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GCSE COMBINED SCIENCE: TRILOGY

(8464)

Specification
For teaching from September 2016 onwards
For exams in 2018 onwards

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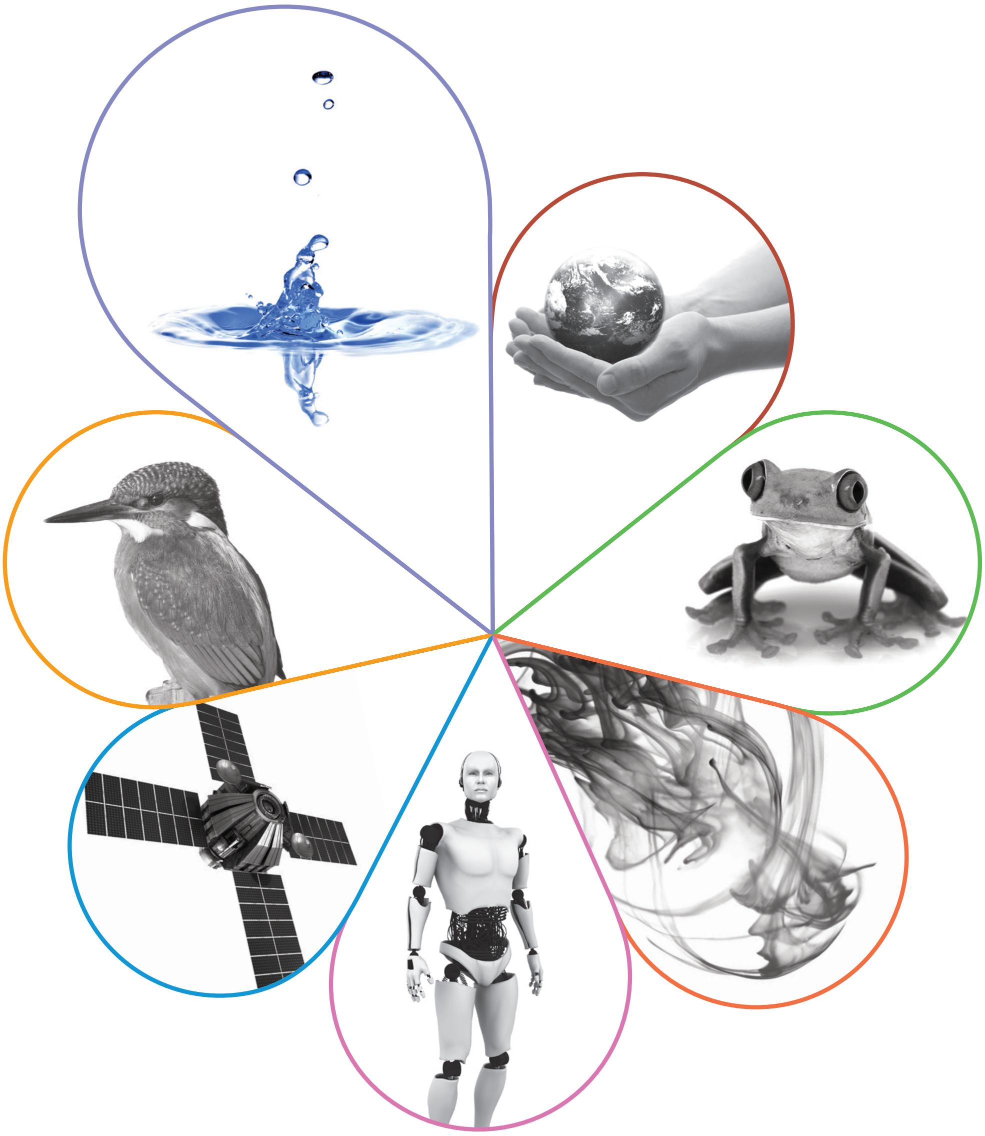

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- You will always find the most up-to-date version of this specification on our website at aqa.org.uk/8464
- We will write to you if there are significant changes to the specification.

1 Introduction

1.1 Why choose AQA for GCSE Combined Science: Trilogy

Our philosophy: science for all

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

The subject content and required practicals in this specification are also in our GCSE Biology, Chemistry and Physics. So you have the flexibility to co-teach and to move your students between courses.

Our specification has been developed with teachers

We've involved over a thousand teachers in developing our specification, exams and resources. So you can be confident that our GCSE Combined Science: Trilogy is interesting and relevant to all types of students. We've ensured that:

- the biology, chemistry and physics content is presented clearly, in a logical teaching order. We've also given teaching guidance and signposted opportunities for skills development throughout the specification
- the subject content and required practicals are also in our biology, chemistry and physics GCSEs so you have the flexibility to co-teach or to move your students between courses
- all our science qualifications provide opportunities for progression. Combined Science: Trilogy gives students the option to progress to A-levels in science or other subjects.

Our practicals have been trialled by teachers

There's no better way to learn about science than through purposeful practical activities as part of day to day teaching and learning. Our 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: Trilogy 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/8464 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/8464 for everything you need to prepare for our exams, including:

- past papers, mark schemes and examiners' reports
- specimen papers and mark schemes for new courses
- Exampro: a searchable bank of past AQA exam questions
- exemplar 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/8464

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

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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

Biology

Chemistry

Physics

2.2 Assessments

There are six papers: two biology, two chemistry and two physics. Each of the papers will assess knowledge and understanding from distinct topic areas.

Biology Paper 1
What's assessed Biology topics 1–4: Cell Biology; Organisation; Infection and response; and Bioenergetics.
How it's assessed • Written exam: 1 hour 15 minutes • Foundation and Higher Tier • 70 marks • 16.7% of GCSE
Questions Multiple choice, structured, closed short answer, and open response.

+

Biology Paper 2
What's assessed Biology topics 5–7: Homeostasis and response; Inheritance, variation and evolution; and Ecology.
How it's assessed • Written exam: 1 hour 15 minutes • Foundation and Higher Tier • 70 marks • 16.7% of GCSE
Questions Multiple choice, structured, closed short answer, and open response.

+

Chemistry Paper 1
What's assessed Chemistry topics 8–12: Atomic structure and the periodic table; Bonding, structure, and the properties of matter; Quantitative chemistry; Chemical changes; and Energy changes.
How it's assessed • Written exam: 1 hour 15 minutes • Foundation and Higher Tier • 70 marks • 16.7% of GCSE
Questions Multiple choice, structured, closed short answer, and open response.

+

Chemistry Paper 2
What's assessed Chemistry topics 13–17: The rate and extent of chemical change; Organic chemistry; Chemical analysis; Chemistry of the atmosphere; and Using resources. Questions in Paper 2 may draw on fundamental concepts and principles from Sections 5.1 to 5.3.
How it's assessed • Written exam: 1 hour 15 minutes • Foundation and Higher Tier • 70 marks • 16.7% of GCSE
Questions Multiple choice, structured, closed short answer, and open response.

+

Physics Paper 1
What's assessed Physics topics 18–21: Energy; Electricity; Particle model of matter; and Atomic structure.
How it's assessed • Written exam: 1 hour 15 minutes • Foundation and Higher Tier • 70 marks • 16.7% of GCSE
Questions Multiple choice, structured, closed short answer, and open response.

+

Physics Paper 2
What's assessed Physics topics 22–24: Forces; Waves; and Magnetism and electromagnetism
How it's assessed • Written exam: 1 hour 15 minutes • Foundation and Higher Tier • 70 marks • 16.7% of GCSE
Questions Multiple choice, structured, closed short answer, and open response.

3 Working scientifically

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

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

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

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

1 Development of scientific thinking

Students should be able to:	Examples of what students could be asked to do in an exam
WS 1.1 Understand how scientific methods and theories develop over time.	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 Biology subject content

This specification is presented in a two column format.

The subject content is split into three sections for each of the subject areas: biology, chemistry and physics.

The left hand column contains the subject content that all students must cover, and that can be assessed in the written papers.

The right hand column exemplifies some of the key opportunities for the following skills to be developed throughout the course: WS refers to Working scientifically (page 13), MS refers to Mathematical requirements (page 171) and AT refers to Use of apparatus and techniques (page 173). These are not the only opportunities. Teachers are encouraged to introduce all of these skills where appropriate throughout the course.

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

It is good practice to teach and develop all of the mathematical skills throughout the course. Some mathematical skills will only be assessed in certain subject areas. These are detailed in Mathematical requirements (page 171).

Science is a practical subject. Details of the assessment of required practicals can be found in Required practical activities (page 175).

Working scientifically (page 13) and Use of apparatus and techniques (page 173) skills will be assessed across all papers.

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.

Fundamental biological concepts and principles

Students should have a basic understanding of the following biological principles and be able to apply them in either paper:

- The structure and functioning of cells and how they divide by mitosis and meiosis from sections Cell biology (page 20) and Meiosis (page 50).
- That variation occurs when gametes fuse at fertilisation from section Sexual and asexual reproduction (page 50).
- The two essential reactions for life on Earth: photosynthesis and respiration from sections Photosynthetic reaction (page 39) and Aerobic and anaerobic respiration (page 41).
- Metabolism is the sum of all the reactions happening in a cell or organism, in which molecules are made or broken down from section Metabolism (page 42).
- All molecules are recycled between the living world and the environment to sustain life from section How materials are cycled (page 63).

Students should be able to recall and use this knowledge in questions that link different areas of the specification to develop coherent arguments and explanations.

4.1 Cell biology

Cells are the basic unit of all forms of life. In this section we explore how structural differences between types of cells enables them to perform specific functions within the organism. These differences in cells are controlled by genes in the nucleus. For an organism to grow, cells must divide by mitosis producing two new identical cells. If cells are isolated at an early stage of growth before they have become too specialised, they can retain their ability to grow into a range of different types of cells. This phenomenon has led to the development of stem cell technology. This is a new branch of medicine that allows doctors to repair damaged organs by growing new tissue from stem cells.

4.1.1 Cell structure

4.1.1.1 Eukaryotes and prokaryotes

Content	Key opportunities for skills development
Plant and animal cells (eukaryotic cells) have a cell membrane, cytoplasm and genetic material enclosed in a nucleus.	
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 there may be one or more small rings of DNA called plasmids.	
Students should be able to demonstrate an understanding of the scale and size of cells and be able to make order of magnitude calculations, including the use of standard form.	MS 1b, 2a, 2h WS 4.4 Use prefixes centi, milli, micro and nano.

4.1.1.2 Animal and plant cells

Content	Key opportunities for skills development
Students should be able to explain how the main sub-cellular structures, including the nucleus, cell membranes, mitochondria, chloroplasts in plant cells and plasmids in bacterial cells are related to their functions. Most animal cells have the following parts: • a nucleus • cytoplasm • a cell membrane • mitochondria • ribosomes. 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.	WS 1.2 Recognise, draw and interpret images of cells.
Students should be able to use estimations and explain when they should be used to judge the relative size or area of sub-cellular structures.	MS 1d, 3a AT 7 Images of cells in videos, bioviewers, photographs and micrographs can be used as comparison for students own drawings.

Required practical activity 1: 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 176).

4.1.1.3 Cell specialisation

Content	Key opportunities for skills development
Students should be able to, when provided with appropriate information, explain how the structure of different types of cell relate to their function in a tissue, an organ or organ system, or the whole organism. Cells may be specialised to carry out a particular function: • sperm cells, nerve cells and muscle cells in animals • root hair cells, xylem and phloem cells in plants.	

4.1.1.4 Cell differentiation

Content	Key opportunities for skills development
Students should be able to explain the importance of cell differentiation. As an organism develops, cells differentiate to form different types of cells. • Most types of animal cell differentiate at an early stage. • Many types of plant cells retain the ability to differentiate throughout life. In mature animals, cell division is mainly restricted to repair and replacement. As a cell differentiates it acquires different sub-cellular structures to enable it to carry out a certain function. It has become a specialised cell.	

4.1.1.5 Microscopy

Content	Key opportunities for skills development
Students should be able to: • understand how microscopy techniques have developed over time • explain how electron microscopy has increased understanding of sub-cellular structures. Limited to the differences in magnification and resolution. An electron microscope has much higher magnification and resolving power than a light microscope. This means that it can be used to study cells in much finer detail. This has enabled biologists to see and understand many more sub-cellular structures.	WS 1.1

Content	Key opportunities for skills development
Students should be able to carry out calculations involving magnification, real size and image size using the formula: $\text{magnification} = \frac{\text{size of image}}{\text{size of real object}}$ Students should be able to express answers in standard form if appropriate.	MS 1a, 1b, 2h, 3b WS 4.4 Use prefixes centi, milli, micro and nano.

4.1.2 Cell division

4.1.2.1 Chromosomes

Content	Key opportunities for skills development
The nucleus of a cell contains chromosomes made of DNA molecules. Each chromosome carries a large number of genes. In body cells the chromosomes are normally found in pairs.	WS 1.2 Use models and analogies to develop explanations of how cells divide.

4.1.2.2 Mitosis and the cell cycle

Content	Key opportunities for skills development
Cells divide in a series of stages called the cell cycle. Students should be able to describe the stages of the cell cycle, including mitosis. During the cell cycle the genetic material is doubled and then divided into two identical cells. Before a cell can divide it needs to grow and increase the number of sub-cellular structures such as ribosomes and mitochondria. The DNA replicates to form two copies of each chromosome. In mitosis one set of chromosomes is pulled to each end of the cell and the nucleus divides. Finally the cytoplasm and cell membranes divide to form two identical cells. Students need to understand the three overall stages of the cell cycle but do not need to know the different phases of the mitosis stage. Cell division by mitosis is important in the growth and development of multicellular organisms. Students should be able to recognise and describe situations in given contexts where mitosis is occurring.	

4.1.2.3 Stem cells

Content	Key opportunities for skills development
A stem cell is an undifferentiated cell of an organism which is capable of giving rise to many more cells of the same type, and from which certain other cells can arise from differentiation. Students should be able to describe the function of stem cells in embryos, in adult animals and in the meristems in plants. Stem cells from human embryos can be cloned and made to differentiate into most different types of human cells. Stem cells from adult bone marrow can form many types of cells including blood cells. Meristem tissue in plants can differentiate into any type of plant cell, throughout the life of the plant. Knowledge and understanding of stem cell techniques are not required. Treatment with stem cells may be able to help conditions such as diabetes and paralysis.	
In therapeutic cloning an embryo is produced with the same genes as the patient. Stem cells from the embryo are not rejected by the patient's body so they may be used for medical treatment. The use of stem cells has potential risks such as transfer of viral infection, and some people have ethical or religious objections. Stem cells from meristems in plants can be used to produce clones of plants quickly and economically. • Rare species can be cloned to protect from extinction. • Crop plants with special features such as disease resistance can be cloned to produce large numbers of identical plants for farmers.	WS 1.3 Evaluate the practical risks and benefits, as well as social and ethical issues, of the use of stem cells in medical research and treatments.

4.1.3 Transport in cells

4.1.3.1 Diffusion

Content	Key opportunities for skills development
Substances may move into and out of cells across the cell membranes via diffusion. Diffusion is the spreading out of the particles of any substance in solution, or particles of a gas, resulting in a net movement from an area of higher concentration to an area of lower concentration. Some of the substances transported in and out of cells by diffusion are oxygen and carbon dioxide in gas exchange, and of the waste product urea from cells into the blood plasma for excretion in the kidney. Students should be able to explain how different factors affect the rate of diffusion. Factors which affect the rate of diffusion are: • the difference in concentrations (concentration gradient) • the temperature • the surface area of the membrane. A single-celled organism has a relatively large surface area to volume ratio. This allows sufficient transport of molecules into and out of the cell to meet the needs of the organism.	WS 1.2 Recognise, draw and interpret diagrams that model diffusion. WS 1.5 Use of isotonic drinks and high energy drinks in sport.
Students should be able to calculate and compare surface area to volume ratios. Students should be able to explain the need for exchange surfaces and a transport system in multicellular organisms in terms of surface area to volume ratio. Students should be able to explain how the small intestine and lungs in mammals, gills in fish, and the roots and leaves in plants, are adapted for exchanging materials. In multicellular organisms, surfaces and organ systems are specialised for exchanging materials. This is to allow sufficient molecules to be transported into and out of cells for the organism's needs. 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, 5c

4.1.3.2 Osmosis

Content	Key opportunities for skills development
Water may move across cell membranes via osmosis. Osmosis is the diffusion of water from a dilute solution to a concentrated solution through a partially permeable membrane.	WS 1.2 Recognise, draw and interpret diagrams that model osmosis.
Students should be able to: • use simple compound measures of rate of water uptake • use percentages • calculate percentage gain and loss of mass of plant tissue.	MS 1a, 1c
Students should be able to plot, draw and interpret appropriate graphs.	MS 4a, 4b, 4c, 4d

Required practical activity 2: 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 176).

4.1.3.3 Active transport

Content	Key opportunities for skills development
Active transport moves substances from a more dilute solution to a more concentrated solution (against a concentration gradient). This requires energy from respiration. Active transport allows mineral ions to be absorbed into plant root hairs from very dilute solutions in the soil. Plants require ions for healthy growth. It also allows sugar molecules to be absorbed from lower concentrations in the gut into the blood which has a higher sugar concentration. Sugar molecules are used for cell respiration. Students should be able to: • describe how substances are transported into and out of cells by diffusion, osmosis and active transport • explain the differences between the three processes.	There are links with this content to Cell specialisation (page 22).

4.2 Organisation

In this section we will learn about the human digestive system which provides the body with nutrients and the respiratory system that provides it with oxygen and removes carbon dioxide. In each case they provide dissolved materials that need to be moved quickly around the body in the blood by the circulatory system. Damage to any of these systems can be debilitating if not fatal. Although there has been huge progress in surgical techniques, especially with regard to coronary heart disease, many interventions would not be necessary if individuals reduced their risks through improved diet and lifestyle. We will also learn how the plant's transport system is dependent on environmental conditions to ensure that leaf cells are provided with the water and carbon dioxide that they need for photosynthesis.

4.2.1 Principles of organisation

Content	Key opportunities for skills development
Cells are the basic building blocks of all living organisms. A tissue is a group of cells with a similar structure and function. Organs are aggregations of tissues performing specific functions. Organs are organised into organ systems, which work together to form organisms.	MS 1c Students should be able to develop an understanding of size and scale in relation to cells, tissues, organs and systems.

4.2.2 Animal tissues, organs and organ systems

4.2.2.1 The human digestive system

Content	Key opportunities for skills development
This section assumes knowledge of the digestive system studied in Key Stage 3 science. The digestive system is an example of an organ system in which several organs work together to digest and absorb food. Students should be able to relate knowledge of enzymes to Metabolism (page 42). Students should be able to describe the nature of enzyme molecules and relate their activity to temperature and pH changes.	
Students should be able to carry out rate calculations for chemical reactions. Enzymes catalyse specific reactions in living organisms due to the shape of their active site.	MS 1a, 1c

Content	Key opportunities for skills development
Students should be able to use the 'lock and key theory' as a simplified model to explain enzyme action. Students should be able to recall the sites of production and the action of amylase, proteases and lipases. Students should be able to understand simple word equations but no chemical symbol equations are required. Digestive enzymes convert food into small soluble molecules that can be absorbed into the bloodstream. Carbohydrases break down carbohydrates to simple sugars. Amylase is a carbohydrase which breaks down starch. Proteases break down proteins to amino acids. Lipases break down lipids (fats) to glycerol and fatty acids. The products of digestion are used to build new carbohydrates, lipids and proteins. Some glucose is used in respiration. Bile is made in the liver and stored in the gall bladder. It is alkaline to neutralise hydrochloric acid from the stomach. It also emulsifies fat to form small droplets which increases the surface area. The alkaline conditions and large surface area increase the rate of fat breakdown by lipase.	WS 1.2 Students should be able to use other models to explain enzyme action.

Required practical activity 3: 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 177).

Required practical activity 4: 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).

4.2.2.2 The heart and blood vessels

Content	Key opportunities for skills development
Students should know the structure and functioning of the human heart and lungs, including how lungs are adapted for gaseous exchange. The heart is an organ that pumps blood around the body in a double 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. Knowledge of the blood vessels associated with the heart is limited to the aorta, vena cava, pulmonary artery, pulmonary vein and coronary arteries. Knowledge of the names of the heart valves is not required. Knowledge of the lungs is restricted to the trachea, bronchi, alveoli and the capillary network surrounding the alveoli. The natural resting heart rate is controlled by a group of cells located in the right atrium that act as a pacemaker. 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. Students should be able to explain how the structure of these vessels relates to their functions.	
Students should be able to use simple compound measures such as rate and carry out rate calculations for blood flow.	MS 1a, 1c

4.2.2.3 Blood

Content	Key opportunities for skills development
Blood is a tissue consisting of plasma, in which the red blood cells, white blood cells and platelets are suspended. Students should know the functions of each of these blood components.	AT 7 Observing and drawing blood cells seen under a microscope. WS 1.5 Evaluate risks related to use of blood products.

Content	Key opportunities for skills development
Students should be able to recognise different types of blood cells in a photograph or diagram, and explain how they are adapted to their functions.	WS 3.5

4.2.2.4 Coronary heart disease: a non-communicable disease

Content	Key opportunities for skills development
Students should be able to evaluate the advantages and disadvantages of treating cardiovascular diseases by drugs, mechanical devices or transplant. In coronary heart disease layers of fatty material build up inside the coronary arteries, narrowing them. This reduces the flow of blood through the coronary arteries, resulting in a lack of oxygen for the heart muscle. Stents are used to keep the coronary arteries open. Statins are widely used to reduce blood cholesterol levels which slows down the rate of fatty material deposit. In some people heart valves may become faulty, preventing the valve from opening fully, or the heart valve might develop a leak. Students should understand the consequences of faulty valves. 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 WS 1.3 Evaluate methods of treatment bearing in mind the benefits and risks associated with the treatment.

4.2.2.5 Health issues

Content	Key opportunities for skills development
Students should be able to describe the relationship between health and disease and the interactions between different types of disease. Health is the state of physical and mental well-being. Diseases, both communicable Communicable diseases (page 35) and non-communicable, are major causes of ill health. Other factors including diet, stress and life situations may have a profound effect on both physical and mental health. Different types of disease may interact. • 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.	
Students should be able to translate disease incidence information between graphical and numerical forms, construct and interpret frequency tables and diagrams, bar charts and histograms, and use a scatter diagram to identify a correlation between two variables.	MS 2c, 2g, 4a
Students should understand the principles of sampling as applied to scientific data, including epidemiological data.	MS 2d

4.2.2.6 The effect of lifestyle on some non-communicable diseases

Content	Key opportunities for skills development
Students should be able to: • discuss the human and financial cost of these non-communicable diseases to an individual, a local community, a nation or globally • explain the effect of lifestyle factors including diet, alcohol and smoking on the incidence of non-communicable diseases at local, national and global levels.	WS 1.4

Content	Key opportunities for skills development
Risk factors are linked to an increased rate of a disease. They can be: • aspects of a person's lifestyle • substances in the person's body or environment. A causal mechanism has been proven for some risk factors, but not in others. • The effects of diet, smoking and exercise on cardiovascular disease. • Obesity as a risk factor for Type 2 diabetes. • The effect of alcohol on the liver and brain function. • The effect of smoking on lung disease and lung cancer. • The effects of smoking and alcohol on unborn babies. • Carcinogens, including ionising radiation, as risk factors in cancer. Many diseases are caused by the interaction of a number of factors.	WS 1.5 Interpret data about risk factors for specified diseases.
Students should be able to understand the principles of sampling as applied to scientific data in terms of risk factors.	MS 2d
Students should be able to translate information between graphical and numerical forms; and extract and interpret information from charts, graphs and tables in terms of risk factors.	MS 2c, 4a
Students should be able to use a scatter diagram to identify a correlation between two variables in terms of risk factors.	MS 2g

4.2.2.7 Cancer

Content	Key opportunities for skills development
Students should be able to describe cancer as the result of changes in cells that lead to uncontrolled growth and division. Benign tumours are growths of abnormal cells which are contained in one area, usually within a membrane. They do not invade other parts of the body. Malignant tumour cells are cancers. They invade neighbouring tissues and spread to different parts of the body in the blood where they form secondary tumours. Scientists have identified lifestyle risk factors for various types of cancer. There are also genetic risk factors for some cancers.	

4.2.3 Plant tissues, organs and systems

4.2.3.1 Plant tissues

Content	Key opportunities for skills development
Students should be able to explain how the structures of plant tissues are related to their functions. Plant tissues include: • epidermal tissues • palisade mesophyll • spongy mesophyll • xylem and phloem • meristem tissue found at the growing tips of shoots and roots. The leaf is a plant organ. Knowledge limited to epidermis, palisade and spongy mesophyll, xylem and phloem, and guard cells surrounding stomata.	AT 7 Observation and drawing of a transverse section of leaf.

4.2.3.2 Plant organ system

Content	Key opportunities for skills development
Students should be able to explain how the structure of root hair cells, xylem and phloem are adapted to their functions. Students should be able to explain the effect of changing temperature, humidity, air movement and light intensity on the rate of transpiration.	AT 3, 4, 5 Measure the rate of transpiration by the uptake of water. AT 6, 7 Investigate the distribution of stomata and guard cells. MS 2a, 2d, 5c Process data from investigations involving stomata and transpiration rates to find arithmetic means, understand the principles of sampling and calculate surface areas and volumes.
Students should be able to understand and use simple compound measures such as the rate of transpiration.	MS 1a, 1c

Content	Key opportunities for skills development
Students should be able to: • translate information between graphical and numerical form • plot and draw appropriate graphs, selecting appropriate scales for axes • extract and interpret information from graphs, charts and tables.	MS 2c, 4a, 4c
The roots, stem and leaves form a plant organ system for transport of substances around the plant. Students should be able to describe the process of transpiration and translocation, including the structure and function of the stomata. Root hair cells are adapted for the efficient uptake of water by osmosis, and mineral ions by active transport. Xylem tissue transports water and mineral ions from the roots to the stems and leaves. It is composed of hollow tubes strengthened by lignin adapted for the transport of water in the transpiration stream. The role of stomata and guard cells are to control gas exchange and water loss. Phloem tissue transports dissolved sugars from the leaves to the rest of the plant for immediate use or storage. The movement of food molecules through phloem tissue is called translocation. Phloem is composed of tubes of elongated cells. Cell sap can move from one phloem cell to the next through pores in the end walls. Detailed structure of phloem tissue or the mechanism of transport is not required.	

4.3 Infection and response

Pathogens are microorganisms such as viruses and bacteria that cause infectious diseases in animals and plants. They depend on their host to provide the conditions and nutrients that they need to grow and reproduce. They frequently produce toxins that damage tissues and make us feel ill. This section will explore how we can avoid diseases by reducing contact with them, as well as how the body uses barriers against pathogens. Once inside the body our immune system is triggered which is usually strong enough to destroy the pathogen and prevent disease. When at risk from unusual or dangerous diseases our body's natural system can be enhanced by the use of vaccination. Since the 1940s a range of antibiotics have been developed which have proved successful against a number of lethal diseases caused by bacteria. Unfortunately many groups of bacteria have now become resistant to these antibiotics. The race is now on to develop a new set of antibiotics.

4.3.1 Communicable diseases

4.3.1.1 Communicable (infectious) diseases

Content	Key opportunities for skills development
Students should be able to explain how diseases caused by viruses, bacteria, protists and fungi are spread in animals and plants. Students should be able to explain how the spread of diseases can be reduced or prevented. Pathogens are microorganisms that cause infectious disease. Pathogens may be viruses, bacteria, protists or fungi. They may infect plants or animals and can be spread by direct contact, by water or by air. Bacteria and viruses may reproduce rapidly inside the body. Bacteria may produce poisons (toxins) that damage tissues and make us feel ill. Viruses live and reproduce inside cells, causing cell damage.	WS 1.4

4.3.1.2 Viral diseases

Content	Key opportunities for skills development
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. HIV initially causes a flu-like illness. Unless successfully controlled with antiretroviral drugs the virus attacks the body's immune cells. Late stage HIV infection, or AIDS, occurs when the body's immune system becomes so badly damaged it can no longer deal with other infections or cancers. HIV is spread by sexual contact or exchange of body fluids such as blood which occurs when drug users share needles. Tobacco mosaic virus (TMV) 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.	

4.3.1.3 Bacterial diseases

Content	Key opportunities for skills development
Salmonella food poisoning is spread by bacteria ingested in food, or on food prepared in unhygienic conditions. In the UK, poultry are vaccinated against salmonella to control the spread. Fever, abdominal cramps, vomiting and diarrhoea are caused by the bacteria and the toxins they secrete. 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.	

4.3.1.4 Fungal diseases

Content	Key opportunities for skills development
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. It is spread in the environment by water or wind. Rose black spot can be treated by using fungicides and/or removing and destroying the affected leaves.	

4.3.1.5 Protist diseases

Content	Key opportunities for skills development
The pathogens that cause malaria are protists. The malarial protist has a life cycle that includes the mosquito. Malaria causes recurrent episodes of fever and can be fatal. The spread of malaria is controlled by preventing the vectors, mosquitos, from breeding and by using mosquito nets to avoid being bitten.	

4.3.1.6 Human defence systems

Content	Key opportunities for skills development
Students should be able to describe the non-specific defence systems of the human body against pathogens, including the: • skin • nose • trachea and bronchi • stomach. Students should be able to explain the role of the immune system in the defence against disease. If a pathogen enters the body the immune system tries to destroy the pathogen. White blood cells help to defend against pathogens by: • phagocytosis • antibody production • antitoxin production.	

4.3.1.7 Vaccination

Content	Key opportunities for skills development
Students should be able to explain how vaccination will prevent illness in an individual, and how the spread of pathogens can be reduced by immunising a large proportion of the population. 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 the correct antibodies, preventing infection. Students do not need to know details of vaccination schedules and side effects associated with specific vaccines.	WS 1.4 Evaluate the global use of vaccination in the prevention of disease.

4.3.1.8 Antibiotics and painkillers

Content	Key opportunities for skills development
Students should be able to explain the use of antibiotics and other medicines in treating 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.	WS 1.4

Content	Key opportunities for skills development
The use of antibiotics has greatly reduced deaths from infectious bacterial diseases. However, the emergence of strains resistant to antibiotics is of great concern.	There are links with this content to Resistant bacteria (page 58).
Antibiotics cannot kill viral pathogens. Painkillers and other medicines are used to treat the symptoms of disease but do not kill pathogens. It is difficult to develop drugs that kill viruses without also damaging the body's tissues.	

4.3.1.9 Discovery and development of drugs

Content	Key opportunities for skills development
Students should be able to describe the process of discovery and development of potential new medicines, including preclinical and clinical testing. Traditionally drugs were extracted from plants and microorganisms. • The heart drug digitalis originates from foxgloves. • The painkiller aspirin originates from willow. • Penicillin was discovered by Alexander Fleming from the *Penicillium* mould. Most new drugs are synthesised by chemists in the pharmaceutical industry. However, the starting point may still be a chemical extracted from a plant.	
New medical drugs have to be tested and trialled before being used to check that they are safe and effective. New drugs are extensively tested for toxicity, efficacy and dose. Preclinical testing is done in a laboratory using cells, tissues and live animals. Clinical trials use 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.	WS 1.6 Understand that the results of testing and trials are published only after scrutiny by peer review.

4.4 Bioenergetics

In this section we will explore how plants harness the Sun's energy in photosynthesis in order to make food. This process liberates oxygen which has built up over millions of years in the Earth's atmosphere. Both animals and plants use this oxygen to oxidise food in a process called aerobic respiration which transfers the energy that the organism needs to perform its functions. Conversely, anaerobic respiration does not require oxygen to transfer energy. During vigorous exercise the human body is unable to supply the cells with sufficient oxygen and it switches to anaerobic respiration. This process will supply energy but also causes the build-up of lactic acid in muscles which causes fatigue.

4.4.1 Photosynthesis

4.4.1.1 Photosynthetic reaction

Content	Key opportunities for skills development
Photosynthesis is represented by the equation: carbon dioxide + water $\xrightarrow{\text{light}}$ glucose + oxygen Students should recognise the chemical symbols: CO_2, H_2O, O_2 and $C_6H_{12}O_6$.	
Students should be able to describe photosynthesis as an endothermic reaction in which energy is transferred from the environment to the chloroplasts by light.	There are links with this content to Plant tissues (page 33), the leaf.

4.4.1.2 Rate of photosynthesis

Content	Key opportunities for skills development
Students should be able to explain the effects of temperature, light intensity, carbon dioxide concentration, and the amount of chlorophyll on the rate of photosynthesis.	
Students should be able to: • measure and calculate rates of photosynthesis • extract and interpret graphs of photosynthesis rate involving one limiting factor • plot and draw appropriate graphs selecting appropriate scale for axes • translate information between graphical and numeric form.	MS 3d Solve simple algebraic equations. MS 1a, 1c, 2c, 3d, 4a, 4c

Content	Key opportunities for skills development
(HT only) These factors interact and any one of them may be the factor that limits photosynthesis. (HT only) Students should be able to explain graphs of photosynthesis rate involving two or three factors and decide which is the limiting factor.	
(HT only) Students should understand and use inverse proportion – the inverse square law and light intensity in the context of photosynthesis. (HT only) Limiting factors are important in the economics of enhancing the conditions in greenhouses to gain the maximum rate of photosynthesis while still maintaining profit.	MS 3a, 3d (HT only) WS 1.4 Use data to relate limiting factors to the cost effectiveness of adding heat, light or carbon dioxide to greenhouses.

Required practical activity 5: 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 178).

4.4.1.3 Uses of glucose from photosynthesis

Content	Key opportunities for skills development
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 from the soil.	

4.4.2 Respiration

4.4.2.1 Aerobic and anaerobic respiration

Content	Key opportunities for skills development
Students should be able to describe cellular respiration as an exothermic reaction which is continuously occurring in living cells. The energy transferred supplies all the energy needed for living processes. Respiration in cells can take place aerobically (using oxygen) or anaerobically (without oxygen), to transfer energy. Students should be able to compare the processes of aerobic and anaerobic respiration with regard to the need for oxygen, the differing products and the relative amounts of energy transferred. Organisms need energy for: • chemical reactions to build larger molecules • movement • keeping warm. Aerobic respiration is represented by the equation: glucose + oxygen → carbon dioxide + water Students should recognise the chemical symbols: $C_6H_{12}O_6$, O_2, CO_2 and H_2O. Anaerobic respiration in muscles is represented by the equation: glucose → lactic acid As the oxidation of glucose is incomplete in anaerobic respiration much less energy is transferred than in aerobic respiration. Anaerobic respiration in plant and yeast cells is represented by the equation: glucose → ethanol + carbon dioxide Anaerobic respiration in yeast cells is called fermentation and has economic importance in the manufacture of bread and alcoholic drinks.	

4.4.2.2 Response to exercise

Content	Key opportunities for skills development
During exercise the human body reacts to the increased demand for energy. The heart rate, breathing rate and breath volume increase during exercise to supply the muscles with more oxygenated blood. 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. During long periods of vigorous activity muscles become fatigued and stop contracting efficiently.	AT 1, 3, 4 Investigations into the effect of exercise on the body.
(HT only) Blood flowing through the muscles transports the lactic acid to the liver where it is converted back into glucose. 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.	

4.4.2.3 Metabolism

Content	Key opportunities for skills development
Students should be able to explain the importance of sugars, amino acids, fatty acids and glycerol in the synthesis and breakdown of carbohydrates, proteins and lipids. Metabolism is the sum of all the reactions in a cell or the body. The energy transferred by respiration in cells is used by the organism for the continual enzyme controlled processes of metabolism that synthesise new molecules. Metabolism includes: • conversion of glucose to starch, glycogen and cellulose • the formation of lipid molecules from a molecule of glycerol and three molecules of fatty acids • the use of glucose and nitrate ions to form amino acids which in turn are used to synthesise proteins • respiration • breakdown of excess proteins to form urea for excretion. All of these aspects are covered in more detail in the relevant specification section but are linked together here.	

4.5 Homeostasis and response

Cells in the body can only survive within narrow physical and chemical limits. They require a constant temperature and pH as well as a constant supply of dissolved food and water. In order to do this the body requires control systems that constantly monitor and adjust the composition of the blood and tissues. These control systems include receptors which sense changes and effectors that bring about changes. In this section we will explore the structure and function of the nervous system and how it can bring about fast responses. We will also explore the hormonal system which usually brings about much slower changes. Hormonal coordination is particularly important in reproduction since it controls the menstrual cycle. An understanding of the role of hormones in reproduction has allowed scientists to develop not only contraceptive drugs but also drugs which can increase fertility.

4.5.1 Homeostasis

Content	Key opportunities for skills development
Students should be able to explain that 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 maintains optimal conditions for enzyme action and all cell functions. In the human body, these include control of: • blood glucose concentration • body temperature • water levels. These automatic control systems may involve nervous responses or chemical responses. All control systems include: • cells called receptors, which detect stimuli (changes in the environment) • coordination centres (such as the brain, spinal cord and pancreas) that receive and process information from receptors • effectors, muscles or glands, which bring about responses which restore optimum levels.	

4.5.2 The human nervous system

Content	Key opportunities for skills development
Students should be able to explain how the structure of the nervous system 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 electrical impulses to the central nervous system (CNS). The CNS is the brain and spinal cord. The CNS coordinates the response of effectors which may be muscles contracting or glands secreting hormones. stimulus → receptor → coordinator → effector → response Students should be able to explain how the various structures in a reflex arc – including the sensory neurone, synapse relay neurone and motor neurone – relate to their function. Students should understand why reflex actions are important. Reflex actions are automatic and rapid; they do not involve the conscious part of the brain.	
Students should be able to extract and interpret data from graphs, charts and tables, about the functioning of the nervous system.	MS 2c
Students should be able to translate information about reaction times between numerical and graphical forms.	MS 4a

Required practical activity 6: 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 179).

4.5.3 Hormonal coordination in humans

4.5.3.1 Human endocrine system

Content	Key opportunities for skills development
Students should be able to describe the principles of hormonal coordination and control by the human endocrine system. The endocrine system is composed of glands which secrete chemicals called hormones directly into the bloodstream. 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' which secretes several hormones into the blood in response to body conditions. These hormones in turn act on other glands to stimulate other hormones to be released to bring about effects. Students should be able to identify the position of the following on a diagram of the human body: • pituitary gland • pancreas • thyroid • adrenal gland • ovary • testes.	

4.5.3.2 Control of blood glucose concentration

Content	Key opportunities for skills development
Blood glucose concentration is monitored and controlled by the pancreas. If the blood glucose concentration is too high, the pancreas produces the hormone insulin that causes glucose to move from the blood into the cells. In liver and muscle cells excess glucose is converted to glycogen for storage. Students should be able to explain how insulin controls blood glucose (sugar) levels in the body. 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. Students should be able to compare Type 1 and Type 2 diabetes and explain how they can be treated.	WS 1.3 Evaluate information around the relationship between obesity and diabetes, and make recommendations taking into account social and ethical issues.
Students should be able to extract information and interpret data from graphs that show the effect of insulin in blood glucose levels in both people with diabetes and people without diabetes.	MS 2c
(HT only) If the blood glucose concentration is too low, the pancreas produces the hormone glucagon that causes glycogen to be converted into glucose and released into the blood. (HT only) Students should be able to explain how glucagon interacts with insulin in a negative feedback cycle to control blood glucose (sugar) levels in the body.	

4.5.3.3 Hormones in human reproduction

Content	Key opportunities for skills development
Students should be able to describe the roles of hormones in human reproduction, including 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.	
(HT only) Students should be able to explain the interactions of FSH, oestrogen, LH and progesterone, in the control of the menstrual cycle.	
(HT only) Students should be able to extract and interpret data from graphs showing hormone levels during the menstrual cycle.	MS 2c

4.5.3.4 Contraception

Content	Key opportunities for skills development
Students should be able to evaluate the different 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 to inhibit FSH production so that no eggs mature • injection, implant or skin patch of slow release progesterone to inhibit the maturation and release of eggs for a number of months or years • barrier methods such as condoms and diaphragms which prevent the sperm reaching an egg • intrauterine devices which prevent the implantation of an embryo or release a hormone • spermicidal agents which kill or disable sperm • abstaining from intercourse when an egg may be in the oviduct • surgical methods of male and female sterilisation.	WS 1.3 Show why issues around contraception cannot be answered by science alone. 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.

4.5.3.5 The use of hormones to treat infertility (HT only)

Content	Key opportunities for skills development
Students should be able to explain the use of hormones in modern reproductive technologies to treat infertility. This includes giving FSH and LH in a 'fertility drug' to a woman. She may then become pregnant in the normal way. In Vitro Fertilisation (IVF) treatment. • IVF involves giving a mother FSH and LH to stimulate the maturation of several eggs. • The eggs are collected from the mother and fertilised by sperm from the father in the laboratory. • The fertilised eggs develop into embryos. • At the stage when they are tiny balls of cells, one or two embryos are inserted into the mother's uterus (womb).	WS 1.1 Developments of microscopy techniques have enabled IVF treatments to develop. WS 1.3 Understand social and ethical issues associated with IVF treatments.

Content	Key opportunities for skills development
Although fertility treatment gives a woman the chance to have a baby of her own: • it is very emotionally and physically stressful • the success rates are not high • it can lead to multiple births which are a risk to both the babies and the mother.	WS 1.4 Evaluate from the perspective of patients and doctors the methods of treating infertility.

4.5.3.6 Feedback systems (HT only)

Content	Key opportunities for skills development
Students should be able to explain the roles of thyroxine and adrenaline in the body. Adrenaline is produced by the adrenal glands in times of fear or stress. It increases the heart rate and boosts the delivery of oxygen and glucose to the brain and muscles, preparing the body for ‘flight or fight’. Thyroxine from the thyroid gland stimulates the basal metabolic rate. It plays an important role in growth and development.	
Thyroxine levels are controlled by negative feedback.	WS 1.2, MS 2c Interpret and explain simple diagrams of negative feedback control.

4.6 Inheritance, variation and evolution

In this section we will discover how the number of chromosomes are halved during meiosis and then combined with new genes from the sexual partner to produce unique offspring. Gene mutations occur continuously and on rare occasions can affect the functioning of the animal or plant. These mutations may be damaging and lead to a number of genetic disorders or death. Very rarely a new mutation can be beneficial and consequently, lead to increased fitness in the individual. Variation generated by mutations and sexual reproduction is the basis for natural selection; this is how species evolve. An understanding of these processes has allowed scientists to intervene through selective breeding to produce livestock with favoured characteristics. Once new varieties of plants or animals have been produced it is possible to clone individuals to produce larger numbers of identical individuals all carrying the favourable characteristic. Scientists have now discovered how to take genes from one species and introduce them in to the genome of another by a process called genetic engineering. In spite of the huge potential benefits that this technology can offer, genetic modification still remains highly controversial.

4.6.1 Reproduction

4.6.1.1 Sexual and asexual reproduction

Content	Key opportunities for skills development
Students should understand that meiosis leads to non-identical cells being formed while mitosis leads to identical cells being formed. Sexual reproduction involves the joining (fusion) of male and female gametes: • sperm and egg cells in animals • pollen and egg cells in flowering plants. In sexual reproduction there is mixing of genetic information which leads to variety in the offspring. The formation of gametes involves meiosis. Asexual reproduction involves only one parent and no fusion of gametes. There is no mixing of genetic information. This leads to genetically identical offspring (clones). Only mitosis is involved.	There are links with this content to Mitosis and the cell cycle (page 23).

4.6.1.2 Meiosis

Content	Key opportunities for skills development
Students should be able to explain how meiosis halves the number of chromosomes in gametes and fertilisation restores the full number of chromosomes. Cells in reproductive organs divide by meiosis to form gametes. 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 restore the normal number of chromosomes. The new cell divides by mitosis. The number of cells increases. As the embryo develops cells differentiate. Knowledge of the stages of meiosis is not required.	WS 1.2 Modelling behaviour of chromosomes during meiosis.

4.6.1.3 DNA and the genome

Content	Key opportunities for skills development
Students should be able to describe the structure of DNA and define genome. The genetic material in the nucleus of a cell is composed of a chemical called DNA. DNA is a polymer made up of two strands forming a double helix. The DNA is contained in structures called chromosomes. A gene is a small section of DNA on a chromosome. Each gene codes for a particular sequence of amino acids, to make a specific protein. The genome of an organism is the entire genetic material of that organism. The whole human genome has now been studied and this will have great importance for medicine in the future.	
Students should be able to discuss the importance of understanding the human genome. This is limited to the: • search for genes linked to different types of disease • understanding and treatment of inherited disorders • use in tracing human migration patterns from the past.	WS 1.1, 1.4

4.6.1.4 Genetic inheritance

Content	Key opportunities for skills development
Students should be able to explain the terms: • gamete • chromosome • gene • allele • dominant • recessive • homozygous • heterozygous • genotype • phenotype. Some characteristics are controlled by a single gene, such as: fur colour in mice; and red-green colour blindness in humans. Each gene may have different forms called alleles. The alleles present, or genotype, operate at a molecular level to develop characteristics that can be expressed as a phenotype. 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. Most characteristics are a result of multiple genes interacting, rather than a single gene.	
Students should be able to understand the concept of probability in predicting the results of a single gene cross, but recall that most phenotype features are the result of multiple genes rather than single gene inheritance.	MS 2e
Students should be able to use direct proportion and simple ratios to express the outcome of a genetic cross.	MS 1c, 3a
Students should be able to complete a Punnett square diagram and extract and interpret information from genetic crosses and family trees.	MS 2c, 4a
(HT only) Students should be able to construct a genetic cross by Punnett square diagram and use it to make predictions using the theory of probability.	MS 2e, WS 1.2

4.6.1.5 Inherited disorders

Content	Key opportunities for skills development
Some disorders are inherited. These disorders are caused by the inheritance of certain alleles. • Polydactyly (having extra fingers or toes) is caused by a dominant allele. • Cystic fibrosis (a disorder of cell membranes) is caused by a recessive allele. Students should make informed judgements about the economic, social and ethical issues concerning embryo screening, given appropriate information.	WS 1.3 Appreciate that embryo screening and gene therapy may alleviate suffering but consider the ethical issues which arise.

4.6.1.6 Sex determination

Content	Key opportunities for skills development
Ordinary human body cells contain 23 pairs of chromosomes. 22 pairs control characteristics only, but one of the pairs carries the genes that determine sex. • In females the sex chromosomes are the same (XX). • In males the chromosomes are different (XY).	
Students should to be able to carry out a genetic cross to show sex inheritance. Students should understand and use direct proportion and simple ratios in genetic crosses.	MS 1c, 3a

4.6.2 Variation and evolution

4.6.2.1 Variation

Content	Key opportunities for skills development
Students should be able to describe simply how the genome and its interaction with the environment influence the development of the phenotype of an organism. Differences in the characteristics of individuals in a population is called variation and 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.	

Content	Key opportunities for skills development
Students should be able to: • 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 phenotype; very few determine phenotype. Mutations occur continuously. Very rarely a mutation will lead to a new phenotype. If the new phenotype is suited to an environmental change it can lead to a relatively rapid change in the species.	

4.6.2.2 Evolution

Content	Key opportunities for skills development
Students should be able to 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 a new species. The theory of evolution by natural selection states that all species of living things have evolved from simple life forms that first developed more than three billion years ago. Students should be able to explain how evolution occurs through natural selection of variants that give rise to phenotypes best suited to their environment. If two populations of one species become so different in phenotype 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.

4.6.2.3 Selective breeding

Content	Key opportunities for skills development
Students should be able to explain the impact of 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 characteristics. Humans have been doing this for thousands of years since they first bred food crops from wild plants and domesticated animals. Selective breeding involves choosing parents with the desired characteristic from a mixed population. 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 characteristic can be chosen for usefulness or appearance: • Disease resistance in food crops. • Animals which produce more meat or milk. • Domestic dogs with a gentle nature. • Large or unusual flowers. Selective breeding can lead to 'inbreeding' where some breeds are particularly prone to disease or inherited defects.	WS 1.3, 1.4 Explain the benefits and risks of selective breeding given appropriate information and consider related ethical issues.

4.6.2.4 Genetic engineering

Content	Key opportunities for skills development
Students should be able to describe genetic engineering as a process which involves modifying the genome of an organism by introducing a gene from another organism to give a desired characteristic. Plant crops have been genetically engineered to be resistant to diseases or to produce bigger better fruits.	
Bacterial cells have been genetically engineered to produce useful substances such as human insulin to treat diabetes.	

Content	Key opportunities for skills development
Students should be able to explain the potential benefits and risks of genetic engineering in agriculture and in medicine and that some people have objections. In genetic engineering, genes from the chromosomes of humans and other organisms can be 'cut out' and transferred to cells of other organisms. Crops that have had their genes modified in this way are called genetically modified (GM) crops. GM crops include ones that are resistant to insect attack or to herbicides. GM crops generally show increased yields. Concerns about GM crops include the effect on populations of wild flowers and insects. Some people feel the effects of eating GM crops on human health have not been fully explored. Modern medical research is exploring the possibility of genetic modification to overcome some inherited disorders.	WS 1.3, 1.4
(HT only) Students should be able to describe the main steps in the process of genetic engineering. (HT only) In genetic engineering: • enzymes are used to isolate the required gene; this gene is inserted into a vector, usually a bacterial plasmid or a virus • the vector is used to insert the gene into the required cells • genes are transferred to the cells of animals, plants or microorganisms at an early stage in their development so that they develop with desired characteristics.	(HT only) WS 1.4 Interpret information about genetic engineering techniques and to make informed judgements about issues concerning cloning and genetic engineering, including GM crops.

4.6.3 The development of understanding of genetics and evolution

4.6.3.1 Evidence for evolution

Content	Key opportunities for skills development
Students should be able to describe the evidence for evolution including fossils and antibiotic resistance in bacteria. The theory of evolution by natural selection is now widely accepted. Evidence for Darwin's theory is now available as it has been shown that characteristics are passed on to offspring in genes. There is further evidence in the fossil record and the knowledge of how resistance to antibiotics evolves in bacteria.	WS 1.3 Data is now available to support the theory of evolution.

4.6.3.2 Fossils

Content	Key opportunities for skills development
Fossils are the ‘remains’ of organisms from millions of years ago, which are found in rocks. Fossils may be formed: • from parts of organisms that have not decayed because one or more of the conditions needed for decay are absent • when parts of the organism are replaced by minerals as they decay • as preserved traces of organisms, such as footprints, burrows and rootlet traces.	MS 2c, 4a Extract and interpret information from charts, graphs and tables.
Many early forms of life were soft-bodied, which means that they have left few traces behind. What traces there were have been mainly destroyed by geological activity. This is why scientists cannot be certain about how life began on Earth.	WS 1.3 Appreciate why the fossil record is incomplete.
We can learn from fossils how much or how little different organisms have changed as life developed on Earth.	WS 1.1 Understand how scientific methods and theories develop over time.
Students should be able to extract and interpret information from charts, graphs and tables such as evolutionary trees.	MS 2c, 4a

4.6.3.3 Extinction

Content	Key opportunities for skills development
Extinctions occur when there are no remaining individuals of a species still alive. Students should be able to describe factors which may contribute to the extinction of a species.	

4.6.3.4 Resistant bacteria

Content	Key opportunities for skills development
Bacteria can evolve rapidly because they reproduce at a fast rate. Mutations of bacterial pathogens produce new strains. Some strains might be resistant to antibiotics, and so are not killed. They survive and reproduce, so the population of the resistant strain rises. The resistant strain will then spread because people are not immune to it and there is no effective treatment.	
MRSA is resistant to antibiotics. To reduce the rate of development of antibiotic resistant strains: • doctors should not prescribe antibiotics inappropriately, such as treating non-serious or viral infections • patients should complete their course of antibiotics so all bacteria are killed and none survive to mutate and form resistant strains • the agricultural use of antibiotics should be restricted. The development of new antibiotics is costly and slow. It is unlikely to keep up with the emergence of new resistant strains.	There are links with this content to Antibiotics and painkillers (page 37).

4.6.4 Classification of living organisms

Content	Key opportunities for skills development
Traditionally living things have been classified into groups depending on their structure and characteristics in a system developed by Carl Linnaeus. Linnaeus classified living things into kingdom, phylum, class, order, family, genus and species. Organisms are named by the binomial system of genus and species.	

Content	Key opportunities for skills development
Students should be able to use information given to show understanding of the Linnaean system. Students should be able to describe the impact of developments in biology on classification systems. As evidence of internal structures became more developed due to improvements in microscopes, and the understanding of biochemical processes progressed, new models of classification were proposed. Due to evidence available from chemical analysis there is now a 'three-domain system' developed by Carl Woese. In this system organisms are divided into: • Archaea (primitive bacteria usually living in extreme environments) • Bacteria (true bacteria) • Eukaryota (which includes protists, fungi, plants and animals).	WS 1.1 Understand how scientific methods and theories develop over time.
Evolutionary trees are a method used by scientists to show how they believe organisms are related. They use current classification data for living organisms and fossil data for extinct organisms.	WS 1.2 Interpret evolutionary trees.

4.7 Ecology

The Sun is a source of energy that passes through ecosystems. Materials including carbon and water are continually recycled by the living world, being released through respiration of animals, plants and decomposing microorganisms and taken up by plants in photosynthesis. All species live in ecosystems composed of complex communities of animals and plants dependent on each other and that are adapted to particular conditions, both abiotic and biotic. These ecosystems provide essential services that support human life and continued development. In order to continue to benefit from these services humans need to engage with the environment in a sustainable way. In this section we will explore how humans are threatening biodiversity as well as the natural systems that support it. We will also consider some actions we need to take to ensure our future health, prosperity and well-being.

4.7.1 Adaptations, interdependence and competition

4.7.1.1 Communities

Content	Key opportunities for skills development
Students should be able to describe: • different levels of organisation in an ecosystem from individual organisms to the whole ecosystem • the importance of interdependence and competition in a community. Students should be able to, when provided with appropriate information: • suggest the factors for which organisms are competing in a given habitat • suggest how organisms are adapted to the conditions in which they live. An ecosystem is the interaction of a community of living organisms (biotic) with the non-living (abiotic) parts of their environment. To survive and reproduce, organisms require a supply of materials from their surroundings and from the other living organisms there. Plants in a community or habitat often compete with each other for light and space, and for water and mineral ions 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 can affect the whole community. This is called interdependence. A stable community is one where all the species and environmental factors are in balance so that population sizes remain fairly constant.	WS 2.6 Recording first-hand observations of organisms.
Students should be able to extract and interpret information from charts, graphs and tables relating to the interaction of organisms within a community.	MS 2c, 4a Extract and interpret information from charts, graphs and tables.

4.7.1.2 Abiotic factors

Content	Key opportunities for skills development
Students should be able to explain how a change in an abiotic factor would affect a given community given appropriate data or context. Abiotic (non-living) factors which 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.	WS 1.2
Students should be able to extract and interpret information from charts, graphs and tables relating to the effect of abiotic factors on organisms within a community.	MS 2c, 4a Extract and interpret information from charts, graphs and tables.

4.7.1.3 Biotic factors

Content	Key opportunities for skills development
Students should be able to explain how a change in a biotic factor might affect a given community given appropriate data or context. Biotic (living) factors which can affect a community are: • availability of food • new predators arriving • new pathogens • one species outcompeting another so the numbers are no longer sufficient to breed.	WS 1.2
Students should be able to extract and interpret information from charts, graphs and tables relating to the effect of biotic factors on organisms within a community.	MS 2c, 4a Extract and interpret information from charts, graphs and tables.

4.7.1.4 Adaptations

Content	Key opportunities for skills development
Students should be able to explain how organisms are adapted to live in their natural environment, given appropriate information. Organisms have features (adaptations) that enable them to survive in the conditions in which they normally live. These adaptations may be structural, behavioural or functional.	
Some organisms live in environments that are very extreme, such as at high temperature, pressure, or salt concentration. These organisms are called extremophiles. Bacteria living in deep sea vents are extremophiles.	

4.7.2 Organisation of an ecosystem

4.7.2.1 Levels of organisation

Content	Key opportunities for skills development
Students should understand that photosynthetic organisms are the producers of biomass for life on Earth. Feeding relationships within a community can be represented by food chains. All food chains begin with a producer which synthesises molecules. This is usually a green plant or alga which makes glucose by photosynthesis. A range of experimental methods using transects and quadrats are used by ecologists to determine the distribution and abundance of species in an ecosystem.	
In relation to abundance of organisms students should be able to: • understand the terms mean, mode and median • calculate arithmetic means • plot and draw appropriate graphs selecting appropriate scales for the axes.	MS 2b, 2f, 4a, 4c
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 stable community the numbers of predators and prey rise and fall in cycles.	WS 1.2 Interpret graphs used to model predator-prey cycles.
Students should be able to interpret graphs used to model these cycles.	MS 4a

Required practical activity 7: 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 179).

4.7.2.2 How materials are cycled

Content	Key opportunities for skills development
Students should: • recall that many different materials cycle through the abiotic and biotic components of an ecosystem • explain the importance of the carbon and water cycles to living organisms. All materials in the living world are recycled to provide the building blocks for future organisms. The carbon cycle returns carbon from organisms to the atmosphere as carbon dioxide to be used by plants in photosynthesis. The water cycle provides fresh water for plants and animals on land before draining into the seas. Water is continuously evaporated and precipitated. Students are not expected to study the nitrogen cycle. Students should be able to explain the role of microorganisms in cycling materials through an ecosystem by returning carbon to the atmosphere as carbon dioxide and mineral ions to the soil.	WS 1.2 Interpret and explain the processes in diagrams of the carbon cycle, the water cycle. There are links with the water cycle to GCSE Chemistry The Earth's early atmosphere. WS 1.2

4.7.3 Biodiversity and the effect of human interaction on ecosystems

4.7.3.1 Biodiversity

Content	Key opportunities for skills development
Biodiversity is the variety of all the different species of organisms on earth, or within an ecosystem. A great biodiversity ensures the stability of ecosystems by reducing the dependence of one species on another for food, shelter and the maintenance of the physical environment. The future of the human species on Earth relies on us maintaining a good level of biodiversity. Many human activities are reducing biodiversity and only recently have measures been taken to try to stop this reduction.	WS 1.4 Explain how waste, deforestation and global warming have an impact on biodiversity.

4.7.3.2 Waste management

Content	Key opportunities for skills development
Rapid growth in the human population and an increase in the standard of living mean that increasingly more resources are used and more waste is produced. Unless waste and chemical materials are properly handled, more pollution will be caused. Pollution can occur: • in water, from sewage, fertiliser or toxic chemicals • in air, from smoke and acidic gases • on land, from landfill and from toxic chemicals. Pollution kills plants and animals which can reduce biodiversity.	There are links with this content to GCSE Chemistry 5.9.3.1 Atmospheric pollutants from fuels.

4.7.3.3 Land use

Content	Key opportunities for skills development
Humans reduce the amount of land available for other animals and plants by building, quarrying, farming and dumping waste.	
The destruction of peat bogs, and other areas of peat to produce garden compost, reduces the area of this habitat and thus the variety of different plant, animal and microorganism species that live there (biodiversity). The decay or burning of the peat releases carbon dioxide into the atmosphere.	WS 1.4, 1.5 Understand the conflict between the need for cheap available compost to increase food production and the need to conserve peat bogs and peatlands as habitats for biodiversity and to reduce carbon dioxide emissions. There are links within this section to Global warming (page 65).

4.7.3.4 Deforestation

Content	Key opportunities for skills development
Large-scale deforestation in tropical areas has occurred to: • provide land for cattle and rice fields • grow crops for biofuels	WS 1.4 Evaluate the environmental implications of deforestation.

4.7.3.5 Global warming

Content	Key opportunities for skills development
Students should be able to describe some of the biological consequences of global warming. Levels of carbon dioxide and methane in the atmosphere are increasing, and contribute to 'global warming'.	WS 1.6 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.

4.7.3.6 Maintaining biodiversity

Content	Key opportunities for skills development
Students should be able to describe both positive and negative human interactions in an ecosystem and explain their impact on biodiversity. Scientists and concerned citizens have put in place programmes to reduce the negative effects of humans on ecosystems and biodiversity. These include: • breeding programmes for endangered species • protection and regeneration of rare habitats • reintroduction of field margins and hedgerows in agricultural areas where farmers grow only one type of crop • reduction of deforestation and carbon dioxide emissions by some governments • recycling resources rather than dumping waste in landfill.	WS 1.4, 1.5 Evaluate given information about methods that can be used to tackle problems caused by human impacts on the environment. Explain and evaluate the conflicting pressures on maintaining biodiversity given appropriate information.

4.8 Key ideas

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

These key ideas are of universal application, and we have embedded them throughout the subject content. They underpin many aspects of the science assessment.

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.

5 Chemistry subject content

This specification is presented in a two column format.

The subject content is split into three sections for each of the subject areas: biology, chemistry and physics.

The left hand column contains the subject content that all students must cover, and that can be assessed in the written papers.

The right hand column exemplifies some of the key opportunities for the following skills to be developed throughout the course: WS refers to Working scientifically (page 13), MS refers to Mathematical requirements (page 171) and AT refers to Use of apparatus and techniques (page 173). These are not the only opportunities. Teachers are encouraged to introduce all of these skills where appropriate throughout the course.

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

It is good practice to teach and develop all of the mathematical skills throughout the course. Some mathematical skills will only be assessed in certain subject areas. These are detailed in Mathematical requirements (page 171).

Science is a practical subject. Details of the assessment of required practicals can be found in Required practical activities (page 175).

Working scientifically (page 13) and Use of apparatus and techniques (page 173) skills will be assessed across all papers.

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.

The concepts and principles in sections 5.1, 5.2 and 5.3 are fundamental to an understanding of chemistry and underpin much of the content detailed in later sections of the specification.

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

5.1 Atomic structure and the periodic table

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

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

5.1.1.1 Atoms, elements and compounds

Content	Key opportunities for skills development
All substances are made of atoms. An atom is the smallest part of an element that can exist. 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. Chemical reactions always involve the formation of one or more new substances, and often involve a detectable energy change. Compounds contain two or more elements chemically combined in fixed proportions and can be represented by formulae using the symbols of the atoms from which they were formed. Compounds can only be separated into elements by chemical reactions. Chemical reactions can be represented by word equations or equations using symbols and formulae. Students will be supplied with a periodic table for the exam and should be able to: • use the names and symbols of the first 20 elements in the periodic table, the elements in Groups 1 and 7, and other elements in this specification • name compounds of these elements from given formulae or symbol equations • write word equations for the reactions in this specification • write formulae and balanced chemical equations for the reactions in this specification. (HT only) write balanced half equations and ionic equations where appropriate.	

5.1.1.2 Mixtures

Content	Key opportunities for skills development
A mixture consists of two or more elements or compounds not chemically combined together. The chemical properties of each substance in the mixture are unchanged. Mixtures can be separated by physical processes such as filtration, crystallisation, simple distillation, fractional distillation and chromatography. These physical processes do not involve chemical reactions and no new substances are made. Students should be able to: • describe, explain and give examples of the specified processes of separation • suggest suitable separation and purification techniques for mixtures when given appropriate information.	WS 2.2, 2.3 AT 4 Safe use of a range of equipment to separate chemical mixtures.

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

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

Content	Key opportunities for skills development
• why the new evidence from the scattering experiment led to a change in the atomic model	WS 1.1
• the difference between the plum pudding model of the atom and the nuclear model of the atom.	WS 1.2
Details of experimental work supporting the Bohr model are not required. Details of Chadwick's experimental work are not required.	

5.1.1.4 Relative electrical charges of subatomic particles

Content	Key opportunities for skills development
The relative electrical charges of the particles in atoms are: **Name of particle** / **Relative charge**: Proton +1; Neutron 0; Electron –1 In an atom, the number of electrons is equal to the number of protons in the nucleus. Atoms have no overall electrical charge. 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.	
Students should be able to use the nuclear model to describe atoms.	WS 1.2

Name of particle	Relative charge
Proton	+1
Neutron	0
Electron	–1

5.1.1.5 Size and mass of atoms

Content	Key opportunities for skills development
Atoms are very small, having a radius of about 0.1 nm (1×10^{-10} m).	WS 4.3, 4
The radius of a nucleus is less than 1/10 000 of that of the atom (about 1×10^{-14} m).	Use SI units and the prefix nano.
Almost all of the mass of an atom is in the nucleus.	MS 1b
The relative masses of protons, neutrons and electrons are:	Recognise expressions in standard form.

Name of particle	Relative mass
Proton	1
Neutron	1
Electron	Very small

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) 23
(Atomic number) 11 Na

$$^{23}_{11}\text{Na}$$

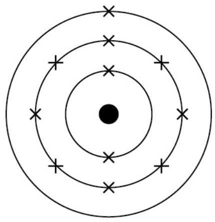
Students should be able to calculate the numbers of protons, neutrons and electrons in an atom or ion, given its atomic number and mass number.

Content	Key opportunities for skills development
Students should be able to relate size and scale of atoms to objects in the physical world.	MS 1d

5.1.1.6 Relative atomic mass

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

5.1.1.7 Electronic structure

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

5.1.2 The periodic table

5.1.2.1 The periodic table

Content	Key opportunities for skills development
The elements in the periodic table are arranged in order of atomic (proton) number and so that elements with similar properties are in columns, known as groups. The table is called a periodic table because similar properties occur at regular intervals. 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.	
Students should be able to: • explain how the position of an element in the periodic table is related to the arrangement of electrons in its atoms and hence to its atomic number • predict possible reactions and probable reactivity of elements from their positions in the periodic table.	WS 1.2

5.1.2.2 Development of the periodic table

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

5.1.2.3 Metals and non-metals

Content	Key opportunities for skills development
Elements that react to form positive ions are metals. Elements that do not form positive ions are non-metals. 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. Students should be able to: • explain the differences between metals and non-metals on the basis of their characteristic physical and chemical properties. This links to Group 0 (page 74), Group 1 (page 74), Group 7 (page 75) and Bonding, structure and the properties of matter (page 75) • 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.	

5.1.2.4 Group 0

Content	Key opportunities for skills development
The elements in Group 0 of the periodic table are called the noble gases. They are unreactive and do not easily form molecules because their atoms have stable arrangements of electrons. The noble gases have eight electrons in their outer shell, except for helium, which has only two electrons. The boiling points of the noble gases increase with increasing relative atomic mass (going down the group).	
Students should be able to: • explain how properties of the elements in Group 0 depend on the outer shell of electrons of the atoms • predict properties from given trends down the group.	WS 1.2

5.1.2.5 Group 1

Content	Key opportunities for skills development
The elements in Group 1 of the periodic table are known as the alkali metals and have characteristic properties because of the single electron in their outer shell. Students should be able to describe the reactions of the first three alkali metals with oxygen, chlorine and water. In Group 1, the reactivity of the elements increases going down the group.	
Students should be able to: • explain how properties of the elements in Group 1 depend on the outer shell of electrons of the atoms • predict properties from given trends down the group.	WS 1.2

5.1.2.6 Group 7

Content	Key opportunities for skills development
The elements in Group 7 of the periodic table are known as the halogens and have similar reactions because they all have seven electrons in their outer shell. The halogens are non-metals and consist of molecules made of pairs of atoms. Students should be able to describe the nature of the compounds formed when chlorine, bromine and iodine react with metals and non-metals. 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, the 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.	AT 6 Offers an opportunity within displacement reactions of halogens.
Students should be able to: • explain how properties of the elements in Group 7 depend on the outer shell of electrons of the atoms • predict properties from given trends down the group.	WS 1.2

5.2 Bonding, structure, and the properties of matter

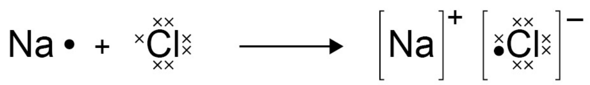
Chemists use theories of structure and bonding to explain the physical and chemical properties of materials. Analysis of structures shows that atoms can be arranged in a variety of ways, some of which are molecular while others are giant structures. Theories of bonding explain how atoms are held together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

5.2.1 Chemical bonds, ionic, covalent and metallic

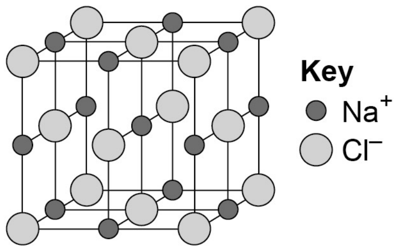
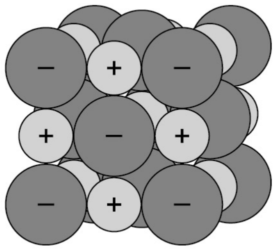
5.2.1.1 Chemical bonds

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

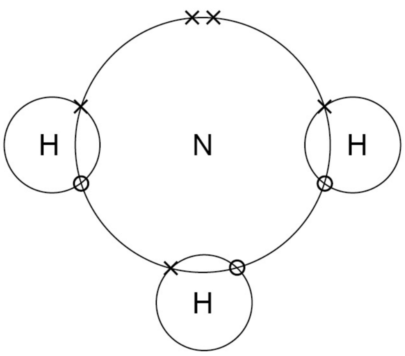
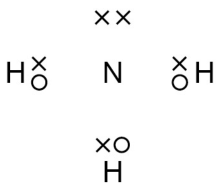
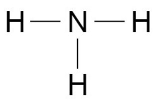
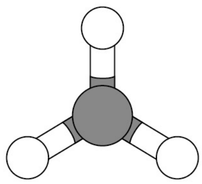
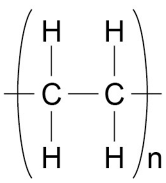
5.2.1.2 Ionic bonding

Content	Key opportunities for skills development
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  (2,8,1) (2,8,7) (2,8) (2,8,8)	MS 5b Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects.
Students should be able to draw dot and cross diagrams for ionic compounds formed by metals in Groups 1 and 2 with non-metals in Groups 6 and 7. 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. Students should be able to work out the charge on the ions of metals and non-metals from the group number of the element, limited to the metals in Groups 1 and 2, and non-metals in Groups 6 and 7.	WS 1.2

5.2.1.3 Ionic compounds

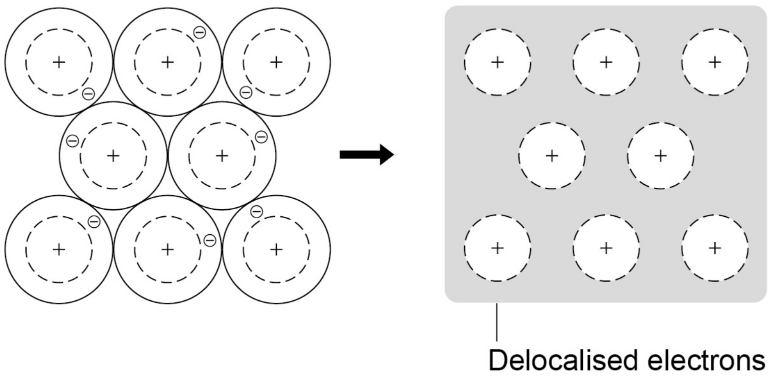
Content	Key opportunities for skills development
An ionic compound is a giant structure of ions. Ionic compounds are held together by strong electrostatic forces of attraction between oppositely charged ions. These forces act in all directions in the lattice and this is called ionic bonding. The structure of sodium chloride can be represented in the following forms:  	MS 5b Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects.
Students should be able to: • deduce that a compound is ionic from a diagram of its structure in one of the specified forms • describe the limitations of using dot and cross, ball and stick, two and three-dimensional diagrams to represent a giant ionic structure • work out the empirical formula of an ionic compound from a given model or diagram that shows the ions in the structure. Students should be familiar with the structure of sodium chloride but do not need to know the structures of other ionic compounds.	WS 1.2 MS 4a MS 1a, 1c

5.2.1.4 Covalent bonding

Content	Key opportunities for skills development
When atoms share pairs of electrons, they form covalent bonds. These bonds between atoms are strong. Covalently bonded substances may consist of small molecules. Students should be able to recognise common substances that consist of small molecules from their chemical formula. 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.

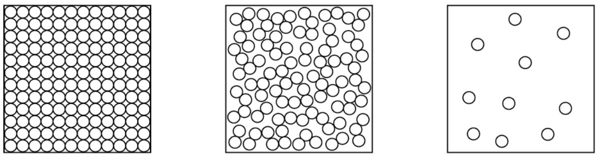
Content	Key opportunities for skills development
Students should be able to: • draw dot and cross diagrams for the molecules of hydrogen, chlorine, oxygen, nitrogen, hydrogen chloride, water, ammonia and methane • represent the covalent bonds in small molecules, in the repeating units of polymers and in part of giant covalent structures, using a line to represent a single bond • describe the limitations of using dot and cross, ball and stick, two and three-dimensional diagrams to represent molecules or giant structures • deduce the molecular formula of a substance from a given model or diagram in these forms showing the atoms and bonds in the molecule.	MS 5b

5.2.1.5 Metallic bonding

Content	Key opportunities for skills development
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:  	WS 1.2 Recognise substances as metallic giant structures from diagrams showing their bonding. MS 5b Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects.

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

5.2.2.1 The three states of matter

Content	Key opportunities for skills development
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.  Solid Liquid Gas 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. (HT only) Limitations of the simple model above include that in the model there are no forces, that all particles are represented as spheres and that the spheres are solid.	MS 5b Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects.
Students should be able to: • predict the states of substances at different temperatures given appropriate data • explain the different temperatures at which changes of state occur in terms of energy transfers and types of bonding • recognise that atoms themselves do not have the bulk properties of materials • (HT only) explain the limitations of the particle theory in relation to changes of state when particles are represented by solid inelastic spheres which have no forces between them.	WS 1.2

5.2.2.2 State symbols

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

5.2.2.3 Properties of ionic compounds

Content	Key opportunities for skills development
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. Knowledge of the structures of specific ionic compounds other than sodium chloride is not required.	

5.2.2.4 Properties of small molecules

Content	Key opportunities for skills development
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. Students should be able to use the idea that intermolecular forces are weak compared with covalent bonds to explain the bulk properties of molecular substances.	WS 1.2

5.2.2.5 Polymers

Content	Key opportunities for skills development
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. Students should be able to recognise polymers from diagrams showing their bonding and structure.	

5.2.2.6 Giant covalent structures

Content	Key opportunities for skills development
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. Students should be able to recognise giant covalent structures from diagrams showing their bonding and structure.	MS 5b Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects. WS 1.2

5.2.2.7 Properties of metals and alloys

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

5.2.2.8 Metals as conductors

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

5.2.3 Structure and bonding of carbon

5.2.3.1 Diamond

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

5.2.3.2 Graphite

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

5.2.3.3 Graphene and fullerenes

Content	Key opportunities for skills development
Graphene is a single layer of graphite and has properties that make it useful in electronics and composites. Students should be able to explain the properties of graphene in terms of its structure and bonding. 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. Students should be able to: • recognise graphene and fullerenes from diagrams and descriptions of their bonding and structure • give examples of the uses of fullerenes, including carbon nanotubes.	WS 1.2, 1.4 MS 5b Visualise and represent 2D and 3D forms including two-dimensional representations of 3D objects.

5.3 Quantitative chemistry

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

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

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

5.3.1.1 Conservation of mass and balanced chemical equations

Content	Key opportunities for skills development
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 which are balanced in terms of the numbers of atoms of each element involved on both sides of the equation. Students should understand the use of the multipliers in equations in normal script before a formula and in subscript within a formula.	WS 1.2

5.3.1.2 Relative formula mass

Content	Key opportunities for skills development
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 should be able to calculate the percentage by mass in a compound given the relative formula mass and the relative atomic masses.	

5.3.1.3 Mass changes when a reactant or product is a gas

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

5.3.1.4 Chemical measurements

Content	Key opportunities for skills development
Whenever a measurement is made there is always some uncertainty about the result obtained. Students should be able to: • represent the distribution of results and make estimations of uncertainty • use the range of a set of measurements about the mean as a measure of uncertainty.	WS 3.4

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

5.3.2.1 Moles (HT only)

Content	Key opportunities for skills development
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. Students should understand that the measurement of amounts in moles can apply to atoms, molecules, ions, electrons, formulae and equations, for example that in one mole of carbon (C) the number of atoms is the same as the number of molecules in one mole of carbon dioxide (CO_2).	WS 4.1, 4.2, 4.3, 4.5, 4.6 MS 1a Recognise and use expressions in decimal form. MS 1b Recognise and use expressions in standard form. MS 2a Use an appropriate number of significant figures. MS 3a Understand and use the symbols: =, <, <<, >>, >, ∝, ~ MS 3b Change the subject of an equation.
Students should be able to use the relative formula mass of a substance to calculate the number of moles in a given mass of that substance and vice versa.	MS 1c

5.3.2.2 Amounts of substances in equations (HT only)

Content	Key opportunities for skills development
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. Students should be able to: • calculate the masses of substances shown in a balanced symbol equation • calculate the masses of reactants and products from the balanced symbol equation and the mass of a given reactant or product.	MS 1a Recognise and use expressions in decimal form. MS 1c Use ratios, fractions and percentages. MS 3b Change the subject of an equation. MS 3c Substitute numerical values into algebraic equations using appropriate units for physical quantities.

5.3.2.3 Using moles to balance equations (HT only)

Content	Key opportunities for skills development
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. Students should be able to balance an equation given the masses of reactants and products. Students should be able to change the subject of a mathematical equation.	MS 3b Change the subject of an equation. MS 3c Substitute numerical values into algebraic equations using appropriate units for physical quantities.

5.3.2.4 Limiting reactants (HT only)

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

5.3.2.5 Concentration of solutions

Content	Key opportunities for skills development
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). Students should be able to: • calculate the mass of solute in a given volume of solution of known concentration in terms of mass per given volume of solution • (HT only) explain how the mass of a solute and the volume of a solution is related to the concentration of the solution.	MS 1c Use ratios, fractions and percentages. MS 3b Change the subject of an equation.

5.4 Chemical changes

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

5.4.1 Reactivity of metals

5.4.1.1 Metal oxides

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

5.4.1.2 The reactivity series

Content	Key opportunities for skills development
When metals react with other substances the metal atoms form positive ions. The reactivity of a metal is related to its tendency to form positive ions. Metals can be arranged in order of their reactivity in a reactivity series. The metals potassium, sodium, lithium, calcium, magnesium, zinc, iron and copper can be put in order of their reactivity from their reactions with water and dilute acids. 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. Students should be able to: • recall and describe the reactions, if any, of potassium, sodium, lithium, calcium, magnesium, zinc, iron and copper with water or dilute acids and where appropriate, to place these metals in order of reactivity • explain how the reactivity of metals with water or dilute acids is related to the tendency of the metal to form its positive ion • deduce an order of reactivity of metals based on experimental results. The reactions of metals with water and acids are limited to room temperature and do not include reactions with steam.	AT 6 Mixing of reagents to explore chemical changes and/or products.

5.4.1.3 Extraction of metals and reduction

Content	Key opportunities for skills development
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. Metals less reactive than carbon can be extracted from their oxides by reduction with carbon. Reduction involves the loss of oxygen. Knowledge and understanding are limited to the reduction of oxides using carbon. Knowledge of the details of processes used in the extraction of metals is not required. Students should be able to: • interpret or evaluate specific metal extraction processes when given appropriate information • identify the substances which are oxidised or reduced in terms of gain or loss of oxygen.	

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

Content	Key opportunities for skills development
Oxidation is the loss of electrons and reduction is the gain of electrons. Student should be able to: • write ionic equations for displacement reactions • identify in a given reaction, symbol equation or half equation which species are oxidised and which are reduced.	

5.4.2 Reactions of acids

5.4.2.1 Reactions of acids with metals

Content	Key opportunities for skills development
Acids react with some metals to produce salts and hydrogen. (HT only) Students should be able to: • explain in terms of gain or loss of electrons, that these are redox reactions • identify which species are oxidised and which are reduced in given chemical equations. Knowledge of reactions limited to those of magnesium, zinc and iron with hydrochloric and sulfuric acids.	

5.4.2.2 Neutralisation of acids and salt production

Content	Key opportunities for skills development
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, sulfuric acid produces sulfates) • the positive ions in the base, alkali or carbonate. Students should be able to: • predict products from given reactants • use the formulae of common ions to deduce the formulae of salts.	

5.4.2.3 Soluble salts

Content	Key opportunities for skills development
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. Students should be able to describe how to make pure, dry samples of named soluble salts from information provided.	

Required practical activity 8: preparation of a pure, dry sample of a soluble salt from an insoluble oxide or carbonate, using a Bunsen burner to heat dilute acid and a water bath or electric heater to evaporate the solution.

AT skills covered by this practical activity: 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 180).

5.4.2.4 The pH scale and neutralisation

Content	Key opportunities for skills development
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. This reaction can be represented by the equation: $H^+(aq) + OH^-(aq) \longrightarrow H_2O(l)$ Students should be able to: • describe the use of universal indicator or a wide range indicator to measure the approximate pH of a solution • use the pH scale to identify acidic or alkaline solutions.	AT 3 This is an opportunity to investigate pH changes when a strong acid neutralises a strong alkali.

5.4.2.5 Strong and weak acids (HT only)

Content	Key opportunities for skills development
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. As the pH decreases by one unit, the hydrogen ion concentration of the solution increases by a factor of 10. Students should be able to: • use and explain the terms dilute and concentrated (in terms of amount of substance), and weak and strong (in terms of the degree of ionisation) in relation to acids	An opportunity to measure the pH of different acids at different concentrations.
• describe neutrality and relative acidity in terms of the effect on hydrogen ion concentration and the numerical value of pH (whole numbers only).	MS 2h Make order of magnitude calculations.

5.4.3 Electrolysis

5.4.3.1 The process of electrolysis

Content	Key opportunities for skills development
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. (HT only) Throughout Section 4.4.3 Higher Tier students should be able to write half equations for the reactions occurring at the electrodes during electrolysis, and may be required to complete and balance supplied half equations.	

5.4.3.2 Electrolysis of molten ionic compounds

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

5.4.3.3 Using electrolysis to extract metals

Content	Key opportunities for skills development
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 carbon as the positive electrode (anode). Students should be able to: • explain why a mixture is used as the electrolyte • explain why the positive electrode must be continually replaced.	

5.4.3.4 Electrolysis of aqueous solutions

Content	Key opportunities for skills development
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.	
Students should be able to predict the products of the electrolysis of aqueous solutions containing a single ionic compound.	WS 1.2

Required practical activity 9: 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 180).

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

Content	Key opportunities for skills development
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. Reactions at electrodes can be represented by half equations, for example: $2H^+ + 2e^- \rightarrow H_2$ and $4OH^- \rightarrow O_2 + 2H_2O + 4e^-$ or $4OH^- - 4e^- \rightarrow O_2 + 2H_2O$	

5.5 Energy changes

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

5.5.1 Exothermic and endothermic reactions

5.5.1.1 Energy transfer during exothermic and endothermic reactions

Content	Key opportunities for skills development
Energy is conserved in chemical reactions. The amount of energy in the universe at the end of a chemical reaction is the same as before the reaction takes place. If a reaction transfers energy to the surroundings the product molecules must have less energy than the reactants, by the amount transferred. An exothermic reaction is one that transfers energy to the surroundings so the temperature of the surroundings increases. Exothermic reactions include combustion, many oxidation reactions and neutralisation. Everyday uses of exothermic reactions include self-heating cans and hand warmers. An endothermic reaction is one that takes in energy from the surroundings so the temperature of the surroundings decreases. Endothermic reactions include thermal decompositions and the reaction of citric acid and sodium hydrogencarbonate. Some sports injury packs are based on endothermic reactions. Students should be able to: • distinguish between exothermic and endothermic reactions on the basis of the temperature change of the surroundings • evaluate uses and applications of exothermic and endothermic reactions given appropriate information. Limited to measurement of temperature change. Calculation of energy changes or ΔH is not required.	AT 5 An opportunity to measure temperature changes when substances react or dissolve in water.

Required practical activity 10: investigate the variables that affect temperature changes in reacting solutions such as, eg acid plus metals, acid plus carbonates, neutralisations, displacement of metals.

AT skills covered by this practical activity: 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 181).

5.5.1.2 Reaction profiles

Content	Key opportunities for skills development
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.	
Students should be able to: • draw simple reaction profiles (energy level diagrams) for exothermic and endothermic reactions showing the relative energies of reactants and products, the activation energy and the overall energy change, with a curved line to show the energy as the reaction proceeds • use reaction profiles to identify reactions as exothermic or endothermic • explain that the activation energy is the energy needed for a reaction to occur.	

5.5.1.3 The energy change of reactions (HT only)

Content	Key opportunities for skills development
During a chemical reaction: • energy must be supplied to break bonds in the reactants • energy is released when bonds in the products are formed. The energy needed to break bonds and the energy released 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 released when bonds in the products are formed is the overall energy change of the reaction. In an exothermic reaction, the energy released 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 released from forming new bonds.	
Students should be able to calculate the energy transferred in chemical reactions using bond energies supplied.	MS 1a

5.6 The rate and extent of chemical change

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

5.6.1 Rate of reaction

5.6.1.1 Calculating rates of reactions

Content	Key opportunities for skills development
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 or by a volume in cm^3. The units of rate of reaction may be given as g/s or cm^3/s. For the Higher Tier, students are also required to use quantity of reactants in terms of moles and units for rate of reaction in mol/s. Students should be able to: • calculate the mean rate of a reaction from given information about the quantity of a reactant used or the quantity of a product formed and the time taken • draw, and interpret, graphs showing the quantity of product formed or quantity of reactant used up against time • draw tangents to the curves on these graphs and use the slope of the tangent as a measure of the rate of reaction • (HT only) calculate the gradient of a tangent to the curve on these graphs as a measure of rate of reaction at a specific time.	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 4a Translate information between graphical and numeric form. MS 4b Drawing and interpreting appropriate graphs from data to determine rate of reaction. 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.

5.6.1.2 Factors which affect the rates of chemical reactions

Content	Key opportunities for skills development
Factors which affect the rates of chemical reactions include: the concentrations of reactants in solution, the pressure of reacting gases, the surface area of solid reactants, the temperature and the presence of catalysts.	
Students should be able to recall how changing these factors affects the rate of chemical reactions.	This topic offers opportunities for practical work and investigations in addition to required practical 11.

Required practical activity 11: investigate how changes in concentration affect the rates of reactions by a method involving measuring the volume of a gas produced and a method involving a change in colour or turbidity.

This should be an investigation involving developing a hypothesis.

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

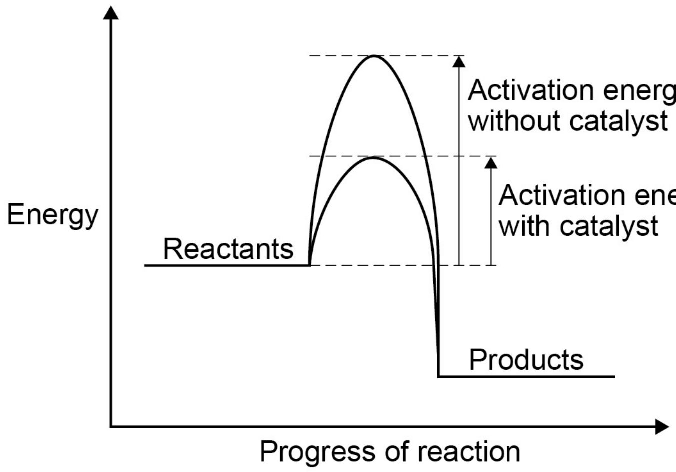
This practical activity also provides opportunities to develop WS and MS. Details of all skills are given in Key opportunities for skills development (page 182)

5.6.1.3 Collision theory and activation energy

Content	Key opportunities for skills development
Collision theory explains how various factors affect rates of reactions. According to this theory, chemical reactions can occur only when reacting particles collide with each other and with sufficient energy. The minimum amount of energy that particles must have to react is called the activation energy. 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.	
Students should be able to : • predict and explain using collision theory the effects of changing conditions of concentration, pressure and temperature on the rate of a reaction	WS 1.2

Content	Key opportunities for skills development
• predict and explain the effects of changes in the size of pieces of a reacting solid in terms of surface area to volume ratio • use simple ideas about proportionality when using collision theory to explain the effect of a factor on the rate of a reaction.	MS 5c MS 1c

5.6.1.4 Catalysts

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

5.6.2 Reversible reactions and dynamic equilibrium

5.6.2.1 Reversible reactions

Content	Key opportunities for skills development
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 conditions. For example: ammonium chloride $\underset{\text{cool}}{\overset{\text{heat}}{\rightleftharpoons}}$ ammonia + hydrogen chloride	

5.6.2.2 Energy changes and reversible reactions

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

5.6.2.3 Equilibrium

Content	Key opportunities for skills development
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.	WS 1.2

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

Content	Key opportunities for skills development
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. The effects of changing conditions on a system at equilibrium can be predicted using Le Chatelier's Principle. Students should be able to make qualitative predictions about the effect of changes on systems at equilibrium when given appropriate information.	

5.6.2.5 The effect of changing concentration (HT only)

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

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

Content	Key opportunities for skills development
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. Students should be able to interpret appropriate given data to predict the effect of a change in temperature on given reactions at equilibrium.	

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

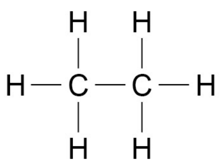
Content	Key opportunities for skills development
For gaseous reactions at equilibrium: • an increase in pressure causes the equilibrium position to shift towards the side with the smaller number of molecules as shown by the symbol equation for that reaction • a decrease in pressure causes the equilibrium position to shift towards the side with the larger number of molecules as shown by the symbol equation for that reaction. Students should be able to interpret appropriate given data to predict the effect of pressure changes on given reactions at equilibrium.	

5.7 Organic chemistry

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

5.7.1 Carbon compounds as fuels and feedstock

5.7.1.1 Crude oil, hydrocarbons and alkanes

Content	Key opportunities for skills development
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. Most of the hydrocarbons in crude oil are hydrocarbons called alkanes. The general formula for the homologous series of alkanes is C_nH_{2n+2} The first four members of the alkanes are methane, ethane, propane and butane. Alkane molecules can be represented in the following forms: C_2H_6 or  Students should be able to recognise substances as alkanes given their formulae in these forms. Students do not need to know the names of specific alkanes other than methane, ethane, propane and butane.	WS 1.2 Make models of alkane molecules using the molecular modelling kits.

5.7.1.2 Fractional distillation and petrochemicals

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

5.7.1.3 Properties of hydrocarbons

Content	Key opportunities for skills development
Some properties of hydrocarbons depend on the size of their molecules, including boiling point, viscosity and flammability. These properties influence how hydrocarbons are used as fuels. Students should be able to recall how boiling point, viscosity and flammability change with increasing molecular size. 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. Students should be able to write balanced equations for the complete combustion of hydrocarbons with a given formula. Knowledge of trends in properties of hydrocarbons is limited to: • boiling points • viscosity • flammability.	WS 1.2, 4.1 Investigate the properties of different hydrocarbons.

5.7.1.4 Cracking and alkenes

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

5.8 Chemical analysis

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

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

5.8.1 Purity, formulations and chromatography

5.8.1.1 Pure substances

Content	Key opportunities for skills development
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, eg pure milk. Students should be able to use melting point and boiling point data to distinguish pure from impure substances.	WS 2.2, 4.1

5.8.1.2 Formulations

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

5.8.1.3 Chromatography

Content	Key opportunities for skills development
Chromatography can be used to separate mixtures and can give information to help identify substances. Chromatography involves a stationary phase and a mobile phase. Separation depends on the distribution of substances between the phases. 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 will produce a single spot in all solvents. Students should be able to: • explain how paper chromatography separates mixtures • suggest how chromatographic methods can be used for distinguishing pure substances from impure substances • interpret chromatograms and determine R_f values from chromatograms	WS 2.2, 3.1, 2, 3 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.
• provide answers to an appropriate number of significant figures.	MS 2a

Required practical activity 12: 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 183).

5.8.2 Identification of common gases

5.8.2.1 Test for hydrogen

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

5.8.2.2 Test for oxygen

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

5.8.2.3 Test for carbon dioxide

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

5.8.2.4 Test for chlorine

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

5.9 Chemistry of the atmosphere

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

5.9.1 The composition and evolution of the Earth's atmosphere

5.9.1.1 The proportions of different gases in the atmosphere

Content	Key opportunities for skills development
For 200 million years, the proportions of different gases in the atmosphere have been much the same as they are today: • about four-fifths (approximately 80%) nitrogen • about one-fifth (approximately 20%) oxygen • small proportions of various other gases, including carbon dioxide, water vapour and noble gases.	MS 1c To use ratios, fractions and percentages.

5.9.1.2 The Earth's early atmosphere

Content	Key opportunities for skills development
Theories about what was in the Earth's early atmosphere and how the atmosphere was formed have changed and developed over time. Evidence for the early atmosphere is limited because of the time scale of 4.6 billion years. One theory suggests that during the first billion years of the Earth's existence there was intense volcanic activity that released gases that formed the early atmosphere and water vapour that condensed to form the oceans. At the start of this period the Earth's atmosphere may have been like the atmospheres of Mars and Venus today, consisting of mainly carbon dioxide with little or no oxygen gas. 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. No knowledge of other theories is required. Students should be able to, given appropriate information, interpret evidence and evaluate different theories about the Earth's early atmosphere.	WS 1.1, 1.2, 1.3, 3.5, 3.6, 4.1

5.9.1.3 How oxygen increased

Content	Key opportunities for skills development
Algae and plants produced the oxygen that is now in the atmosphere by photosynthesis, which can be represented by the equation: $6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$ carbon dioxide + water $\xrightarrow{\text{light}}$ glucose + oxygen 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.	WS 1.2 An opportunity to show that aquatic plants produce oxygen in daylight.

5.9.1.4 How carbon dioxide decreased

Content	Key opportunities for skills development
Algae and plants decreased the percentage of carbon dioxide in the atmosphere by photosynthesis. Carbon dioxide was also decreased by the formation of sedimentary rocks and fossil fuels that contain carbon.	
Students should be able to: • describe the main changes in the atmosphere over time and some of the likely causes of these changes • describe and explain the formation of deposits of limestone, coal, crude oil and natural gas.	WS 1.2, 4.1

5.9.2 Carbon dioxide and methane as greenhouse gases

5.9.2.1 Greenhouse gases

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

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

Content	Key opportunities for skills development
Some human activities increase the amounts of greenhouse gases in the atmosphere. These include: • carbon dioxide • methane. Students should be able to recall two human activities that increase the amounts of each of the greenhouse gases carbon dioxide and methane. Based on peer-reviewed evidence, many scientists believe that human activities will cause the temperature of the Earth's atmosphere to increase at the surface and that this will result in global climate change. However, it is difficult to model such complex systems as global climate change. This leads to simplified models, speculation and opinions presented in the media that may be based on only parts of the evidence and which may be biased.	
Students should be able to: • evaluate the quality of evidence in a report about global climate change given appropriate information • describe uncertainties in the evidence base • recognise the importance of peer review of results and of communicating results to a wide range of audiences.	WS 1.2, 1.3, 1.6

5.9.2.3 Global climate change

Content	Key opportunities for skills development
An increase in average global temperature is a major cause of climate change. There are several potential effects of global climate change. Students should be able to: • describe briefly four potential effects of global climate change • discuss the scale, risk and environmental implications of global climate change.	WS 1.5

5.9.2.4 The carbon footprint and its reduction

Content	Key opportunities for skills development
The carbon footprint is the total amount of carbon dioxide and other greenhouse gases emitted over the full life cycle of a product, service or event. The carbon footprint can be reduced by reducing emissions of carbon dioxide and methane. Students should be able to: • describe actions to reduce emissions of carbon dioxide and methane • give reasons why actions may be limited.	WS 1.3

5.9.3 Common atmospheric pollutants and their sources

5.9.3.1 Atmospheric pollutants from fuels

Content	Key opportunities for skills development
The combustion of fuels is a major source of atmospheric pollutants. Most fuels, including coal, contain carbon and/or hydrogen and may also contain some sulfur. The gases released into the atmosphere when a fuel is burned may include carbon dioxide, water vapour, carbon monoxide, sulfur dioxide and oxides of nitrogen. Solid particles and unburned hydrocarbons may also be released that form particulates in the atmosphere. Students should be able to: • describe how carbon monoxide, soot (carbon particles), sulfur dioxide and oxides of nitrogen are produced by burning fuels	
• predict the products of combustion of a fuel given appropriate information about the composition of the fuel and the conditions in which it is used.	WS 1.2

5.9.3.2 Properties and effects of atmospheric pollutants

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

5.10 Using resources

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

5.10.1 Using the Earth's resources and obtaining potable water

5.10.1.1 Using the Earth's resources and sustainable development

Content	Key opportunities for skills development
Humans use the Earth's resources to provide warmth, shelter, food and transport. Natural resources, supplemented by agriculture, provide food, timber, clothing and fuels. Finite resources from the Earth, oceans and atmosphere are processed to provide energy and materials. Chemistry plays an important role in improving agricultural and industrial processes to provide new products and in sustainable development, which is development that meets the needs of current generations without compromising the ability of future generations to meet their own needs. Students should be able to: • state examples of natural products that are supplemented or replaced by agricultural and synthetic products • distinguish between finite and renewable resources given appropriate information. Students should be able to:	
• extract and interpret information about resources from charts, graphs and tables	WS 3.2 MS 2c, 4a
• use orders of magnitude to evaluate the significance of data.	MS 2h Translate information between graphical and numeric form.

5.10.1.2 Potable water

Content	Key opportunities for skills development
Water of appropriate quality is essential for life. For humans, drinking water should have sufficiently low levels of dissolved salts and microbes. Water that is safe to drink is called potable water. Potable water is not pure water in the chemical sense because it contains dissolved substances. The methods used to produce potable water depend on available supplies of water and local conditions. In the United Kingdom (UK), rain provides water with low levels of dissolved substances (fresh water) that collects in the ground and in lakes and rivers, and most potable water is produced by: • choosing an appropriate source of fresh water • passing the water through filter beds • 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. These processes require large amounts of energy. Students should be able to: • distinguish between potable water and pure water • describe the differences in treatment of ground water and salty water • give reasons for the steps used to produce potable water.	

Required practical activity 13: 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 183).

5.10.1.3 Waste water treatment

Content	Key opportunities for skills development
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. Students should be able to comment on the relative ease of obtaining potable water from waste, ground and salt water.	

5.10.1.4 Alternative methods of extracting metals (HT only)

Content	Key opportunities for skills development
The Earth's resources of metal ores are limited. 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. Students should be able to evaluate alternative biological methods of metal extraction, given appropriate information.	

5.10.2 Life cycle assessment and recycling

5.10.2.1 Life cycle assessment

Content	Key opportunities for skills development
Life cycle assessments (LCAs) are carried out to assess the environmental impact of 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. Use of water, resources, energy sources and production of some wastes can be fairly easily quantified. Allocating numerical values to pollutant effects is less straightforward and requires value judgements, so LCA is not a purely objective process. 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. Students should be able to carry out simple comparative LCAs for shopping bags made from plastic and paper.	WS 1.3, 4, 5 LCAs should be done as a comparison of the impact on the environment of the stages in the life of a product, and only quantified where data is readily available for energy, water, resources and wastes. Interpret LCAs of materials or products given appropriate information. 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 4a Translate information between graphical and numeric form.

5.10.2.2 Ways of reducing the use of resources

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

5.11 Key ideas

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

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

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.

6 Physics subject content

This specification is presented in a two column format.

The subject content is split into three sections for each of the subject areas: biology, chemistry and physics.

The left hand column contains the subject content that all students must cover, and that can be assessed in the written papers.

The right hand column exemplifies some of the key opportunities for the following skills to be developed throughout the course: WS refers to Working scientifically (page 13), MS refers to Mathematical requirements (page 171) and AT refers to Use of apparatus and techniques (page 173). These are not the only opportunities. Teachers are encouraged to introduce all of these skills where appropriate throughout the course.

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

It is good practice to teach and develop all of the mathematical skills throughout the course. Some mathematical skills will only be assessed in certain subject areas. These are detailed in Mathematical requirements (page 171).

Science is a practical subject. Details of the assessment of required practicals can be found in Required practical activities (page 175).

Working scientifically (page 13) and Use of apparatus and techniques (page 173) skills will be assessed across all papers.

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.

Questions in paper 2 may draw on an understanding of energy changes and transfers due to heating, mechanical and electrical work and the concept of energy conservation from sections Energy (page 121) and Electricity (page 127).

6.1 Energy

The concept of energy emerged in the 19th century. The idea was used to explain the work output of steam engines and then generalised to understand other heat engines. It also became a key tool for understanding chemical reactions and biological systems.

Limits to the use of fossil fuels and global warming are critical problems for this century. Physicists and engineers are working hard to identify ways to reduce our energy usage.

6.1.1 Energy changes in a system, and the ways energy is stored before and after such changes

6.1.1.1 Energy stores and systems

Content	Key opportunities for skills development
A system is an object or group of objects. There are changes in the way energy is stored when a system changes. Students should be able to describe all the changes involved in the way energy is stored when a system changes, for common situations. For example: • an object projected upwards • a moving object hitting an obstacle • an object accelerated by a constant force • a vehicle slowing down • bringing water to a boil in an electric kettle. Throughout this section on Energy students should be able to calculate the changes in energy involved when a system is changed by: • heating • work done by forces • work done when a current flows	The link between work done (energy transfer) and current flow in a circuit is covered in Work done and energy transfer (page 146). WS 4.5
• use calculations to show on a common scale how the overall energy in a system is redistributed when the system is changed.	WS 1.2, 4.3, 4.5, 4.6 MS 1a, c, 3b, c

6.1.1.2 Changes in energy

Content	Key opportunities for skills development
Students should be able to calculate the amount of energy associated with a moving object, a stretched spring and an object raised above ground level.	WS 1.2, 4.3, 4.4, 4.6 MS 1a, c, 3b, c

Content	Key opportunities for skills development
The kinetic energy of a moving object can be calculated using the equation: $kinetic\ energy = 0.5 \times mass \times (speed)^2$ $[E_k = \frac{1}{2} m v^2]$ kinetic energy, E_k, in joules, J mass, m, in kilograms, kg speed, v, in metres per second, m/s The amount of elastic potential energy stored in a stretched spring can be calculated using the equation:	MS 3b, c Students should be able to recall and apply this equation.
$elastic\ potential\ energy = 0.5 \times spring\ constant \times (extension)^2$ $[E_e = \frac{1}{2} k e^2]$ (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 The amount of gravitational potential energy gained by an object raised above ground level can be calculated using the equation:	MS 3b, c Students should be able to apply this equation which is given on the *Physics equation sheet*.
$g.p.e. = mass \times gravitational\ field\ strength \times height$ $[E_p = m g h]$ gravitational potential energy, E_p, in joules, J mass, m, in kilograms, kg gravitational field strength, g, in newtons per kilogram, N/kg (In any calculation the value of the gravitational field strength (g) will be given). height, h, in metres, m	MS 3b, c Students should be able to recall and apply this equation. AT 1 Investigate the transfer of energy from a gravitational potential energy store to a kinetic energy store.

6.1.1.3 Energy changes in systems

Content	Key opportunities for skills development
The amount of energy stored in or released from a system as its temperature changes can be calculated using the equation:	

Content	Key opportunities for skills development
change in thermal energy = *mass* × *specific heat capacity* × *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.	MS 3b, c Students should be able to apply this equation which is given on the *Physics equation sheet*. This equation and specific heat capacity are also included in Temperature changes in a system and specific heat capacity (page 137).

Required practical activity 14: 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 184).

6.1.1.4 Power

Content	Key opportunities for skills development
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. Students should be able to give examples that illustrate the definition of power eg comparing two electric motors that both lift the same weight through the same height but one does it faster than the other.	MS 3b, c Students should be able to recall and apply both equations.

6.1.2 Conservation and dissipation of energy

6.1.2.1 Energy transfers in a system

Content	Key opportunities for skills development
Energy can be transferred usefully, stored or dissipated, but cannot be created or destroyed. Students should be able to describe with examples where there are energy transfers in a closed system, that there is no net change to the total energy. Students should be able to describe, with examples, how in all system changes energy is dissipated, so that it is stored in less useful ways. This energy is often described as being 'wasted'.	

Content	Key opportunities for skills development
Students should be able to explain ways of reducing unwanted energy transfers, for example through lubrication and 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. Students should be able to describe how the rate of cooling of a building is affected by the thickness and thermal conductivity of its walls. Students do not need to know the definition of thermal conductivity.	WS 1.4 AT 1, 5 Investigate thermal conductivity using rods of different materials.

6.1.2.2 Efficiency

Content	Key opportunities for skills development
The energy efficiency for any energy transfer can be calculated using the equation: $efficiency = \frac{useful\ output\ energy\ transfer}{total\ input\ energy\ transfer}$ Efficiency may also be calculated using the equation: $efficiency = \frac{useful\ power\ output}{total\ power\ input}$	MS 3b, c Students should be able to recall and apply both equations. MS 1a, c, 3b, c Students may be required to calculate or use efficiency values as a decimal or as a percentage.
(HT only) Students should be able to describe ways to increase the efficiency of an intended energy transfer.	(HT only) WS 1.4

6.1.3 National and global energy resources

Content	Key opportunities for skills development
The main energy resources available for use on Earth include: fossil fuels (coal, oil and gas), nuclear fuel, bio-fuel, wind, hydro-electricity, geothermal, the tides, the Sun and water waves. A renewable energy resource is one that is being (or can be) replenished as it is used. The uses of energy resources include: transport, electricity generation and heating. Students should be able to: • describe the main energy sources available • distinguish between energy resources that are renewable and energy resources that are non-renewable • compare ways that different energy resources are used, the uses to include transport, electricity generation and heating • understand why some energy resources are more reliable than others	WS 4.4
• describe the environmental impact arising from the use of different energy resources	WS 1.3, 1.4
• explain patterns and trends in the use of energy resources.	WS 3.5
Descriptions of how energy resources are used to generate electricity are **not** required.	
Students should be able to: • consider the environmental issues that may arise from the use of different energy resources • show that science has the ability to identify environmental issues arising from the use of energy resources but not always the power to deal with the issues because of political, social, ethical or economic considerations.	WS 1.3, 1.4, 4.4 MS 1c, 2c, 4a

6.2 Electricity

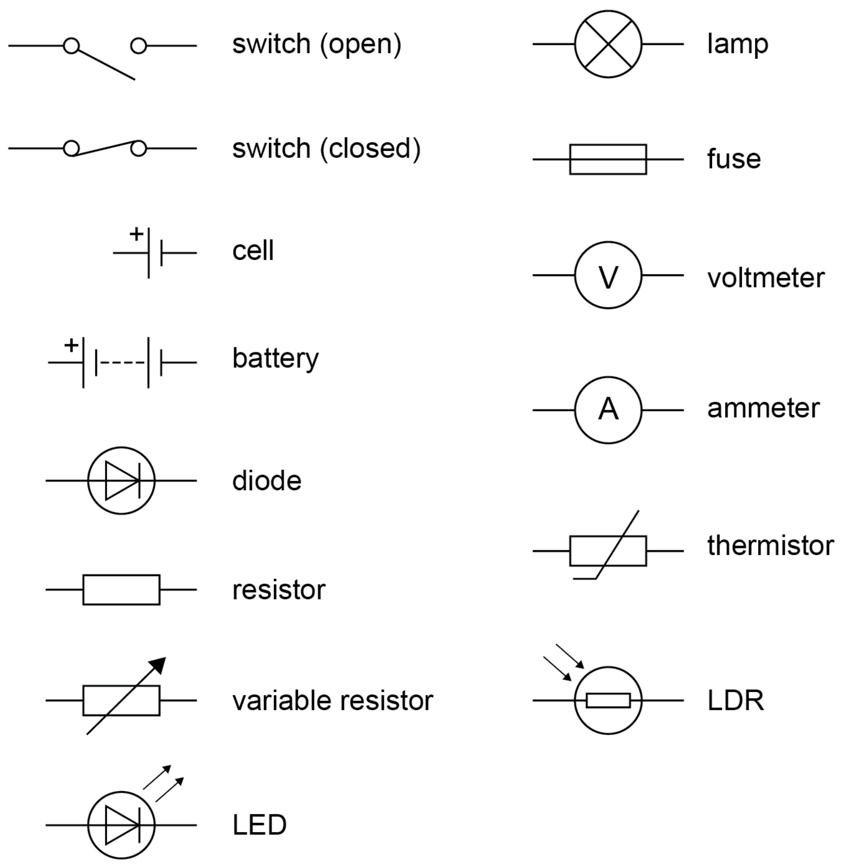
Electric charge is a fundamental property of matter everywhere. Understanding the difference in the microstructure of conductors, semiconductors and insulators makes it possible to design components and build electric circuits. Many circuits are powered with mains electricity, but portable electrical devices must use batteries of some kind.

Electrical power fills the modern world with artificial light and sound, information and entertainment, remote sensing and control. The fundamentals of electromagnetism were worked out by scientists of the 19^{th} century. However, power stations, like all machines, have a limited lifetime. If we all continue to demand more electricity this means building new power stations in every generation – but what mix of power stations can promise a sustainable future?

6.2.1 Current, potential difference and resistance

6.2.1.1 Standard circuit diagram symbols

<table>
<tr><th>Content</th><th>Key opportunities for skills development</th></tr>
<tr><td>
Circuit diagrams use standard symbols.



Students should be able to draw and interpret circuit diagrams.
</td><td>WS 1.2</td></tr>
</table>

6.2.1.2 Electrical charge and current

Content	Key opportunities for skills development
For electrical charge to flow through a closed circuit the circuit must include a source of potential difference.	

Content	Key opportunities for skills development
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 and time are linked by the equation: $charge\ flow = current \times time$ $[\ Q = I\ t\ ]$ 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.	MS 3b, c Students should be able to recall and apply this equation.

6.2.1.3 Current, resistance and potential difference

Content	Key opportunities for skills development
The current (*I*) through a component depends on both the resistance (*R*) of the component and the potential difference (*V*) across the component. The greater the resistance of the component the smaller the current for a given potential difference (pd) across the component. Questions will be set using the term potential difference. Students will gain credit for the correct use of either potential difference or voltage.	
Current, potential difference or resistance can be calculated using the equation: $potential\ difference = current \times resistance$ $[\ V = I\ R\ ]$ potential difference, *V*, in volts, V current, *I*, in amperes, A (amp is acceptable for ampere) resistance, *R*, in ohms, Ω	MS 3b, c Students should be able to recall and apply this equation.

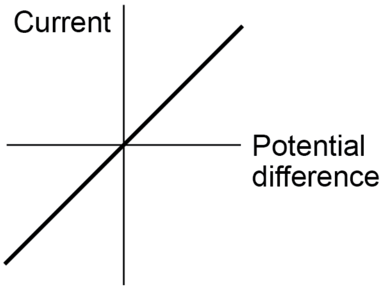
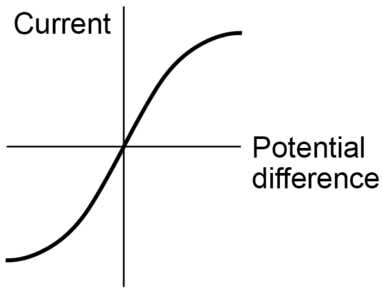
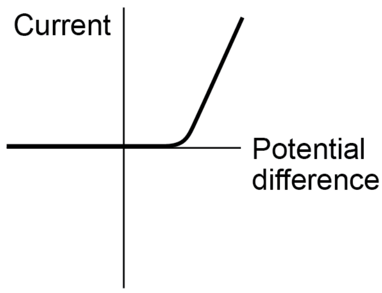
Required practical activity 15: use circuit diagrams to set up and check appropriate circuits to investigate the factors affecting the resistance of electrical circuits. This should include:

- the length of a wire at constant temperature
- combinations of resistors in series and 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 185).

6.2.1.4 Resistors

Content	Key opportunities for skills development
Students should be able to explain that, for some resistors, the value of *R* remains constant but that in others it can change as the current changes. The current through an ohmic conductor (at a constant temperature) is directly proportional to the potential difference across the resistor. This means that the resistance remains constant as the current changes.  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.  	

Content	Key opportunities for skills development
The resistance of a thermistor decreases as the temperature increases. The applications of thermistors in circuits eg a thermostat is required. The resistance of an LDR decreases as light intensity increases.	
The application of LDRs in circuits eg switching lights on when it gets dark is required. Students should be able to:	WS 1.2, 1.4
• explain the design and use of a circuit to measure the resistance of a component by measuring the current through, and potential difference across, the component • draw an appropriate circuit diagram using correct circuit symbols.	AT 6 Investigate the relationship between the resistance of a thermistor and temperature. Investigate the relationship between the resistance of an LDR and light intensity.
Students should be able to use graphs to explore whether circuit elements are linear or non-linear and relate the curves produced to their function and properties.	WS 1.2, 1.4 MS 4c, 4d, 4e

Required practical activity 16: 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 186).

6.2.2 Series and parallel circuits

Content	Key opportunities for skills development
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.	

Content	Key opportunities for skills development
$R_{total} = R_1 + R_2$ 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. Students should be able to:	MS 1c, 3b, 3c, 3d
• use circuit diagrams to construct and check series and parallel circuits that include a variety of common circuit components • describe the difference between series and parallel circuits • explain qualitatively why adding resistors in series increases the total resistance whilst adding resistors in parallel decreases the total resistance	AT 7
• explain the design and use of dc series circuits for measurement and testing purposes	WS 1.4
• calculate the currents, potential differences and resistances in dc series circuits • solve problems for circuits which include resistors in series using the concept of equivalent resistance. Students are **not** required to calculate the total resistance of two resistors joined in parallel.	MS 1c, 3b, c, d

6.2.3 Domestic uses and safety

6.2.3.1 Direct and alternating potential difference

Content	Key opportunities for skills development
Mains electricity is an ac supply. In the United Kingdom the domestic electricity supply has a frequency of 50 Hz and is about 230 V. Students should be able to explain the difference between direct and alternating potential difference.	

6.2.3.2 Mains electricity

Content	Key opportunities for skills development
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 only carries a current if there is a fault. Students should be able to explain: • that a live wire may be dangerous even when a switch in the mains circuit is open • the dangers of providing any connection between the live wire and earth.	WS 1.5

6.2.4 Energy transfers

6.2.4.1 Power

Content	Key opportunities for skills development
Students should be able to explain how the power transfer in any circuit device is related to the potential difference across it and the current through it, and to the energy changes over time: $power = potential\ difference \times current$ $[P = V I]$ $power = (\text{current})^2 \times resistance$ $[P = I^2 R]$ 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	MS 3b, c WS 4.5 Students should be able to recall and apply both equations.

6.2.4.2 Energy transfers in everyday appliances

Content	Key opportunities for skills development
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. Students should be able to describe how different domestic appliances transfer energy from batteries or ac mains to the kinetic energy of electric motors or the energy of heating devices. Work is done when charge flows in a circuit. The amount of energy transferred by electrical work can be calculated using the equation:	
$energy\ transferred = power \times time$ $[\ E = P\ t\ ]$ $energy\ transferred = charge\ flow \times potential\ difference$ $[\ E = Q\ V\ ]$ 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	MS 3b, c Students should be able to recall and apply both equations. WS 1.4
Students should be able to explain how the power of a circuit device is related to: • the potential difference across it and the current through it • the energy transferred over a given time. Students should be able to describe, with examples, the relationship between the power ratings for domestic electrical appliances and the changes in stored energy when they are in use.	WS 1.2

6.2.4.3 The National Grid

Content	Key opportunities for skills development
The National Grid is a system of cables and transformers linking power stations to consumers.	

Content	Key opportunities for skills development
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, to a much lower value, the potential difference for domestic use. Students should be able to explain why the National Grid system is an efficient way to transfer energy. Higher tier 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 Detailed knowledge of the structure of a transformer is not required.

6.3 Particle model of matter

The particle model is widely used to predict the behaviour of solids, liquids and gases and this has many applications in everyday life. It helps us to explain a wide range of observations and engineers use these principles when designing vessels to withstand high pressures and temperatures, such as submarines and spacecraft. It also explains why it is difficult to make a good cup of tea high up a mountain!

6.3.1 Changes of state and the particle model

6.3.1.1 Density of materials

Content	Key opportunities for skills development
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 The particle model can be used to explain • the different states of matter • differences in density.	MS 1a, b, c, 3b, c Students should be able to recall and apply this equation to changes where mass is conserved.

Content	Key opportunities for skills development
Students should be able to recognise/draw simple diagrams to model the difference between solids, liquids and gases.	WS 1.2
Students should be able to explain the differences in density between the different states of matter in terms of the arrangement of atoms or molecules.	WS 1.2

Required practical activity 17: 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 regularly shaped objects, 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 187).

6.3.1.2 Changes of state

Content	Key opportunities for skills development
Students should be able to describe how, when substances change state (melt, freeze, boil, evaporate, condense or sublimate), mass is conserved. Changes of state are physical changes which differ from chemical changes because the material recovers its original properties if the change is reversed.	

6.3.2 Internal energy and energy transfers

6.3.2.1 Internal energy

Content	Key opportunities for skills development
Energy is stored inside a system by the particles (atoms and molecules) that make up the system. This is called internal energy. Internal energy is the total kinetic energy and potential energy of all the particles (atoms and molecules) that make up a system. Heating changes the energy stored within the system by increasing the energy of the particles that make up the system. This either raises the temperature of the system or produces a change of state.	

6.3.2.2 Temperature changes in a system and specific heat capacity

Content	Key opportunities for skills development
If the temperature of the system increases: The increase in temperature depends on the mass of the substance heated, the type of material and the energy input to the system.	
The following equation 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.	MS 1a, 3b, 3c, 3d Students should be able to apply this equation, which is given on the *Physics equation sheet*, to calculate the energy change involved when the temperature of a material changes. This equation and specific heat capacity are also included in Energy changes in systems (page 123).

6.3.2.3 Changes of state and specific latent heat

Content	Key opportunities for skills development
If a change of state happens: 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. 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.	

Content	Key opportunities for skills development
$energy\ for\ a\ change\ of\ state = mass \times specific\ latent\ heat$ $[E = m\,L]$ 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	MS 1a, 3b, c, d Students should be able to apply this equation, which is given on the *Physics equation sheet*, to calculate the energy change involved in a change of state. MS 4a AT 5 Perform an experiment to measure the latent heat of fusion of water.
Students should be able to interpret heating and cooling graphs that include changes of state. Students should be able to distinguish between specific heat capacity and specific latent heat.	WS 3.5

6.3.3 Particle model and pressure

6.3.3.1 Particle motion in gases

Content	Key opportunities for skills development
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. Changing the temperature of a gas, held at constant volume, changes the pressure exerted by the gas.	WS 1.2
Students should be able to: • explain how the motion of the molecules in a gas is related to both its temperature and its pressure • explain qualitatively the relation between the temperature of a gas and its pressure at constant volume.	WS 1.2

6.4 Atomic structure

Ionising radiation is hazardous but can be very useful. Although radioactivity was discovered over a century ago, it took many nuclear physicists several decades to understand the structure of atoms, nuclear forces and stability. Early researchers suffered from their exposure to ionising radiation. Rules for radiological protection were first introduced in the 1930s and subsequently improved. Today radioactive materials are widely used in medicine, industry, agriculture and electrical power generation.

6.4.1 Atoms and isotopes

6.4.1.1 The structure of an atom

Content	Key opportunities for skills development
Atoms are very small, having a radius of about 1×10^{-10} metres. The basic structure of an atom is a positively charged nucleus composed of both protons and neutrons surrounded by negatively charged electrons. The radius of a nucleus is less than 1/10 000 of the radius of an atom. Most of the mass of an atom is concentrated in the nucleus. The electrons are arranged at different distances from the nucleus (different energy levels). The electron arrangements may change with the absorption of electromagnetic radiation (move further from the nucleus; a higher energy level) or by the emission of electromagnetic radiation (move closer to the nucleus; a lower energy level).	MS 1b WS 4.4 Students should be able to recognise expressions given in standard form.

6.4.1.2 Mass number, atomic number and isotopes

Content	Key opportunities for skills development
In an atom the number of electrons is equal to the number of protons in the nucleus. Atoms have no overall electrical charge. All atoms of a particular element have the same number of protons. The number of protons in an atom of an element is called its atomic number. The total number of protons and neutrons in an atom is called its mass number. Atoms can be represented as shown in this example: (Mass number) 23 (Atomic number) 11 $^{23}_{11}\text{Na}$ Atoms of the same element can have different numbers of neutrons; these atoms are called isotopes of that element. Atoms turn into positive ions if they lose one or more outer electron(s).	
Students should be able to relate differences between isotopes to differences in conventional representations of their identities, charges and masses.	WS 4.1

6.4.1.3 The development of the model of the atom (common content with chemistry)

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

6.4.2 Atoms and nuclear radiation

6.4.2.1 Radioactive decay and nuclear radiation

Content	Key opportunities for skills development
Some atomic nuclei are unstable. The nucleus gives out radiation as it changes to become more stable. This is a random process called radioactive decay. Activity is the rate at which a source of unstable nuclei decays. Activity is measured in becquerel (Bq) Count-rate is the number of decays recorded each second by a detector (eg Geiger-Muller tube). The nuclear radiation emitted may be: • an alpha particle (α) – this consists of two neutrons and two protons, it is the same as a helium nucleus • 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).	
Required knowledge of the properties of alpha particles, beta particles and gamma rays is limited to their penetration through materials, their range in air and ionising power. Students should be able to apply their knowledge to the uses of radiation and evaluate the best sources of radiation to use in a given situation.	WS 1.4, 1.5

6.4.2.2 Nuclear equations

Content	Key opportunities for skills development
Nuclear equations are used to represent radioactive decay. In a nuclear equation an alpha particle may be represented by the symbol: $^{4}_{2}\mathrm{He}$ and a beta particle by the symbol: $^{0}_{-1}\mathrm{e}$ The emission of the different types of nuclear radiation may cause a change in the mass and /or the charge of the nucleus. For example: $^{219}_{86}\mathrm{radon} \longrightarrow {}^{215}_{84}\mathrm{polonium} + {}^{4}_{2}\mathrm{He}$ So alpha decay causes both the mass and charge of the nucleus to decrease. $^{14}_{6}\mathrm{carbon} \longrightarrow {}^{14}_{7}\mathrm{nitrogen} + {}^{0}_{-1}\mathrm{e}$ So beta decay does not cause the mass of the nucleus to change but does cause the charge of the nucleus to increase. Students are not required to recall these two examples. Students should be able to use the names and symbols of common nuclei and particles to write balanced equations that show single alpha (α) and beta (β) decay. This is limited to balancing the atomic numbers and mass numbers. The identification of daughter elements from such decays is not required. The emission of a gamma ray does not cause the mass or the charge of the nucleus to change.	WS 1.2, 4.1 MS 1b, c, 3c

6.4.2.3 Half-lives and the random nature of radioactive decay

Content	Key opportunities for skills development
Radioactive decay is random. The half-life of a radioactive isotope is the time it takes for the number of nuclei of the isotope in a sample to halve, or the time it takes for the count rate (or activity) from a sample containing the isotope to fall to half its initial level.	

Content	Key opportunities for skills development
Students should be able to explain the concept of half-life and how it is related to the random nature of radioactive decay.	WS 1.2
Students should be able to determine the half-life of a radioactive isotope from given information.	MS 4a
(HT only) Students should be able to calculate the net decline, expressed as a ratio, in a radioactive emission after a given number of half-lives.	(HT only) MS 1c, 3d

6.4.2.4 Radioactive contamination

Content	Key opportunities for skills development
Radioactive contamination is the unwanted presence of materials containing radioactive atoms on other materials. The hazard from contamination is due to the decay of the contaminating atoms. The type of radiation emitted affects the level of hazard. Irradiation is the process of exposing an object to nuclear radiation. The irradiated object does not become radioactive.	WS 1.5
Students should be able to compare the hazards associated with contamination and irradiation.	WS 1.5
Suitable precautions must be taken to protect against any hazard that the radioactive source used in the process of irradiation may present.	WS 1.5
Students should understand that it is important for the findings of studies into the effects of radiation on humans to be published and shared with other scientists so that the findings can be checked by peer review.	WS 1.6

6.5 Forces

Engineers analyse forces when designing a great variety of machines and instruments, from road bridges and fairground rides to atomic force microscopes. Anything mechanical can be analysed in this way. Recent developments in artificial limbs use the analysis of forces to make movement possible.

6.5.1 Forces and their interactions

6.5.1.1 Scalar and vector quantities

Content	Key opportunities for skills development
Scalar quantities have magnitude only. Vector quantities have magnitude and an associated direction. 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.	

6.5.1.2 Contact and non-contact forces

Content	Key opportunities for skills development
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 • non-contact forces – the objects are physically separated. Examples of contact forces include friction, air resistance, tension and normal contact force. Examples of non-contact forces are gravitational force, electrostatic force and magnetic force. Force is a vector quantity. Students should be able to describe the interaction between pairs of objects which produce a force on each object. The forces to be represented as vectors.	

6.5.1.3 Gravity

Content	Key opportunities for skills development
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.	

Content	Key opportunities for skills development
The weight of an object can be calculated using the equation: 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 (In any calculation the value of the gravitational field strength (*g*) will be given.) The weight of an object may be considered to act at a single point referred to as the object's 'centre of mass'.	MS 3b, c Students should be able to recall and apply this equation.
The weight of an object and the mass of an object are directly proportional. Weight is measured using a calibrated spring-balance (a newtonmeter).	MS 3a Students should recognise and be able to use the symbol for proportionality, ∝

6.5.1.4 Resultant forces

Content	Key opportunities for skills development
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. Students should be able to calculate the resultant of two forces that act in a straight line. (HT only) Students should be able to: • describe examples of the forces acting on an isolated object or system	
• use free body diagrams to describe qualitatively examples where several forces lead to a resultant force on an object, including balanced forces when the resultant force is zero. (HT only) 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
(HT only) Students should be able to use vector diagrams to illustrate resolution of forces, equilibrium situations and determine the resultant of two forces, to include both magnitude and direction (scale drawings only).	MS 4a, 5a, b

6.5.2 Work done and energy transfer

Content	Key opportunities for skills development
When a force causes an object to move through a distance work is done on the object. So a force does work on an object when the force causes a displacement of the object.	
The work done by a force on an object can be calculated using the equation: 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	MS 3b, c Students should be able to recall and apply this equation.
One joule of work is done when a force of one newton causes a displacement of one metre. 1 joule = 1 newton-metre Students should be able to describe the energy transfer involved when work is done.	WS 4.5
Students should be able to convert between newton-metres and joules. Work done against the frictional forces acting on an object causes a rise in the temperature of the object.	MS 1c WS 4.5

6.5.3 Forces and elasticity

Content	Key opportunities for skills development
Students should be able to: • give examples of the forces involved in stretching, bending or compressing an object • explain why, to change the shape of an object (by stretching, bending or compressing), more than one force has to be applied – this is limited to stationary objects only • describe the difference between elastic deformation and inelastic deformation caused by stretching forces. 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.	

Content	Key opportunities for skills development
$force = spring\ constant \times extension$ $[F = k\ e]$ force, *F*, in newtons, N spring constant, *k*, in newtons per metre, N/m extension, *e*, in metres, m	MS 3b, c, 4a Students should be able to recall and apply this equation.
This relationship also applies to the compression of an elastic object, where '*e*' would be the compression of the object. A force that stretches (or compresses) a spring does work and elastic potential energy is stored in the spring. Provided the spring is not inelastically deformed, the work done on the spring and the elastic potential energy stored are equal. Students should be able to: • describe the difference between a linear and non-linear relationship between force and extension • calculate a spring constant in linear cases	MS 3b, c, 4a
• interpret data from an investigation of the relationship between force and extension	WS 3.5
• calculate work done in stretching (or compressing) a spring (up to the limit of proportionality) using the equation: $elastic\ potential\ energy = 0.5 \times spring\ constant \times (extension)^2$ $[E_e = \frac{1}{2} k\ e^2]$	MS 3c Students should be able to apply this equation which is given on the *Physics equation sheet*. This equation is also given in Changes in energy (page 122).
Students should be able to calculate relevant values of stored energy and energy transfers.	MS 3c

Required practical activity 18: 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 188).

6.5.4 Forces and motion

6.5.4.1 Describing motion along a line

6.5.4.1.1 Distance and displacement

Content	Key opportunities for skills development
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. Students should be able to express a displacement in terms of both the magnitude and direction.	MS 1, 3c Throughout this section (Forces and motion), students should be able to use ratios and proportional reasoning to convert units and to compute rates.

6.5.4.1.2 Speed

Content	Key opportunities for skills development
Speed does not involve direction. Speed is a scalar quantity. 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 at which a person can walk, run or cycle depends on many factors including: age, terrain, fitness and distance travelled. Typical values may be taken as: walking ~ 1.5 m/s running ~ 3 m/s cycling ~ 6 m/s. Students should be able to recall typical values of speed for a person walking, running and cycling as well as the typical values of speed for different types of transportation systems. 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 in air is 330 m/s.	
Students should be able to make measurements of distance and time and then calculate speeds of objects. For an object moving at constant speed the distance travelled in a specific time can be calculated using the equation:	MS 1a, c, 2f

Content	Key opportunities for skills development
distance travelled = *speed* × *time* [$s = v\,t$] distance, *s*, in metres, m speed, *v*, in metres per second, m/s time, *t*, in seconds, s	MS 3b, 3c Students should be able to recall and apply this equation.
Students should be able to calculate average speed for non-uniform motion.	MS 3b, 3c

6.5.4.1.3 Velocity

Content	Key opportunities for skills development
The velocity of an object is its speed in a given direction. Velocity is a vector quantity. Students should be able to explain the vector–scalar distinction as it applies to displacement, distance, velocity and speed. (HT only) Students should be able to explain qualitatively, with examples, that motion in a circle involves constant speed but changing velocity.	

6.5.4.1.4 The distance–time relationship

Content	Key opportunities for skills development
If an object moves along a straight line, the distance travelled 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. Students should be able to draw distance–time graphs from measurements and extract and interpret lines and slopes of distance–time graphs, translating information between graphical and numerical form. Students should be able to determine speed from a distance–time graph.	MS 4a, b, c, d, f

6.5.4.1.5 Acceleration

Content	Key opportunities for skills development
The average acceleration of an object can be calculated using the equation:	
$acceleration = \frac{change\ in\ velocity}{time\ taken}$ $\left[a = \frac{\Delta v}{t} \right]$ 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 is decelerating. Students should be able to estimate the magnitude of everyday accelerations.	MS 1d, 3b, 3c Students should be able to recall and apply this equation.
The acceleration of an object can be calculated from the gradient of a velocity–time graph. (HT only) The distance travelled by an object (or displacement of an object) can be calculated from the area under a velocity–time graph. Students should be able to:	MS 4a, b, c, d, f
• draw velocity–time graphs from measurements and interpret lines and slopes to determine acceleration • (HT only) interpret enclosed areas in velocity–time graphs to determine distance travelled (or displacement)	WS 3.3
• (HT only) measure, when appropriate, the area under a velocity–time graph by counting squares.	WS 3.3
The following equation applies to uniform acceleration: $(final\ velocity)^2 - (initial\ velocity)^2 = 2 \times acceleration \times distance$ $\left[v^2 - u^2 = 2\,a\,s \right]$ 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.	MS 3b, 3c Students should be able to apply this equation which is given on the *Physics equation sheet*.

Content	Key opportunities for skills development
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.	

6.5.4.2 Forces, accelerations and Newton's Laws of motion

6.5.4.2.1 Newton's First Law

Content	Key opportunities for skills development
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. So, when a vehicle travels at a steady speed the resistive forces balance the driving force. So, the velocity (speed and/or direction) of an object will only change if a resultant force is acting on the object. Students should be able to apply Newton's First Law to explain the motion of objects moving with a uniform velocity and objects where the speed and/or direction changes. (HT only) The tendency of objects to continue in their state of rest or of uniform motion is called inertia.	

6.5.4.2.2 Newton's Second Law

Content	Key opportunities for skills development
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. As an equation:	MS 3a Students should recognise and be able to use the symbol for proportionality, $\propto$

Content	Key opportunities for skills development
$resultant\ force = mass \times acceleration$ $F = m\,a$ force, *F*, in newtons, N mass, *m*, in kilograms, kg acceleration, *a*, in metres per second squared, m/s^2	MS 3b, c WS 4.2 Students should be able to recall and apply this equation.
(HT only) Students should be able to explain that: • inertial mass is a measure of how difficult it is to change the velocity of an object • inertial mass is defined as the ratio of force over acceleration.	MS 3a
Students should be able to estimate the speed, accelerations and forces involved in large accelerations for everyday road transport. Students should recognise and be able to use the symbol that indicates an approximate value or approximate answer, ~	MS 1d

Required practical activity 19: 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 189).

6.5.4.2.3 Newton's Third Law

Content	Key opportunities for skills development
Newton's Third Law:	
Whenever two objects interact, the forces they exert on each other are equal and opposite. Students should be able to apply Newton's Third Law to examples of equilibrium situations.	WS 1.2

6.5.4.3 Forces and braking

6.5.4.3.1 Stopping distance

Content	Key opportunities for skills development
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.	

6.5.4.3.2 Reaction time

Content	Key opportunities for skills development
Reaction times vary from person to person. Typical values range from 0.2 s to 0.9 s. A driver's reaction time can be affected by tiredness, drugs and alcohol. Distractions may also affect a driver's ability to react. Students should be able to: • explain methods used to measure human reaction times and recall typical results	
• interpret and evaluate measurements from simple methods to measure the different reaction times of students	WS 3.5, 3.7
• evaluate the effect of various factors on thinking distance based on given data.	WS 1.5, 2.2 MS 1a, c AT 1 Measure the effect of distractions on reaction time.

6.5.4.3.3 Factors affecting braking distance 1

Content	Key opportunities for skills development
The braking distance of a vehicle can be affected by adverse road and weather conditions and poor condition of the vehicle. Adverse road conditions include wet or icy conditions. Poor condition of the vehicle is limited to the vehicle's brakes or tyres. Students should be able to: • explain the factors which affect the distance required for road transport vehicles to come to rest in emergencies, and the implications for safety	

Content	Key opportunities for skills development
• estimate how the distance required for road vehicles to stop in an emergency varies over a range of typical speeds.	MS 1c, 1d, 2c, 2d, 2f, 2h, 3b, 3c

6.5.4.3.4 Factors affecting braking distance 2

Content	Key opportunities for skills development
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. Students should be able to:	
• explain the dangers caused by large decelerations	WS 1.5
• (HT only) estimate the forces involved in the deceleration of road vehicles in typical situations on a public road.	(HT only) MS 1d

6.5.5 Momentum (HT only)

6.5.5.1 Momentum is a property of moving objects

Content	Key opportunities for skills development
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	WS 1.2 MS 3b, c Students should be able to recall and apply this equation.

6.5.5.2 Conservation of momentum

Content	Key opportunities for skills development
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. Students should be able to use the concept of momentum as a model to describe and explain examples of momentum in an event, such as a collision.	AT 1, 2, 3 Investigate collisions between laboratory trollies using light gates, data loggers or ticker timers to measure and record data.

6.6 Waves

Wave behaviour is common in both natural and man-made systems. Waves carry energy from one place to another and can also carry information. Designing comfortable and safe structures such as bridges, houses and music performance halls requires an understanding of mechanical waves. Modern technologies such as imaging and communication systems show how we can make the most of electromagnetic waves.

6.6.1 Waves in air, fluids and solids

6.6.1.1 Transverse and longitudinal waves

Content	Key opportunities for skills development
Waves may be either transverse or longitudinal. The ripples on a water surface are an example of a transverse wave. Longitudinal waves show areas of compression and rarefaction. Sound waves travelling through air are longitudinal.	
Students should be able to describe the difference between longitudinal and transverse waves.	WS 1.2
Students should be able to describe evidence that, for both ripples on a water surface and sound waves in air, it is the wave and not the water or air itself that travels.	WS 1.2, 2.2

6.6.1.2 Properties of waves

Content	Key opportunities for skills development
Students should be able to describe wave motion in terms of 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.	MS 1c, 3b, c
$period = \frac{1}{frequency}$ $\left[T = \frac{1}{f} \right]$ period, *T*, in seconds, s frequency, *f*, in hertz, Hz 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:	MS 1c, 3b, c Students should be able to apply this equation which is given on the *Physics equation sheet*.
$wave\ speed = frequency \times wavelength$ $[\ v = f\ \lambda\ ]$ wave speed, *v*, in metres per second, m/s frequency, *f*, in hertz, Hz wavelength, *λ*, in metres, m Students should be able to: • identify amplitude and wavelength from given diagrams	MS 1c, 3b, 3c Students should be able to recall and apply this equation.
• describe a method to measure the speed of sound waves in air	AT 1 WS 2.3, 2.4, 2.6, 2.7, 3.1, 3.5
• describe a method to measure the speed of ripples on a water surface.	AT 1, AT 4 WS 2.3, 2.4, 2.6, 2.7, 3.1, 3.5

Required practical activity 20: 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 191).

6.6.2 Electromagnetic waves

6.6.2.1 Types of electromagnetic waves

Content	Key opportunities for skills development
Electromagnetic waves are transverse waves that transfer energy from the source of the waves to an absorber. Electromagnetic waves form a continuous spectrum and all types of electromagnetic wave travel at the same velocity through a vacuum (space) or air. The waves that form the electromagnetic spectrum are grouped in terms of their wavelength and their frequency. Going from long to short wavelength (or from low to high frequency) the groups are: radio, microwave, infrared, visible light (red to violet), ultraviolet, X-rays and gamma rays.	

Long wavelength → Short wavelength

Radio waves	Microwaves	Infrared	Visible light	Ultraviolet	X-rays	Gamma rays

Low frequency → High frequency

Our eyes only detect visible light and so detect a limited range of electromagnetic waves. Students should be able to give examples that illustrate the transfer of energy by electromagnetic waves.	

6.6.2.2 Properties of electromagnetic waves 1

Content	Key opportunities for skills development
(HT only) Different substances may absorb, transmit, refract or reflect electromagnetic waves in ways that vary with wavelength. (HT only) Some effects, for example refraction, are due to the difference in velocity of the waves in different substances. Students should be able to construct ray diagrams to illustrate the refraction of a wave at the boundary between two different media.	
(HT only) Students should be able to use wave front diagrams to explain refraction in terms of the change of speed that happens when a wave travels from one medium to a different medium.	WS 1.2

Required practical activity 21: 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 191).

6.6.2.3 Properties of electromagnetic waves 2

Content	Key opportunities for skills development
(HT only) Radio waves can be produced by oscillations in electrical circuits. (HT only) 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. Changes in atoms and the nuclei of atoms can result in electromagnetic waves being generated or absorbed over a wide frequency range. Gamma rays originate from changes in the nucleus of an atom.	
Ultraviolet waves, X-rays and gamma rays can have hazardous effects on human body tissue. The effects 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.	WS 1.5
1000 millisieverts (mSv) = 1 sievert (Sv) Students will not be required to recall the unit of radiation dose. Students should be able to draw conclusions from given data about the risks and consequences of exposure to radiation. Ultraviolet waves can cause skin to age prematurely and increase the risk of skin cancer. X-rays and gamma rays are ionising radiation that can cause the mutation of genes and cancer.	WS 1.5

6.6.2.4 Uses and applications of electromagnetic waves

Content	Key opportunities for skills development
Electromagnetic waves have many practical applications. For example: • radio waves – television and radio • microwaves – satellite communications, cooking food • infrared – electrical heaters, cooking food, infrared cameras • visible light – fibre optic communications • ultraviolet – energy efficient lamps, sun tanning • X-rays and gamma rays – medical imaging and treatments.	

Content	Key opportunities for skills development
(HT only) Students should be able to give brief explanations why each type of electromagnetic wave is suitable for the practical application.	(HT only) WS 1.4

6.7 Magnetism and electromagnetism

Electromagnetic effects are used in a wide variety of devices. Engineers make use of the fact that a magnet moving in a coil can produce electric current and also that when current flows around a magnet it can produce movement. It means that systems that involve control or communications can take full advantage of this.

6.7.1 Permanent and induced magnetism, magnetic forces and fields

6.7.1.1 Poles of a magnet

Content	Key opportunities for skills development
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. Two like poles repel each other. Two unlike poles attract 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. Students should be able to describe: • the attraction and repulsion between unlike and like poles for permanent magnets • the difference between permanent and induced magnets.	

6.7.1.2 Magnetic fields

Content	Key opportunities for skills development
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. 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. Students should be able to: • describe how to plot the magnetic field pattern of a magnet using a compass • draw the magnetic field pattern of a bar magnet showing how strength and direction change from one point to another • explain how the behaviour of a magnetic compass is related to evidence that the core of the Earth must be magnetic.	WS 2.2

6.7.2 The motor effect

6.7.2.1 Electromagnetism

Content	Key opportunities for skills development
When a current flows through a conducting wire a magnetic field is produced around the wire. 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 strength of the magnetic field of a solenoid. An electromagnet is a solenoid with an iron core. Students should be able to:	
• describe how the magnetic effect of a current can be demonstrated • draw the magnetic field pattern for a straight wire carrying a current and for a solenoid (showing the direction of the field) • explain how a solenoid arrangement can increase the magnetic effect of the current.	WS 2.2

6.7.2.2 Fleming's left-hand rule (HT only)

Content	Key opportunities for skills development
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. Students should be able to show that Fleming's left-hand rule represents the relative orientation of the force, the current in the conductor and the magnetic field. Students should be able to recall the factors that affect the size of the force on the conductor.	

Content	Key opportunities for skills development
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 3b, c Students should be able to apply this equation which is given on the *physics equation sheet*.

6.7.2.3 Electric motors (HT only)

Content	Key opportunities for skills development
A coil of wire carrying a current in a magnetic field tends to rotate. This is the basis of an electric motor. Students should be able to explain how the force on a conductor in a magnetic field causes the rotation of the coil in an electric motor.	

6.8 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 physics.

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 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.

7 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: Trilogy include questions that allow students to demonstrate:

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

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

7.1 Aims and learning outcomes

Courses based on this specification should encourage students to:

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 the three subjects as part of combined science: examples of their relevance are given for each subject in the introductions: Biology subject content (page 19), Chemistry subject content (page 67) and Physics subject content (page 121).

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.

Biology, chemistry and physics 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.

7.2 Assessment objectives

Assessment objectives (AOs) are set by Ofqual and are the same across all GCSE Combined Science: Trilogy 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.

7.2.1 Assessment objective weightings for GCSE Combined Science: Trilogy

Assessment objectives (AOs)	Component weightings (approx %)						Overall weighting (approx %)
	Biology Paper 1	Biology Paper 2	Chemistry Paper 1	Chemistry Paper 2	Physics Paper 1	Physics Paper 2	
AO1	37–43	37–43	37–43	37–43	37–43	37–43	40
AO2	37–43	37–43	37–43	37–43	37–43	37–43	40
AO3	17–23	17–23	17–23	17–23	17–23	17–23	20
Overall weighting of components	16.6	16.6	16.6	16.6	16.6	16.6	100

7.3 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
Biology Paper 1	70	x1	70
Biology Paper 2	70	x1	70
Chemistry Paper 1	70	x1	70
Chemistry Paper 2	70	x1	70
Physics Paper 1	70	x1	70
Physics Paper 2	70	x1	70
		Total scaled mark:	420

8 General administration

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

8.1 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: Trilogy	Foundation	8464F	TBC
	Higher	8464H	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 601/8758/X.

8.2 Overlaps with other qualifications

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

8.3 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.

8.4 Resits and shelf life

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

8.5 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.

8.6 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

8.6.1 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

8.6.2 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

8.7 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

8.8 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 21 experiments are required for this combined science specification. 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 173). 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

9 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.

10 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 Combined Science: Trilogy scheme of work will provide ideas and suggestions for good practical activities that are manageable with large classes.

10.1 Use of apparatus and techniques

All students are expected to have carried out the required practical activities in Required practical activities (page 175). 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.

10.1.1 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).

10.1.2 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).

10.1.3 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).

10.2 Required practical activities

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

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

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

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

This list is not designed to limit the practical activities carried out by students. A rich practical experience will include more than the 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 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.

10.2.1 Required practical activity 1

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.

10.2.2 Required practical activity 2

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.

10.2.3 Required practical activity 3

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.

10.2.4 Required practical activity 4

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.

10.2.5 Required practical activity 5

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

10.2.6 Required practical activity 6

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.

10.2.7 Required practical activity 7

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.

10.2.8 Required practical activity 8

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.

10.2.9 Required practical activity 9

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.

10.2.10 Required practical activity 10

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

Apparatus and techniques

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

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.

10.2.11 Required practical activity 11

Investigate how changes in concentration affect the rates of reactions by a method involving measuring the volume of a gas produced and a method involving a change in colour or turbidity.

This should be an investigation involving developing a hypothesis.

Apparatus and techniques

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

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

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.

10.2.12 Required practical activity 12

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.

10.2.13 Required practical activity 13

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.

10.2.14 Required practical activity 14

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.

10.2.15 Required practical activity 15

Use circuit diagrams to set up and check appropriate circuits to investigate the factors affecting the resistance of electrical circuits. This should include:

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

10.2.16 Required practical activity 16

Use circuit diagrams to construct appropriate circuits to investigate the I–V characteristics of 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.

10.2.17 Required practical activity 17

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 regularly shaped objects and by a displacement technique for irregularly shaped objects. Dimensions to be measured using appropriate apparatus such as a ruler, micrometrer 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.

10.2.18 Required practical activity 18

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.

10.2.19 Required practical activity 19

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.

10.2.20 Required practical activity 20

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 AT4 – 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.

10.2.21 Required practical activity 21

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.

11 Appendix A: Periodic table

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.

12 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 × (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 = (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	(final velocity)^2 – (initial velocity)^2 = 2 × acceleration × distance	$v^2 - u^2 = 2\ a\ s$
2	elastic potential energy = 0.5 × spring constant × (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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