Realising potential

GCSE COMBINED SCIENCE: SYNERGY

(8465)

Specification

For teaching from September 2016 onwards

For exams in 2018 onwards

Version 1.1 30 September 2019

Contents

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/8465
- We will write to you if there are significant changes to the specification.

1 Introduction

1.1 Why choose AQA for GCSE Combined Science: Synergy

Our philosophy: science for all

We believe that science has something to offer every student, and that everyone needs some level of relevant scientific understanding.

That's why we have a suite of science qualifications for Key Stage 4 – so that students of all abilities and all aspirations can realise their potential.

Two sections for two teachers

Teachers have told us that:

- many schools organise their curriculum drawing on the experience of two teachers
- science teachers tend to be more confident around either the life sciences or the physical sciences
- science learning is enriched when teaching draws on different areas that can be naturally linked together.

We have divided the content into two main sections, which contain connections between areas of biology, physics and chemistry that sit together as part of good science.

Life and environmental sciences (4.1–4.4)

- 4.1 Building blocks: from atoms to cells, behaviour and transport on the small scale.
- 4.2 Transport over larger distances: systems in animals and plants and how these systems interact.
- 4.3 Interactions with the environment: the effects of factors in the environment on organisms, how our choices affect our health.
- 4.4 Explaining change: how organisms, species, living and non-living systems change over time.

Physical sciences (4.5–4.8)

- 4.5 Building blocks for understanding: organising, patterns, properties and analysis.
- 4.6 Interactions over small and large distances: strong and weak forces between atoms, molecules and larger structures and how they interact.
- 4.7 Movement and interactions: rates of change of motion and direction of large and small objects, and chemical changes.
- 4.8 Guiding Spaceship Earth towards a sustainable future: resources of materials and energy.

Both sections include topics that draw together and apply key concepts. Examples in Life and environmental sciences include Radiation and risk (page 55) and The Earth's atmosphere (page 67). In these topics, earlier work on atomic structure, waves and electromagnetic radiation is used to explain the effects of different types of radiation on human tissues and on the climate. An example in Physical sciences is Resources of materials and energy (page 141), which introduces life cycle assessment as a way of evaluating the impacts of using materials and energy to manufacture useful products.

Inspire students with rich practical activities

There's no better way to learn about science than through purposeful practical activities as part of day-to-day teaching and learning. Our 21 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 Mathematics 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 about all our Combined Science: Synergy qualifications at 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/8465 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/8465 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

For information about results, including maintaining standards over time, grade boundaries and our post-results services, visit aqa.org.uk/results

Keep your skills up-to-date with professional development

Wherever you are in your career, there's always something new to learn. As well as subject-specific training, we offer a range of courses to help boost your skills.

- Improve your teaching skills in areas including differentiation, teaching literacy and meeting Ofsted requirements.
- Prepare for a new role with our leadership and management courses.

You can attend a course at venues around the country, in your school or online – whatever suits your needs and availability. Find out more at coursesandevents.aqa.org.uk

Help and support available

Visit our website for information, guidance, support and resources at aqa.org.uk/8465

If you'd like us to share news and information about this qualification, sign up for emails and updates at aqa.org.uk/keepinformedscience

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

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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

2.2 Assessments

Paper 1
What's assessed Life and environmental sciences Topics 4.1–4.4: Building blocks; Transport over larger distances; Interactions with the environment and Explaining change.
How it's assessed • Written exam: 1 hour 45 minutes • Foundation or Higher Tier • 100 marks • 25% of GCSE
Questions Multiple choice, structured, closed and open short answer questions, with greater emphasis on knowledge and application (AO1 and AO2) than analysis and evaluation (AO3).

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Paper 2
What's assessed Life and environmental sciences Topics 4.1–4.4: Building blocks; Transport over larger distances; Interactions with the environment and Explaining change.
How it's assessed • Written exam: 1 hour 45 minutes • Foundation and Higher Tier • 100 marks • 25% of GCSE
Questions Multiple choice, structured, closed and open short answer questions. This paper assesses most of the analysis and evaluation (AO3) skills, and most of the work on the required practicals, for the topics.

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Paper 3
What's assessed Physical sciences Topics 4.5–4.8: Building blocks for understanding; Interactions over small and large distances; Movement and interactions and Guiding Spaceship Earth towards a sustainable future.
How it's assessed • Written exam: 1 hour 45 minutes • Foundation and Higher Tier • 100 marks • 25% of GCSE
Questions Multiple choice, structured, closed and open short answer questions, with greater emphasis on knowledge and application (AO1 and AO2) than analysis and evaluation (AO3).

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Paper 4
What's assessed Physical sciences Topics 4.5–4.8: Building blocks for understanding; Interactions over small and large distances; Movement and interactions and Guiding Spaceship Earth towards a sustainable future.
How it's assessed • Written exam: 1 hour 45 minutes • Foundation and Higher Tier • 100 marks • 25% of GCSE
Questions Multiple choice, structured, closed and open short answer questions. This paper assesses most of the analysis and evaluation (AO3) skills, and most of the work on the required practicals, for the topics.

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.	Give examples to show how scientific methods and theories have changed over time. Explain, with an example, why new data from experiments or observations led to changes in models or theories. Decide whether or not given data supports a particular theory.
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.	Recognise/draw/interpret diagrams. Translate from data to a representation with a model. Use models in explanations, or match features of a model to the data from experiments or observations that the model describes or explains. Make predictions or calculate quantities based on the model or show its limitations. Give examples of ways in which a model can be tested by observation or experiment.

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.	Explain why data is needed to answer scientific questions, and why it may be uncertain, incomplete or not available. Outline a simple ethical argument about the rights and wrongs of a new technology.
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.	Describe and explain specified examples of the technological applications of science. Describe and evaluate, with the help of data, methods that can be used to tackle problems caused by human impacts on the environment.
WS 1.5 Evaluate risks both in practical science and the wider societal context, including perception of risk in relation to data and consequences.	Give examples to show that there are hazards associated with science-based technologies which have to be considered alongside the benefits. 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).
WS 1.6 Recognise the importance of peer review of results and of communicating results to a range of audiences.	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. Explain that reports of scientific developments in the popular media are not subject to peer review and may be oversimplified, inaccurate or biased.

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.	Describe a practical procedure for a specified purpose. Explain why a given practical procedure is well designed for its specified purpose. Explain the need to manipulate and control variables. Identify in a given context: • 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. Apply understanding of apparatus and techniques to suggest a procedure for a specified purpose.
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.	Identify the main hazards in specified practical contexts. Suggest methods of reducing the risk of harm in practical contexts.
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.	Assess whether sufficient, precise measurements have been taken in an experiment. Evaluate methods with a view to determining whether or not they are valid.

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: • 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
WS 3.7 Being objective, evaluating data in terms of accuracy, precision, repeatability and reproducibility and identifying potential sources of random and systematic error.	Apply the following ideas to evaluate data to suggest improvements to procedures and techniques. • 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.
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.	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.

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

4 Subject content

The specification is presented in a three-column format.

The left-hand column includes all the Department for Education (DfE) combined science content statements. These statements specify the science that students are expected to recall, describe, define, explain or evaluate. Some statements have been edited slightly, where one part of a statement appears in one topic and the rest in another topic.

The middle column indicates the breadth and depth of treatment of the specified science. This column includes the terminology and conventions that students are required to be familiar with. It is the left-hand and middle columns taken together that specify the required science content.

The right-hand column exemplifies opportunities for skills to be developed throughout the course:

- WS refers to skills of Working scientifically (page 13)
- MS refers to the DfE 'Use of Mathematics' statements and the mathematical skills listed in Mathematical requirements (page 157)

Some of the 'discuss' and 'evaluate' statements from the DfE combined science content are included in the right-hand column because they describe skills more than content. All of the DfE 'Use of Mathematics' statements are referenced in the right-hand column against the relevant subject content.

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.

Content of all three columns is assessable. Content of topics 4.1–4.4 will be assessed in Paper 1 and Paper 2. Content of topics 4.5–4.8 will be assessed in Paper 3 and Paper 4.

There are 21 required practicals in this specification. These are listed at appropriate points in the subject content. Within these practicals, AT refers to the list of apparatus and techniques given in Use of apparatus and techniques (page 159).

4.1 Building blocks

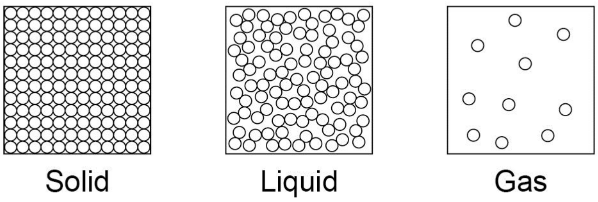
These are the important building blocks for developing scientific ideas and explanations. The topic moves from particles to atoms to cells, showing the links between the world of ideas and the real world of objects and events. The behaviour of particles in liquids and gases can explain how substances move between cells and through membranes. The topic discusses how cells replicate and how the universal genetic code is a particle pattern. The transfer of energy over small and large distances in living and non-living systems helps us to understand the importance of the way these systems react with each other.

4.1.1 States of matter

The model of particles in motion can be used to account for states of matter, differences in density, the pressure of gases, and changes of state. This model is applied in Transport into and out of cells (page 30) to explain how substances are transported into and out of cells through diffusion and osmosis, and in Systems in the human body (page 36), where it is applied to substances crossing exchange surfaces. The nature of the particles (atoms, molecules and ions) is examined in more detail in Atomic structure (page 24) and Structure and bonding (page 98).

There are two required practicals: one to study the density of solid and liquid objects, another to investigate energy transfers by measuring the specific heat capacity of materials.

4.1.1.1 A particle model

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall and explain the main features of the particle model in terms of the states of matter and change of state, distinguishing between physical and chemical changes. (HT only) Explain the limitations of the particle model in relation to changes of state when particles are represented by inelastic spheres.	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. 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.  (HT only) Limitations of the simple model include that there are no forces between the spheres, and that atoms, molecules and ions are not solid spheres.	WS 1.2 Recognise/draw simple diagrams to model the difference between substances in the solid, liquid and gas states. WS 3.5 Predict the states of substances at different temperatures given appropriate data. MS 1d Relate the size and scale of atoms to objects in the physical world.

4.1.1.2 Density

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Define density and explain the differences in density between the different states of matter in terms of the arrangements of the atoms or molecules.	The density of a material is defined by the equation: $density = \frac{mass}{volume}$ $\left[\rho = \frac{m}{V} \right]$ density, ρ, in kilograms per metre cubed, kg/m^3 mass, m, in kilograms, kg volume, V, in metres cubed, m^3	MS 1a, 1b, 1c, 3c Recall and apply this equation to changes where mass is conserved. WS 3.3 Carry out and represent mathematical and statistical analysis. WS 4.3, 4.5 Use and interconvert SI units in calculations.

Required practical activity 1: use appropriate apparatus to make and record the densities of regular and irregular solid objects and liquids. Volume should be determined from the dimensions of a regularly shaped object and by a displacement technique for irregularly shaped objects. Dimensions to be measured using appropriate apparatus such as a ruler, micrometer or Vernier callipers.

AT skills covered by this practical activity: physics AT 1.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in Key opportunities for skills development (page 162).

4.1.1.3 Gas pressure

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain how the motion of the molecules in a gas is related both to its temperature and its pressure: hence explain the relation between the temperature of a gas and its pressure at constant volume (qualitative only).	The molecules of a gas are in constant random motion. The temperature of the gas is related to the average kinetic energy of the molecules. The higher the temperature, the greater the average kinetic energy and so the faster the average speed of the molecules. When the molecules collide with the wall of their container they exert a force on the wall. The total force exerted by all of the molecules inside the container on a unit area of the walls is the gas pressure. Changing the temperature of a gas, held at constant volume, changes the pressure exerted by the gas.	

4.1.1.4 Heating and changes of state

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe how heating a system will change the energy stored within the system and raise its temperature or produce changes of state. Describe how, when substances melt, freeze, evaporate, condense or sublimate, mass is conserved but that these physical changes differ from chemical changes because the material recovers its original properties if the change is reversed.	Energy is stored inside a system by the particles (atoms and molecules) that make up the system. This is called internal energy. 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.	This topic links with Structure and bonding. (page 98) WS 3.3 Carry out and represent mathematical and statistical analysis.

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Define the term specific heat capacity and distinguish between it and the term specific latent heat.	The increase in temperature of a system depends on the mass of the substance heated, the type of material and the energy input. The following equation, given on the Physics equations sheet, applies: $change\ in\ thermal\ energy = mass \times specific\ heat\ capacity \times temperature\ change$ $[\Delta E = m\,c\,\Delta\theta]$ change in thermal energy, ΔE, in joules, J mass, m, in kilograms, kg specific heat capacity, c, in joules per kilogram per degree Celsius, J/kg °C temperature change, $\Delta\theta$, in degrees Celsius, °C The specific heat capacity of a substance is the amount of energy required to raise the temperature of one kilogram of the substance by one degree Celsius. The energy needed for a substance to change state is called latent heat. When a change of state occurs, the energy supplied changes the energy stored (internal energy) but not the temperature.	WS 3.5, MS 4a Interpret heating and cooling graphs that include changes of state. WS 4.3, 4.5, MS 1a, 3c, 3d Apply this equation, which is given on the Physics equations sheet, to calculate energy changes when a material is heated or cooled. WS 3.3 Carry out and represent mathematical and statistical analysis.
Describe and calculate the changes in energy involved when a system is changed by heating (in terms of temperature change and specific heat capacity).	The specific latent heat of a substance is the amount of energy required to change the state of one kilogram of the substance with no change in temperature. The following equation, given on the Physics equations sheet, applies: $energy\ for\ a\ change\ of\ state = mass \times specific\ latent\ heat$ $[E = m\,L]$ energy, E, in joules , J mass, m, in kilograms, kg specific latent heat, L, in joules per kilogram, J/kg Specific latent heat of fusion – change of state from solid to liquid. Specific latent heat of vaporisation – change of state from liquid to vapour.	WS 4.3, 4.5, MS 1a, 3c, 3d Apply this equation, which is given on the Physics equations sheet, to calculate energy changes during changes of state.

Required practical activity 2: an investigation to determine the specific heat capacity of one or more materials. The investigation will involve linking the decrease of one energy store (or work done) to the increase in temperature and subsequent increase in thermal energy stored.

AT skills covered by this practical activity: physics AT 1 and 5.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in Key opportunities for skills development (page 163).

4.1.1.5 Meanings of purity

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain what is meant by the purity of a substance, distinguishing between the scientific and everyday use of the term 'pure'.	In chemistry, a pure substance is a single element or compound, not mixed with any other substance. 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. 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.	WS 3.5 Use melting point data to distinguish pure from impure substances.

4.1.2 Atomic structure

The study of atomic structure provides a good opportunity to show how scientific methods and theories develop over time. The model introduced in this topic describes atoms in terms of a central nucleus with protons and neutrons surrounded by electrons in a series of energy levels (shells). The ideas in this topic can account for the existence of isotopes and underpin the study of radioactivity (Radiation and risk (page 55)), chemical bonding (Structure and bonding (page 98)) and the periodic table (The periodic table (page 87)).

4.1.2.1 Scientific models of the atom

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe how and why the atomic model has changed over time.	Stages in the development of atomic models: • Dalton atoms (1804) – spherical atoms that cannot be split up to explain the properties of gases and the formulae of compounds • Plum pudding model (1897) – it was found that the mass of electrons, which had recently been discovered, was very much less than the mass of atoms so they must be sub-atomic particles • the nuclear atom (1911) – an experiment which showed that most of the alpha particles directed at thin gold foil passed through but a few bounced back, suggesting the positive charge was concentrated at the centre of each gold atom • discovery of neutrons in the nucleus (1932) – explained why the mass of atoms was greater than could be accounted for by the mass of the protons. Students are not required to recall dates or the names of scientists.	WS 1.1 Explain, with examples, why new data from experiments or observations led to changes in atomic models. Decide whether or not given data supports a particular theory.

4.1.2.2 The size of atoms

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall the typical size (order of magnitude) of atoms and small molecules.	Atoms are very small, having a radius of about 0.1 nm (1 x 10^{-10} m). The radius of a small molecule such as methane, CH_4, is about 0.5 nm (5 x 10^{-10} m).	MS 1b Interpret expressions in standard form. WS 4.4 Use SI units and the prefix nano. MS 1d Estimate the size of atoms based on scale diagrams.

4.1.2.3 Sub-atomic particles

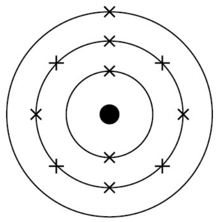
GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the atom as a positively charged nucleus surrounded by negatively charged electrons, with the nuclear radius much smaller than that of the atom and with almost all of the mass in the nucleus. Recall that atomic nuclei are composed of both protons and neutrons, that the nucleus of each element has a characteristic positive charge, but that elements can differ in nuclear mass by having different numbers of neutrons. Recall relative charges and approximate relative masses of protons, neutrons and electrons.	The radius of a nucleus is less than 1/10 000 of that of the atom (about 1×10^{-14} m). The relative masses and charges of protons, neutrons and electrons are: **Name of particle** / **Relative mass** / **Charge** Proton / 1 / +1 Neutron / 1 / 0 Electron / Very small / –1 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. In an atom, the number of electrons is equal to the number of protons in the nucleus. Atoms have no overall electrical charge.	WS 1.2 Interpret and draw diagrams to represent atoms.

Name of particle	Relative mass	Charge
Proton	1	+1
Neutron	1	0
Electron	Very small	–1

4.1.2.4 Isotopes

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Relate differences between isotopes to differences in conventional representations of their identities, charges and masses.	The sum of the protons and neutrons in an atom is its mass number. Atoms of the same element can have different numbers of neutrons; these atoms are called isotopes of that element. Atoms can be represented as shown in this example: (Mass number) (Atomic number) $^{23}_{11}\mathrm{Na}$	WS 1.2 Work out numbers of protons, neutrons and electrons in atoms and ions, given atomic number and mass number of isotopes.

4.1.2.5 Electrons in atoms

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall that in each atom its electrons are arranged at different distances from the nucleus.	The electrons in an atom occupy the lowest available energy levels (innermost available shells closest to the nucleus). 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  showing two electrons in the lowest energy level, eight in the second energy level and one in the third energy level.	This topic links with Atomic number and the periodic table (page 87).

4.1.3 Cells in animals and plants

Understanding the structure of cells, the transport of substances into and out of cells, cell division by mitosis and meiosis and cell differentiation lays the foundations for the study of systems in the human body in Systems in the human body (page 36), of plant biology in Plants and photosynthesis (page 42) and of inheritance in Inheritance (page 79).

There are two required practicals: an activity observing cells under a light microscope and an investigation of the effect of different concentrations of salt or sugar solutions on plant tissues.

Microscopes are used to study cells and so practical work can include the microscopic examination of plant and animal cells.

4.1.3.1 Electron microscopy

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain how electron microscopy has increased our understanding of sub-cellular structures.	An electron microscope has a much higher resolving power than a light microscope. This means that it can be used to study cells in much finer detail. An electron microscope can magnify up to a million times (× 1000 000) or more, which is much more than a light microscope which has a useful magnification of only about a thousand times (× 1000). $\text{magnification} = \frac{\text{size of image}}{\text{size of real object}}$	MS 2a, 2h Demonstrate understanding of number, size and scale and the quantitative relationship between units. WS 4.5 Interconvert units. MS 1a,1b, 1c, 2h Carry out calculations involving magnification, real size and image size including numbers written in standard form. WS 3.3 Carry out and represent mathematical and statistical analysis. WS 4.6 Use an appropriate number of significant figures. WS4.4 Use prefixes centi, milli, micro and nano. MS 1d, 2h Make order of magnitude calculations. MS 1d Use estimations and explain when they should be used.

4.1.3.2 Cell structures

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain how the main sub-cellular structures of eukaryotic cells (plants and animals) and prokaryotic cells are related to their functions, including the nucleus/genetic material, plasmids, mitochondria, chloroplasts and cell membranes.	Plant and animal cells (eukaryotic cells) have a cell membrane, cytoplasm and a nucleus containing the genetic material. Bacterial cells (prokaryotic cells) are much smaller in comparison. They have cytoplasm and a cell membrane surrounded by a cell wall. The genetic material is not enclosed in a nucleus. It is a single DNA loop and may have one or more small rings of DNA called plasmids. Most animal cells have the following parts: • a nucleus • cytoplasm • a cell membrane • mitochondria • ribosomes. Most human cells are like most other animal cells. In addition to the parts found in animal cells, plant cells often have: • chloroplasts • a permanent vacuole filled with cell sap. Plant and algal cells also have a cell wall made of cellulose, which strengthens the cell.	

Required practical activity 3: use a light microscope to observe, draw and label a selection of plant and animal cells. A magnification scale must be included.

AT skills covered by this practical activity: biology AT 1 and 7.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in Key opportunities for skills development (page 164).

4.1.3.3 Transport into and out of cells

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain how substances are transported into and out of cells through diffusion, osmosis and active transport.	Some substances move across cell membranes via diffusion. Diffusion is a spreading out and mixing process. Particles move from a region where they are in higher concentration to a region where their concentration is lower. Factors that affect the rate of diffusion across a membrane are: • the difference in concentration • the temperature • the surface area of the membrane. Water may move across cell membranes by osmosis. Cell membranes are partially permeable: they allow small molecules such as water through but not larger molecules. During osmosis water diffuses from where it is more concentrated (because the solute concentration is lower), through a partially permeable membrane to where water is less concentrated (because the solute concentration is higher). Some substances move across cell membranes via active transport. Active transport involves the movement of a dissolved substance from a region where it is less concentrated to a region where it is more concentrated. This requires energy from respiration. Active transport allows mineral ions to be absorbed into plant root hairs from very dilute solutions in the soil. It also allows sugar molecules to be absorbed from lower concentrations in the gut into the blood with a higher sugar concentration.	MS 4a, 4b, 4c, 4d Plot, draw and interpret appropriate graphs. WS 3.4 Represent the distribution of results and make estimations of uncertainty. MS 1c Calculate percentage gain and loss of mass. WS 3.3 Carry out and represent mathematical and statistical analysis.

Required practical activity 4: investigate the effect of a range of concentrations of salt or sugar solutions on the mass of plant tissue.

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

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in Key opportunities for skills development (page 165).

4.1.3.4 Mitosis and the cell cycle

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the process of mitosis in growth, including the cell cycle.	The nucleus of body cells contains chromosomes. In body cells the chromosomes are normally found in pairs. There are 46 chromosomes in human body cells. DNA is in the chromosomes and each chromosome carries a large number of genes. Cells divide so that organisms can grow during the development of multicellular organisms, and repair damaged tissues. Dividing cells go through a series of stages called the cell cycle. During the cell cycle the genetic material doubles and then divides to give two new cells that are genetically identical to each other and to the original cell. Knowledge of the stages of the cell cycle and mitosis is not required. Before a cell can divide it must grow, and make copies of all the organelles such as mitochondria and ribosomes. It must also replicate the chromosomes in the nucleus. Then it can divide by mitosis. During mitosis, the two complete sets of chromosomes are pulled to opposite sides of the cell. Two new nuclei form. Then the cell splits into two.	

4.1.3.5 Meiosis

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain the role of meiotic cell division in halving the chromosome number to form gametes.	Cells in reproductive organs divide by meiosis to form gametes (egg and sperm cells). Knowledge of the stages of meiosis is not required. When a cell divides to form gametes: • copies of the genetic information are made • the cell divides twice to form four gametes, each with a single set of chromosomes • all gametes are genetically different from each other. Gametes join at fertilisation to make a new cell with the normal number of chromosomes. The new cell divides by mitosis to grow.	

4.1.3.6 Cell differentiation

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the function of stem cells in embryonic and adult animals. Explain the importance of cell differentiation.	At first the cells in an embryo can grow and divide to form any type of cell. They are stem cells. As an embryo develops most of the cells differentiate and become specialised. Specialised cells carry out a particular function. Differentiation is essential to produce a variety of cells with different functions in multicellular organisms (animals and plants). Cells that have become specialised cannot later change into different kinds of cells. However, there are some stem cells in most adult tissues that are ready to start dividing to replace old cells or to repair damage in the tissues where they are found.	This section links with Stem cells (page 66).

4.1.4 Waves

Water waves and sound waves are used here to distinguish between transverse and longitudinal waves, which transfer energy and information without transferring matter. This leads to the study of the continuous spectrum of electromagnetic waves. The hazards associated with some electromagnetic waves feature in Radiation and risk (page 55).

There are two required practicals: one studying waves in a ripple tank and a metal rod, and the other looking at infrared radiation from different surfaces. Knowledge of properties of parts of the electromagnetic spectrum is needed to explain the greenhouse effect (see The greenhouse effect (page 69)).

4.1.4.1 Transverse and longitudinal waves

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the difference between transverse and longitudinal waves. Describe how ripples on water surfaces are examples of transverse waves whilst sound waves in air are longitudinal waves, and how the speed of each may be measured. Describe evidence that in both cases it is the wave and not the water or air itself that travels.	In a transverse wave the oscillations are perpendicular to the direction of energy transfer. The ripples on a water surface are an example of a transverse wave. In a longitudinal wave the oscillations are parallel to the direction of energy transfer. Longitudinal waves show areas of compression and rarefaction. Sound waves travelling through air are longitudinal.	WS 2.3 Describe one method to measure the speed of sound waves in air. WS 2.2, 2.3 Describe one method to measure the speed of ripples on a water surface. WS 3.5 Interpret given data from experiments to measure the speed of sound or water waves.

Required practical activity 5: make observations to identify the suitability of apparatus to measure the frequency, wavelength and speed of waves in a ripple tank and waves in a solid and take appropriate measurements.

AT skills covered by this practical activity: physics AT 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 165).

4.1.4.2 A wave equation

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe wave motion in terms of amplitude, wavelength, frequency, and period; define wavelength and frequency and describe and apply the relationship between these and the wave velocity.	Waves are described by their amplitude, wavelength, frequency and period. The amplitude of a wave is the maximum displacement of a point on a wave away from its undisturbed position. The wavelength of a wave is the distance from a point on one wave to the equivalent point on the adjacent wave. The frequency of a wave is the number of waves passing a point each second. The wave speed is the speed at which the energy is transferred (or the wave moves) through the medium. All waves obey the wave equation: $wave\ speed = frequency \times wavelength$ $[\ v = f\lambda\ ]$ wave speed, v, in metres per second, m/s frequency, f, in hertz, Hz wavelength, λ, in metres, m Students should be able to apply the relationship: $period = \frac{1}{frequency}$ $\left[\ T = \frac{1}{f}\ \right]$ period, T, in seconds, s frequency, f, in hertz, Hz	WS 4.6, MS 1b, 2a Calculate with numbers written in standard form and give answers to an appropriate number of significant figures. MS 1c, 3b, 3c Recall and apply the wave equation. MS1a, 1c, 3b, 3c Apply the equation for relationship between period and frequency, which is given on the Physics equations sheet. WS 3.3 Carry out and represent mathematical and statistical analysis.

4.1.4.3 Electromagnetic waves

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall that electromagnetic waves are transverse, are transmitted through space where all have the same velocity, and explain, with examples, that they transfer energy from source to absorber. Recall that light is an electromagnetic wave. Describe the main groupings of the spectrum – radio, microwave, infrared, visible (red to violet), ultraviolet, X-rays and gamma rays, that these range from long to short wavelengths and from low to high frequencies, and that our eyes can only detect a limited range. Give examples of some practical uses of electromagnetic waves in the radio, microwave, infrared, visible, ultraviolet, X-ray and gamma ray regions.	Electromagnetic waves form a continuous spectrum. Examples of uses of electromagnetic waves include: • radio waves – television, radio and radio telescopes • microwaves – satellite communications, cooking food • infrared – electrical heaters, cooking food, infrared cameras • visible light – fibre optic communications • ultraviolet – fluorescent lamps, sun tanning • X-rays – medical imaging and treatments • gamma rays – sterilising surgical instruments, treatment of cancer.	WS 1.2 Show that the uses of electromagnetic waves illustrate the transfer of energy from source to absorber. MS 1a, 1c, 3c Recall and apply the relationship between frequency and wavelength across the electromagnetic spectrum.

Required practical activity 6: investigate how the amount of infrared radiation absorbed or radiated by a surface depends on the nature of that surface.

AT skills covered by this practical activity: physics AT 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 166).

4.1.4.4 Radio waves (HT only)

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall that radio waves can be produced by, or can themselves induce, oscillations in electrical circuits.	When radio waves are absorbed they may create an alternating current with the same frequency as the radio wave itself, so radio waves can themselves induce oscillations in an electrical circuit.	

4.1.4.5 Reflection and refraction of electromagnetic waves (HT only)

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall that different substances may refract, or reflect these waves; explain how some effects are related to differences in the velocity of the waves in different substances.	Shiny surfaces act as mirrors when they reflect waves. Rough surfaces scatter waves in all directions. Electromagnetic waves change speed when they travel between different substances such as from air to glass or water. As a result they change direction. This is refraction.	WS 1.2 Construct ray diagrams to illustrate the refraction of a wave at the boundary between two different media. Use wavefront diagrams to explain refraction in terms of the change of wave speed.

4.2 Transport over larger distances

Larger organisms need systems to transport solids, liquids and gases over larger distances. These systems and processes are monitored and controlled by the human body, but this delicate balance can be disrupted. The topic moves from simple to complex, and outlines the challenges that this presents for any transport system in plants and animals.

4.2.1 Systems in the human body

Systems in the human body can be studied at macroscopic, microscopic and molecular scales. The study of respiration helps to account for the need for exchange surfaces in multicellular organisms, illustrated by the human circulatory system. The study of the digestive system focuses on the chemical changes to the main nutrients in the diet. Finally, examples of the way that body systems are controlled is illustrated with reference to the nervous system and the endocrine system. In Lifestyle and health (page 50) the importance of the endocrine system is further illustrated in the context of lifestyle and health.

There are two required practicals: one is using reagents to test for a range of carbohydrates, lipids and proteins, the other is an investigation into the effect of a factor on human reaction times, which can be related to road safety in Stopping distances (page 115).

4.2.1.1 Respiration

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe cellular respiration as an exothermic reaction which is continuously occurring in all living cells.	Respiration in cells can take place aerobically (using oxygen) or anaerobically (without oxygen). Aerobic respiration is an exothermic reaction that can be represented by word and symbol equations. glucose + oxygen → carbon dioxide + water An exothermic reaction is one that transfers energy to its surroundings. Organisms need energy for: • chemical reactions to build larger molecules • movement • keeping warm.	WS 1.2 (HT only) Write a balanced symbol equation for respiration, given the formula of glucose.
Compare the processes of aerobic and anaerobic respiration.	Anaerobic respiration in muscles is also exothermic but it gives out less energy. It is represented by the word equation: glucose → lactic acid Because the oxidation of glucose is incomplete in anaerobic respiration much less energy is given out than in aerobic respiration. If insufficient oxygen is supplied, anaerobic respiration takes place in muscles. The incomplete oxidation of glucose causes a build-up of lactic acid and creates an oxygen debt. Oxygen debt is the amount of extra oxygen the body needs after exercise to react with the accumulated lactic acid and remove it from the cells.	

4.2.1.2 Exchange surfaces

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain the need for exchange surfaces and a transport system in multicellular organisms in terms of surface area:volume ratio.	A single-celled organism has a relatively large surface area:volume ratio. The tissues of a multicellular organism consist of cells with a similar structure and function. Organs, such as the heart and lungs, are made of tissues. One organ may consist of several tissues. Organ systems, such as the circulatory system, are groups of organs that perform a particular function. In multicellular organisms many organ systems are specialised for exchanging materials. The effectiveness of an exchange surface is increased by: • having a large surface area • a membrane that is thin, to provide a short diffusion path • (in animals) having an efficient blood supply • (in animals, for gaseous exchange) being ventilated.	MS 1c Calculate and compare surface area:volume ratios.

4.2.1.3 The human circulatory system

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the human circulatory system, including the relationship with the gaseous exchange system, and explain how the structure of the heart and the blood vessels are adapted to their functions. Describe some of the substances transported into and out of a range of organisms in terms of the requirements of those organisms, to include oxygen, carbon dioxide and dissolved food molecules.	The heart is a muscular organ that pumps blood around the body in a dual circulatory system. The right ventricle pumps blood to the lungs, where gas exchange takes place. The left ventricle pumps blood around the rest of the body. Valves prevent the blood from flowing back from the ventricles to the atria. Knowledge of the names of the heart valves is not required. Blood vessels associated with the heart include the aorta, vena cava, pulmonary artery, pulmonary vein and coronary arteries. Gas exchange takes place in the lungs. Important features of the lungs are the trachea, bronchi, alveoli and the capillary network surrounding the alveoli. The alveoli have the specialised surfaces for gas exchange between air and the blood. The natural resting heart rate is controlled by a group of cells that act as a pacemaker, located in the right atrium. Artificial pacemakers are electrical devices used to correct irregularities in the heart rate. The body contains three different types of blood vessel: • arteries • veins • capillaries.	MS 1a, 1c Use simple compound measures such as rate. MS 1a, 1c Carry out rate calculations.

4.2.1.4 Blood cells

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain how red blood cells, white blood cells, platelets and plasma are adapted to their functions in the blood.	Blood is a tissue consisting of plasma, in which are suspended: • red blood cells • white blood cells • platelets.	WS 3.5 Identify different types of blood cells in a photograph or diagram.

4.2.1.5 The human digestive system

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain the importance of sugars, amino acids, fatty acids and glycerol in the synthesis and breakdown of carbohydrates, lipids and proteins. Describe some of the substances transported into and out of a range of organisms in terms of the requirements of those organisms, to include dissolved food molecules and urea.	The digestive system uses enzymes to break down large molecules in food into small soluble molecules that can be absorbed into the blood through the walls of the gut. The blood carries the small molecules to the cells of the body where they can be used for respiration or to make the new large molecules that the cells need as reserves of energy or for growth and repair. Starch is a carbohydrate. Its molecules consist of a long chain of glucose molecules. Digestion by carbohydrase enzymes breaks down insoluble starch to water-soluble glucose. Cells use glucose during respiration. Lipids are fats and oils. Digestion by lipase enzymes breaks down lipids to glycerol and fatty acids. Cells reform fats from the fatty acids and glycerol molecules. Fats are stored as a source of energy because cells can break them down and use them in respiration. Proteins are long-chain molecules made up of many amino acids linked together. Digestion by protease enzymes breaks down proteins to amino acids. Cells use amino acids to make new proteins. The liver breaks down unwanted amino acids to urea, which is then carried by the blood to the kidneys. The kidneys excrete urea in solution as urine.	

Required practical activity 7: use qualitative reagents to test for a range of carbohydrates, lipids and proteins. To include: Benedict's test for sugars, iodine test for starch and Biuret reagent for protein.

AT skills covered by this practical activity: biology AT 2.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in Key opportunities for skills development (page 166).

4.2.1.6 The human nervous system

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain how the structure of the nervous system (including the central nervous system, sensory and motor neurones and sensory receptors) is adapted to its functions.	The nervous system enables humans to react to their surroundings and to coordinate their behaviour. Information from receptors passes along cells (neurones) as impulses to the central nervous system, or CNS (the brain or the spinal cord). The CNS coordinates the response of effectors which may be muscles contracting or glands secreting hormones. stimulus → receptor → coordinator → effector → response	
Explain how the structure of a reflex arc is related to its function.	Reflex actions are automatic and rapid; they do not involve the conscious part of the brain. An example of a simple reflex action is the pain withdrawal reflex. This can be explained in terms of a reflex arc. Sensory neurones carry impulses from receptors to the spinal cord and brain. Relay neurones carry impulses within the CNS. Motor neurones carry impulses from the CNS to effectors. Where two neurones meet, there is a tiny gap called a synapse. Impulses cross this gap using chemicals.	
Explain methods of measuring human reaction times and recall typical results.	Reaction times vary from person to person. Typical values range from 0.3s to 0.9s.	This topic links with Stopping distances (page 115).

Required practical activity 8: plan and carry out an investigation into the effect of a factor on human reaction time.

AT skills covered by this practical activity: biology AT 1, 3 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 167).

4.2.1.7 The human endocrine system

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the principles of hormonal coordination and control by the human endocrine system.	The endocrine system is composed of glands that secrete hormones directly into the bloodstream. Hormones are large molecules. The blood carries the hormone to a target organ where it produces an effect. Compared to the nervous system the effects are slower but act for longer. The pituitary gland in the brain is a 'master gland'. It secretes several hormones that act on other glands to stimulate other hormones to be released.	
(HT only) Explain the roles of thyroxine and adrenaline in the body including thyroxine as an example of a negative feedback system.	(HT only) Adrenaline is produced by the adrenal gland. It boosts the delivery of oxygen and glucose to the brain and muscles and prepares the body for 'flight or fight'. (HT only) Thyroxine from the thyroid gland stimulates the basal metabolic rate. It plays an important role in growth and development. (HT only) The control of thyroxine levels involves negative feedback. Negative feedback tends to stabilise a system. Any change in the system leads to a response that tends to reverse the change.	WS1.2, MS 2c (HT only) Interpret and explain simple diagrams of negative feedback control.

4.2.2 Plants and photosynthesis

The study of cells and transport into and out of cells in Cells in animals and plants (page 27) is developed and exemplified here in the context of plant science. A key part is the study of photosynthesis because this underpins work on the carbon cycle and climate change in The Earth's atmosphere (page 67) and the study of ecosystems in Ecosystems and biodiversity (page 75).

Plants can be attacked by bacteria and viruses so the successful growth of crops depends on methods to prevent or control infection.

There are two required practicals: one to investigate plant pigments by paper chromatography, another to investigate the effect of light intensity on the rate of photosynthesis.

4.2.2.1 Meristem tissue

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the function of meristems in plants.	Meristem tissue contains the cells in a plant that divide as the plant grows. This type of tissue is found at the growing tips of shoots and roots. The cells differentiate into different types of plant cells depending on where they are in the plant.	WS 1.4 Describe and explain the use of stem cells from meristems to produce clones of plants quickly and economically.

4.2.2.2 Plant structures

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe some of the substances transported into and out of a range of organisms, in terms of the requirements of those organisms, to include oxygen, carbon dioxide, water and mineral ions.	Plants, like other multicellular organisms, need specialised structures for transporting and exchanging materials. The roots, stem and leaves form a plant organ system for transport of substances around the plant. Plants take in carbon dioxide from the atmosphere for photosynthesis and oxygen for respiration. Plants take in water from the soil with dissolved ions including nitrate ions to make proteins and magnesium ions to make chlorophyll.	

4.2.2.3 Transpiration

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain the need for exchange surfaces and a transport system in multicellular organisms. Explain how water and mineral ions are taken up by plants, relating the structure of the root hair cells to their function. Explain how the structure of xylem is adapted to its functions in the plant. Describe the process of transpiration including the structure and function of the stomata.	Water is drawn into the roots of plants from the soil. Water moves into the root hairs by osmosis. Mineral ions move from the soil into the root hairs by active transport. Water flows from the roots through xylem in its stems to its leaves. Xylem tissue is composed of hollow tubes strengthened by lignin adapted for the transport of water in the transpiration stream from the roots to the leaves. Water evaporates in the leaves and the water vapour escapes through tiny holes in the surface of leaves called stomata. The stomata can open or close as conditions change because the guard cells can gain or lose water by osmosis.	

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain the effect of a variety of environmental factors on the rate of water uptake by a plant, to include light intensity, air movement and temperature.	The rate of transpiration varies with: • light intensity, which affects the opening of stomata • air movements, which affect the concentration of water vapour in the air around leaves • temperature, which affects the rate at which water evaporates.	MS 1a, 1c Understand and use simple compound measures such as the rate of a reaction. MS 4a Translate information between graphical and numerical form. MS 4a, 4c Plot and draw appropriate graphs, selecting appropriate scales for axes. WS 3.3 Carry out and represent mathematical and statistical analysis. MS 2c, 4a Extract and interpret information from graphs, charts and tables.

4.2.2.4 Chlorophyll and other plant pigments

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall that chromatography involves a stationary and a mobile phase and that separation depends on the distribution between the phases. Interpret chromatograms, including measuring R_f values. Suggest chromatographic methods for distinguishing pure from impure substances.	The chlorophyll and other pigments in plant leaves can be separated and identified by chromatography. Chromatography can be used to separate mixtures and can give information to help identify substances. 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: $R_f = \frac{\text{distance moved by substance}}{\text{distance moved by solvent}}$ 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 produces a single spot in all solvents.	MS 1a Recognise and use expressions in decimal form. MS 1c Use ratios and percentages. WS 3.3 Carry out and represent mathematical and statistical analysis. MS 1d Make estimates of the results of simple calculations. WS 4.6, MS 2a Use an appropriate number of significant figures. MS 4a Extract and interpret information from charts and tables. Translate information between graphical and numeric form when calculating R_f values.

Required practical activity 9: 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: chemistry AT 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 167).

4.2.2.5 Photosynthesis

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the process of photosynthesis and describe photosynthesis as an endothermic reaction.	Photosynthesis takes place in the chloroplasts in the cells of the leaves of plants. The chloroplasts contain the chlorophyll, which absorbs sunlight. Photosynthesis is an endothermic reaction that can be represented by word and symbol equations. carbon dioxide + water $\xrightarrow{\text{light}}$ glucose + oxygen Energy is transferred to the plant cells by light. The glucose produced in photosynthesis may be: • used for respiration • converted into insoluble starch for storage • used to produce fat or oil for storage • used to produce cellulose, which strengthens the cell wall • used to produce amino acids for protein synthesis. To produce proteins, plants also use nitrate ions that are absorbed in solution from the soil.	WS 1.2 (HT only) Write a balanced symbol equation for photosynthesis given the formula of glucose.

4.2.2.6 Factors affecting the rate of photosynthesis

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain the effect of temperature, light intensity and carbon dioxide concentration on the rate of photosynthesis.	The rate of photosynthesis depends on: • the energy available from light • the concentration of carbon dioxide in the air • the temperature.	MS 1a, 1c Carry out rate calculations for photosynthesis.

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
(HT only) Explain the interaction of these factors in limiting the rate of photosynthesis.	(HT only) The rate of photosynthesis may be limited by: • low temperature • shortage of carbon dioxide • shortage of light. (HT only) Increasing any one of the factors speeds up photosynthesis until the rate is limited by the factor which is in shortest supply.	WS 1.4 (HT only) Use data to relate limiting factors to the cost effectiveness of adding heat, light or carbon dioxide to greenhouses. MS 1a, 1c, 2c, 4a, 4c Translate information between numerical and graphical forms and extract and interpret information from graphs, charts and tables. WS 3.5 (HT only) Understand and use inverse proportion – the inverse square law – and light intensity in the context of factors affecting photosynthesis.

Required practical activity 10: investigate the effect of light intensity on the rate of photosynthesis using an aquatic organism such as pondweed.

AT skills covered by this practical activity: biology AT 1, 2, 3, 4 and 5.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in Key opportunities for skills development (page 168).

4.2.2.7 Translocation

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the process of translocation. Explain how the structure of phloem is adapted to its functions in the plant.	Phloem tissue is composed of tubes of elongated living cells adapted for translocation of sugars from where they are produced by photosynthesis in the leaves to other parts of the plant for immediate use or storage. Cell sap containing sugars and other nutrients is able to move easily from one phloem cell to the next as the end walls have pores.	

4.2.2.8 Plant diseases

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain how communicable diseases are spread in plants.	Tobacco mosaic virus is a widespread plant pathogen affecting many species of plants, including tomatoes. It gives a distinctive 'mosaic' pattern of discolouration on the leaves, which affects the growth of the plant due to lack of photosynthesis. Rose black spot is a fungal disease where purple or black spots develop on leaves, which often turn yellow and drop early. It affects the growth of the plant as photosynthesis is reduced. The disease is spread by spores of the fungus that are produced in the black spots.	
Explain how the spread of communicable diseases may be reduced or prevented in plants, to include a minimum of one plant disease.	Common control methods for tobacco mosaic virus include: • removing and destroying infected plants • washing hands and tools after handling infected plants • crop rotation to avoid planting in soil that has been infected for at least two years. Methods to control black spot include: • not planting roses too close together – to allow the air to flow freely around them • avoiding wetting the leaves when watering – wet leaves encourage the fungal disease • cleaning up any infected leaves from the ground round the roses – to avoid spores spreading • using a fungicide to prevent infection – spraying, especially in advance of warm, wet weather.	WS 1.4 Explain applications of science to prevent the spread of plant diseases.

4.3 Interactions with the environment

This topic looks at the macro- and micro-effects of the interaction between organisms and the environment. It introduces the effects of lifestyle on the delicate balance within the human body. The topic shows how our understanding of electromagnetic waves has developed by investigating how they interact with different materials.

4.3.1 Lifestyle and health

The way in which people live their lives can have long-term consequences for their health. The chances that someone will be affected by conditions such as cardiovascular disease, diabetes or cancer may depend on lifestyle factors, including exercise, diet, alcohol consumption and smoking.

Treatments are available to control the symptoms of non-communicable diseases (see also Preventing, treating and curing diseases (page 60)) but the benefits have to be weighed against the risks.

The scientific understanding of the reproductive hormones can help people to control their fertility and also to receive treatment for infertility.

4.3.1.1 Health and disease

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the relationship between health and disease. Describe different types of diseases (including communicable and non-communicable diseases).	Health can be defined as 'a state of physical, mental and social well-being' and not merely the absence of disease. Factors including diet, stress and life situations can affect both physical and mental health. Diseases stop part of the body from working properly. This causes symptoms, which are experienced by the person affected by the disease. Communicable (infectious) diseases are caused by microorganisms called pathogens. They may infect plants as well as animals and are spread by direct contact, by water or by air. Non-communicable diseases, such as heart disease, cancer and diabetes, are the leading cause of death in the world.	

4.3.1.2 Risk factors for non-communicable diseases

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall that many non-communicable human diseases are caused by the interaction of a number of factors. To include cardiovascular diseases, many forms of cancer, some lung and liver diseases and diseases influenced by nutrition, including Type 2 diabetes. Explain the effect of lifestyle factors, including exercise, diet, alcohol and smoking, on the incidence of non-communicable diseases at local, national and global levels.	Risk factors are aspects of a person's lifestyle, or substances present in a person's body or environment, that have been shown to be linked to an increased rate of a disease. For some a causal mechanism has been proven. Examples are: • the effects of diet, smoking and exercise on cardiovascular disease • obesity as a risk factor for Type 2 diabetes • the effect of alcohol on liver and brain function • the effect of smoking on lung disease and lung cancer • the effects of smoking and alcohol on unborn babies • carcinogens and ionising radiation as risk factors in cancer.	WS 1.5 Interpret data about risk factors, or about differences in the incidence of non-communicable diseases in different parts of the world. WS 1.4 Discuss the human and financial cost of these non-communicable diseases to an individual, a local community, a nation or globally. MS 4a Translate information between graphical and numerical forms. MS 2c, 4a Extract and interpret information from charts, graphs and tables. MS 2d Understand the principles of sampling as applied to scientific data in terms of risk factors. MS 2c Construct and interpret frequency tables and diagrams, bar charts and histograms. MS 2g Use a scatter diagram to identify a correlation between two variables.

4.3.1.3 Treatments for cardiovascular disease

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Evaluate some different treatments for cardiovascular disease.	In coronary heart disease layers of fatty material build up inside the coronary arteries. This reduces the flow of blood through the coronary arteries. This can lead to a heart attack. Statins are widely used to reduce blood cholesterol levels, which slows down the rate of fatty material deposit. Stents are used to keep the coronary arteries open. In some people heart valves may become faulty, preventing the valve from opening fully, or the heart valve might develop a leak. Faulty heart valves can be replaced using biological or mechanical valves. In the case of heart failure, a donor heart, or heart and lungs, can be transplanted. Artificial hearts are occasionally used to keep patients alive whilst waiting for a heart transplant, or to allow the heart to rest as an aid to recovery.	WS 1.4 Evaluate given information about the advantages and disadvantages of treating cardiovascular diseases by drugs, mechanical devices or transplant. WS 1.3 Evaluate methods of treatment bearing in mind the benefits and risks associated with the treatment.

4.3.1.4 Homeostasis

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain the importance of maintaining a constant internal environment in response to internal and external change.	Homeostasis is the regulation of the internal conditions of a cell or organism to maintain optimum conditions for function in response to internal and external changes. Homeostasis is important because it maintains optimal conditions for enzyme action and all cell functions. Control of blood glucose concentration, control of body temperature and control of water levels in the human body are examples of homeostasis. An organism maintains homeostasis by monitoring its internal conditions and responding appropriately when these conditions deviate from their optimal state. These automatic control systems may involve nervous responses or chemical responses. Many of the processes are coordinated by hormones.	

4.3.1.5 Insulin and diabetes

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain how insulin controls blood sugar levels in the body. (HT only) Explain how glucagon interacts with insulin to control blood sugar levels in the body.	Blood glucose concentration is monitored and controlled by the pancreas. If the blood glucose concentration is too high, the pancreas produces the hormone insulin, which causes glucose to move from the blood into the cells. In liver and muscle cells excess glucose is converted to glycogen for storage. (HT only) If the blood glucose concentration is too low, the pancreas produces glucagon, which causes glycogen to be converted into glucose and released into the blood.	MS 1a, 1c, 2c, 4a, 4c Translate information between numerical and graphical forms and extract and interpret information from graphs, charts and tables.

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Compare Type 1 and Type 2 diabetes and explain how they can be treated.	Type 1 diabetes is a disorder in which the pancreas fails to produce sufficient insulin. It is characterised by uncontrolled high blood glucose levels and is normally treated with insulin injections. In Type 2 diabetes the body cells no longer respond to insulin produced by the pancreas. A carbohydrate controlled diet and an exercise regime are common treatments. Obesity is a risk factor for Type 2 diabetes.	

4.3.1.6 Human reproductive hormones

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the roles of hormones in human reproduction, including the menstrual cycle. (HT only) Explain the interactions of FSH, LH, oestrogen and progesterone in the control of the menstrual cycle.	During puberty reproductive hormones cause secondary sex characteristics to develop. Oestrogen is the main female reproductive hormone produced in the ovary. At puberty eggs begin to mature and one is released approximately every 28 days. This is called ovulation. Testosterone is the main male reproductive hormone produced by the testes and it stimulates sperm production. Several hormones are involved in the menstrual cycle of a woman. • Follicle-stimulating hormone (FSH) causes maturation of an egg in the ovary. • Luteinising hormone (LH) stimulates the release of the egg. • Oestrogen and progesterone are involved in maintaining the uterus lining.	MS 2c, 4a (HT only) Extract and interpret data from graphs showing hormone levels during the menstrual cycle.

4.3.1.7 Contraception

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain the use of hormones in contraception and evaluate hormonal and non-hormonal methods of contraception.	Fertility can be controlled by a variety of hormonal and non-hormonal methods of contraception. These include: • oral contraceptives that contain hormones • injection, implant or skin patch of slow-release progesterone • barrier methods such as condoms and diaphragms • intrauterine devices • spermicidal agents • abstaining from intercourse at times when an egg may be fertilised • surgical methods of male and female sterilisation.	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.

4.3.1.8 Treatments for infertility (HT only)

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain the use of hormones in modern reproductive technologies to treat infertility.	The uses of hormones in controlling fertility include: • giving FSH and LH in a 'fertility drug' to a woman whose own level of FSH is too low • In Vitro Fertilisation (IVF) treatment, which involves giving a mother FSH and LH to stimulate the maturation of several eggs.	WS 1.4 Evaluate, from the perspective of patients and doctors, the methods of treating fertility bearing in mind that although fertility treatment gives couples the chance to have a baby of their own it is very emotionally and physically stressful; the success rates are not high and it can lead to multiple births which are a risk to both the babies and the mother.

4.3.2 Radiation and risk

Ionising radiations include some types of electromagnetic radiation and particles emitted from radioactive atoms. The risks from exposure to ionising radiation can be overestimated in some contexts but underestimated in others. This matters because ionising radiation can damage living cells in ways that lead to the development of malignant tumours. Understanding of the properties of the different types of ionising radiation helps people to protect themselves and avoid unnecessary exposure to risk.

4.3.2.1 Absorption and emission of radiation

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall that the arrangements of electrons in atoms may change with absorption or emission of electromagnetic radiation.	When atoms gain energy by heating, from electricity, or by absorbing electromagnetic radiation, some electrons jump to higher energy levels. Electromagnetic radiation is given out when the electrons drop back to lower levels. The frequency of the radiation depends on the size of the energy jump. Atoms of elements such as neon and sodium give out light in the visible region of the spectrum. Other atoms, such as mercury atoms, give out light in the ultraviolet region.	WS 1.2 Use of the energy level model of the atom.

4.3.2.2 Radioactive decay

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall that some nuclei are unstable and may emit alpha particles, beta particles, or neutrons, and electromagnetic radiation as gamma rays; relate these emissions to possible changes in the mass or the charge of the nucleus, or both. Use names and symbols of common nuclei and particles to write balanced equations that represent radioactive decay.	The nuclear radiation emitted may be: • an alpha particle (α) – this consists of two neutrons and two protons; it is identical to the nucleus of a helium atom • a beta particle (β) – a high-speed electron ejected from the nucleus as a neutron turns into a proton • a gamma ray (γ) – electromagnetic radiation from the nucleus • a neutron (n). Nuclear equations are used to represent radioactive decay. In a nuclear equation an alpha particle may be represented by the symbol: $^{4}_{2}He$ and a beta particle by the symbol: $^{0}_{-1}e$ The emission of the different types of ionising radiation may cause a change in the mass and/or the charge of the nucleus. For example, alpha decay causes the atomic number to decrease by two units and the mass number by four units: $^{219}_{86}Ra \longrightarrow ^{215}_{84}Po + ^{4}_{2}He$ There is no change in mass number during beta decay but the atomic number increases by one unit. $^{14}_{6}C \longrightarrow ^{14}_{7}N + ^{0}_{-1}e$ Students are not required to recall these two examples. The emission of a gamma ray does not cause the mass or the charge of the nucleus to change.	WS 1.2, MS 1b, 1c, 3c Refer to a copy of the periodic table and use the names and symbols of common nuclei and particles to write balanced equations that show single alpha (α) and beta (β) decay. This includes balancing atomic numbers and mass numbers.

4.3.2.3 Half-life

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain the concept of half-life and how this is related to the random nature of radioactive decay.	Radioactive decay is random, so it is not possible to predict which individual nucleus will decay next. But with a large enough number of nuclei it is possible to predict how many will decay in a certain amount of time. The half-life of a radioactive isotope is the average time it takes for the number of nuclei of the isotope in a sample to halve, or the average time it takes for the count rate from a sample containing a radioactive isotope to fall to half its initial level. Count rate is the number of decays recorded each second by a detector (such as a Geiger–Müller tube).	WS 3.3 Carry out and represent mathematical and statistical analysis. MS 4a Determine the half-life of a radioactive isotope from given information. MS 1c, 3d (HT only) Calculate the net decline, expressed as a ratio, in a radioactive emission after a given number of half-lives.

4.3.2.4 Penetration properties of radiations

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall the differences in the penetration properties of alpha particles, beta particles and gamma rays.	Alpha particles are absorbed by just a few millimetres of air or by a thin sheet of paper. Beta particles can pass through air and paper but are completely absorbed by a sheet of metal just a few millimetres thick. Gamma rays pass through most materials easily but are absorbed by a thick sheet of lead or by several metres of concrete.	

4.3.2.5 Contamination and irradiation

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall the differences between contamination and irradiation effects and compare the hazards associated with these two.	Irradiation is the process of exposing an object to radiation from an outside source. Irradiation can be reduced by screening the source or moving the object away from it. The irradiated object does not become radioactive. Radioactive contamination is the unwanted presence of a source of radiation inside, or on the surface of, other materials. It is often difficult to remove the contaminating source so that it continues to add to the radiation dose for as long as it emits radiation.	

4.3.2.6 Ionising radiations

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall that changes in atoms and nuclei can also generate and absorb radiations over a wide frequency range. Describe how ultraviolet waves, X-rays and gamma rays can have hazardous effects, notably on human bodily tissues. Recall that atoms can become ions by loss of outer electrons.	The hazardous effects of ultraviolet (UV) waves, X-rays, alpha, beta and gamma rays depend on the type of radiation and the size of the dose. Radiation dose (in Sieverts) is a measure of the risk of harm resulting from an exposure of the body to the radiation. 1 Sievert (Sv) = 1000 millisieverts (mSv). Ultraviolet waves, X-rays, alpha, beta and gamma rays are all examples of ionising radiation. They can turn atoms into ions and break up molecules. Ionising radiations can change DNA, causing mutation of genes that may lead to cancer. High-energy gamma rays can be used to destroy cancer cells.	WS 1.5 Interpret simple measures of risk showing the probability of harm from different types of radiation. Describe precautions that can be taken to reduce the risks from ionising radiation. Give examples to show that the perceived risk can be very different from the measured risk, especially if the cause of the risk is unfamiliar or invisible.

4.3.2.7 Cancer

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe cancer as the result of changes in cells that lead to uncontrolled growth and division.	Tumours form when cells start growing and dividing in an uncontrolled way. Some tumours are benign; they stay in the same place and stop growing before they get too large. Cancer is caused by malignant tumours that are able to invade neighbouring tissues and spread to different parts of the body in the blood so that more tumours start to grow in other parts of the body.	

4.3.3 Preventing, treating and curing diseases

The human body has defence systems to protect it from the pathogens that cause communicable diseases. However, these defences can be breached.

Vaccination helps to protect people from diseases that were once widespread. If the immune system fails, then antibiotics can be used to treat bacterial infections.

The increasing problem of antibiotic resistance (see Evidence for evolution (page 84)) means that research to develop new medicines has to continue. Clinical trials of new drugs have to be carefully planned and the results published so that claims can be subject to peer review and checked by other scientists replicating the investigations.

New technologies based on genetic modification and stem cells are making it possible to provide effective treatments for non-communicable diseases but, in many cases, these are still at an early stage of development. The development and application of new technologies in medicine can raise ethical issues.

4.3.3.1 Spread of communicable diseases

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain how communicable diseases (caused by viruses, bacteria, protists and fungi) are spread in animals.	Harmful microorganisms (pathogens) that cause disease can spread: • through the air when people cough or sneeze • through food that is contaminated with bacteria • through drinking water that is contaminated with microorganisms • through contact with other people, or surfaces that infected people have touched • by animals that scratch, bite or draw blood.	WS 1.2 Apply the ideas in this section to the transmission of the common cold, flu, cholera, athlete's foot and malaria.

4.3.3.2 Human communicable diseases

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe a minimum of one common human infection, and sexually transmitted infections in humans, including HIV/AIDS. Explain how the spread of communicable diseases may be reduced or prevented in animals. This should include a minimum of one common human infection, and sexually transmitted infections in humans including HIV/AIDS.	Salmonella food poisoning is spread by bacteria ingested in food, or on food prepared in unhygienic conditions. Fever, abdominal cramps, vomiting and diarrhoea are caused by the bacteria and the toxins they secrete. Salmonella bacteria are killed by cooking and pasteurisation. In the UK, poultry are vaccinated against Salmonella to control the spread. Measles is a viral disease showing symptoms of fever and a red skin rash. Measles is a serious illness that can be fatal if complications arise. For this reason most young children are vaccinated against measles. The measles virus is spread by inhalation of droplets from sneezes and coughs. Gonorrhoea is a sexually transmitted disease (STD) with symptoms of a thick yellow or green discharge from the vagina or penis and pain on urinating. It is caused by a bacterium and was easily treated with the antibiotic penicillin until many resistant strains appeared. Gonorrhoea is spread by sexual contact. The spread can be controlled by treatment with antibiotics or the use of a barrier method of contraception such as a condom. HIV initially causes a 'flu like illness'. Unless successfully treated with antiretroviral drugs the virus attacks the body's immune cells. Late-stage HIV, or AIDS, occurs when the body's immune system is no longer able to deal with other infections or cancers. HIV is spread by sexual contact or exchange of body fluids such as blood.	WS 1.4 Explain applications of science to prevent the spread of diseases.

4.3.3.3 Defences against pathogens

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the non-specific defence systems of the human body against pathogens.	The human body defends itself against the entry of pathogens in the following ways: • the skin is a barrier and produces antimicrobial secretions • the nose catches particles • the trachea and bronchi secrete mucus that is moved by cilia • the stomach produces acid, which kills the majority of pathogens that enter via the mouth.	

4.3.3.4 The human immune system

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain the role of the immune system of the human body in defence against disease.	If a pathogen enters the body the immune system tries to destroy the pathogen. White blood cells are an important part of the immune system. They help to defend against pathogens through: • phagocytosis • producing antibodies • producing antitoxins.	

4.3.3.5 Vaccination

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain the use of vaccines in the prevention and treatment of disease.	Vaccination involves introducing small quantities of dead or inactive forms of a pathogen into the body to stimulate the white blood cells to produce antibodies. If the same pathogen re-enters the body the white blood cells respond quickly to produce antibodies, preventing infection. If a large proportion of the population is immune to a pathogen, the spread of the pathogen is very much reduced. Students do not need to know details of vaccination schedules and side effects associated with specific vaccines.	

4.3.3.6 Medicines

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain the use of medicines in the prevention and treatment of disease.	Antibiotics, such as penicillin, are medicines that help to cure bacterial disease by killing infective bacteria inside the body. It is important that specific bacteria should be treated by specific antibiotics. The use of antibiotics has greatly reduced deaths from infectious bacterial diseases. However, the emergence of strains of bacteria resistant to antibiotics is becoming a serious threat. Antibiotics cannot kill viral pathogens. Painkillers and other medicines are used to treat the symptoms of disease. They do not kill pathogens.	This topic links with Variation and evolution (page 82).
Explain that many useful materials are formulations of mixtures.	Most medicines are mixtures. They are formulations made by mixing the ingredients in carefully measured quantities to ensure that the product has the required properties. One or more of the ingredients may be the drug, such as aspirin, but other ingredients make it easier or more pleasant for a patient to take the drug in solution or as a capsule or tablet.	

4.3.3.7 Testing new drugs

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the process of discovery and development of potential new medicines, including preclinical and clinical testing.	When new medical drugs are devised, they have to be extensively tested and trialled before being used. Drugs are tested in a series of stages to find out if they are safe and effective. New drugs are extensively tested for toxicity, efficacy and dose: • in the laboratory, using cells, tissues and live animals • then in clinical trials involving healthy volunteers and patients. Very low doses of the drug are given at the start of the clinical trial. If the drug is found to be safe, further clinical trials are carried out to find the optimum dose for the drug. In double-blind trials, some patients are given a placebo. Patients are allocated randomly to groups so that neither the doctors nor the patients know who has received a placebo and who has received the drug until the trial is complete.	WS 1.6 Explain that the results of testing and trials, like the findings of all scientific research, are published only after evaluation by peer review.

4.3.3.8 Genetic modification

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain some of the possible benefits and risks, including practical and ethical considerations, of using gene technology in modern medicine.	New medical products have been produced by genetically modifying bacteria. Insulin for the treatment of Type 1 diabetes is produced by cultivating genetically modified bacteria. Sheep and goats have been genetically modified to produce chemicals in their milk that can be used to treat disease. In one example the milk produced contains a protein needed to treat patients with cystic fibrosis. Research is also exploring the possibility of providing tissues needed for transplants from animals that have been genetically modified so that the tissues are not rejected by the human immune system.	WS 1.3 Evaluate gene technologies, taking into account benefits, risks, and the ethical issues raised by the use of animals in medical research. This topic links with Variation and evolution (page 82).

4.3.3.9 Stem cells

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Discuss potential benefits and risks associated with the use of stem cells in medicine.	One medical use of stem cells is well established: this is the use of stem cells from bone marrow in transplants to provide a supply of new blood cells for the person receiving the transplant. This is used to treat leukaemia. Stem cells for research may be based on: • stem cells from embryos that are a few days old • adult stem cells from selected parts of the body such as bone marrow • fetal stem cells taken from blood in the umbilical cord. Embryonic stem cells can develop into any of the many types of cells in the body. Adult stem cells can only give rise to the types of cells found in the tissues that the adult stem cells come from. Most medical uses of stem cells are still experimental. Treatments based on stem cells are being investigated for treating diseases such as: • heart disease – using the patient's own stem cells from bone marrow • Type 1 diabetes – using embryo or fetal stem cells. The properties of stem cells are not fully understood. Scientists do not yet know how their differentiation is controlled. This means that there is a fear that their ability to proliferate could lead to cancer when they are transplanted into a patient.	WS 1.3 Give a simple ethical argument about the rights and wrongs of the uses of stem cells. Evaluate possible uses of stem cells taking into account benefits, risks and the ethical issues raised by sources of the cells.

4.3.3.10 Interactions between different types of disease

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the interactions between different types of disease.	Different types of disease may interact. Some examples include: • defects in the immune system mean that an individual is more likely to suffer from infectious diseases • viruses living in cells can be the trigger for cancers • immune reactions initially caused by a pathogen can trigger allergies such as skin rashes and asthma • severe physical ill health can lead to depression and other mental illness.	

4.4 Explaining change

This topic explores how species, living systems and non-living systems change over time. It explores how scientists think the changes happen in global systems such as Spaceship Earth as well as the tiny changes that happen at a molecular level in the cells of living organisms. The topic discusses how humans affect systems and speculates on how our impact can become benign.

4.4.1 The Earth's atmosphere

The study of the development of the Earth's atmosphere shows how scientists base their theories on clues from the past that may be uncertain or incomplete.

Knowledge of the carbon cycle is crucial to understanding how human activities have changed the atmosphere on a global scale in ways that affect the climate.

Climate scientists explore climate change with the help of models. Earth systems are very complex and the data is often incomplete, so simplifying assumptions have to be made when setting up and testing the models that can then be used to evaluate possible methods for mitigating changes to the climate.

Human activities can also cause pollution on a more local scale, affecting air quality in areas with high traffic levels and contaminating water supplies with sewage.

Water cycles through the environment and is crucial to all living organisms. Various technologies have been developed to purify water so that it is safe to drink, and to treat sewage so that it does not harm the environment.

The required practical investigates the use of distillation to purify water.

4.4.1.1 Development of the Earth's atmosphere

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe how it is thought an oxygen-rich atmosphere developed over time.	Evidence for the early atmosphere is limited because of the time scale of 4.6 billion years. One theory suggests that during the first billion years of the Earth's existence there was intense volcanic activity, which 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 mainly of carbon dioxide with little or no oxygen gas. Volcanoes also produced nitrogen, which gradually built up in the atmosphere, and there may have been small proportions of methane and ammonia. 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. Algae and plants produced the oxygen that is now in the atmosphere by photosynthesis. 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. Photosynthesis by algae and plants also decreased the percentage of carbon dioxide in the atmosphere. Carbon dioxide was also used up in the formation of sedimentary rocks, such as limestone, and fossil fuels such as coal, natural gas and oil.	WS 1.1 Given appropriate information, interpret evidence and evaluate different theories about the Earth's early atmosphere. WS 1.3 Explain why evidence is uncertain or incomplete in a complex context. MS 1c Use ratios, fractions and percentages.

4.4.1.2 The carbon cycle

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall that many different materials cycle through the abiotic and biotic components of an ecosystem. Explain the importance of the carbon cycle to living organisms. Describe photosynthetic organisms as the main producers of food and therefore biomass for life on Earth. Explain the role of microorganisms in the cycling of materials through an ecosystem.	The element carbon is found as carbon dioxide in the atmosphere, dissolved in the water of the oceans, as calcium carbonate in sea shells, in fossil fuels and in limestone rocks, and as carbohydrates and other large molecules in all living organisms. Carbon cycles through the environment by processes that include photosynthesis, respiration, combustion of fuels and the industrial uses of limestone. Life depends on photosynthesis in producers such as green plants, which make carbohydrates from carbon dioxide in the air. Animals feed on plants, passing the carbon compounds along food chains. Animals and plants respire and release carbon dioxide back into the air. Decay of dead plants and animals by microorganisms returns carbon to the atmosphere as carbon dioxide and mineral ions to the soil.	WS 1.2 Draw and interpret diagrams to represent the main stores of carbon and the flows of carbon between them in the cycle. This topic links with Ecosystems and biodiversity (page 75).

4.4.1.3 The greenhouse effect

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the greenhouse effect in terms of the interaction of radiation with matter. (HT only) Recall that different substances may absorb, transmit or reflect these waves in ways that vary with wavelength.	Greenhouse gases in the atmosphere maintain temperatures on Earth high enough to support life. They allow short-wavelength radiation from the Sun to pass through the atmosphere to the Earth's surface but absorb the outgoing long-wavelength radiation from the Earth's surface, causing an increase in temperature. Water vapour, carbon dioxide and methane are greenhouse gases that increase the absorption of outgoing, long-wavelength radiation.	WS 1.2 Interpret and draw diagrams to describe the greenhouse effect.

4.4.1.4 Human impacts on the climate

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Evaluate the evidence for additional anthropogenic causes of climate change, including the correlation between change in atmospheric carbon dioxide concentration and the consumption of fossil fuels, and describe the uncertainties in the evidence base.	Human activities that involve burning fossil fuels (coal, oil and gas) for generating electricity, transport and industry all add carbon dioxide to the atmosphere. These activities have led to a large rise in the concentration of carbon dioxide in the air over the last 150 years. Over the same time the average temperature of the surface of the Earth has risen. The scientific consensus is that this is more than correlation and that the rise in greenhouse gas concentrations has caused the rise in temperature. Climate describes the long-term patterns of weather in different parts of the world. Climate change is shown by changes to patterns in measures of such things as air temperature, rainfall, sunshine and wind speed. Scientists analyse data on climate change using computer models based on the physics that describes the movements of mass and energy in the climate system. Many complex changes on Earth affect the climate, and detailed data about the scale of the changes is not available from all over the world. Also, when predicting climate change, scientists have to make assumptions about future greenhouse gas emissions. This means that there are uncertainties in the predictions.	WS 1.6 Explain the importance of scientists publishing their findings and theories so that they can be evaluated critically by other scientists. Understand that the scientific consensus about global warming and climate change is based on systematic reviews of thousands of peer reviewed publications. WS 1.3 Explain why evidence is uncertain or incomplete in a complex context. MS 2c, 4a Extract and interpret information from charts, graphs and tables. MS 2h Use orders of magnitude to evaluate the significance of data.

4.4.1.5 Climate change: impacts and mitigation

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the potential effects of increased levels of carbon dioxide and methane on the Earth's climate and how these effects may be mitigated, including consideration of scale, risk and environmental implications.	Consequences of global warming and climate change include: • sea-level rise • loss of habitats • changes to weather extremes • changes in the amount, timing and distribution of rainfall • temperature and water stress for humans and wildlife • changes in the distribution of species • changes in the food-producing capacity of some regions. Steps can be taken to mitigate the effects of climate change by reducing the overall rate at which greenhouse gases are added to the atmosphere. Examples of mitigation include: • using energy resources more efficiently • using renewable sources of energy in place of fossil fuels (see Resources of materials and energy (page 141)) • reducing waste by recycling • stopping the destruction of forests • regenerating forests • developing techniques to capture and store carbon dioxide from power stations.	WS 1.4 In the context of climate change, evaluate associated economic and environmental implications; and make decisions based on the evaluation of evidence and arguments.

4.4.1.6 Pollutants that affect air quality

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the major sources of carbon monoxide, sulfur dioxide, oxides of nitrogen and particulates in the atmosphere and explain the problems caused by increased amounts of these substances.	The combustion of fuels is a major source of atmospheric pollutants that can be harmful to health and the environment. Carbon monoxide is formed by the incomplete combustion of hydrocarbon fuels when there is not enough air. Carbon monoxide is a toxic gas that combines very strongly with haemoglobin in the blood. At low doses it puts a strain on the heart by reducing the capacity of the blood to carry oxygen. At high doses it kills. Sulfur dioxide is produced by burning fuels that contain some sulfur. These include coal in power stations and some diesel fuel burnt in ships and heavy vehicles. Sulfur dioxide turns to sulfuric acid in moist air. Oxides of nitrogen are produced by the reaction of nitrogen and oxygen from the air at the high temperatures involved when fuels are burned. Sulfur dioxide and oxides of nitrogen cause respiratory problems in humans and cause acid rain. Acid rain damages plants and buildings. It also harms living organisms in ponds, rivers and lakes. Particulates in the air include soot (carbon) from diesel engines and dust from roads and industry. The smaller particulates can go deep into people's lungs and cause damage that can lead to heart disease and lung cancer.	WS 1.4 Describe, explain or evaluate ways in which human activities affect the environment.

4.4.1.7 The water cycle

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain the importance of the water cycle to living organisms.	Water is found in the solid state in glaciers and ice sheets, in the liquid state in the oceans, rivers, lakes and aquifers and in the gas state in the atmosphere. Water cycles through the environment by processes that include melting, freezing, evaporation and condensation. Precipitation of water from the atmosphere can take the form of rain, sleet or snow. Life on Earth depends on water, on land and in the seas. Water acts as the solvent for chemical reactions in cells. It also helps transport dissolved compounds into and out of cells. Water is either a reactant or a product of biochemical changes such as respiration, photosynthesis and digestion. Rivers, lakes and seas provide habitats for many living organisms.	WS 1.2 Draw and interpret diagrams to represent the main stores of water and the flows of water between them in the cycle.

4.4.1.8 Sources of potable water

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the principal methods for increasing the availability of potable water in terms of the separation techniques used, including ease of treatment of waste, ground and salt water. Describe, explain and exemplify the processes of simple distillation.	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. The methods used to produce potable water depend on available supplies of water and local conditions. In the 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: • choosing an appropriate source of fresh water • passing the water through filters • sterilising. Sterilising agents used for potable water include chlorine, ozone or ultraviolet light. 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. Energy resources have to be used to run these processes. 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. Sewage treatment includes: • screening and grit removal • sedimentation to produce sewage sludge and effluent • anaerobic digestion of sewage sludge • aerobic biological treatment of effluent.	WS 1.4 Explain everyday and technological applications of science; evaluate associated personal, social, economic and environmental implications with reference to the sources of potable water and treatment of waste water.

Required practical activity 11: analysis and purification of water samples from different sources, including pH, dissolved solids and distillation.

AT skills covered by this practical activity: chemistry AT 2, 3 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 168).

4.4.2 Ecosystems and biodiversity

Ecosystems with high levels of biodiversity help to provide the resources needed to sustain life on Earth, including human life. This makes it very important that scientists understand the relationships within and between communities of organisms. The science helps to evaluate the negative and positive human impacts on biodiversity of human activities both locally and globally.

The required practical is an investigation of factors affecting population size of a common species in a habitat.

4.4.2.1 Levels of organisation in an ecosystem

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe different levels of organisation in an ecosystem from individual organisms to the whole ecosystem.	An ecosystem is made up of all the living organisms in a particular environment together with the non-living components such as soil, air and water. A habitat is where a particular organism lives in an ecosystem. A population is made up of all the individuals of the same species in a habitat. A community is made up of all the populations of different organisms that live in the same habitat. Feeding relationships within a community can be represented by food chains. All food chains begin with a producer that synthesises molecules. This is usually a green plant, which absorbs light to make glucose. A food web can be used to understand the interdependence of species within an ecosystem in terms of food sources. Producers are eaten by primary consumers, which in turn may be eaten by secondary consumers and then tertiary consumers. Consumers that kill and eat other animals are predators, and those eaten are prey. In a community the numbers of predators and prey rise and fall in cycles.	WS 1.2 Interpret graphs used to model predator–prey cycles.

4.4.2.2 Interdependence and competition

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the importance of interdependence and competition in a community.	To survive and reproduce, organisms require a supply of materials from their surroundings and from the other living organisms in an ecosystem. Plants often compete with each other for light and space, and for water and nutrients from the soil. Animals often compete with each other for food, mates and territory. Within a community each species depends on other species for food, shelter, pollination, seed dispersal etc. If one species is removed it affects the whole community. A stable community is one where all the species and environmental factors are in balance so that population sizes remain fairly constant.	

4.4.2.3 Factors that affect communities

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain how some abiotic and biotic factors affect communities.	Abiotic factors that can affect a community are: • light intensity • temperature • moisture levels • soil pH and mineral content • wind intensity and direction • carbon dioxide levels for plants • oxygen levels for aquatic animals. Biotic factors that can affect a community are: • availability of food • new predators arriving • new diseases • one species outcompeting another.	WS 1.2 Predict how a change in an abiotic, or biotic, factor would affect a given community given appropriate data or context. MS 1c Calculate the percentage of mass. MS 2c, 4a Extract and interpret information from charts, graphs and tables.

4.4.2.4 Field investigations

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe how to carry out a field investigation into the distribution and abundance of organisms in an ecosystem and explain how to determine their numbers in a given area.	Ecologists use a range of investigation methods using transects and quadrats to determine the distribution and abundance of species in an ecosystem.	MS 2b Calculate arithmetic means. WS 3.3 Carry out and represent mathematical and statistical analysis. MS 4a, 4c Plot and draw appropriate graphs, selecting appropriate scales for the axes. MS 2d Understand the principles of sampling as applied to scientific data.

Required practical activity 12: measure the population size of a common species in a habitat. Use sampling techniques to investigate the effect of a factor on the distribution of this species.

AT skills covered by this practical activity: biology AT 1, 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 169).

4.4.2.5 Biodiversity

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain some of the benefits and challenges of maintaining local and global biodiversity.	Biodiversity is greater in ecosystems that provide a bigger range of different habitats, which are home to larger populations of a variety of organisms. Small populations are in greater danger of dying out if an ecosystem is disrupted in some way. Ecosystems with high levels of biodiversity help to provide the resources needed to sustain life, including human life. Ecosystems with higher biodiversity offer economic benefits by sustaining the resources needed for agriculture, fishing and forestry.	

4.4.2.6 Negative human impacts on ecosystems

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe negative human interactions within ecosystems and explain their impact on biodiversity.	Examples of human interactions with local ecosystems that can diminish or destroy biodiversity include: • building, quarrying, farming, clearing woods and other activities that destroy habitats • the destruction of peat bogs, and other areas of peat, to produce garden compost • pollution of streams, rivers and lakes by sewage, toxic wastes and fertilisers. An example of a global impact of human activities is global warming leading to climate change (The Earth's atmosphere (page 67)).	WS 1.4 Evaluate given information about ways in which human activities affect the environment.

4.4.2.7 Positive human impacts on ecosystems

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe positive human interactions within ecosystems and explain their impact on biodiversity.	There are programmes to reduce these negative effects on ecosystems and biodiversity. These include: • breeding programmes for endangered species • protecting and regenerating habitats • reintroducing wider field margins and hedgerows in areas of monoculture • recycling resources rather than dumping waste in landfill • production of peat-free composts • reducing deforestation and carbon dioxide emissions.	WS 1.4 Evaluate given information about methods that can be used to tackle problems caused by human impacts on the environment.

4.4.3 Inheritance

This topic builds on the study of cells in Cells in animals and plants (page 27) to explore the relationships from the molecular level upwards between genes, chromosomes and phenotypic features. Content covered includes sex determination in humans and single gene inheritance of particular characteristics. Included is the understanding that most phenotypic features are the result of multiple genes rather than single gene inheritance. The ideas presented here lead on to the study of mutations, selective breeding and genetic engineering in Variation and evolution (page 82).

4.4.3.1 Chromosomes and genes

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain the following terms: gamete, chromosome and gene. Describe DNA as a polymer made up of two strands forming a double helix. Describe the genome as the entire genetic material of an organism.	Sexual reproduction involves the joining (fusion) of male and female gametes (sperm and egg cells in animals). In sexual reproduction there is mixing of genetic information, which leads to variety in the offspring. The formation of gametes involves meiosis. The genetic material in the nucleus of a cell is composed of a chemical called DNA contained in the chromosomes. Human body cells contain 23 pairs of chromosomes. DNA is made of very large molecules in long strands, twisted to form a double helix. A gene is a small section of DNA on a chromosome. Each gene contains the code for a particular combination of amino acids to make a specific protein. The genome of an organism is made up of all the genes in the DNA of its body cells.	This topic has links with Cells in animals and plants (page 27).

4.4.3.2 Sex determination in humans

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe sex determination in humans.	In human cells, one of the 23 pairs of chromosomes carries the genes that determine sex. In females the sex chromosomes are the same (XX); in males the chromosomes are different (XY). All eggs contain an X chromosome. Sperm cells contain either an X or a Y chromosome.	

4.4.3.3 Single gene inheritance

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain single gene inheritance. Predict the results of single gene crosses. Explain the terms allele/variant, dominant, recessive, homozygous, heterozygous.	Some characteristics are controlled by a single gene. Examples are fur colour in mice and red–green colour blindness in humans. Each gene may have different forms called alleles. A dominant allele is always expressed, even if only one copy is present. A recessive allele is only expressed if two copies are present (therefore no dominant allele present). If the two alleles present are the same the organism is homozygous for that trait, but if the alleles are different they are heterozygous.	WS 1.2 Complete a Punnett square diagram or interpret the results of a genetic cross diagram for a single gene, and understand family trees. MS 2e (HT only) Construct a Punnett square diagram to make predictions based on simple probability. MS 1c Use direct proportion and simple ratios in genetic crosses.

4.4.3.4 Genotype and phenotype

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe simply how the genome, and its interaction with the environment, influences the development of the phenotype of an organism. Explain the terms genotype and phenotype. Recall that most phenotypic features are the result of multiple genes rather than single gene inheritance.	All the genes present in an individual organism interact with the environment in which the organism grows and develops its observable appearance and character. These characteristics are its phenotype. The variation in the characteristics of individuals of the same kind may be due to differences in: • the genes they have inherited (genetic causes) • the conditions in which they have developed (environmental causes) • a combination of genes and the environment. Human height is an example of a characteristic determined by many genes, each with different alleles. The set of alleles that determine the height of a person is the genotype for that characteristic. Height is also affected by diet and exercise which are part of the environment in which an individual grows up.	WS 1.2 Explain why studies involving identical twins help to separate the contribution of genes and the environment to the development of their phenotypes. WS 1.1 Given a context and related information, discuss the potential importance for medicine of our increasing understanding of the human genome.

4.4.4 Variation and evolution

An understanding of the interplay between evidence and theory in the development of scientific thinking about evolution by natural selection and the classification of living organisms has enabled scientists to develop technologies to make agriculture more productive by means of selective breeding and genetic engineering. These technologies raise ethical issues.

4.4.4.1 Mutations

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
State that there is usually extensive genetic variation within a population of a species. Recall that all variants arise from mutations, and that most have no effect on the phenotype, some influence the phenotype and a very few determine the phenotype.	Mutations are changes in DNA molecules that may affect genes. Mutation of a gene can alter the proteins that it contains the code for, or even prevent the protein being produced in cells. Mutations can happen when DNA is copied during cell division or when cells are affected by environmental factors such as ionising radiation.	

4.4.4.2 Evolution through natural selection

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe evolution as a change in the inherited characteristics of a population over time through a process of natural selection which may result in the formation of new species. Explain how evolution occurs through natural selection of variants that give rise to phenotypes best suited to their environment.	The theory of evolution by natural selection explains the evolution of all species of living things from simple life forms that first developed more than three billion years ago. If two populations of one species become isolated geographically or environmentally they may evolve in different ways to suit different conditions. If they become so different that they can no longer interbreed to produce fertile offspring they have formed two new species.	WS 1.2 Use the theory of evolution by natural selection in an explanation.

4.4.4.3 Evidence for evolution

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the evidence for evolution, including fossils and antibiotic resistance in bacteria.	Evidence for evolution comes from the study of fossils that show how much or how little different organisms have changed as life developed on Earth. Evolution of bacteria can be observed happening in a much shorter time because they reproduce so fast. Bacteria that cause disease evolve by natural selection when exposed to antibiotics; this gives rise to a resistant strain.	MS 2c, 4a Extract and interpret information from charts, graphs and tables.

4.4.4.4 Identification and classification of living things

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the impact of developments in biology on classification systems.	In studies of evolution it is essential to be able to identify and classify living things. Traditionally living things have been classified into groups depending on their structure and characteristics. Organisms are named by the binomial system of genus and species. As evidence of internal structures became more developed due to improvements in microscopes and progress with the understanding of biochemical processes, new models of classification have been proposed. Modern classifications systems are based on theories about evolution developed from analysis of differences in DNA molecules.	WS 1.1 Show how new methods of investigation and new discoveries led to new scientific ideas.

4.4.4.5 Selective breeding

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain the impact of the selective breeding of food plants and domesticated animals.	Selective breeding (artificial selection) is the process by which humans breed plants and animals for particular genetic traits. Selective breeding involves choosing parents from a mixed population with the desired characteristic. They are bred together. From the offspring those with the desired characteristic are bred together. This continues over many generations until all the offspring show the desired characteristic. The trait can be chosen for usefulness or appearance. Selective breeding can lead to 'inbreeding' where some breeds are particularly prone to disease or inherited defects.	WS 1.3, 1.4 Evaluate the benefits and risks of selective breeding given appropriate information and consider related ethical issues.

4.4.4.6 Genetic engineering

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe genetic engineering as a process which involves modifying the genome of an organism to introduce desirable characteristics. (HT only) Describe the main steps in the process of genetic engineering. Explain some of the possible benefits and risks, including practical and ethical considerations, of using gene technology in modern agriculture.	In genetic engineering, selected genes from one organism are transferred to another organism which may, or may not, belong to the same species. This process for genetic modification uses enzymes and vectors (such as bacterial plasmids or viruses) to transfer genes. It is much faster than selective breeding. Genes can be transferred to the cells of animals, plants or microorganisms at an early stage in their development so that they develop with the desired characteristics. Crops that have had their genes modified in this way are called genetically modified crops (GM crops). Crops can be genetically modified to give increased yields or to increase the amount of a vitamin in the food from the crop. Genetically modified crops also include ones that are resistant to insect attack or to herbicides. This means that farmers can cut down on the use of pesticides. They can also spray to kill weeds while leaving the crop plant unaffected. Concerns about GM crops include the effect on populations of wild flowers and insects as a result of cross-pollination. Insects may evolve to become resistant so that the GM crops are no longer protected.	WS 1.4 Evaluate the advantages and disadvantages of GM technologies based on data or other information. WS 1.3 Give a simple ethical argument about the rights and wrongs of a GM technology. Recognise, in given information, the difference between a practical and an ethical argument.

4.5 Building blocks for understanding

The periodic table has many patterns and relationships, and is used by chemists to observe patterns and relationships between the elements. These patterns help to predict properties. For example, elements to the bottom and far left of the table are the most metallic and elements on the top right are the least metallic.

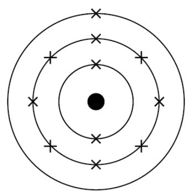
It is also possible to analyse substances to find out how these elements have combined to form compounds and from this to deduce chemical equations. Chemists have a common language for talking about reactions that is understood across the world. This means that they can share their knowledge about chemical reactions and solutions to problems such as ways to improve product yield.

4.5.1 The periodic table

The model of atomic structure introduced in Atomic structure (page 24) is further developed and applied here. The arrangement of elements in the periodic table can be explained in terms of atomic structure, which is evidence for the model of a nuclear atom with electrons in energy levels. The periodic table organises the known chemical elements in a way that helps to account for their physical and chemical properties.

The focus is on the elements in groups 1, 7 and 0.

4.5.1.1 Atomic number and the periodic table

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
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.	The elements in the periodic table are arranged in order of atomic (proton) number, 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. Electrons occupy particular energy levels. Each electron in an atom is at a particular energy level (in a particular shell). The electrons in an atom occupy the lowest available energy levels (innermost available shells). 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.	WS 1.2 Represent the electronic structure of the first 20 elements of the periodic table in the following forms:  sodium 2,8,1 Predict possible reactions and probable reactivity of elements from their positions in the periodic table. This topic links with Atomic structure (page 24).
Explain in terms of isotopes how this changes the arrangement proposed by Mendeleev.	Following Mendeleev, the elements in the periodic table were arranged in order of relative atomic mass. In this order some elements appeared to be in the wrong group. These problems were solved once it was realised that most elements occur as mixtures of isotopes and that elements should be arranged in the table in order of atomic number.	WS 1.1 Show how scientific methods and theories have changed over time. This topic links with Atomic structure (page 24).

4.5.1.2 Metals and non-metals

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
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.	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. Elements that react by losing their outer electrons to form positive ions are metals. Elements that do not form positive ions are non-metals. The more reactive non-metals, such as the halogens, react with metals by gaining electrons to form negative ions.	WS 1.2 Describe metals and non-metals and explain the differences between them in terms of their characteristic physical and chemical properties (see Structure and bonding (page 98) and the sections about groups 1, 7 and 0 in this topic).

4.5.1.3 Group 0

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall the simple properties of Group 0. Explain how the observed simple properties of Group 0 depend on the outer shell of electrons of the atoms and predict properties from given trends down the group.	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 highest energy level (outer shell), except for helium, which has only two electrons. The boiling points of the noble gases increase with increasing relative atomic mass (going down the group).	WS 1.2 Predict properties from given trends down Group 0.

4.5.1.4 Group 1

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall the simple properties of Group 1. Explain how the observed simple properties of Group 1 depend on the outer shell of electrons of the atoms and predict properties from given trends down the group.	The elements in Group 1 of the periodic table are known as the alkali metals. They: • are soft metals with low density • react with non-metals, including chlorine and oxygen, to form colourless ionic compounds • react with water • form hydroxides that give alkaline solutions in water. In Group 1, the further down the group an element is, the more reactive the element.	WS 1.2 Predict properties from given trends down Group 1.

4.5.1.5 Group 7

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall the simple properties of Group 7. Explain how the observed simple properties of Group 7 depend on the outer shell of electrons of the atoms and predict properties from given trends down the group.	The elements in Group 7 of the periodic table are known as the halogens. They: • are non-metals • consist of molecules • react with metals to form ionic compounds • form molecular compounds with other non-metallic elements. In Group 7, the further down the group an element is the higher its relative molecular mass, melting point and boiling point. In Group 7, reactivity of the elements decreases going down the group. A more reactive halogen can displace a less reactive halogen from an aqueous solution of its salt.	WS 1.2 Predict properties from given trends down Group 7.

4.5.2 Chemical quantities

This topic shows how chemists use quantitative methods to determine the formulae of compounds and the equations for reactions. Given this information, they can determine reacting quantities, assess the purity of products and monitor the yield from chemical reactions. The methods can be developed and applied in the context of other chemical topics in this specification. Note that arithmetic computation, ratio, percentage and multi-step calculations feature throughout this section.

4.5.2.1 Chemical equations

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Use the names and symbols of common elements and compounds and the principle of conservation of mass to write formulae and balanced chemical equations. (HT only) and half equations. Use chemical symbols to write the formulae of elements and simple covalent and ionic compounds. Describe the physical states of products and reactants using state symbols (s, l, g and aq).	Atoms of each element are represented by a chemical symbol, eg O represents an atom of oxygen, Na represents an atom of sodium. There are about 100 different elements. Elements are shown in the periodic table. Compounds are formed from elements by chemical reactions. 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. Chemical reactions always involve the formation of one or more new substances, and often involve a detectable energy change. Chemical reactions can be represented by word equations or equations using symbols and formulae. In chemical equations, the three states of matter are shown as (s), (l) and (g), with (aq) for aqueous solutions.	WS 4.1 Use the names and symbols of the first 20 elements, groups 1, 7 and 0 and other common elements from a supplied periodic table to write formulae and balanced chemical equations where appropriate. 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.

4.5.2.2 Conservation of mass

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall and use the law of conservation of mass.	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. This means that chemical reactions can be represented by symbol equations that are balanced in terms of the numbers of atoms of each element involved on both sides of the equation.	MS 1a Use arithmetic computation and ratio when writing and balancing equations.

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain any observed changes in mass in non-enclosed systems during a chemical reaction and explain them using the particle model.	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.	WS 1.2 Explain any observed changes in mass in non-enclosed systems during a chemical reaction given the balanced symbol equation for the reaction.

4.5.2.3 Relative formula masses

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Calculate relative formula masses of species separately and in a balanced chemical equation. Students should be able to calculate the percentage by mass in a compound given the relative formula mass and the relative atomic masses.	The relative atomic mass of an element compares the mass of atoms of the element with the ^{12}C isotope. It is an average value for the isotopes of the element. 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. 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. Students will not be expected to calculate relative atomic masses from isotopic abundances.	MS 1a, 3a Calculate the relative formula mass (M_r) of a compound from its formula, given the relative atomic masses. WS 3.3 Carry out and represent mathematical and statistical analysis.

4.5.2.4 Amounts in moles (HT only)

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain how the mass of a given substance is related to the amount of that substance in moles and vice versa. Recall and use the definitions of the Avogadro constant (in standard form) and of the mole.	Chemical amounts are measured in moles. The symbol for the unit mole is mol. The mass of one mole of a substance in grams is numerically equal to its relative formula mass. One mole of a substance contains the same number of the stated particles, atoms, molecules or ions as one mole of any other substance. 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.	MS 1a, 1b, 1c, 2a Recognise and use expressions in decimal form when using the relative formula mass of a substance to calculate the amount in moles in a given mass of that substance and vice versa, giving the answer in the appropriate units. MS 3b, 3c Change the subject of a mathematical equation. WS 4.6, MS 2a Provide answers to an appropriate number of significant figures. MS 1b Calculate with numbers written in standard form when using the Avogadro constant. MS 3a Understand and use the symbols: $=, <, \ll, \gg, >, \propto, \sim$

4.5.2.5 Calculations based on equations (HT only)

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Deduce the stoichiometry of an equation from the masses of reactants and products and explain the effect of a limiting quantity of a reactant.	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. 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.	MS 3c, 3d Balance an equation given the masses of reactants and products. 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.
Use a balanced equation to calculate masses of reactants or products.	The masses of reactants and products can be calculated from balanced symbol equations. Chemical equations can be interpreted in terms of moles. For example: $Mg + 2HCl \rightarrow MgCl_2 + H_2$ 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.	MS 1a, 1c, 3c, 3d Calculate the masses of reactants and products from the balanced symbol equation and the mass of a given reactant or product. WS 4.6, MS 2a Provide answers to an appropriate number of significant figures.

4.5.2.6 Concentrations of solutions

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
(HT only) Explain how the mass of a solute and the volume of the solution is related to the concentration of the solution.	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 dm^3 (g/dm^3).	MS 1c, 3c Calculate the mass of solute in a given volume of solution of known concentration in terms of mass per given volume of solution.

4.6 Interactions over small and large distances

This topic looks at strong forces and weak forces between atoms, molecules and much larger structures. Understanding how these interactions take place helps to explain how matter behaves, and enables engineers and scientists to design materials that can withstand forces and to provide the materials and devices that we need for a wide range of purposes. The communications, security and transport industries make great use of electromagnetic forces to control and move devices.

4.6.1 Forces and energy changes

By representing forces as vectors it is possible to explain how objects interact by a variety of contact and non-contact forces. Work is introduced as an important means of energy transfer. A force acts on an object with mass when in a gravitational field and thus distinguishes between mass and weight. An object gains potential energy when raised in a gravitational field because of the work done. Forces can stretch, bend or compress objects. The deformation may be elastic or inelastic depending on the material and the size of the forces involved. The work done in stretching can be used to calculate the potential energy of a spring.

The required practical is an investigation of the relationship between force and extension for a spring.

4.6.1.1 Forces as vectors

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall examples of ways in which objects interact: by gravity, electrostatics, magnetism and by contact (including normal contact force and friction), and describe how such examples involve interactions between pairs of objects which produce a force on each object, representing such forces as vectors.	Scalar quantities have magnitude only. Vector quantities have magnitude and an associated direction. Force is a vector quantity. A vector quantity may be represented by an arrow. The length of the arrow represents the magnitude, and the direction of the arrow the direction of the vector quantity. A force is a push or pull that acts on an object due to the interaction with another object. All forces between objects are either: • contact forces – the objects are physically touching or • non-contact forces – the objects are physically separated.	

4.6.1.2 Resolving forces (HT only)

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe examples of the forces acting on an isolated solid object or system; describe, using free body diagrams, examples where several forces lead to a resultant force on an object and the special case of balanced forces when the resultant force is zero (qualitative only).	A number of forces acting on an object may be replaced by a single force that has the same effect as all the original forces acting together. This single force is called the resultant force. A free body diagram shows the magnitude and direction of the forces acting on an object. A single force can be resolved into two components acting at right angles to each other. The two component forces together have the same effect as the single force.	WS 1.2, MS 4a, 5a, 5b Use vector diagrams to illustrate resolution of forces and equilibrium situations and determine the resultant of two forces, to include both magnitude and direction (scale drawings only).

4.6.1.3 Work

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe and calculate the changes in energy involved when a system is changed by the work done by forces acting upon it. Use the relationship between work done, force and distance moved along the line of action of the force, describing the energy transfer involved.	A force does work on an object when the force causes a displacement of the object. work done = force × distance (moved along the line of action of the force) [$W = F s$] work done, *W*, in joules, J force, *F*, in newtons, N distance, *s*, in metres One joule of work is done when a force of one newton causes a displacement of one metre. 1 joule = 1 newton-metre	WS 1.2, MS 3b, 3c Recall and apply this equation to calculate energy transfers. WS 4.5, MS 1c, 3c Convert between newton-metres and joules.

4.6.1.4 Mass and weight

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Define weight, describe how it is measured and describe the relationship between the weight of that body and the gravitational field strength.	Weight is the force acting on an object due to gravity. The force of gravity close to the Earth is due to the gravitational field around the Earth. The weight of an object depends on the gravitational field strength at the point where the object is: weight = mass × gravitational field strength [$W = m\,g$] weight, *W*, in newtons , N mass, *m*, in kilograms, kg gravitational field strength, *g*, in newtons per kilogram, N/kg The weight of an object and the mass of an object are directly proportional. Weight is measured using a calibrated spring balance (a newtonmeter).	WS 1.2, MS 3b, 3c Recall and apply this equation. In any calculation the value of the gravitational field strength (*g*) will be given. MS 3a Understand and use the symbol for proportionality, ∝

4.6.1.5 Gravitational potential energy

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Calculate the amounts of energy associated with an object raised above ground level.	An object raised above ground level gains gravitational potential energy $g.p.e. = mass \times gravitational\ field\ strength \times height$ $E_p = m\,g\,h$ gravitational potential energy, E_p, in joules, J mass, *m*, in kilograms, kg gravitational field strength, *g*, in newtons per kilogram, N/kg height, *h*, in metres, m	WS 1.2, MS 3c Recall and apply this equation to calculate changes in stored energy. In any calculation the value of the gravitational field strength (*g*) will be given.

4.6.1.6 Elastic deformation

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain, with examples, that to stretch, bend or compress an object, more than one force has to be applied. Describe the difference between elastic and inelastic distortions caused by stretching forces; describe the relationship between force and extension for a spring and other simple systems; describe the difference between linear and non-linear relationships between force and extension, and calculate a spring constant in linear cases.	An object that has been stretched has been elastically deformed if the object returns to its original length after the forces are removed. An object that does not return to its original length after the forces have been removed has been inelastically deformed. The extension of an elastic object, such as a spring, is directly proportional to the force applied, provided that the limit of proportionality is not exceeded. *force = spring constant x extension* [$F = k e$] force, F, in newtons, N spring constant, k, in newtons per metre, N/m extension, e, in metres, m A force that stretches (or compresses) a spring does work, and elastic potential energy is stored in the spring. Provided the spring does not go past the limit of proportionality the work done on the spring and the elastic potential energy stored are equal.	WS 1.2, MS 3c, 4a, 4b, 4c Recall and apply this equation

Required practical activity 13: investigate the relationship between force and extension for a spring.

AT skills covered by this practical activity: physics AT 1 and 2.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in Key opportunities for skills development (page 169)

4.6.1.7 Energy stored in a stretched spring

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Calculate the amounts of energy associated with a stretched spring.	Elastic potential energy is stored in a stretched spring. $\textit{elastic potential energy} = 0.5 \times \textit{spring constant} \times (\textit{extension})^2$ $[E_e = \frac{1}{2} k e^2]$ (assuming the limit of proportionality has not been exceeded) elastic potential energy, E_e, in joules, J spring constant, k, in newtons per metre, N/m extension, e, in metres, m	WS 1.2, MS 1c, 3c Calculate the work done in stretching. MS 3b, 3c Apply this equation, which is given on the Physics equations sheet.

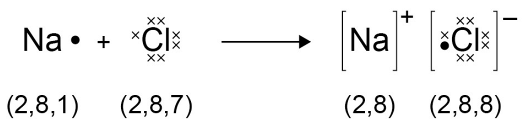
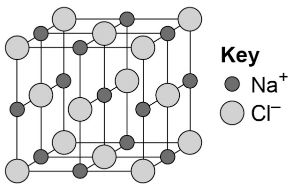
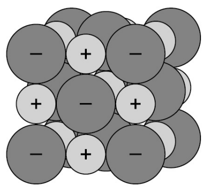
4.6.2 Structure and bonding

The theories of structure and bonding can 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. Materials scientists use this knowledge of structure and bonding to engineer new materials with desirable properties (see Carbon chemistry (page 137)).

4.6.2.1 Types of chemical bonding

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe and compare the nature and arrangement of chemical bonds in ionic compounds, simple molecules, giant covalent structures, and polymers and metals.	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 that share pairs of electrons. For metallic bonding the particles are atoms that share delocalised electrons. Ionic bonding occurs in compounds formed from metals combined with non-metals. Covalent bonding occurs in non-metallic elements and in compounds of non-metals. Metallic bonding occurs in metallic elements and alloys.	

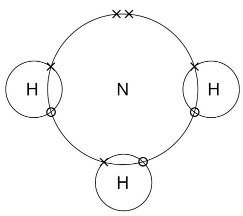
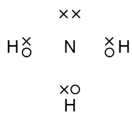
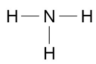
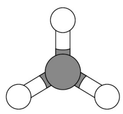
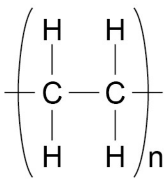
4.6.2.2 Ionic bonding

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain chemical bonding in terms of electrostatic forces and the transfer of electrons. Construct dot and cross diagrams for simple ionic substances. Deduce the empirical formula of a compound from the relative numbers of atoms present or from a model or diagram and vice versa. Use the formulae of common ions to deduce the formula of a compound.	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). The electron transfer during the formation of an ionic compound can be represented by a dot and cross diagram, eg for sodium chloride:  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. 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. The structure of sodium chloride can be represented in the following forms:   Knowledge of the structures of specific ionic compounds other than sodium chloride is not required.	WS 1.2 Draw dot and cross diagrams for ionic compounds formed by metals in groups 1 and 2 with non-metals in groups 6 and 7. 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. Describe the limitations of particular representations and models to include dot and cross diagrams, ball and stick models and two- and three-dimensional representations. MS 4a Translate data between diagrammatic and numeric forms. MS 5b Draw or complete diagrams to represent 2D and 3D forms including two-dimensional representations of 3D structures. MS 1a Use arithmetic computation and ratio when determining empirical formulae.

4.6.2.3 Properties of ionic compounds

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain how the bulk properties of materials are related to the different types of bonds they contain, their bond strengths and the ways in which their bonds are arranged, recognising that the atoms themselves do not have these properties.	Ionic compounds have regular structures (giant ionic lattices) in which there are strong electrostatic forces of attraction in all directions between oppositely charged ions. These compounds have high melting points and high boiling points because of the large amounts of energy needed to break the many strong bonds. When melted or dissolved in water, ionic compounds conduct electricity because the ions are free to move and so charge can flow.	WS 1.2 Use ideas about energy transfers and the relative strength of chemical bonds and intermolecular forces to explain the different temperatures at which changes of state occur. Use data to predict states of substances under given conditions.

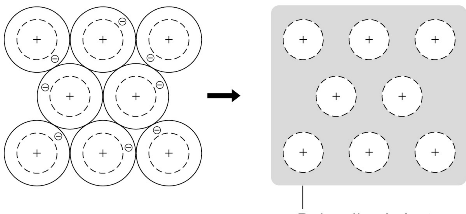
4.6.2.4 Covalent bonding

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain chemical bonding in terms of electrostatic forces and the sharing of electrons. Construct dot and cross diagrams for simple covalent substances. Deduce the empirical formula of a compound from the relative numbers of atoms present or from a model or diagram and vice versa.	When atoms share pairs of electrons they form covalent bonds. These bonds between atoms are strong. Covalently bonded substances may consist of small molecules. Some covalently bonded substances have very large molecules, such as polymers. Some covalently bonded substances have giant covalent structures, such as diamond and silicon dioxide. The covalent bonds in molecules and giant structures can be represented in the following forms: For ammonia (NH_3)  and/or  and/or  and/or  Polymers can be represented in the form:  poly(ethene) where n is a large number.	WS 1.2 Recognise substances as small molecules, polymers or giant structures from diagrams showing their bonding. 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 particular representations and models to include dot and cross diagrams, ball and stick models and two- and three-dimensional representations. MS 5b Draw or complete diagrams to represent 2D and 3D forms including two-dimensional representations of 3D molecules. MS 1a Use arithmetic computation and ratio when determining empirical formulae.

4.6.2.5 Properties of substances with covalent bonding

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain how the bulk properties of materials are related to the different types of bonds they contain, their bond strengths in relation to intermolecular forces and the ways in which their bonds are arranged, recognising that the atoms themselves do not have these properties.	Substances that consist of small molecules are usually gases or liquids that have relatively low melting points and boiling points. 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. The intermolecular forces increase with the size of the molecules, so larger molecules have higher melting and boiling points. These substances do not conduct electricity because the molecules do not have an overall electric charge. 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. 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.	WS 1.2 Use the idea that intermolecular forces are weak compared with covalent bonds to explain the bulk properties of molecular substances. Use ideas about energy transfers and the relative strength of chemical bonds and intermolecular forces to explain the different temperatures at which changes of state occur. Recognise polymers from diagrams showing their bonding. Recognise giant covalent structures from diagrams showing their bonding. Use data to predict states of substances under given conditions.

4.6.2.6 Metallic bonding

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain chemical bonding in terms of electrostatic forces and the sharing of electrons.	Metals consist of giant structures of atoms arranged in a regular pattern. 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:  	MS 5b Draw or complete diagrams to represent 2D and 3D forms including two-dimensional representations of 3D structures.

4.6.2.7 Properties of metals

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain how the bulk properties of materials are related to the different types of bonds they contain, their bond strengths and the ways in which their bonds are arranged, recognising that the atoms themselves do not have these properties.	Metals have giant structures of atoms with strong metallic bonding. This means that most metals have high melting and boiling points. The layers of atoms in a metal crystal can slide over each other. This means metals can be bent and shaped. Pure metals are too soft for many uses and so are mixed with other metals to make alloys. The different sizes of atoms in an alloy distort the crystal structure, making alloys harder than pure metals. Metals are good conductors of electricity because the delocalised electrons in the metal carry electrical charge through the metal.	WS 1.2 Use ideas about energy transfers and the relative strength of chemical bonds and intermolecular forces to explain the different temperatures at which changes of state occur. Use data to predict states of substances under given conditions.

4.6.3 Magnetism and electromagnetism

This topic starts with a study of the magnetic fields around permanent magnets and the Earth. The study of the Earth's magnetism can be used to provide clues to the planet's internal structure. Electric currents produce magnetic fields. Forces produced in magnetic fields can be used to make things move. This is called the motor effect and is how an electric motor creates movement.

4.6.3.1 Magnets

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the attraction and repulsion between unlike and like poles for permanent magnets and describe the difference between permanent and induced magnets.	The poles of a magnet are the places where the magnetic forces are strongest. When two magnets are brought close together they exert a force on each other. Attraction and repulsion between two magnetic poles are examples of non-contact force. A permanent magnet produces its own magnetic field. An induced magnet is a material that becomes a magnet when it is placed in a magnetic field. Induced magnetism always causes a force of attraction. When removed from the magnetic field an induced magnet loses most/all of its magnetism quickly.	

4.6.3.2 Magnetic fields

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the characteristics of the magnetic field of a magnet, showing how strength and direction change from one point to another.	The region around a magnet where a force acts on another magnet or on a magnetic material (iron, steel, cobalt and nickel) is called the magnetic field. The force between a magnet and a magnetic material is always one of attraction. The strength of the magnetic field depends on the distance from the magnet. The field is strongest at the poles of the magnet. The direction of the magnetic field at any point is given by the direction of the force that would act on another north pole placed at that point. The direction of a magnetic field line is from the north (seeking) pole of a magnet to the south (seeking) pole of the magnet.	WS 2.2 Draw the magnetic field pattern of a bar magnet and describe how to plot the magnetic field pattern using a compass.

4.6.3.3 The Earth's magnetism

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain how the behaviour of a magnetic compass is related to evidence that the core of the Earth must be magnetic.	A magnetic compass contains a small bar magnet. The Earth has a magnetic field. The compass needle points in the direction of the Earth's magnetic field. The Earth's magnetic field is probably caused by movements in the liquid, iron-rich part of the outer core of the Earth. The slow changes to the positions of the magnetic north and south poles, and the way that the field reverses its direction from time to time, show that the magnetism of the core is dynamic and not static. The intervals between reversals are not uniform. The last reversal happened about 800,000 years ago.	WS 1.3 Explain why the data needed to answer a scientific question, in a given context, may not be available because of matters of scale and complexity.

4.6.3.4 The magnetic effect of an electric current

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe how to show that a current can create a magnetic effect and describe the directions of the magnetic field around a conducting wire.	When a current flows through a conducting wire a magnetic field is produced around the wire. The shape of the magnetic field can be seen as a series of concentric circles in a plane perpendicular to the wire. The direction of these field lines depends on the direction of the current.	WS 1.2, 3.1 Draw the magnetic field pattern for a straight wire carrying a current (showing the direction of the field). WS 1.2 Use the 'right-hand grip rule' to predict the direction of the field.

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall that the strength of the field depends on the current and the distance from the conductor, and explain how solenoid arrangements can enhance the magnetic effect.	The strength of the magnetic field depends on the current through the wire and the distance from the wire. Shaping a wire to form a solenoid increases the strength of the magnetic field created by a current through the wire. The magnetic field inside a solenoid is strong and uniform. The magnetic field around a solenoid has a similar shape to that of a bar magnet. Adding an iron core increases the magnetic field strength of a solenoid. An electromagnet is a solenoid with an iron core.	WS 3.1 Draw the magnetic field pattern for a solenoid carrying a current (showing the direction of the field). WS 1.4 Compare the advantages and disadvantages of permanent and electromagnets for particular uses.

4.6.3.5 The motor effect (HT only)

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe how a magnet and a current-carrying conductor exert a force on one another and show that Fleming's left-hand rule represents the relative orientations of the force, the conductor and the magnetic field.	When a conductor carrying a current is placed in a magnetic field the magnet producing the field and the conductor exert a force on each other. This is called the motor effect. The direction of the force on the conductor is reversed if either the direction of the current or the direction of the magnetic field is reversed.	WS 1.2 Use Fleming's left-hand rule to predict the direction of the force on a conductor.

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Apply the equation that links the force on a conductor to the magnetic flux density, the current and the length of conductor to calculate the forces involved.	The size of the force on the conductor depends on: • the magnetic flux density • the current in the conductor • the length of conductor in the magnetic field. For a conductor at right angles to a magnetic field and carrying a current: $force = magnetic\ flux\ density \times current \times length$ $[\ F = B\ I\ l\ ]$ force, *F*, in newtons, N magnetic flux density, *B*, in tesla, T current, *I*, in amperes, A (amp is acceptable for ampere) length, *l*, in metres, m	MS 3c Apply this equation, which is given on the Physics equations sheet. WS 3.3 Carry out and represent mathematical and statistical analysis.

4.6.3.6 Electric motors (HT only)

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain how this force is used to cause rotation in electric motors.	A simple electric motor consists of a rectangular coil of wire that is free to turn in the magnetic field of a permanent magnet. A commutator reverses the direction of the current every half turn, to allow the rotation to continue.	WS 1.2 Apply Fleming's left-hand rule to a simple electric motor. WS 1.4 Explain everyday and technological applications of science.

4.7 Movement and interactions

Movement can take place over small and large distances, and can happen at very different speeds. Crashes, bangs and collisions can take place between sub-atomic particles or between large, moving vehicles. Scientists try to learn as much as possible about these interactions so that they can make it safer and healthier to travel and keep our homes and cities running.

4.7.1 Forces and motion

Forces can change the motion of objects. Objects can move in a straight line at a constant speed. They can also change their speed and/or direction (accelerate or decelerate). This topic shows how observations of moving objects can be accounted for in terms of Newton's laws of motion. Graphs can help to describe the movement of objects. These may be distance–time or velocity–time graphs. When an object speeds up or slows down, its kinetic energy increases or decreases. The forces that cause the change in speed do so by doing work. The topic ends by showing that these ideas can be applied to the issue of road safety.

The required practical in this topic is an investigation of the effects of varying the force and/or mass on the acceleration of an object.

In this topic students have to be able to apply formulae relating distance, time and speed, for uniform motion and for motion with uniform acceleration, and calculate average speed for non-uniform motion (MS 1a, 1c, 2b, 3c).

4.7.1.1 Speed and velocity

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain the vector–scalar distinction as it applies to displacement, distance, velocity and speed.	Distance is how far an object moves. Distance does not involve direction. Distance is a scalar quantity. Displacement includes both the distance an object moves, measured in a straight line from the start point to the finish point, and the direction of that straight line. Displacement is a vector quantity. Speed does not involve direction. Speed is a scalar quantity. The velocity of an object is its speed in a given direction. Velocity is a vector quantity.	

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall typical speeds encountered in everyday experience for wind and sound, and for walking, running, cycling and other transportation systems.	The speed of a moving object is rarely constant. When people walk, run or travel in a car their speed is constantly changing. The speed that a person can walk, run or cycle depends on many factors, including age, terrain, fitness and distance travelled. Typical mean values are: • walking 1.5 m/s • running 3 m/s • cycling 6 m/s. It is not only moving objects that have varying speed. The speed of sound and the speed of the wind also vary. A typical value for the speed of sound is 330 m/s.	

4.7.1.2 Distance, speed and time

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Make measurements of distances and times, calculate speeds, and make and use graphs of these to determine the speeds and accelerations involved.	The distance travelled by an object moving at constant speed increases with time. $distance\ travelled = speed \times time$ $s = v\,t$ distance, *s*, in metres, m speed, *v*, in metres per second, m/s time, *t*, in seconds, s If an object moves along a straight line, how far it is from a certain point can be represented by a distance–time graph. The speed of an object can be calculated from the gradient of its distance–time graph. (HT only) If an object is accelerating, its speed at any particular time can be determined by drawing a tangent and measuring the gradient of the distance–time graph at that time.	MS 3b, 3c Recall and apply this equation. WS 4.5, MS 1c, 3b, 3c Use ratios and proportional reasoning to convert units and to compute rates. WS 1.2, 3.5, MS 4a, 4b, 4c, 4d, 4f Relate changes and differences in motion to appropriate distance–time, and velocity–time graphs, and interpret lines, slopes and enclosed areas in such graphs. MS 1a, 1c, 2f, 3c Calculate average speed for non-uniform motion.

4.7.1.3 Circular motion (HT only)

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain with examples that motion in a circular orbit involves constant speed but changing velocity (qualitative only).	The velocity of an object is its speed in a given direction. Velocity is a vector quantity. When an object moves in a circle the direction of the object is continually changing. This means that an object moving in a circle at constant speed has a continually changing velocity.	

4.7.1.4 Free fall

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall the acceleration in free fall and estimate the magnitudes of everyday accelerations.	Acceleration is the rate at which the velocity of an object changes. $acceleration = \frac{change\ in\ velocity}{time\ taken}$ $a = \frac{\Delta v}{t}$ acceleration, *a*, in metres per second squared, m/s^2 change in velocity, Δv, in metres per second, m/s time, *t*, in seconds, s An object that slows down (decelerates) has a negative acceleration. The acceleration of an object can be calculated from the gradient of a velocity–time graph. The distance travelled by an object (or displacement of an object) can be calculated from the area under a velocity–time graph.	WS 1.2, 3.3, MS 3b, 3c Recall and apply this equation. WS 1.2, 3.5, MS 4a, 4b, 4c, 4d, 4f, 5c Relate changes and differences in motion to appropriate velocity–time graphs, and interpret lines and slopes to determine acceleration. (HT only) Interpret enclosed areas in such graphs to determine distance travelled (or displacement). (HT only) Measure, when appropriate, the area under a velocity–time graph by counting squares.

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
	(HT only) The following equation applies to uniform motion: $(final\ velocity)^2 - (initial\ velocity)^2 = 2 \times acceleration \times distance$ $\left[v^2 - u^2 = 2\,a\,s\right]$ final velocity, *v*, in metres per second, m/s initial velocity, *u*, in metres per second, m/s acceleration, *a*, in metres per second squared, m/s^2 distance, *s*, in metres, m Near the Earth's surface any object falling freely under gravity has an acceleration of about 9.8 m/s^2. An object falling through a fluid initially accelerates due to the force of gravity. Eventually the resultant force will be zero and the object will move at its terminal velocity.	WS 1.2, 3.3, MS 3c (HT only) Apply this equation, which is given on the *Physics equation sheet*.

4.7.1.5 Newton's First Law

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Apply Newton's First Law to explain the motion of objects moving with uniform velocity and also objects where the speed and/or direction change.	Newton's First Law: If the resultant force acting on an object is zero and: • the object is stationary, the object remains stationary • the object is moving, the object continues to move at the same speed and in the same direction. So the object continues to move at the same velocity.	

4.7.1.6 Newton's Second Law

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Apply Newton's Second Law in calculations relating forces, masses and accelerations.	Newton's Second Law: The acceleration of an object is proportional to the resultant force acting on the object, and inversely proportional to the mass of the object. $resultant\ force = mass \times acceleration$ $F = m\,a$ force, *F*, in newtons, N mass, *m*, in kilograms, kg acceleration, *a*, in metres per second squared, m/s^2	MS 3a Recognise and be able to use the symbol: • for proportionality, α • that indicates an approximate value or answer, ~ WS 1.2, 3.3, MS 3c Recall and apply this equation.
(HT only) Explain that inertial mass is a measure of how difficult it is to change the velocity of an object and that it is defined as the ratio of force over acceleration.	(HT only) The tendency of objects to continue in their state of rest or of uniform motion is called inertia. Inertial mass is a measure of how difficult it is to change the velocity of an object. Inertial mass is defined by the ratio of force over acceleration.	

Required practical activity 14: investigate the effect of varying the force on the acceleration of an object of constant mass and the effect of varying the mass of an object on the acceleration produced by a constant force.

AT skills covered by this practical activity: physics AT 1, 2 and 3.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in Key opportunities for skills development (page 170).

4.7.1.7 Newton's Third Law

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall Newton's Third Law and apply it to examples of equilibrium situations.	Newton's Third Law: Whenever two objects interact, the forces they exert on each other are equal and opposite.	

4.7.1.8 Momentum (HT only)

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Define momentum and describe examples of momentum in collisions.	Momentum is a property of moving objects. Momentum is defined by the equation: $momentum = mass \times velocity$ $p = m\,v$ momentum, p, in kilograms metre per second, kg m/s mass, m, in kilograms, kg velocity, v, in metres per second, m/s In a closed system, the total momentum before an event is equal to the total momentum after the event. This is called conservation of momentum.	WS 1.2, 3.3, MS 3c Recall and apply this equation. WS 1.2 Use the concept of momentum as a model to analyse an event such as a collision.

4.7.1.9 Kinetic energy

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Calculate the amounts of energy associated with a moving body. Describe all the changes involved in the way energy is stored when a system changes for common situations: a moving object hitting an obstacle, or an object being accelerated by a constant force.	The kinetic energy of a moving object depends on the mass and the velocity of the object. $kinetic\ energy = 0.5 \times mass \times (speed)^2$ $\left[E_k = \frac{1}{2}\,m\,v^2\right]$ kinetic energy, E_k, in joules, J mass, m, in kilograms, kg speed, v, in metres per second, m/s	WS 1.2, 3.3, MS 3c Recall and apply this equation.

4.7.1.10 Stopping distances

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain the factors which affect the distance required for road transport vehicles to come to rest in emergencies and the implications for safety.	The stopping distance of a vehicle is the sum of the distance the vehicle travels during the driver's reaction time (thinking distance) and the distance it travels under the braking force (braking distance). For a given braking force the greater the speed of the vehicle, the greater the stopping distance. The braking distance of a vehicle can be affected by wet or icy weather and poor condition of the vehicle's brakes or tyres. A driver's reaction time (see The human nervous system (page 41)) can be affected by tiredness, drugs and alcohol. Distractions may also affect a driver's ability to react.	WS 3.6 Analyse a given situation to explain why braking could be affected. WS 1.5 Discuss the implications for safety. WS 3.5, MS 4a Interpret graphs relating speed to stopping distance for different types of vehicles. WS 1.5, 2.2, MS 1a, 1c Evaluate the effect of various factors on thinking distance based on given data.
Explain the dangers caused by large decelerations. Describe all the changes involved in the way energy is stored when a system changes, for common situations, like a vehicle slowing down.	When a force is applied to the brakes of a vehicle, work done by the friction force between the brakes and the wheel reduces the kinetic energy of the vehicle and the temperature of the brakes increases. The greater the speed of a vehicle the greater the braking force needed to stop the vehicle in a certain distance. The greater the braking force the greater the deceleration of the vehicle. Large decelerations may lead to brakes overheating and/or loss of control.	WS 1.5, MS 1d (HT only) Estimate the forces involved in typical situations on a public road.

4.7.2 Electricity

A quantitative study of electric currents in circuits leads on to an introduction of the alternating currents used in the mains electricity supply. Electricity is distributed to consumers via the National Grid. The rate of energy transfer depends on the power of the appliances connected to the supply.

In this topic students have to be able to apply the equations relating potential difference, current, quantity of charge, resistance, power, energy and time, and solve problems for circuits which include resistors in series, using the concept of equivalent resistance (MS 1c, 3b, 3c, 3d).

There are two required practicals in this topic. One is to investigate the I–V characteristics of a variety of circuit elements at constant temperature. The other is to set up and use appropriate circuits to investigate factors that affect the resistance of an electrical component. The practical activities give students experience of the apparatus and techniques related to the use of circuit diagrams to construct and check series and parallel circuits that include a variety of common circuit components.

4.7.2.1 Electric current

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall that current is a rate of flow of charge, that for a charge to flow a source of potential difference and a closed circuit are needed and that a current has the same value at any point in a single closed loop. Recall and use the relationship between quantity of charge, current and time.	For electrical charge to flow through a closed circuit the circuit must include a source of potential difference. Electric current is a flow of electrical charge. The size of the electric current is the rate of flow of electrical charge. $charge\ flow = current \times time$ [$Q = I\,t$] charge flow, *Q*, in coulombs, C current, *I*, in amperes, A (amp is acceptable for ampere) time, *t*, in seconds, s A current has the same value at any point in a single closed loop.	WS 3.3, MS 3b, 3c Recall and apply this equation.

4.7.2.2 Current, resistance and potential difference

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall that current (I) depends on both resistance (R) and potential difference (V) and the units in which these are measured; recall and apply the relationship between I, R and V, and explain that for some resistors the value of R remains constant.	The current through a component depends on both the resistance of the component and the potential difference across the component. The greater the resistance of the component the smaller the current for a given potential difference across the component. $potential\ difference = current \times resistance$ $[\ V = I\ R\ ]$ potential difference, *V*, in volts, V current, *I*, in amperes, A (amp is acceptable for ampere) resistance, *R*, in ohms, Ω The current through an ohmic conductor (at a constant temperature) is directly proportional to the potential difference across the conductor. This means that the resistance remains constant as the current changes.	WS 3.3, MS 3c Recall and apply this equation.
Explain that in other types of resistor the value of R can change as the current changes; explain the design and use of circuits to explore such effects – including lamps, diodes, thermistors and light-dependent resistors (LDRs).	The resistance of components such as lamps, diodes, thermistors and LDRs is not constant; it changes with the current through the component. The resistance of a filament lamp increases as the temperature of the filament increases. The current through a diode flows in one direction only. The diode has a very high resistance in the reverse direction. The resistance of a thermistor decreases as the temperature increases. The resistance of an LDR decreases as light intensity increases.	WS 1.2, 3.5, MS 4c, 4d, 4e Use graphs to determine whether circuit components are linear or non-linear and relate the curves produced to the function and properties of the component.

Required practical activity 15: use circuit diagrams to construct appropriate circuits to investigate the I–V characteristics of a variety of circuit elements including a filament lamp, a diode and a resistor at constant temperature.

AT skills covered by this practical activity: physics AT 6 and 7.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in Key opportunities for skills development (page 172).

Required practical activity 16: use circuit diagrams to set up an appropriate circuit to investigate the factors affecting the resistance of an electrical component. This should include:

- the length of a wire at constant temperature
- combinations of resistors in series and in parallel.

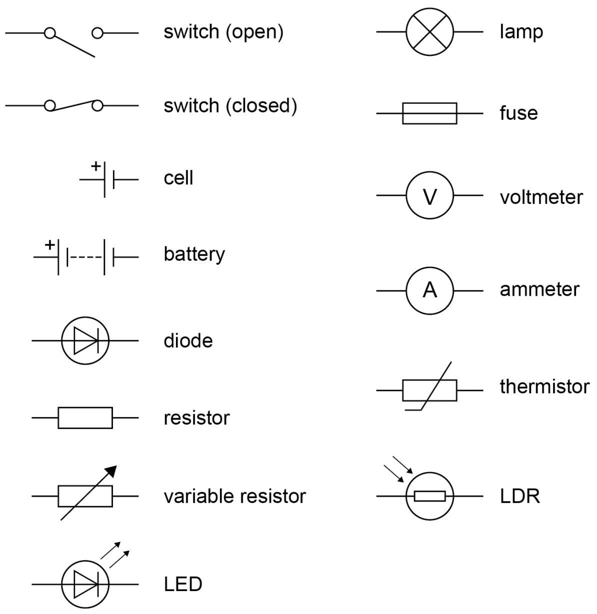
AT skills covered by this practical activity: physics AT 1, 6 and 7.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in Key opportunities for skills development (page 173).

4.7.2.3 Series and parallel circuits

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the difference between series and parallel circuits; explain why, if two resistors are in series, the net resistance is increased, whereas with two in parallel the net resistance is decreased (qualitative explanation only). Calculate the currents, potential differences and resistances in direct current (dc) series circuits, and explain the design and use of such circuits for measurement and testing purposes.	There are two ways of joining electrical components: in series and in parallel. Some circuits include both series and parallel parts. For components connected in series: • there is the same current through each component • the total potential difference of the power supply is shared between the components • the total resistance of two components is the sum of the resistance of each component. $R_{total} = R_1 + R_2$ resistance, *R*, in ohms, Ω For components connected in parallel: • the potential difference across each component is the same • the total current through the whole circuit is the sum of the currents through the separate components • the total resistance of two resistors is less than the resistance of the smallest individual resistor.	WS 3.3, MS 1c, 3b, 3c, 3d Solve problems for circuits which include resistors in series using the concept of equivalent resistance. WS 3.3, MS 1c, 3b, 3c, 3d Calculate the currents, potential differences and resistances in dc series circuits. Calculating the total resistance of two resistors joined in parallel is not required.

4.7.2.4 Circuit elements

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Represent in dc series circuits with the conventions of positive and negative terminals, the symbols that represent common circuit elements, including diodes, LDRs and thermistors.	Circuit diagrams use standard symbols. 	

4.7.2.5 Direct and alternating currents

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall that the domestic supply in the UK is ac, at 50Hz and about 230 volts; explain the difference between direct and alternating voltage.	Cells and batteries supply current that always passes in the same direction. This is called direct current (dc). An alternating current (ac) is one that changes direction. In the UK ac supply the current changes direction 50 times per second.	

4.7.2.6 Mains cables

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall the differences in function between the live, neutral and earth mains wires, and the potential differences between these wires; hence explain that a live wire may be dangerous even when a switch in a mains circuit is open, and explain the dangers of providing any connection between the live wire and earth.	Most electrical appliances are connected to the mains using three-core cable. The insulation covering each wire is colour coded for easy identification. • Live wire – brown • Neutral wire – blue • Earth wire – green and yellow stripes The live wire carries the alternating potential difference from the supply. The neutral wire completes the circuit. The earth wire is a safety wire to stop the appliance becoming live. The potential difference between the live wire and earth (0 V) is about 230 V. The neutral wire is at or close to earth potential (0 V). The earth wire is at 0 V; it carries a current only if there is a fault. Our bodies are at earth potential (0 V). Touching the live wire produces a large potential difference across our body. This causes a current to flow through our body, resulting in an electric shock.	WS 1.5 Identify an electrical hazard in a given context.

4.7.2.7 Power

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain, with reference to examples, the definition of power as the rate at which energy is transferred.	Power is defined as the rate at which energy is transferred or the rate at which work is done. $power = \frac{energy\ transferred}{time}$ $\left[P = \frac{E}{t}\right]$ $power = \frac{work\ done}{time}$ $\left[P = \frac{W}{t}\right]$ power, *P*, in watts, W energy transferred, *E*, in joules, J time, *t*, in seconds, s work done, *W*, in joules, J An energy transfer of 1 joule per second is equal to a power of 1 watt.	WS 1.2, 3.3,MS 3b, 3c Recall and apply both of these equations.
Explain how the power transfer in any circuit device is related to the potential difference across it and the current, and to the energy changes over a given time.	The power of an electrical device is related to the potential difference across it and the current through it by the equation: $power = potential\ difference \times current$ $[P = V\ I]$ $power = (\text{current})^2 \times resistance$ $[P = I^2\ R]$ power, *P*, in watts, W potential difference, *V*, in volts, V current, *I*, in amperes, A (amp is acceptable for ampere) resistance, *R*, in ohms, Ω	WS 1.2, 3.3, MS 3b, 3c Recall and apply both of these equations.

4.7.2.8 Power and domestic electric appliances

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe how, in different domestic devices, energy is transferred from batteries and the ac mains to the energy of motors or of heating devices. Describe all the changes involved in the way energy is stored when a system changes, for common situations: bringing water to a boil in an electric kettle. Describe, with examples, the relationship between the power ratings for domestic electrical appliances and the changes in stored energy when they are in use. Describe and calculate the changes in energy involved when a system is changed by work done when a current flows.	Everyday electrical appliances are designed to bring about energy transfers. The amount of energy an appliance transfers depends on how long the appliance is switched on for and the power of the appliance. Work is done when charge flows in a circuit. The amount of energy transferred can be calculated using the equations: $energy\ transferred = power \times time$ $[\ E = P\ t\ ]$ $energy\ transferred = charge\ flow \times potential\ difference$ $[\ E = Q\ V\ ]$ energy transferred, *E*, in joules, J power, *P*, in watts, W time, *t*, in seconds, s charge flow, *Q*, in coulombs, C potential difference, *V*, in volts, V	WS 1.4 Explain everyday and technological applications of science. WS 1.2, 3.3, MS 3c Recall and apply both of these equations.

4.7.2.9 The National Grid

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall that, in the national grid, electrical power is transferred at high voltages from power stations and then transferred at lower voltages in each locality for domestic use; and explain how this system is an efficient way to transfer energy.	The National Grid is a system of cables and transformers linking power stations to consumers. Electrical power is transferred from power stations to consumers using the National Grid. Step-up transformers are used to increase the potential difference from the power station to the transmission cables then step-down transformers are used to decrease the potential difference to a much lower value for domestic use. (HT only) Students should be able to select and use the equation: potential difference across primary coil x current in primary coil = potential difference across secondary coil x current in secondary coil as given on the equation sheet.	WS 1.4 Explain everyday and technological applications of science. Detailed knowledge of the structure of a transformer is not required.

4.7.3 Acids and alkalis

Some chemical substances can be classified as acids or alkalis. Characterising substances in this way helps to make sense of how chemicals react together, to establish patterns and to make predictions about chemical changes. This topic provides opportunities to write chemical formulae and equations, and apply the quantitative methods from Chemical quantities (page 89). Practical content includes methods used to prepare and purify soluble salts. Theoretical content includes how to describe the energy changes associated with neutralisation reactions and how ionic theory can account for the similarities in the reactions of acids.

There are two required practicals: one is the preparation of a pure, dry sample of a soluble salt from an insoluble substance. The other investigates the variables that affect temperature changes in solutions.

4.7.3.1 Reactions of acids

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall that acids react with some metals and with carbonates, and write equations predicting products from given reactants. Describe tests to identify selected gases including hydrogen and carbon dioxide.	Acids react with some metals to produce salts and hydrogen. Knowledge of reactions with metals is limited to those of magnesium, zinc and iron with hydrochloric and sulfuric acids. The test for hydrogen uses a burning splint held at the open end of a test tube of the gas. Acids react with metal carbonates to produce salts, water and carbon dioxide. The test for carbon dioxide uses an aqueous solution of calcium hydroxide (limewater).	WS 1.2 (HT only) Explain, in terms of gain or loss of electrons, that the reactions of metals with acids are redox reactions (see Atoms into ions and ions into atoms (page 134)). WS 4.1 (HT only) Identify which species are oxidised and which are reduced in given chemical reactions.

4.7.3.2 Making salts

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe neutralisation as acid reacting with alkali to form a salt plus water. Describe, explain and exemplify the processes of filtration and crystallisation. Suggest suitable purification techniques given information about the substances involved.	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. The particular salt produced in any reaction between an acid and a base or alkali depends on: • the acid used (hydrochloric acid produces chlorides, nitric acid produces nitrates and sulfuric acid produces sulfates) • the positive ions in the base, alkali or carbonate. 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. Salt solutions can be crystallised to produce solid salts.	WS 1.2 Predict products from given reactants. Use the formulae of common ions to deduce the formulae of salts.

Required practical activity 17: preparation of a pure, dry sample of a soluble salt from an insoluble oxide or carbonate, using a Bunsen burner and a water bath or electric heater to evaporate the solution.

AT skills covered by this practical activity: chemistry AT 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 174).

4.7.3.3 Energy changes and reactions

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Distinguish between endothermic and exothermic reactions on the basis of the temperature change of the surroundings.	When chemical reactions occur, energy is transferred to or from the surroundings. Energy is conserved in chemical reactions. The total amount of energy in the reaction mixture and its surroundings at the end of a chemical reaction is the same as it was at the start. An exothermic reaction is one that gives out energy. This heats up the reaction mixture. Energy then transfers to the surroundings as the reaction mixture then cools. Neutralisation of an acid with an alkali is an example of an exothermic reaction. An endothermic reaction is one that that takes in energy. This cools the reaction mixture. Energy then transfers from the surroundings as the reaction mixture then warms up again. The reaction of citric acid and sodium hydrogen carbonate is an example of an endothermic reaction.	WS 1.2 Identify examples of exothermic and endothermic reactions based on the temperature change of the reaction mixture.

Required practical activity 18: investigate the variables that affect the temperature changes of a series of reactions in solutions, eg acid plus metals, acid plus carbonates, neutralisations, displacement of metals.

AT skills covered by this practical activity: chemistry AT 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 175).

4.7.3.4 The pH scale and neutralisation

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall that acids form hydrogen ions when they dissolve in water and solutions of alkalis contain hydroxide ions. (HT only) Use the formulae of common ions to write balanced ionic equations. Recall that relative acidity and alkalinity are measured by pH. Recognise that aqueous neutralisation reactions can be generalised to hydrogen ions reacting with hydroxide ions to form water.	Acids produce hydrogen ions (H^+) in aqueous solutions. Aqueous solutions of alkalis contain hydroxide ions (OH^-). 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. 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. In neutralisation reactions between an acid and an alkali, hydrogen ions react with hydroxide ions to produce water.	WS 1.2 Write an ionic equation to represent neutralisation. WS 2.3 Describe the use of universal indicator or a wide range indicator to measure the approximate pH of a solution. WS 3.2 Use the pH scale to identify acidic or alkaline solutions.

4.7.3.5 Strong and weak acids (HT only)

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Use and explain the terms dilute and concentrated (amount of substance) and weak and strong (degree of ionisation) in relation to acids. Recall that as hydrogen ion concentration increases by a factor of ten the pH value of a solution decreases by a factor of one. Describe neutrality and relative acidity and alkalinity in terms of the effect of the concentration of hydrogen ions on the numerical value of pH (whole numbers only).	A strong acid is completely ionised in aqueous solution. Examples of strong acids are hydrochloric, nitric and sulfuric acids. A weak acid is only partially ionised in aqueous solution. Examples of weak acids are ethanoic, citric and carbonic acids. For a given concentration of aqueous solutions, the stronger an acid, the lower the pH.	

4.7.4 The rate and extent of chemical change

Chemical reactions can occur at very different rates. Although 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. Catalysts, including enzymes, can have a very significant effect on reaction rates. An understanding of the energy changes that accompany bond breaking and bond forming can help to account for the effect of temperature on rates. 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.

There are two required practicals: an investigation of the effect of changes in concentration on the rate of a chemical reaction and an investigation of a factor affecting the rate of an enzyme-controlled reaction.

4.7.4.1 Factors that affect reaction rates

GCSE Science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the effect of changes in temperature, concentration, pressure, and surface area on rate of reaction. Suggest practical methods for determining the rate of a given reaction.	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: $\text{mean rate of reaction} = \frac{\text{quantity of reactant used}}{\text{time taken}}$ $\text{mean rate of reaction} = \frac{\text{quantity of product formed}}{\text{time taken}}$ The quantity of reactant or product can be measured by the mass in grams, by a volume in cm^3 ((HT only) or by an amount in moles). The units of rate of reaction may be given as g/s, cm^3/s ((HT only) or mol/s). The rate of a chemical reaction can be determined by measuring: • the loss in mass of a reactant's mixture • the volume of gas produced • the time for a solution to become opaque or coloured.	WS 3.3, MS 1a, 1c 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. WS 3.5, MS 4a, 4b, 4c Draw, and interpret, graphs showing the quantity of product formed or quantity of reactant used up against time to compare or determine rates of reaction. WS 3.3, MS 4e Draw tangents to the curves on these graphs and use the gradient of the tangent as a measure of the rate of reaction. WS 3.3, MS 4d, 4e (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.

4.7.4.2 The effect of surface area on rates of reaction

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain the effects on rates of reaction of changes in the size of the pieces of a reacting solid in terms of surface area to volume ratio.	Breaking up a solid reactant into smaller pieces increases the surface area that can be in contact with any solution with which it reacts. Increasing the ratio of surface area to volume increases the rate of reaction for a given mass of a solid reactant.	MS 1c Use proportionality when comparing factors affecting rate of reaction. MS 5c Calculate surface areas and volumes of cubes.

4.7.4.3 The effect of temperature, concentration and pressure on rates of reaction

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain the effects on rates of reaction of changes in temperature, concentration and pressure in terms of the frequency and energy of collision between particles.	According to collision 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. 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. Increasing the temperature increases the frequency of collisions and makes the collisions more energetic, and so increases the rate of reaction.	WS 1.2 Predict and explain the effects of changing conditions on the rate of a reaction.

Required practical activity 19: investigation of 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: chemistry AT 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 176).

4.7.4.4 Activation energy

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain activation energy as the energy needed for a reaction to occur. Draw and label a reaction profile for an exothermic and an endothermic reaction, identifying activation energy.	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. 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.	WS 3.2, 3.5, MS 4a Interpret reaction profiles, including using them to identify reactions as exothermic or endothermic.

4.7.4.5 Bond breaking and bond forming (HT only)

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Calculate energy changes in a chemical reaction by considering bond making and bond breaking energies.	During a chemical reaction: • energy must be supplied to break bonds in the reactants • energy is given out when bonds in the products are formed. The energy needed to break bonds and the energy given out when bonds are formed can be calculated from bond energies. The difference between the sum of the energy needed to break bonds in the reactants and the sum of the energy given out when bonds in the products are formed is the overall energy change of the reaction. In an exothermic reaction, the energy given out from forming new bonds is greater than the energy needed to break existing bonds. In an endothermic reaction, the energy needed to break existing bonds is greater than the energy given out from forming new bonds.	WS 3.3, MS 1a Use arithmetic computation when calculating energy changes. WS 1.2, 3.3, MS 1a, 4a Calculate the energy transferred in chemical reactions between simple molecules in the gas state using bond energies supplied.

4.7.4.6 Catalysts

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the characteristics of catalysts and their effect on rates of reaction. Identify catalysts in reactions. Explain catalytic action in terms of activation energy.	Catalysts change the rate of chemical reactions but are not used up during the reaction. Different reactions need different catalysts. Knowledge of the names of catalysts other than those specified in the subject content is not required.	WS 3.5 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. WS 1.2 Use reaction profiles to explain catalytic action.

4.7.4.7 Enzymes

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall that enzymes act as catalysts in biological systems. Explain the mechanism of enzyme action including the active site, enzyme specificity and factors affecting the rate of enzymatic reaction.	Enzymes are important as biological catalysts which allow all the reactions in cells to occur. Enzymes are large protein molecules. The shape of an enzyme is vital for its function. Each enzyme has an active site with a unique shape to bind a specific substrate molecule. High temperatures and extremes of pH denature the enzyme, changing the shape of the active site. The 'lock and key' model is a simplified model of enzyme action. Different enzymes work fastest at different temperatures and pH values.	WS 3.3, 3.5, MS 1a, 1c, 1d Carry out rate calculations for chemical reactions and make estimates of simple calculations without using a calculator.

Required practical activity 20: investigate the effect of pH on the rate of reaction of amylase enzyme. Students should use a continuous sampling technique to determine the time taken to completely digest a starch solution at a range of pH values. Iodine reagent is to be used to test for starch every 30 seconds. Temperature must be controlled by use of a water bath or electric heater.

AT skills covered by this practical activity: biology AT 1, 2 and 5.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in Key opportunities for skills development (page 177).

4.7.4.8 Reversible reactions

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall that some reactions may be reversed by altering the reaction conditions.	In some chemical reactions, the products of the reaction can react to produce the original reactants. Such reactions are called reversible reactions and are represented: $A + B \rightleftharpoons C + D$ The direction of reversible reactions can be changed by changing the temperature. Examples include the effect of changing the temperature on the decomposition of ammonium chloride and of hydrated copper(II) sulfate.	

4.7.4.9 Dynamic equilibrium

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall that dynamic equilibrium occurs when the rates of forward and reverse reactions are equal.	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.	

4.7.4.10 Factors affecting the position of equilibrium (HT only)

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Predict the effect of changing reaction conditions on equilibrium position.	The relative amounts of all the reactants and products at equilibrium depend on the conditions of the reaction. If a system is at equilibrium and a change is made to any of the conditions, then the system responds to counteract the change.	WS 1.2 Apply Le Châtelier's principle to make qualitative predictions about the effect of changes on systems at equilibrium when given appropriate information.

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Predict the effect of changing concentration on equilibrium position and suggest appropriate conditions to produce a particular product.	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 change until equilibrium is reached again. If the concentration of a reactant is increased, more products form until equilibrium is reached again. If the concentration of a product is decreased, more reactants react until equilibrium is reached again.	WS 3.5 Interpret appropriate given data to predict the effect of a change in concentration of a reactant or product on given reactions at equilibrium.
Predict the effect of changing temperature on equilibrium position and suggest appropriate conditions to produce a particular product.	If the temperature of a system at equilibrium is increased: • the relative amount of products at equilibrium increases for an endothermic reaction • the relative amount of products at equilibrium decreases for an exothermic reaction. If the temperature of a system at equilibrium is decreased: • the relative amount of products at equilibrium decreases for an endothermic reaction • the relative amount of products at equilibrium increases for an exothermic reaction.	WS 1.2 Apply the idea that if a reversible reaction is exothermic in one direction, it is endothermic in the opposite direction.
Predict the effect of changing pressure on equilibrium position and suggest appropriate conditions to produce a particular product.	For gaseous reactions at equilibrium: • 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.	

4.7.5 Atoms into ions and ions into atoms

Metals can be arranged in an activity series in terms of the ability of their atoms to turn into positive ions. Electrolysis is a process that reverses such changes by turning ions back into atoms (and sometimes molecules). Gas tests are introduced to identify the products of electrolysis. Gain or loss of electrons can be used to classify electrode reactions as reduction or oxidation processes.

The required practical is an investigation of the electrolysis of aqueous solutions using inert electrodes.

4.7.5.1 A reactivity series for metals

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain how the reactivity of metals with water or dilute acids is related to the tendency of the metal to form its positive ion.	When metals react with other substances the metal atoms 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. The non-metals hydrogen and carbon are often included in the reactivity series. A more reactive metal can displace a less reactive metal from a compound. The reactions of metals with water and acids are limited to room temperature and do not include reactions with steam.	WS 3.8 Recall and describe the reactions, if any, of potassium, sodium, lithium, calcium, magnesium, zinc, iron and copper with water or dilute acids. WS 3.5 Deduce an order of reactivity of metals based on experimental results. WS 1.2 (HT only) Write ionic equations for displacement reactions.

4.7.5.2 Electrolysis

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe electrolysis in terms of the ions present and reactions at the electrodes. Recall that metals (or hydrogen) are formed at the cathode and non-metals are formed at the anode in electrolysis using inert electrodes.	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. 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. When a simple ionic compound is electrolysed in the molten state using inert electrodes, the metal is produced at the cathode and the non-metal is produced at the anode.	WS 1.2 Predict the products of electrolysis of binary ionic compounds in the molten state. (HT only) Write half equations for the reactions occurring at the electrodes during electrolysis. Students may be required to complete and balance supplied half equations.

4.7.5.3 Electrolysis of aqueous solutions

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe competing reactions in the electrolysis of aqueous solutions of ionic compounds in terms of the different species present.	The ions discharged when an aqueous solution is electrolysed using inert electrodes depend on the relative reactivity of the elements involved. At the negative electrode (cathode), hydrogen is produced if the metal is more reactive than hydrogen. At the positive electrode (anode), oxygen is produced unless the solution contains halide ions when the halogen is produced. This happens because in the aqueous solution water molecules break down producing hydrogen ions and hydroxide ions that are discharged.	WS 1.2 (HT only) Write half equations for the reactions occurring at the electrodes during electrolysis. Students may be required to complete and balance supplied half equations.

Required practical activity 21: 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: chemistry AT 3 and 7.

This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in Key opportunities for skills development (page 177).

4.7.5.4 Tests for gases

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe tests to identify selected gases including oxygen, hydrogen and chlorine.	The test for hydrogen uses a burning splint held at the open end of a test tube of the gas. The test for oxygen uses a glowing splint inserted into a test tube of the gas. The test for chlorine uses damp litmus paper put into chlorine gas.	WS 3.5 Interpret the observations from gas tests.

4.7.5.5 Electron transfer reactions (HT only)

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain reduction and oxidation in terms of gain or loss of electrons, identifying which species are oxidised and which are reduced.	Oxidation is the loss of electrons and reduction is the gain of electrons. During electrolysis, at the cathode (negative electrode), positively charged ions gain electrons and so the reactions are reductions. At the anode (positive electrode), negatively charged ions lose electrons and so the reactions are oxidations.	WS 4.1 Identify, in a given reaction, symbol equation or half equation, which species are oxidised and which are reduced.

4.8 Guiding Spaceship Earth towards a sustainable future

Many scientists are involved in the search for solutions to the great challenges facing humanity, such as how we might use our resources more effectively. When developing new materials and processes, how do chemists and engineers ensure that their products do no harm?

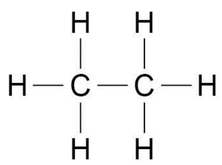
4.8.1 Carbon chemistry

The study of forms of carbon provides an opportunity to revisit ideas about structure and bonding from Chemical quantities (page 89). Other ideas from Structure and bonding (page 98) are applied to explain how new chemicals and materials are made from the hydrocarbons in crude oil. Featured processes include fractional distillation, cracking and polymerisation.

4.8.1.1 Bonding and structure in forms of carbon

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain the properties of diamond, graphite, fullerenes and graphene in terms of their structures and bonding.	Diamond is very hard, has a very high melting point and does not conduct electricity. In diamond, each carbon atom forms four covalent bonds with other carbon atoms in a giant covalent structure. Graphite is soft, has a high melting point and conducts electricity. In graphite, each carbon atom forms three covalent bonds with three other carbon atoms, forming layers of hexagonal rings. There are no covalent bonds between layers. One electron from each carbon is delocalised. Graphene is a single layer of graphite and so is one atom thick. It has properties that make it useful in electronics and composites. 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 (C_{60}), which has a spherical shape. Carbon nanotubes are cylindrical fullerenes with very high length to diameter ratios. Their properties make them useful for nanotechnology, electronics and materials.	MS 5b Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects. WS 1.4 Give examples of the uses of diamond, graphite and fullerenes, including carbon nanotubes.

4.8.1.2 Hydrocarbons in crude oil

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Recall that crude oil is a main source of hydrocarbons and is a feedstock for the petrochemical industry. Recognise that crude oil is a finite resource. Recall that carbon can form four covalent bonds. Explain that the vast array of natural and synthetic organic compounds occur due to the ability of carbon to form families of similar compounds, chains and rings. Describe the fractions as largely a mixture of compounds of formula C_nH_{2n+2} which are members of the alkane homologous series.	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. 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. Alkane molecules can be represented in the following forms: C_2H_6 or  Knowledge of the names of specific alkanes other than methane, ethane, propane and butane is not required.	WS 1.2, MS 5b Recognise substances as alkanes given their formulae.

4.8.1.3 Fractional distillation of crude oil

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe and explain the separation of crude oil by fractional distillation. Describe, explain and exemplify the processes of fractional distillation. Explain how modern life is crucially dependent upon hydrocarbons.	Some properties of hydrocarbons depend on the size of their molecules, including: • boiling point • viscosity, and • flammability. These properties influence how hydrocarbons are separated and how they are used as fuels. Knowledge of trends in properties of hydrocarbons is limited to boiling point, viscosity and flammability. 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. The fractions can be processed to produce fuels and feedstock for the petrochemical industry. Many of the fuels on which our modern lifestyle depends such as petrol, diesel oil, kerosene, heavy fuel oil and liquefied petroleum gases, are produced from crude oil. Knowledge of the names of other specific fractions or fuels is not required. 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. Many useful materials on which modern life depends are produced by the petrochemical industry. These include solvents, lubricants, polymers and detergents.	WS 1.2 Write balanced equations for the complete combustion of hydrocarbons with a given formula. Relate trends in the hydrocarbons to molecular size using ideas in Covalent bonding (page 101).

4.8.1.4 Cracking hydrocarbons

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the production of materials that are more useful by cracking.	Hydrocarbons can be broken down to produce smaller, more useful molecules by catalytic cracking or by steam cracking. The products of cracking include alkanes and another type of hydrocarbon called alkenes. Recall of the formulae or names of individual alkenes, other than ethene, is not required. There is a high demand for fuels with small molecules and so some of the products of cracking are useful as fuels. Alkenes are used to produce polymers and as starting materials for the production of many other chemicals. Small ethene molecules polymerise to produce long-chain molecules of poly(ethene) (see also Covalent bonding (page 101)).	WS 1.2 Balance chemical equations as examples of cracking given the formulae of the reactants and products.

4.8.2 Resources of materials and energy

The example of metal extraction is used to show how the Earth's natural resources are used to manufacture useful products. A variety of renewable and non-renewable energy resources is needed for these and other aspects of modern life. In order to operate sustainably, scientists and engineers seek to minimise the use of limited resources, cut energy consumption, reduce waste and limit environmental impacts. Scientists 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. Life cycle assessments can be used to compare the overall impact of the production, use and disposal of products.

4.8.2.1 Metal extraction by reduction of oxides

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain reduction and oxidation in terms of loss or gain of oxygen, identifying which species are oxidised and which are reduced. Explain, using the position of carbon in the reactivity series, the principles of industrial processes used to extract metals, including extraction of a non-ferrous metal.	Metals react with oxygen to produce metal oxides. These are oxidation reactions. Reduction involves the loss of oxygen. 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. Knowledge and understanding are limited to the reduction of oxides using carbon. Metals less reactive than carbon can be extracted from their oxides by reduction with carbon. Knowledge of the details of processes used in the extraction of metals is not required.	WS 1.2 Identify the substances which are oxidised or reduced in terms of gain or loss of oxygen. WS 1.4 Explain in terms of the reactivity series why some metals are extracted with carbon and others by electrolysis. Interpret or evaluate specific metal extraction processes when given appropriate information.

4.8.2.2 Metal extraction by electrolysis

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain why and how electrolysis is used to extract some metals from their ores.	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. Aluminium is manufactured by the electrolysis of a molten mixture of aluminium oxide and cryolite using positive electrodes (anodes) made of carbon. The anodes have to be replaced from time to time.	WS 1.4 Explain technological applications of science, including the use of cryolite for the extraction of aluminium and the need to replace the anodes.

4.8.2.3 Metal extraction by biological methods (HT only)

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Evaluate alternative biological methods of metal extraction (bacterial and phytoextraction).	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. Phytomining uses plants to absorb metal compounds. The plants are harvested and then burned to produce ash that contains metal compounds. Bioleaching uses bacteria to produce leachate solutions that contain metal compounds. 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.	WS 1.4 Evaluate environmental implications of the applications of science.

4.8.2.4 Energy resources

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the main energy resources available for use on Earth (including fossil fuels, nuclear fuel, biofuel, wind, hydroelectricity, the tides and the Sun); compare the ways in which they are used and distinguish between renewable and non-renewable resources.	Non-renewable resources of energy include: • coal • crude oil • natural gas • nuclear fuel. A renewable energy resource is one that is being (or can be) replenished as it is used. Examples include: • plants that provide biofuel • wind turbines • hydroelectricity • tidal barrages or undersea turbines • solar panels that produce electricity or heat water.	WS 1.4 Explain technological applications of science. Explain patterns and trends in given data about the use of energy resources. Evaluate the use of different energy resources, taking into account reliability, cost and impact on the environment. WS 4.4, MS 1c, 2c, 4a Interpret data with energy quantities given, using the prefixes kilo, mega, giga and tera.

4.8.2.5 Energy conservation and dissipation

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe, with examples, where there are energy transfers in a system and where there is no net change to the total energy of a closed system (qualitative only). Describe, with examples, how in all system changes, energy is dissipated so that it is stored in less useful ways.	Energy can be transferred usefully, stored or dissipated, but cannot be created or destroyed. Whenever there are energy transfers in a system only part of the energy is usefully transferred. The rest of the energy is dissipated so that it is stored in less useful ways. This energy is often described as being 'wasted'.	WS 3.3, MS 1a, 1c, 3c Make calculations of the energy changes associated with changes in a system, recalling or selecting the relevant equations for mechanical, electrical and thermal processes; thereby express in quantitative form and on a common scale the overall redistribution of energy in the system.

4.8.2.6 Preventing unwanted energy transfers

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Explain ways of reducing unwanted energy transfer, eg through lubrication and thermal insulation; describe the effects, on the rate of cooling of a building, of the thickness and thermal conductivity of its walls (qualitative only).	Unwanted energy transfers can be reduced in a number of ways, for example through: • lubrication – work done against the frictional forces acting on an object causes a rise in the temperature of the object and dissipates useful energy • the use of thermal insulation – the higher the thermal conductivity of a material the higher the rate of energy transfer by conduction across the material.	WS 1.4 Explain technological applications of science.

4.8.2.7 Energy efficiency

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Calculate energy efficiency for any energy transfer, (HT only) and describe ways to increase efficiency.	The energy efficiency for any energy transfer can be calculated using the equation: $\text{efficiency} = \frac{\text{useful output energy transfer}}{\text{total input energy transfer}}$	WS 3.3, MS 3c Recall and apply this equation. MS 1a, 1c, 3c Calculate or use efficiency values as a decimal or as a percentage.

4.8.2.8 Life cycle assessment

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe the basic principles in carrying out a life cycle assessment of a material or product. Interpret data from a life cycle assessment of a material or product.	Life cycle assessments (LCAs) are carried out to assess the environmental impact of the materials used and the energy resources needed for products in each of these stages: • 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. The use of water, energy resources and materials, as well as the 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. 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.	WS 1.3, 1.4, 3.3, 3.5 Interpret data from LCAs of materials or products given appropriate information. MS 1a Recognise and use expressions in decimal form. MS 1d Make estimates of the results of simple calculations. WS 4.6, MS 2a Use an appropriate number of significant figures. WS 3.5, MS 4a Translate information between graphical and numeric form.

4.8.2.9 Recycling

GCSE science subject content	Details of the science content	Scientific, practical and mathematical skills
Describe a process where a material or product is recycled for a different use, and explain why this is viable.	Reuse and recycling of materials by end users cuts down the use of limited material resources. It can also cut the use of energy resources and the production of waste. Metals can be recycled by melting and recasting or reforming into different products. The amount of separation required for recycling depends on the metal and the properties required of the final product. For example, in steel making some scrap steel is added to the iron from a blast furnace to reduce the amount of iron that needs to be extracted from iron ore.	WS 1.4 Evaluate factors that affect decisions on recycling, given appropriate information.

4.9 Key ideas

The complex and diverse phenomena of the natural and man-made world can be described in terms of a small number of key ideas in biology, chemistry and physics, listed below.

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.

Key ideas in biology:

- life processes depend on molecules whose structure is related to their function
- the fundamental units of living organisms are cells, which may be part of highly adapted structures including tissues, organs and organ systems, enabling living processes to be performed effectively
- living organisms may form populations of single species, communities of many species and ecosystems, interacting with each other, with the environment and with humans in many different ways
- living organisms are interdependent and show adaptations to their environment
- life on Earth is dependent on photosynthesis in which green plants and algae trap light from the Sun to fix carbon dioxide and combine it with hydrogen from water to make organic compounds and oxygen
- organic compounds are used as fuels in cellular respiration to allow the other chemical reactions necessary for life
- the chemicals in ecosystems are continually cycling through the natural world
- the characteristics of a living organism are influenced by its genome and its interaction with the environment
- evolution occurs by a process of natural selection and accounts both for biodiversity and how organisms are all related to varying degrees.

Key ideas in chemistry:

- 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.

Key ideas in physics:

- the use of models, as in the particle model of matter or the wave models of light and of sound
- the concept of cause and effect in explaining such links as those between force and acceleration, or between changes in atomic nuclei and radioactive emissions
- the phenomena of 'action at a distance' and the related concept of the field as the key to analysing electrical, magnetic and gravitational effects
- that differences, for example between pressures or temperatures or electrical potentials, are the drivers of change
- that proportionality, for example between weight and mass of an object or between force and extension in a spring, is an important aspect of many models in science
- that physical laws and models are expressed in mathematical form.

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 Combined Science: Synergy 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
- the ability to apply mathematical and practical skills to areas of content they are not normally developed in or
- the 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

Science 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 combined science 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 and over time 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 are given below.

GCSE specifications in combined award science should enable students to:

- develop scientific knowledge and conceptual understanding through the specific disciplines of biology, chemistry and physics
- 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 science through critical analysis of the methodology, evidence and conclusions, both qualitatively and quantitatively.

The sciences 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 Combined Science: Synergy 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.

The four exam papers for GCSE Combined Science: Synergy have different emphases on the assessment objectives.

- Paper 1 and Paper 3 contain a higher proportion of marks covering knowledge and application (AO1 and AO2) than analysis and evaluation (AO3) for the topics covered.
- Paper 2 and Paper 4 contain most of the analysis and evaluation (AO3) questions for the topics covered, although there are also questions assessing knowledge and application. These papers also contain most of the questions regarding practical work, including required practicals.

The weightings of the assessment objectives in each paper are given in Assessment objective weightings for GCSE Combined Science: Synergy (page 151).

5.2.1 Assessment objective weightings for GCSE Combined Science: Synergy

Assessment objectives (AOs)	Component weightings (approx %)				Overall weighting (approx %)
	Unit 1 Paper 1	Unit 1 Paper 2	Unit 2 Paper 3	Unit 2 Paper 4	
AO1	47–53	27–33	47–53	27–33	40
AO2	41–47	33–39	41–47	33–39	40
AO3	3–9	31–37	3–9	31–37	20
Overall weighting of components	25	25	25	25	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
Paper 3	100	x1	100
Paper 4	100	x1	100
		Total scaled mark:	400

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 Combined Science: Synergy	Foundation	8465F	TBC
	Higher	8465H	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 601/8760/8.

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 17-point scale: 1–1 to 9–9 – where 9–9 is the best grade.

A student taking Foundation Tier assessments will be awarded a grade within the range of 1–1 to 5–5. Students who fail to reach the minimum standard for grade 1–1 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 4–4 to 9–9. A student sitting the Higher Tier who just fails to achieve grade 4–4 will be awarded an allowed grade 4–3. Students who fail to reach the minimum standard for the allowed grade 4–3 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 159). 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 Combined Science 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
d	Understand the principles of sampling as applied to scientific data (biology questions only)
e	Understand simple probability (biology questions only)
f	Understand the terms mean, mode and median
g	Use a scatter diagram to identify a correlation between two variables (biology and physics questions only)
h	Make order of magnitude calculations

3	Algebra
a	Understand and use the symbols: $=$, $<$, $<<$, $>>$, $>$, $\propto$, $\sim$
b	Change the subject of an equation
c	Substitute numerical values into algebraic equations using appropriate units for physical quantities (chemistry and physics questions only)
d	Solve simple algebraic equations (biology and physics questions only)

4	Graphs
a	Translate information between graphical and numeric form
b	Understand that $y = mx + c$ represents a linear relationship

4	Graphs
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 (chemistry and physics questions only)
f	Understand the physical significance of area between a curve and the x-axis and measure it by counting squares as appropriate (physics questions only)

5	Geometry and trigonometry
a	Use angular measures in degrees (physics questions only)
b	Visualise and represent 2D and 3D forms including two dimensional representations of 3D objects (chemistry and physics questions only)
c	Calculate areas of triangles and rectangles, surface areas and volumes of cubes

Mathematical skills references are taken from the DfE subject criteria.

8 Practical assessment

Practical work is at the heart of science, 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 Synergy 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 161). 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.

Biology

	Apparatus and techniques
AT 1	Use of appropriate apparatus to make and record a range of measurements accurately, including length, area, mass, time, temperature, volume of liquids and gases, and pH (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 a).
AT 3	Use of appropriate apparatus and techniques for the observation and measurement of biological changes and/or processes.
AT 4	Safe and ethical use of living organisms (plants or animals) to measure physiological functions and responses to the environment (links to A-level AT h).
AT 5	Measurement of rates of reaction by a variety of methods including production of gas, uptake of water and colour change of indicator.
AT 6	Application of appropriate sampling techniques to investigate the distribution and abundance of organisms in an ecosystem via direct use in the field (links to A-level AT k).
AT 7	Use of appropriate apparatus, techniques and magnification, including microscopes, to make observations of biological specimens and produce labelled scientific drawings (links to A-level AT d and e).

Chemistry

	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).

	Apparatus and techniques
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).

Physics

	Apparatus and techniques
AT 1	Use of appropriate apparatus to make and record a range of measurements accurately, including length, area, mass, time, volume and temperature. Use of such measurements to determine densities of solid and liquid objects (links to A-level AT a and b).
AT 2	Use of appropriate apparatus to measure and observe the effects of forces including the extension of springs (links to A-level AT a).
AT 3	Use of appropriate apparatus and techniques for measuring motion, including determination of speed and rate of change of speed (acceleration/deceleration) (links to A-level AT a, b and d).
AT 4	Making observations of waves in fluids and solids to identify the suitability of apparatus to measure speed/frequency/wavelength. Making observations of the effects of the interaction of electromagnetic waves with matter (links to A-level AT i and j).
AT 5	Safe use of appropriate apparatus in a range of contexts to measure energy changes/ transfers and associated values such as work done (links to A-level AT a, b).
AT 6	Use of appropriate apparatus to measure current, potential difference (voltage) and resistance, and to explore the characteristics of a variety of circuit elements (links to A-level AT f).
AT 7	Use of circuit diagrams to construct and check series and parallel circuits including a variety of common circuit elements (links to A-level AT g).

8.2 Required practical activities

The following practical activities must be carried out by all students taking GCSE Combined Science: Synergy.

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; 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 21 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 written 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 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.

8.2.1 Required practical activity 1

Use appropriate apparatus to make and record the measurements needed to determine the densities of regular and irregular solid objects and liquids. Volume should be determined from the dimensions of a regularly shaped object and by a displacement technique for irregularly shaped objects. Dimensions to be measured using appropriate apparatus such as a ruler, micrometer or Vernier callipers.

Apparatus and techniques

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

Physics AT 1 – use appropriate apparatus to make and record measurements of length, area, mass and volume accurately. Use such measurements to determine the density of solid objects and liquids.

Key opportunities for skills development

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

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.

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.

WS 3.1 – present observations and other data using appropriate methods.

WS 3.5 – interpret observations and other data (presented in verbal, diagrammatic, graphical, symbolic or numerical form), including identifying patterns and trends, making inferences and drawing conclusions.

WS 3.8 – communicate the scientific rationale for investigations, methods used, findings and reasoned conclusions through written and electronic reports and presentations using verbal, diagrammatic, graphical, numerical and symbolic forms.

WS 4.2 – recognise the importance of scientific quantities and understand how they are determined.

WS 4.3 – use SI units (eg kg, g, mg; km, m, mm; kJ, J) and IUPAC chemical nomenclature unless inappropriate.

WS 4.6 – use an appropriate number of significant figures in calculation.

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

MS 2b – find arithmetic means.

MS 5c – calculate areas of triangles and rectangles, surface areas and volumes of cubes.

8.2.2 Required practical activity 2

An investigation to determine the specific heat capacity of one or more materials. The investigation will involve linking the decrease of one energy store (or work done) to the increase in temperature and subsequent increase in thermal energy stored.

Apparatus and techniques

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

Physics AT 1 – use appropriate apparatus to make and record measurements of mass, time and temperature accurately.

Physics AT 5 – use, in a safe manner, appropriate apparatus to measure energy changes/transfers and associated values such as work done.

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.

WS 3.1 – present observations and other data using appropriate methods.

WS 3.2 – translate data from one form to another.

WS 3.3 – carry out and represent mathematical and statistical analysis.

WS 3.4 – represent the distribution of results and make estimations of uncertainty.

WS 3.5 – interpret observations and other data (presented in verbal, diagrammatic, graphical, symbolic or numerical form), including identifying patterns and trends, making inferences and drawing conclusions.

WS 3.6 – present reasoned explanations including relating data to hypotheses.

WS 3.7 – be objective, evaluate data in terms of accuracy, precision, repeatability and reproducibility and identify potential sources of random and systematic error.

WS 3.8 – communicate the scientific rationale for investigations, methods used, findings and reasoned conclusions through written and electronic reports and presentations using verbal, diagrammatic, graphical, numerical and symbolic forms.

WS 4.2 – recognise the importance of scientific quantities and understand how they are determined.

WS 4.3 – use SI units (eg kg, g, mg; km, m, mm; kJ, J) and IUPAC chemical nomenclature unless inappropriate.

WS 4.6 – use an appropriate number of significant figures in calculation.

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

MS 2b – find arithmetic means.

MS 3b – change the subject of an equation.

MS 3c – substitute numerical values into algebraic equations using appropriate units for physical quantities.

8.2.3 Required practical activity 3

Use a light microscope to observe, draw and label a selection of plant and animal cells. A magnification scale must be included.

Apparatus and techniques

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

Biology AT 1 – use appropriate apparatus to record length and area.

Biology AT 7 – use a microscope to make observations of biological specimens and produce labelled scientific drawings.

Key opportunities for skills development

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

MS 1d, 3a – use estimations to judge the relative size or area of sub-cellular structures.

8.2.4 Required practical activity 4

Investigate the effect of a range of concentrations of salt or sugar solutions on the mass of plant tissue.

Apparatus and techniques

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

Biology AT 1 – use appropriate apparatus to record mass and time.

Biology AT 3 – use appropriate apparatus and techniques to observe and measure the process of osmosis.

Biology AT 5 – measure the rate of osmosis by water uptake.

Key opportunities for skills development

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

WS 2.1 – use the theory of osmosis to create hypotheses on plant tissue.

WS 2.2 – plan experiments to test hypotheses.

WS 2.4 – have due regard for accuracy of measurements and health and safety.

WS 2.6 – make and record observations and measurements of mass.

WS 2.7 – evaluate the method and suggest possible improvements and further investigations.

WS 3.1 – present observations and other data in graphical form.

WS 3.2 – translate mass data into graphical form.

MS 1a, 1c – use simple compound measures of rate of water uptake.

MS 1c – use percentiles and calculate percentage gain and loss of mass of plant tissue.

MS 2b – find mean mass of plant tissue.

MS 4a, 4b, 4c, 4d – plot, draw and interpret appropriate graphs.

8.2.5 Required practical activity 5

Make observations to identify the suitability of apparatus to measure the frequency, wavelength and speed of waves in a ripple tank and waves in a solid and take appropriate measurements.

Apparatus and techniques

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

Physics AT 4 – make observations of waves in fluids and solids to identify the suitability of apparatus to measure speed, frequency and wavelength.

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

WS 3.8 – communicate the scientific rationale for investigations, methods used, findings and reasoned conclusions through written and electronic reports and presentations using verbal, diagrammatic, graphical, numerical and symbolic forms.

WS 4.2 – recognise the importance of scientific quantities and understand how they are determined.

WS 4.3 – use SI units (eg kg, g, mg; km, m, mm; kJ, J) and IUPAC chemical nomenclature unless inappropriate.

8.2.6 Required practical activity 6

Investigate how the amount of infrared radiation absorbed or radiated by a surface depends on the nature of that surface.

Apparatus and techniques

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

Physics AT 1 – use appropriate apparatus to make and record temperature accurately.

Physics AT 4 – make observations of the effects of the interaction of electromagnetic waves with matter.

Key opportunities for skills development

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

WS 3.8 – communicate the scientific rationale for investigations, methods used, findings and reasoned conclusions through written and electronic reports and presentations using verbal, diagrammatic, graphical, numerical and symbolic forms.

WS 4.2 – recognise the importance of scientific quantities and understand how they are determined.

WS 4.3 – use SI units (eg kg, g, mg; km, m, mm; kJ, J) and IUPAC chemical nomenclature unless inappropriate.

WS 4.6 – use an appropriate number of significant figures in calculation.

MS 2c – construct and interpret frequency tables and diagrams, bar charts and histograms.

8.2.7 Required practical activity 7

Use qualitative reagents to test for a range of carbohydrates, lipids and proteins. To include: Benedict's test for sugars, iodine test for starch and Biuret reagent for protein.

Apparatus and techniques

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

Biology AT 2 – safe use of a Bunsen burner and a boiling water bath.

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, and health and safety considerations.

8.2.8 Required practical activity 8

Plan and carry out an investigation into the effect of a factor on human reaction time.

Apparatus and techniques

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

Biology AT 1 – use appropriate apparatus to record time.

Biology AT 3 – selecting appropriate apparatus and techniques to measure the process of reaction time.

Biology AT 4 – safe and ethical use of humans to measure physiological function of reaction time and responses to a chosen factor.

Key opportunities for skills development

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

MS 4a – translate information between numerical and graphical forms.

8.2.9 Required practical activity 9

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.

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

Chemistry 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.

8.2.10 Required practical activity 10

Investigate the effect of light intensity on the rate of photosynthesis using an aquatic organism such as pondweed.

Apparatus and techniques

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

Biology AT 1 – use appropriate apparatus to record the rate of production of oxygen gas produced; and to measure and control the temperature of water in a large beaker that acts as a 'heat shield'.

Biology AT 2 – use a thermometer to measure and control temperature of a water bath.

Biology AT 3 – use appropriate apparatus and techniques to observe and measure the process of oxygen gas production.

Biology AT 4 – safe and ethical use and disposal of living pondweed to measure physiological functions and responses to light.

Biology AT 5 – measuring rate of reaction by oxygen gas production.

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 on how light intensity affects the rate of photosynthesis.

WS 2.2 – plan experiments to test hypotheses.

WS 2.5 – recognise that multiple samples will be needed at each light intensity.

WS 2.6 – make and record observations of gas production.

WS 3.1 – present a graph of light intensity against rate of photosynthesis.

WS 3.2 – translate numeric data into graphical form.

MS 1a, 1c – measure and understand the rate of photosynthesis reactions.

MS 4a, 4c – plot and draw appropriate graphs of rate of photosynthesis against light intensity selecting appropriate scale for axes.

MS 3d (HT) – understand and use inverse proportion; the inverse square law and light intensity in the context of photosynthesis.

8.2.11 Required practical activity 11

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.

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

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

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

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.

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.

8.2.12 Required practical activity 12

Measure the population size of a common species in a habitat. Use sampling techniques to investigate the effect of a factor on the distribution of this species.

Apparatus and techniques

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

Biology AT 1 – use appropriate apparatus to record length and area.

Biology AT 3 – use transect lines and quadrats to measure distribution of a species.

Biology AT 4 – safe and ethical use of organisms and response to a factor in the environment.

Biology AT 6 – application of appropriate sampling techniques to investigate the distribution and abundance of organisms in an ecosystem via direct use in the field.

Key opportunities for skills development

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

WS 2.1 – develop hypotheses regarding distribution of a species as a consequence of a factor.

WS 2.2 – plan experiments to test hypotheses on distribution.

WS 2.3 – apply a range of techniques, including the use of transects and quadrats, and the measurement of an abiotic factor.

MS 1d, 3a – estimates of population size based on sampling.

MS 2b – calculate arithmetic means.

MS 2d – understand principles of sampling.

MS 2f – understand the terms mean, mode and median as applied to ecological data.

MS 4c – plot and draw appropriate graphs selecting appropriate scales for the axes.

8.2.13 Required practical activity 13

Investigate the relationship between force and extension for a spring.

Apparatus and techniques

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

Physics AT 1 – use appropriate apparatus to make and record length accurately.

Physics AT 2 – use appropriate apparatus to measure and observe the effect of force on the extension of springs and collect the data required to plot a force–extension graph.

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 3.1 – present observations and other data using appropriate methods.

WS 3.2 – translate data from one form to another.

WS 3.3 – carry out and represent mathematical and statistical analysis.

WS 3.5 – interpret observations and other data (presented in verbal, diagrammatic, graphical, symbolic or numerical form), including identifying patterns and trends, making inferences and drawing conclusions.

WS 3.8 – communicate the scientific rationale for investigations, methods used, findings and reasoned conclusions through written and electronic reports and presentations using verbal, diagrammatic, graphical, numerical and symbolic forms.

WS 4.6 – use an appropriate number of significant figures in calculation.

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.

8.2.14 Required practical activity 14

Investigate the effect of varying the force on the acceleration of an object of constant mass and the effect of varying the mass of an object on the acceleration produced by a constant force.

Apparatus and techniques

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

Physics AT 1 – use appropriate apparatus to make and record measurements of length, mass and time accurately.

Physics AT 2 – use appropriate apparatus to measure and observe the effect of force.

Physics AT 3 – use appropriate apparatus and techniques for measuring motion, including determination of speed and rate of change of speed (acceleration/deceleration).

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.

WS 3.1 – present observations and other data using appropriate methods.

WS 3.2 – translate data from one form to another.

WS 3.3 – carry out and represent mathematical and statistical analysis.

WS 3.4 – represent the distribution of results and make estimations of uncertainty.

WS 3.5 – interpret observations and other data (presented in verbal, diagrammatic, graphical, symbolic or numerical form), including identifying patterns and trends, making inferences and drawing conclusions.

WS 3.6 – present reasoned explanations including relating data to hypotheses.

WS 3.7 – be objective, evaluate data in terms of accuracy, precision, repeatability and reproducibility and identify potential sources of random and systematic error.

WS 3.8 – communicate the scientific rationale for investigations, methods used, findings and reasoned conclusions through written and electronic reports and presentations using verbal, diagrammatic, graphical, numerical and symbolic forms.

WS 4.2 – recognise the importance of scientific quantities and understand how they are determined.

WS 4.3 – use SI units (eg kg, g, mg; km, m, mm; kJ, J) and IUPAC chemical nomenclature unless inappropriate.

WS 4.6 – use an appropriate number of significant figures in calculation.

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

MS 2b – find arithmetic means.

MS 2g – use a scatter diagram to identify a correlation between two variables.

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.

8.2.15 Required practical activity 15

Use circuit diagrams to construct appropriate circuits to investigate the I–V characteristics of a variety of circuit elements including a filament lamp, a diode and a resistor at constant temperature.

Apparatus and techniques

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

Physics AT 6 – use appropriate apparatus to measure current and potential difference and to explore the characteristics of a variety of circuit elements.

Physics AT 7 – use circuit diagrams to construct and check series and parallel circuits including a variety of common circuit elements.

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 2.5 – 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.

WS 3.1 – present observations and other data using appropriate methods.

WS 3.2 – translate data from one form to another.

WS 3.3 – carry out and represent mathematical and statistical analysis.

WS 3.4 – represent the distribution of results and make estimations of uncertainty.

WS 3.5 – interpret observations and other data (presented in verbal, diagrammatic, graphical, symbolic or numerical form), including identifying patterns and trends, making inferences and drawing conclusions.

WS 3.6 – present reasoned explanations including relating data to hypotheses.

WS 3.7 – be objective, evaluate data in terms of accuracy, precision, repeatability and reproducibility and identify potential sources of random and systematic error.

WS 3.8 – communicate the scientific rationale for investigations, methods used, findings and reasoned conclusions through written and electronic reports and presentations using verbal, diagrammatic, graphical, numerical and symbolic forms.

WS 4.2 – recognise the importance of scientific quantities and understand how they are determined.

WS 4.3 – use SI units (eg kg, g, mg; km, m, mm; kJ, J) and IUPAC chemical nomenclature unless inappropriate.

WS 4.6 – use an appropriate number of significant figures in calculation.

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

MS 2g – use a scatter diagram to identify a correlation between two variables.

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

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

8.2.16 Required practical activity 16

Use circuit diagrams to set up an appropriate circuit to investigate the factors affecting the resistance of an electrical component. This should include:

- the length of a wire at constant temperature
- combinations of resistors in series and in parallel.

Apparatus and techniques

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

Physics AT 1 – use appropriate apparatus to measure and record length accurately.

Physics AT 6 – use appropriate apparatus to measure current, potential difference and resistance.

Physics AT 7 – use circuit diagrams to construct and check series and parallel circuits.

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 2.5 – 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.

WS 3.1 – present observations and other data using appropriate methods.

WS 3.2 – translate data from one form to another.

WS 3.3 – carry out and represent mathematical and statistical analysis.

WS 3.4 – represent the distribution of results and make estimations of uncertainty.

WS 3.5 – interpret observations and other data (presented in verbal, diagrammatic, graphical, symbolic or numerical form), including identifying patterns and trends, making inferences and drawing conclusions.

WS 3.6 – present reasoned explanations including relating data to hypotheses.

WS 3.7 – be objective, evaluate data in terms of accuracy, precision, repeatability and reproducibility and identify potential sources of random and systematic error.

WS 3.8 – communicate the scientific rationale for investigations, methods used, findings and reasoned conclusions through written and electronic reports and presentations using verbal, diagrammatic, graphical, numerical and symbolic forms.

WS 4.2 – recognise the importance of scientific quantities and understand how they are determined.

WS 4.3 – use SI units (eg kg, g, mg; km, m, mm; kJ, J) and IUPAC chemical nomenclature unless inappropriate.

WS 4.6 – use an appropriate number of significant figures in calculation.

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

MS 2b – find arithmetic means.

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.

8.2.17 Required practical activity 17

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.

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

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

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

Chemistry 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.

8.2.18 Required practical activity 18

Investigate the variables that affect the temperature changes of a series of reactions in solutions, 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.

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

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

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

Chemistry 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 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.

8.2.19 Required practical activity 19

Investigation of 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.

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

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

Chemistry 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.

Chemistry 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.

8.2.20 Required practical activity 20

Investigate the effect of pH on the rate of reaction of amylase enzyme.

Students should use a continuous sampling technique to determine the time taken to completely digest a starch solution at a range of pH values. Iodine reagent is to be used to test for starch every 30 seconds. Temperature must be controlled by use of a water bath or electric heater.

Apparatus and techniques

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

Biology AT 1 – use appropriate apparatus to record the volumes of liquids, time and pH.

Biology AT 2 – safe use of a water bath or electric heater.

Biology AT 5 – measure the rate of reaction by the colour change of iodine indicator.

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 and hypothesis on how pH affects amylase activity.

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

WS 2.5 – describe the appropriate sampling technique to ensure samples are representative.

WS 2.6 – make and record observations and measurements of time.

WS 3.1 – present a graph of amylase activity against pH.

WS 3.2 – translate numeric data into graphical form.

MS 1a, 1c – carry out rate calculations for chemical reactions.

8.2.21 Required practical activity 21

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.

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

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

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.

9 Appendix A: Periodic table

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

Key

relative atomic mass **atomic symbol** name atomic (proton) number

1	2											3	4	5	6	7	0
							1 **H** hydrogen 1										4 **He** helium 2
7 **Li** lithium 3	9 **Be** beryllium 4											11 **B** boron 5	12 **C** carbon 6	14 **N** nitrogen 7	16 **O** oxygen 8	19 **F** fluorine 9	20 **Ne** neon 10
23 **Na** sodium 11	24 **Mg** magnesium 12											27 **Al** aluminium 13	28 **Si** silicon 14	31 **P** phosphorus 15	32 **S** sulfur 16	35.5 **Cl** chlorine 17	40 **Ar** argon 18
39 **K** potassium 19	40 **Ca** calcium 20	45 **Sc** scandium 21	48 **Ti** titanium 22	51 **V** vanadium 23	52 **Cr** chromium 24	55 **Mn** manganese 25	56 **Fe** iron 26	59 **Co** cobalt 27	59 **Ni** nickel 28	63.5 **Cu** copper 29	65 **Zn** zinc 30	70 **Ga** gallium 31	73 **Ge** germanium 32	75 **As** arsenic 33	79 **Se** selenium 34	80 **Br** bromine 35	84 **Kr** krypton 36
85 **Rb** rubidium 37	88 **Sr** strontium 38	89 **Y** yttrium 39	91 **Zr** zirconium 40	93 **Nb** niobium 41	96 **Mo** molybdenum 42	[98] **Tc** technetium 43	101 **Ru** ruthenium 44	103 **Rh** rhodium 45	106 **Pd** palladium 46	108 **Ag** silver 47	112 **Cd** cadmium 48	115 **In** indium 49	119 **Sn** tin 50	122 **Sb** antimony 51	128 **Te** tellurium 52	127 **I** iodine 53	131 **Xe** xenon 54
133 **Cs** caesium 55	137 **Ba** barium 56	139 **La*** lanthanum 57	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	[209] **Po** polonium 84	[210] **At** astatine 85	[222] **Rn** radon 86
[223] **Fr** francium 87	[226] **Ra** radium 88	[227] **Ac*** actinium 89	[261] **Rf** rutherfordium 104	[262] **Db** dubnium 105	[266] **Sg** seaborgium 106	[264] **Bh** bohrium 107	[277] **Hs** hassium 108	[268] **Mt** meitnerium 109	[271] **Ds** darmstadtium 110	[272] **Rg** roentgenium 111	[285] **Cn** copernicium 112	[286] **Uut** ununtrium 113	[289] **Fl** flerovium 114	[289] **Uup** ununpentium 115	[293] **Lv** livermorium 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.

10 Appendix B: Physics equations

In solving quantitative problems, students should be able to recall and apply the following equations, using standard SI units.

Equations required for Higher Tier papers only are indicated by HT in the left-hand column.

Equation number	Word equation	Symbol equation
1	weight = mass × gravitational field strength (g)	$W = m\ g$
2	work done = force × distance (along the line of action of the force)	$W = F\ s$
3	force applied to a spring = spring constant × extension	$F = k\ e$
4	distance travelled = speed × time	$s = v\ t$
5	acceleration = $\frac{\text{change in velocity}}{\text{time taken}}$	$a = \frac{\Delta v}{t}$
6	resultant force = mass × acceleration	$F = m\ a$
7 HT	momentum = mass × velocity	$p = m\ v$
8	kinetic energy = 0.5 × mass × $(\text{speed})^2$	$E_k = \frac{1}{2} m\ v^2$
9	gravitational potential energy = mass × gravitational field strength (g) × height	$E_p = m\ g\ h$
10	power = $\frac{\text{energy transferred}}{\text{time}}$	$P = \frac{E}{t}$
11	power = $\frac{\text{work done}}{\text{time}}$	$P = \frac{W}{t}$
12	efficiency = $\frac{\text{useful output energy transfer}}{\text{total input energy transfer}}$	
13	efficiency = $\frac{\text{useful power output}}{\text{total power input}}$	
14	wave speed = frequency × wavelength	$v = f\ \lambda$

Equation number	Word equation	Symbol equation
15	charge flow = current × time	$Q = I\ t$
16	potential difference = current × resistance	$V = I\ R$
17	power = potential difference × current	$P = V\ I$
18	power = $(\text{current})^2$ × resistance	$P = I^2\ R$
19	energy transferred = power × time	$E = P\ t$
20	energy transferred = charge flow × potential difference	$E = Q\ V$
21	density = $\frac{\text{mass}}{\text{volume}}$	$\rho = \frac{m}{V}$

Students should be able to select and apply the following equations from the *Physics equation sheet*.

Equations required for higher tier papers only are indicated by HT in the left-hand column.

Equation number	Word equation	Symbol equation
1	$(\text{final velocity})^2 - (\text{initial velocity})^2$ = 2 × acceleration × distance	$v^2 - u^2 = 2\ a\ s$
2	elastic potential energy = 0.5 × spring constant × $(\text{extension})^2$	$E_e = \frac{1}{2}\ k\ e^2$
3	change in thermal energy = mass × specific heat capacity × temperature change	$\Delta E = m\ c\ \Delta\theta$
4	period = $\frac{1}{\text{frequency}}$	
5 HT	force on a conductor (at right angles to a magnetic field) carrying a current = magnetic flux density × current × length	$F = B\ I\ l$
6	thermal energy for a change of state = mass × specific latent heat	$E = m\ L$
7 HT	potential difference across primary coil × current in primary coil = potential difference across secondary coil × current in secondary coil	$V_p\ I_p = V_s\ I_s$

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