1	100	x1	100
Paper 2	100	x1	100
Total scaled mark:			200

6 General administration

You can find information about all aspects of administration, as well as all the forms you need, at aqa.org.uk/examsadmin

6.1 Entries and codes

You only need to make one entry for each qualification – this will cover all the question papers, non-exam assessment and certification.

Every specification is given a national discount (classification) code by the Department for Education (DfE), which indicates its subject area.

If a student takes two specifications with the same discount code:

- further and higher education providers are likely to take the view that they have only achieved one of the two qualifications
- only one of them will be counted for the purpose of the *School and College Performance tables* – the DfE's rules on 'early entry' will determine which one.

Please check this before your students start their course.

Qualification title	Tier	AQA entry code	DfE discount code
AQA GCSE in Chemistry	Foundation	8462F	TBC
	Higher	8462H	TBC

This specification complies with:

- Ofqual *General conditions of recognition* that apply to all regulated qualifications
- Ofqual GCSE qualification level conditions that apply to all GCSEs
- Ofqual GCSE subject level conditions that apply to all GCSEs in this subject
- all other relevant regulatory documents.

The Ofqual qualification accreditation number (QAN) is 601/8757/8.

6.2 Overlaps with other qualifications

There are no overlaps with any other AQA qualifications at this level.

6.3 Awarding grades and reporting results

The qualification will be graded on a nine-point scale: 1–9 – where 9 is the best grade.

A student taking Foundation Tier assessments will be awarded a grade within the range of 1 to 5. Students who fail to reach the minimum standard for grade 1 will be recorded as U (unclassified) and will not receive a qualification certificate.

A student taking Higher Tier assessments will be awarded a grade within the range of 4 to 9. A student sitting the Higher Tier who just fails to achieve grade 4 will be awarded an allowed grade 3. Students who fail to reach the minimum standard for the allowed grade 3 will be recorded as U (unclassified) and will not receive a qualification certificate.

6.4 Resits and shelf life

Students can resit the qualification as many times as they wish, within the shelf life of the qualification.

6.5 Previous learning and prerequisites

There are no previous learning requirements. Any requirements for entry to a course based on this specification are at the discretion of schools and colleges.

6.6 Access to assessment: diversity and inclusion

General qualifications are designed to prepare students for a wide range of occupations and further study. Therefore our qualifications must assess a wide range of competences.

The subject criteria have been assessed to see if any of the skills or knowledge required present any possible difficulty to any students, whatever their ethnic background, religion, sex, age, disability or sexuality. If any difficulties were encountered, the criteria were reviewed again to make sure that tests of specific competences were only included if they were important to the subject.

As members of the Joint Council for Qualifications (JCQ) we participate in the production of the JCQ document *Access Arrangements and Reasonable Adjustments: General and Vocational qualifications*. We follow these guidelines when assessing the needs of individual students who may require an access arrangement or reasonable adjustment. This document is published on the JCQ website at jcq.org.uk

6.6.1 Students with disabilities and special needs

We can make arrangements for disabled students and students with special needs to help them access the assessments, as long as the competences being tested are not changed. Access arrangements must be agreed **before** the assessment. For example, a Braille paper would be a reasonable adjustment for a Braille reader but not for a student who does not read Braille.

We are required by the Equality Act 2010 to make reasonable adjustments to remove or lessen any disadvantage that affects a disabled student.

If you have students who need access arrangements or reasonable adjustments, you can apply using the Access arrangements online service at aqa.org.uk/eaqa

6.6.2 Special consideration

We can give special consideration to students who have been disadvantaged at the time of the assessment through no fault of their own – for example a temporary illness, injury or serious problem such as the death of a relative. We can only do this **after** the assessment.

Your exams officer should apply online for special consideration at aqa.org.uk/eaqa

For more information and advice about access arrangements, reasonable adjustments and special consideration please see aqa.org.uk/access or email accessarrangementsqueries@aqa.org.uk

6.7 Working with AQA for the first time

If your school or college has not previously offered any AQA specification, you need to register as an AQA centre to offer our specifications to your students. Find out how at aqa.org.uk/becomeacentre

6.8 Private candidates

A private candidate is someone who enters for exams through an AQA-approved school or college but is not enrolled as a student there.

If you are a private candidate you may be self-taught, home-schooled or have private tuition, with a tutor or distance learning organisation. You must be based in the UK.

All GCSE science students need to complete practical experiments as part of their learning. A minimum of eight experiments are required for single science qualifications and 16 for double science qualifications. This equips students with essential practical knowledge and experiences, enables them to put theory into practice and helps them develop skills for higher education.

Private candidates wishing to study GCSE sciences need to find a school or college who will let them carry out the required practicals. Schools and colleges accepting private candidates must make provision for them to carry out all of the required practical activities as specified in [Practical assessment](#) (page 101). This is likely to incur a cost. We recommend you contact your local schools and colleges to organise this as early as possible.

Students won't be assessed whilst conducting their practical work, but the written exam will include questions on it. Therefore, candidates lacking hands on experience will be at an immediate disadvantage.

If you have any queries as a private candidate, you can:

- speak to the exams officer at the school or college where you intend to take your exams
- visit our website at aqa.org.uk/exams-administration
- email: privatecandidates@aqa.org.uk

7 Mathematical requirements

Students will be required to demonstrate the following mathematics skills in GCSE Chemistry assessments. Questions will target maths skills at a level of demand appropriate to each subject. In Foundation Tier papers questions assessing maths requirements will not be lower than that expected at Key Stage 3 (as outlined in *Mathematics Programmes of Study: Key Stage 3*, by the DfE, document reference DFE-00179-2013). In Higher Tier papers questions assessing maths requirements will not be lower than that of questions and tasks in assessments for the Foundation Tier in a GCSE Qualification in Mathematics.

1	Arithmetic and numerical computation
a	Recognise and use expressions in decimal form
b	Recognise and use expressions in standard form
c	Use ratios, fractions and percentages
d	Make estimates of the results of simple calculations

2	Handling data
a	Use an appropriate number of significant figures
b	Find arithmetic means
c	Construct and interpret frequency tables and diagrams, bar charts and histograms
h	Make order of magnitude calculations

3	Algebra
a	Understand and use the symbols: =, <, <<, >>, >, ∞ , ~
b	Change the subject of an equation
c	Substitute numerical values into algebraic equations using appropriate units for physical quantities

4	Graphs
a	Translate information between graphical and numeric form
b	Understand that $y = mx + c$ represents a linear relationship
c	Plot two variables from experimental or other data
d	Determine the slope and intercept of a linear graph
e	Draw and use the slope of a tangent to a curve as a measure of rate of change

5	Geometry and trigonometry
b	Visualise and represent 2D and 3D forms including two dimensional representations of 3D objects
c	Calculate areas of triangles and rectangles, surface areas and volumes of cubes

Mathematical skills references are taken from the DfE subject criteria. Where there is a break in a sequence, the 'missing' references are criteria **not** applicable to GCSE Chemistry and have been deliberately omitted from this list.

8 Practical assessment

Practical work is at the heart of chemistry, so we have placed it at the heart of this specification.

There are three interconnected, but separate reasons for doing practical work in schools. They are:

1. To support and consolidate scientific concepts (knowledge and understanding).

This is done by applying and developing what is known and understood of abstract ideas and models. Through practical work we are able to make sense of new information and observations, and provide insights into the development of scientific thinking.

2. To develop investigative skills. These transferable skills include:

- devising and investigating testable questions
- identifying and controlling variables
- analysing, interpreting and evaluating data.

3. To build and master practical skills such as:

- using specialist equipment to take measurements
- handling and manipulating equipment with confidence and fluency
- recognising hazards and planning how to minimise risk.

By focusing on the reasons for carrying out a particular practical, teachers will help their students understand the subject better, to develop the skills of a scientist and to master the manipulative skills required for further study or jobs in STEM subjects.

Questions in the written exams will draw on the knowledge and understanding students have gained by carrying out the practical activities listed below. These questions will count for at least 15% of the overall marks for the qualification. Many of our questions will also focus on investigative skills and how well students can apply what they know to practical situations often in novel contexts.

The practical handbook will help teachers plan purposeful practical work that develops both practical and investigative skills and encourages the thinking behind the doing so that they can reach their potential.

Teachers are encouraged to further develop students' abilities by providing other opportunities for practical work throughout the course. Opportunities are signposted in the right-hand column of the content section of this specification for further skills development.

Our chemistry scheme of work will provide ideas and suggestions for good practical activities that are manageable with large classes.

8.1 Use of apparatus and techniques

All students are expected to have carried out the required practical activities in [Required practical activities](#) (page 102).

The following list includes opportunities for choice and use of appropriate laboratory apparatus for a variety of experimental problem-solving and/or enquiry-based activities.

Safety is an overriding requirement for all practical work. Schools and colleges are responsible for ensuring that appropriate safety procedures are followed whenever their students undertake practical work, and should undertake full risk assessments.

Use and production of appropriate scientific diagrams to set up and record apparatus and procedures used in practical work is common to all science subjects and should be included wherever appropriate.

AT 1–7 are common with combined science. AT 8 is chemistry only.

Apparatus and techniques	
AT 1	Use of appropriate apparatus to make and record a range of measurements accurately, including mass, time, temperature, and volume of liquids and gases (links to A-level AT a).
AT 2	Safe use of appropriate heating devices and techniques including use of a Bunsen burner and a water bath or electric heater (links to A-level AT b).
AT 3	Use of appropriate apparatus and techniques for conducting and monitoring chemical reactions, including appropriate reagents and/or techniques for the measurement of pH in different situations (links to A-level AT a and d).
AT 4	Safe use of a range of equipment to purify and/or separate chemical mixtures including evaporation, filtration, crystallisation, chromatography and distillation (links to A-level AT d and g).
AT 5	Making and recording of appropriate observations during chemical reactions including changes in temperature and the measurement of rates of reaction by a variety of methods such as production of gas and colour change (links to A-level AT a and l).
AT 6	Safe use and careful handling of gases, liquids and solids, including careful mixing of reagents under controlled conditions, using appropriate apparatus to explore chemical changes and/or products (links to A-level AT a and k).
AT 7	Use of appropriate apparatus and techniques to draw, set up and use electrochemical cells for separation and production of elements and compounds (links to A-level AT d and j).
AT 8 (chemistry only)	Use of appropriate qualitative reagents and techniques to analyse and identify unknown samples or products including gas tests, flame tests, precipitation reactions, and the determination of concentrations of strong acids and strong alkalis (links to A-level AT d).

8.2 Required practical activities

The following practical activities must be carried out by all students taking GCSE Chemistry.

Following any revision by the Secretary of State of the apparatus or techniques specified, we will review and revise the required practical activities as appropriate.

Schools and colleges will be informed of any changes in a timely manner and the amended specification will be published highlighting the changes accordingly.

Teachers are encouraged to vary their approach to these practical activities. Some are more suitable for highly structured approaches that develop key techniques while others allow opportunities for students to develop investigative approaches.

This list is not designed to limit the practical activities carried out by students. A rich practical experience will include more than the eight required practical activities. The explicit teaching of practical skills will build students' competence. Many teachers will also use practical approaches to introduce content knowledge in the course of their normal teaching.

Schools and colleges are required to provide a practical science statement to AQA, that is a true and accurate written statement, which confirms that it has taken reasonable steps to secure that each student has:

- completed the required practical activities as detailed in this specification
- made a contemporaneous record of such work undertaken during the activities and the knowledge, skills and understanding derived from those activities.

We will provide a form for the head of centre to sign. You must submit the form to us by the date published at aqa.org.uk/science. We will contact schools and colleges directly with the deadline date and send timely reminders if the form is not received. Failure to send this form counts as malpractice/maladministration, and may result in formal action or warning for the school or college.

Practicals 1, 3, 4, 5, 6 and 8 are common with GCSE Combined Science: Trilogy and GCSE Combined Science: Synergy. Practical 2 and 7 are GCSE Chemistry only.

8.2.1 Required practical activity 1

Preparation of a pure, dry sample of a soluble salt from an insoluble oxide or carbonate, using a Bunsen burner to heat dilute acid and a water bath or electric heater to evaporate the solution.

Apparatus and techniques

In doing this practical students should cover these parts of the apparatus and techniques requirements.

AT 2 – safe use of appropriate heating devices and techniques including use of a Bunsen burner and a water bath or electric heater.

AT 3 – use of appropriate apparatus and techniques for conducting chemical reactions, including appropriate reagents.

AT 4 – safe use of a range of equipment to purify and/or separate chemical mixtures including evaporation, filtration, crystallisation.

AT 6 – safe use and careful handling of liquids and solids, including careful mixing of reagents under controlled conditions.

Key opportunities for skills development

In doing this practical there are key opportunities for students to develop the following skills.

WS 2.3 – apply a knowledge of a range of techniques, instruments, apparatus, and materials to select those appropriate to the experiment.

WS 2.4 – carry out experiments appropriately having due regard for the correct manipulation of apparatus, the accuracy of measurements and health and safety considerations.

8.2.2 Required practical activity 2

(Chemistry only) determination of the reacting volumes of solutions of a strong acid and a strong alkali by titration.

(HT only) determination of the concentration of one of the solutions in mol/dm³ and g/dm³ from the reacting volumes and the known concentration of the other solution.

Apparatus and techniques

In doing this practical students should cover these parts of the apparatus and techniques requirements.

AT 1 – use of appropriate apparatus to make and record a range of measurements accurately, including volume of liquids.

AT 8 – the determination of concentrations of strong acids and strong alkalis.

Key opportunities and skills development

WS 2.4 – carry out experiments appropriately having due regard for the correct manipulation of apparatus, the accuracy of measurements and health and safety considerations.

WS 2.6 – make and record observations and measurements using a range of apparatus and methods.

MS 1a – recognise and use expressions in decimal form.

MS 1c – use ratios, fractions and percentages.

MS 2a – use an appropriate number of significant figures.

8.2.3 Required practical activity 3

Investigate what happens when aqueous solutions are electrolysed using inert electrodes. This should be an investigation involving developing a hypothesis.

Apparatus and techniques

In doing this practical students should cover these parts of the apparatus and techniques requirements.

AT 3 – use of appropriate apparatus and techniques for conducting and monitoring chemical reactions.

AT 7 – use of appropriate apparatus and techniques to draw, set up and use electrochemical cells for separation and production of elements and compounds.

AT 8 – use of appropriate qualitative reagents and techniques to analyse and identify unknown samples or products including gas tests for hydrogen, oxygen and chlorine.

Key opportunities and skills development

In doing this practical there are key opportunities for students to develop the following skills.

WS 2.1 – use scientific theories and explanations to develop hypotheses.

WS 2.2 – plan experiments or devise procedures to make observations, produce or characterise a substance, test hypotheses, check data or explore phenomena.

WS 2.3 – apply a knowledge of a range of techniques, instruments, apparatus, and materials to select those appropriate to the experiment.

WS 2.4 – carry out experiments appropriately having due regard for the correct manipulation of apparatus, the accuracy of measurements and health and safety considerations.

WS 2.6 – make and record observations and measurements using a range of apparatus and methods.

8.2.4 Required practical activity 4

Investigate the variables that affect temperature changes in reacting solutions such as, eg acid plus metals, acid plus carbonates, neutralisations, displacement of metals.

Apparatus and techniques

In doing this practical students should cover these parts of the apparatus and techniques requirements.

AT 1 – use of appropriate apparatus to make and record a range of measurements accurately, including mass, temperature, and volume of liquids.

AT 3 – use of appropriate apparatus and techniques for conducting and monitoring chemical reactions.

AT 5 – making and recording of appropriate observations during chemical reactions including changes in temperature.

AT 6 – safe use and careful handling of gases, liquids and solids, including careful mixing of reagents under controlled conditions, using appropriate apparatus to explore chemical changes.

Key opportunities and skills development

In doing this practical there are key opportunities for students to develop the following skills.

WS 2.1 – use scientific theories and explanations to develop hypotheses.

WS 2.2 – plan experiments or devise procedures to make observations, produce or characterise a substance, test hypotheses, check data or explore phenomena.

WS 2.3 – apply a knowledge of a range of techniques, instruments, apparatus, and materials to select those appropriate to the experiment.

WS 2.4 – carry out experiments appropriately having due regard for the correct manipulation of apparatus, the accuracy of measurements and health and safety considerations.

WS 2.6 – make and record observations and measurements using a range of apparatus and methods.

WS 2.7 – evaluate methods and suggest possible improvements and further investigations.

MS 1a – recognise and use expressions in decimal form.

MS 2a – use an appropriate number of significant figures.

MS 2b – find arithmetic means.

MS 4a – translate information between graphical and numeric form.

MS 4c – plot two variables from experimental or other data.

8.2.5 Required practical activity 5

Investigate how changes in concentration affect the rates of reactions by a method involving measuring the volume of a gas produced and a method involving a change in colour or turbidity. This should be an investigation involving developing a hypothesis.

Apparatus and techniques

In doing this practical students should cover these parts of the apparatus and techniques requirements.

AT 1 – use of appropriate apparatus to make and record a range of measurements accurately, including mass, time, temperature, and volume of liquids and gases.

AT 3 – use of appropriate apparatus and techniques for conducting and monitoring chemical reactions.

AT 5 – making and recording of appropriate observations during chemical reactions including the measurement of rates of reaction by a variety of methods such as production of gas and colour change.

AT 6 – safe use and careful handling of gases, liquids and solids, including careful mixing of reagents under controlled conditions, using appropriate apparatus to explore chemical changes.

Key opportunities for skills development

In doing this practical there are key opportunities for students to develop the following skills.

WS 2.1 – use scientific theories and explanations to develop hypotheses.

WS 2.2 – plan experiments or devise procedures to make observations, produce or characterise a substance, test hypotheses, check data or explore phenomena.

WS 2.3 – apply a knowledge of a range of techniques, instruments, apparatus, and materials to select those appropriate to the experiment.

WS 2.4 – carry out experiments appropriately having due regard for the correct manipulation of apparatus, the accuracy of measurements and health and safety considerations.

WS 2.6 – make and record observations and measurements using a range of apparatus and methods.

WS 2.7 – evaluate methods and suggest possible improvements and further investigations.

MS 1a – recognise and use expressions in decimal form.

MS 1c – use ratios, fractions and percentages.

MS 1d – make estimates of the results of simple calculations.

MS 2a – use an appropriate number of significant figures.

MS 2b – find arithmetic means.

MS 4a – translate information between graphical and numeric form.

MS 4b – understand that $y = mx + c$ represents a linear relationship.

MS 4c – plot two variables from experimental or other data.

MS 4d – determine the slope and intercept of a linear graph.

MS 4e – draw and use the slope of a tangent to a curve as a measure of rate of change.

8.2.6 Required practical activity 6

Investigate how paper chromatography can be used to separate and tell the difference between coloured substances. Students should calculate R_f values.

Apparatus and techniques

In doing this practical students should cover these parts of the apparatus and techniques requirements.

AT 1 – use of appropriate apparatus to make and record a range of measurements accurately.

AT 4 – safe use of a range of equipment to purify and/or separate chemical mixtures including chromatography.

Key opportunities for skills development

In doing this practical there are key opportunities for students to develop the following skills.

WS 2.4 – carry out experiments appropriately having due regard for the correct manipulation of apparatus, the accuracy of measurements and health and safety considerations.

WS 2.6 – make and record observations and measurements using a range of apparatus and methods.

8.2.7 Required practical activity 7

Use of chemical tests to identify the ions in unknown single ionic compounds covering the ions from sections [Flame tests](#) (page 73) through to [Sulfates](#) (page 74).

Apparatus and techniques

In doing this practical students should cover these parts of the apparatus and techniques requirements.

AT 2 – safe use of a Bunsen burner.

AT 8 – use of appropriate qualitative reagents and techniques to analyse and identify unknown samples or products including gas tests, flame tests, precipitation reactions.

Key opportunities for skills development

In doing this practical there are key opportunities for students to develop the following skills.

WS 2.4 – carry out experiments appropriately having due regard for the correct manipulation of apparatus, the accuracy of measurements and health and safety considerations.

WS 2.6 – make and record observations and measurements using a range of apparatus and methods.

8.2.8 Required practical activity 8

Analysis and purification of water samples from different sources, including pH, dissolved solids and distillation.

Apparatus and techniques

In doing this practical students should cover these parts of the apparatus and techniques requirements.

AT 2 – safe use of appropriate heating devices and techniques including use of a Bunsen burner and a water bath or electric heater.

AT 3 – use of appropriate apparatus and techniques for the measurement of pH in different situations.

AT 4 – safe use of a range of equipment to purify and/or separate chemical mixtures including evaporation, distillation.

Key opportunities and skills development

In doing this practical there are key opportunities for students to develop the following skills.

WS 2.3 – apply a knowledge of a range of techniques, instruments, apparatus, and materials to select those appropriate to the experiment.

WS 2.4 – carry out experiments appropriately having due regard for the correct manipulation of apparatus, the accuracy of measurements and health and safety considerations.

WS 2.5 – recognise when to apply a knowledge of sampling techniques to ensure any samples collected are representative.

WS 2.6 – make and record observations and measurements using a range of apparatus and methods.

WS 2.7 – evaluate methods and suggest possible improvements and further investigations.

9 Appendix A: periodic table

The periodic table has been updated to take into account recent developments.

1 2 3 4 5 6 7 0

1	H	hydrogen	1
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Key

		relative atomic mass		atomic symbol		name		atomic (proton) number			
7	Li	lithium	3	9	Be	beryllium	4	20	Ne	neon	10
23	Na	sodium	11	24	Mg	magnesium	12	31	P	phosphorus	15
39	K	potassium	19	40	Ca	calcium	20	59	Co	cobalt	27
85	Rb	rubidium	37	88	Sr	strontium	38	56	Fe	iron	26
133	Cs	caesium	55	137	Ba	barium	56	55	Mn	manganese	25
								48	Ti	titanium	22
								91	Zr	zirconium	40
								45	Sc	scandium	21
								89	Y	yttrium	39
								178	Hf	hafnium	72
								181	Ta	tantalum	73
								184	W	tungsten	74
								186	Re	rhenium	75
								190	Os	osmium	76
								192	Ir	iridium	77
								195	Pt	platinum	78
								197	Au	gold	79
								201	Hg	mercury	80
								204	Tl	thallium	81
								207	Pb	lead	82
								209	Bi	bismuth	83
								212	Po	polonium	84
								216	At	astatine	85
								222	Rn	radon	86
								228	Fr	francium	87
								226	Ra	radium	88
								227	Ac*	actinium	89
								232	Th	thorium	90
								231	Pa	protactinium	91
								238	U	uranium	92
								238	Np	neptunium	93
								237	Pu	plutonium	94
								244	Am	americium	95
								243	Cm	curium	96
								250	Bk	berkelium	97
								251	Cf	californium	98
								257	Es	einsteinium	99
								261	Fm	fermium	100
								267	Mn	mendelevium	101
								271	Nh	nihonium	102
								285	Fl	flerovium	114
								289	Uup	ununpentium	115
								293	Lv	liveonium	116
								294	Uus	ununseptium	117
								294	Uuo	ununoctium	118

* The Lanthanides (atomic numbers 58 – 71) and the Actinides (atomic numbers 90 – 103) have been omitted.
Relative atomic masses for **Cu** and **Cl** have not been rounded to the nearest whole number.

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